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A comparative analysis of the sustainability of rice cultivation technologies using the analytic network process

E. Reig[1,2]*, J. Aznar[3] and V. Estruch[3]

[1] *Departamento de Economía Aplicada II. Universidad de Valencia.*
Avda. dels Tarongers, s/n. 46022 Valencia. Spain
[2] *Instituto Valenciano de Investigaciones Económicas (IVIE). C/ Guardia Civil, 22. 46020 Valencia. Spain*
[3] *Departamento de Economía y Ciencias Sociales. Universidad Politécnica de Valencia.*
Camí de Vera, s/n. 46022 Valencia. Spain

Abstract

Sustainability of local farming systems and technologies is a very important issue that faces notorious measurement difficulties. Multi-criteria methods may help researchers to solve empirical problems in the construction of composite sustainability indicators and in ranking agricultural technologies according to their sustainability. This paper shows how a multi-criteria decision-making technique, the Analytic Network Process (ANP), can be fruitfully employed to this end. Contrary to simpler and hierarchical goal-criteria-alternative approaches, in ANP all the elements in the network can be related in any possible way, which means that a network can incorporate feedback and interdependent relationships within and between clusters. We illustrate the use of ANP by ranking three rice cultivation technologies —that we call unrestricted traditional, agro-environmental and ecological— in the rice fields of the Albufera Natural Park in Valencia (Spain), using economic, environmental and socio-cultural sustainability criteria. Rice is a multifunctional crop in this area, as flooded rice fields act as semi-natural wetlands, with important ecological consequences, mainly connected with the protection of biodiversity. We show that the ANP methodology is perfectly suited to tackling the complex interrelations involved in sustainability evaluation in this case. We find the ecological cultivation system to be the most sustainable technology. The agro-environmental system ranks second, while the unrestricted system is ranked third. Our results also show that if only the economic dimension of sustainability were considered, the order would be reversed, with traditional unrestricted and ecological technologies exchanging places and the agro-environmental system remaining in second place.

Additional key words: biodiversity protection, ecosystems, multi-criteria decision methods, ranking of technologies.

Resumen

Análisis comparativo de la sostenibilidad de tecnologías de cultivo del arroz mediante el método ANP (analytic network process)

La sostenibilidad de los sistemas y tecnologías agrícolas locales es un tema que encara notables dificultades de medición. Los métodos multicriterio pueden ayudar a los investigadores en la construcción de indicadores agregados de sostenibilidad y en la ordenación de las tecnologías agrícolas de acuerdo con su sostenibilidad. Este trabajo muestra como una técnica de decisión multicriterio, el *Analytic Network Process* (ANP), puede ser empleada al respecto. Contrariamente a otros enfoques, en el ANP todos los elementos de la red pueden ponerse libremente en relación, lo que permite incorporar relaciones de interdependencia y realimentación. Su uso se ilustra ordenando tres tecnologías de cultivo del arroz —tradicional, agroambiental y ecológica—, en los arrozales del Parque Natural de la Albufera (Valencia), con criterios de sostenibilidad económicos, ambientales y socioculturales, que recogen el carácter multifuncional del cultivo del arroz en esta zona. Los resultados muestran que la metodología ANP permite abordar las complejas interrelaciones implícitas en la evaluación de la sostenibilidad en este caso, y que el sistema de cultivo ecológico es el más sostenible. El sistema agroambiental ocupa el segundo lugar y el sistema sin restricciones el tercero. Señalan también que si solamente se considerara la dimensión económica de la sostenibilidad el orden se revertiría, con las tecnologías tradicional (sin restricciones) y ecológica alternando en sus posiciones y el sistema agroambiental permaneciendo en la segunda posición.

Palabras clave adicionales: biodiversidad, ecosistemas, métodos de decisión multicriterio, ranking de tecnologías.

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* Corresponding author: ernest.reig@uv.es
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Introduction

Sustainability is a widely used concept, but despite the popularity it has achieved since the Brundtland Report (WCED, 1987), remains vague and elusive with regard to its empirical implementation. Both the need to lend scientific substance to this multifaceted concept, and a strong political demand for comprehensive assessments of the evolution of economic, social and environmental conditions have been instrumental in the pursuing of quantification of sustainability.

In the specific case of agriculture, considerable research efforts have been undertaken to overcome the conceptual vagueness of sustainability by defining the appropriate scale of reference to assess sustainability and by developing composite indicators able to integrate the diverse aspects of sustainability (Becker, 1997; Rigby *et al.*, 2000). But there has been no agreement to date on a common framework of indicators that could simultaneously meet the needs of policy-makers and researchers in this field.

Policy-making operates on a larger geographical scale than farming-system research and has pushed in the direction of developing analytical frameworks that comprise sets of indicators defined at national level and ready for international comparisons (OECD, 2001a; EEA, 2005). But it has been shown that many internationally publicized composite sustainability indicators neglect basic scientific rules for the selection of input variables, normalization and weighting of these variables and also formal conditions for meaningful aggregation (Böhringer and Jochem, 2007).

On the other hand, for researchers that are concerned with the interaction between agriculture and biodiversity, or the quality of the natural environment, economic and ecological interrelations are most pronounced at farm level, even if environmental information is frequently lacking at that level (Van Wenum *et al.*, 1999). Defining agro-environmental indicators at national or regional level is not appropriate when indicators are meant to provide information regarding the environmental value of agricultural ecosystems. Therefore, the need to collect and use farm or local farming system-specific agro-environmental indicators has been widely recognised (Peco *et al.*, 1999; Andreoli and Tellarini, 2000; Rigby *et al.*, 2001; Van der Werf and Petit, 2002; Pacini *et al.*, 2003).

Two important methodological aspects have been brought to the fore by the literature. The first is that the assessment of a variety of experts from different disciplines is always required, as it is difficult to ascertain whether alternative farming technologies (*i.e.* organic) are universally better than conventional ones in terms of their economic and environmental impact. It is also too simplistic to assume that agriculture sustainability always implies making agricultural systems more extensive (Pretty, 2008). The second consideration has to do with the aggregation issue, for those researchers concerned with the construction of global sustainability indicators. Aggregating impact indicators appears to be particularly difficult when many different sustainability dimensions and scales are being considered (Riley, 2001). Also, some important dimensions lack quantification. Nevertheless, quantitatively-oriented researchers have risen to this challenge and a variety of methods have been developed to compile composite indicators able to summarise complex multi-dimensional issues in order to provide support to decision-makers (see Nardo *et al.,* 2005, for a review).

This paper aims to contribute to the literature on the measurement of the relative sustainability of farming technologies. We believe that even though establishing the sustainability of a local farming technology is plagued with all sorts of difficulties, analysts and policy-makers should at least be able to choose a preferred production system, based on a comparatively more sustainable production technology. Multi-criteria methods of analysis offer important promises and advantages in order to fulfil this particular task. Several considerations avail this opinion. First, multi-criteria analysis (MCA) facilitates the use of both qualitative and quantitative measurement scales. Second, MCA allows taking on board a variety of interests and views from different stakeholders, facilitating a common understanding of the sustainability problem, and receiving input from multidisciplinary expertise. Also, MCA adds value with regards to other decision support methods because of its ability to make people reveal their preferences and reach compromises, facilitating the achievement of more acceptable outcomes. Multi-criteria methods have a long tradition of use in

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Abbreviations used: AHP (analytic hierarchy process), ANP (analytic network process), AWU (annual working unit), EU (European Union), FAO (Food and Agriculture Organisation) MCA (multi-criteria analysis), OECD (Organisation for Economic Co-operation and Development), WCED (World Commission on Environment and Development).

solving problems related to agriculture and forestry (Romero and Rehman, 1989; Hayashi, 2000; Weintraub and Romero, 2006) and have been used for the construction of composite sustainability indicators; see Díaz-Balteiro and Romero (2004) for an application based on goal-programming.

Accordingly, in this paper we propose the use of a multicriteria decision method, the Analytic Network Process (ANP), for ranking a set of cultivation technologies according to their relative sustainability for a local farming system. This task implicitly involves the construction of a composite sustainability indicator, which will take a different value for each technology. We illustrate the effectiveness of ANP for sustainability assessment of crop technologies conducting an empirical analysis of three rice cultivation technologies in a site of great environmental interest, the Albufera Natural Park in Valencia (Spain), using rice farm budgets, environmental regulations and experts' judgments as input data.

Methodology

Main features of the ANP approach

ANP constitutes an analytical tool that is particularly well suited to discriminating between alternative multi attribute options and also offers plenty of opportunities for making use of multidisciplinary expert knowledge (Saaty, 2005). The ANP technique has evolved as a further refinement and improvement of the Analytic Hierarchy Process, or AHP (Saaty, 1980), which has shown satisfactory results when dealing with decision problems in which a hierarchical criteria structure can be established and criteria independence can be assumed and proved. A wide range of applications of AHP have been published since its invention and the ability of AHP to allow for the computation of a composite sustainability index, and depict the relative performance of companies along the three basic dimensions of sustainability has also been demonstrated (Krajnc and Glavic, 2005; Kumar *et al*., 2007). Kallas *et al.* (2007) have used AHP, combined with contingent valuation, for computing the worth of such attributes of agricultural multifunctionality as the contribution to the availability of healthier food products, or the use of environmentally friendly agricultural practices.

Several researchers have used AHP to compare and rank alternative technological scenarios with respect to an overall goal. The target has been to choose the best options for transferring environmentally sound technologies to developing countries (Ramanathan, 2002), to determine the priority of use of alternative irrigation technologies (Karami, 2006), to assess different research trajectories concerning biotechnology in order to select the most promising research activities (Braunschweig, 2000), or to compare conventional cultivation techniques with regard to others judged more environmentally-friendly (Parra *et al.*, 2007, 2008). Even though pursuing this line of research, we intend to avoid some of the shortcomings of AHP that frequently surface when facing complex real-world situations. The hypothesis assumed by AHP of independence among criteria or the existence of a linear bottom-up decision structure, cannot be verified in many cases. ANP shares many of the features of AHP as a method for solving decisional problems, but is able to overcome the problem of interdependence and feedback among criteria.

ANP models the problem as a network of criteria and alternatives (which are all called elements), grouped into clusters. All the elements in the network can be related in any possible way, which means that a network can incorporate feedback and interdependent relationships within and between clusters. The implementation of ANP proceeds by the following main steps (Meade and Sarkis, 1999; Saaty, 2005; Lee *et al.*, 2009):

(i) Structuring the problem as a network. The whole complex of interrelationships can be represented through a *matrix of interfactorial domination* with zero-one entries respectively asserting the absence or presence of influence between the corresponding elements.

(ii) Conducting pairwise comparisons on the elements in the network, when interactions, denoted by unity entries in the matrix of interfactorial domination, are deemed to exist. Experts are individually asked to respond to a series of pairwise comparisons where two components at a time will be compared with respect to their importance towards their particular upper level «control» criteria. Comparisons are performed using a 1 to 9 scale, suggested by Saaty (1980), which reflects a gradually increasing intensity of preferences, dominance, or relative importance, from «equal importance» (1) to «extreme importance» (9) of one criterion with respect the other.

(iii) The priority vectors that have been derived in step (ii) from pairwise comparison matrices are each entered as a part of a column of a larger matrix that is called a *supermatrix*. The supermatrix is a partitioned matrix where each segment represents the influence of a cluster on the left of the matrix on a cluster at the top of the matrix.

(iv) Weighting the blocks of the supermatrix computed in (iii), by the corresponding priorities of the clusters. The vector of cluster priorities is obtained by conducting pairwise comparisons among row clusters with respect to the cluster placed at the top of each column.

(v) The weighted supermatrix is raised itself to powers until the values of the rows converge to the same value for each column of the matrix. This mathematical operation is performed in order to capture the transmission of influence along all possible paths of the supermatrix. The resulting matrix is called the *limit supermatrix*. Every column of the limit supermatrix shows the same solution of the network problem: the global importance or priority of each element of the network.

Some recent applications of ANP to decision making problems include: evaluation of alternative fuels for electricity generation (Köne and Büke, 2007), performing Strengths-Weaknesses-Opportunities and Threats (SWOT) analysis at firm level (Yüksel and Dağdeviren, 2007), asset valuation (Aragonés-Beltrán *et al.*, 2008), evaluation of sustainable forest management strategies (Wolfslehener and Vacik, 2008), and evaluation of soil erosion risk in Spanish mountain olive plantations (Nekhay *et al.*, 2009).

ANP makes it possible to comprehensively sum up the different facets of sustainability of a particular farming system or farming technology. It also enables the views of different stakeholders to be integrated in the decision process, which are encouraged to compare and evaluate alternative goals and criteria. As far as we know, ANP has not been used previously to rank farming cultivation technologies with regards to their sustainability.

The multifunctional role of flooded rice fields in the Albufera Natural Park

The Albufera is a large Mediterranean coastal lake, located south of the Metropolitan Area of Valencia (Spain) and fringed by areas of rice cultivation and sand dunes. The marshy habitat that surrounds the lake has been transformed into paddies throughout and the lake surface is substantially lower nowadays than at the beginning of the 20th century. The transformation was legally stopped some decades ago and the whole area was declared a Natural Park in 1986 and a Ramsar site in 1990, with rice cultivation becoming subjected to Park's regulations. Since 1991, the Albufera has been an Area of Special Protection for birds, according to the Birds Directive of the European Union (EU) (79/409/EEC) and is a site of the European network *Nature 2000*. The total surface area of the Park is 21,120 hectares, of which nearly 15,000 are rice fields and 2,800 belong to the lake itself. This fresh water lake is connected to the Mediterranean Sea through several narrow inlets, endowed with artificial gates. The levels of water in the lake are artificially managed, in relation to the seasonal requirements of rice fields.

Traditional rice cultivation in Spanish marshy areas, besides helping to shape a highly valued traditional landscape, performs important non-marketable functions linked to the protection of biodiversity and the environment (Reig, 2006). The rice fields are flooded during summer, a season in which the Mediterranean wetland areas suffer from droughts and also during part of winter, for ecological reasons, and act as substitutes for natural wetlands (Fasola and Ruiz, 1997; Elphick, 2000). On the other hand, in the specific case of the Albufera in Valencia, the rice fields act as natural sedimentation basins for the urban residual waters that are later emptied into the lake, thus improving the quality of waters in the Park. They also perform an important public health function, by preventing a marsh land area from becoming a source of diseases like malaria (Estruch *et al.*, 2003).

Rice cultivation technologies and evaluation criteria

We compared three cultivation systems that use the same variety of rice. The first, *agro-environmental cultivation*, is currently used and regulated by the Albufera Nature Reserve and by the specific commitments linked to the agro-environmental programme «Flora and Fauna Protection Programme in Coastal Wetlands». The second, *unrestricted traditional cultivation*, is the system that would be used if the restrictions imposed by the abovementioned Reserve and Programme did not exist. Finally, the third type is *ecological cultivation*.

Agro-environmental cultivation is restricted by agro-environmental measures belonging to the aforementioned Programme, and the Reserve's norms. In order to be eligible for EU agro-environmental payments, farmers must fulfil regulations which make it compulsory to flood rice fields in winter, restrict the amount of fertiliser used, treat *Chilo suppressalis* (a stem borer plague) with pheromones and to mechanically control weeds on the edges of fields and in irrigation channels, as well as in the fields themselves, before planting. The main restrictions imposed by the Reserve are infrastructure-related. All building activity, including separating fields and reforming channels and field edges and raising the level of the plots by adding soil are prohibited.

Unrestricted traditional cultivation means that farmers would not be subject to the regulations described above. This would result in inputs being used differently and existing infrastructures being modified. Eliminating the restrictions regarding the use of inputs would have two effects. Firstly, the amount of fertiliser used would increase and, therefore, yields would also rise. Secondly, weed killers would be used before planting. Also, building materials (*i.e.* cement) would be allowed in maintenance work on the edges of rice fields and the banks of irrigation channels, making it easier and cheaper to counteract the damage done by small crustaceans, like the red swamp crayfish. However, the most significant change would involve infrastructure, affecting the network of channels and the size and structure of rice fields. Modifying the irrigation network would consist of increasing the size of *tancats* —communal irrigation units that currently vary a great deal in size— and making them uniform in order to minimise the cost of maintaining the hydrological network. Modifying the size and structure of cultivation fields would also help to reduce mechanisation costs.

Ecological cultivation would be in compliance with the regulations laid down by the Spanish Ecological Agriculture Regulating Council, which means that only natural inputs may be used. The main problem this cultivation system faces in this area is controlling weeds, as it is not possible to rotate crops. For this reason, once all land preparations have been made and before planting, the field has to be flooded in order to cause the weeds to sprout. Then the level of water would be raised by 40-50 cm for a month, hence drowning the weeds. Twenty days after raising the level of water, aerial sowing would take place and ten days later farmers would lower the level of water. From this point onwards, the process is similar to that employed in agro-environmental cultivation, except that post emergency weeds must be killed manually. Winter tasks are also similar and the rice would be fertilised with organic material (hen droppings). However, the smaller doses of fertiliser used and the presence of weeds would reduce yields. This situation would be made worse when facing fungi attacks, as controlling them without the aid of synthetic products is not very effective.

All three technologies have been evaluated using criteria defined by a group of 20 experts in rice cultivation and environment and socio-cultural issues. The group included technical staff from two farmers' professional organisations (5), and also from the Regional Government (4), ecologists' organisations (2), the Albufera Park's office (2), a local irrigation office (1), academics from the High School of Agronomic Engineering of the Polytechnic University of Valencia (2), and some independent professionals and businessmen involved in the rice farming trade, including a rice farmer (4). This group was asked to define criteria to measure the sustainability of the three cultivation systems under analysis. The criteria proposed by these experts were grouped into three different clusters: economic, environmental and socio-cultural criteria.

Economic criteria correspond to short and long term competitiveness defined according to Monke *et al.* (1998). We have computed monetary values for both indicators using average farm budgets obtained from a sample of rice farmers operating in the Park and costing the deviations from current practices implied by farmers' use of alternative technologies, see Table 1.

The figures resulting from computing short and long term competitiveness were directly applied to the ranking of the three rice cultivation technologies. In all the other cases (environmental and socio-cultural criteria), qualitative information has been used, reflec-

Table 1. Economic competitiveness indicators for alternative rice production systems in the Albufera Natural Park. Data in Euros per hectare and AWU of on-farm family labour

	Agroenvironmental cultivation	**Ecological cultivation**	**Unrestricted traditional cultivation**
Short term competitiveness indicator	32,472	36,846	27,406
Long term competitiveness indicator	17,983	19,506	14,595

ting experts' judgment. Short listing a set of environmental and socio-cultural criteria from a large number of potential candidates was the first task. It was possible after consultation with the same group of experts that later provided input in terms of the construction of the pairwise comparison matrices.

Our list of environmental criteria includes the following: biotic environment conservation within the rice fields, water quality maintenance in the Park, air quality maintenance, and biotic environment conservation external to the rice fields, that is, in the lake and the irrigation channels. Socio-cultural criteria include the preservation of the hydrological heritage that has evolved historically as the level of the water in the lake and the irrigated rice fields has been jointly managed by means of a complex network of physical elements (*i.e.* irrigation channels and floodgates, farm buildings) and institutions (*i.e.* collective arrangements for irrigation and drying up of irrigation units, management of the level of water in the lake). The protection of the traditional landscape, the effect on the amount of labour used and the impact on other economic activities linked to rice farming are also included.

Thus, we have finally made use of four clusters of elements for our ANP application. One is made up of the three rice cultivation technologies described above, while the other three correspond to the three sets of aforementioned criteria: economic, environmental and socio-cultural.

Using ANP to rank rice cultivation technologies

We have proceeded in the first place to define and structure our problem in terms of a network of clusters. Clusters have been connected by arrows that depict their mutual influences or relative importance. Loops have also been added to allow for internal relationships within clusters. Figure 1 describes the network as applies in our case.

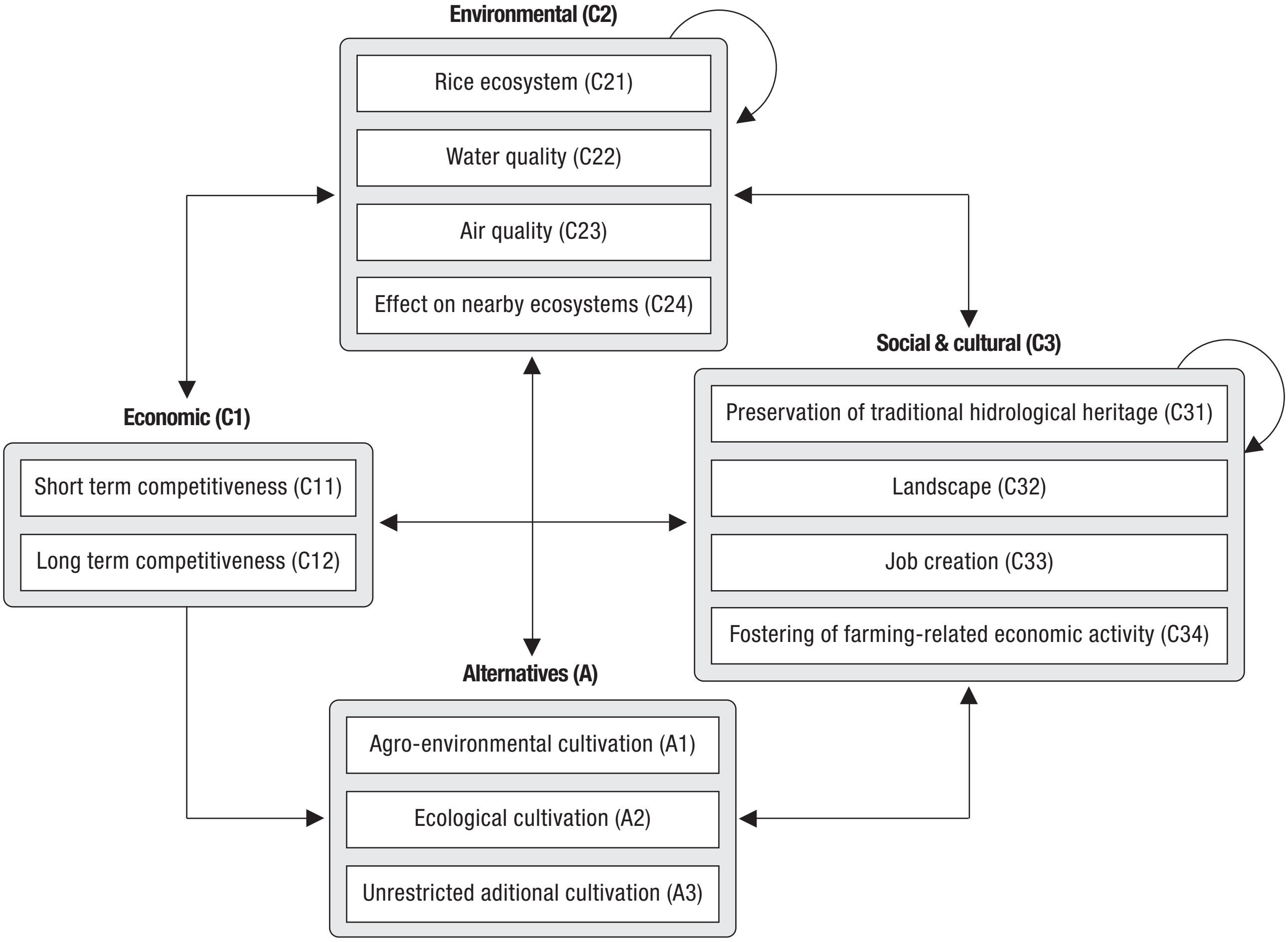

Figure 1. Network of outer and inner dependence.

We now proceed to describe the most important interactions that occur among clusters. One of the most clear-cut cases is the relationship between the economic cluster and rice fields' biotic environment conservation element (C21) in the environmental cluster. The effects of short and long term economic competitiveness on biodiversity protection in the rice fields are grounded on the existence of *production jointness* (OECD, 2001b) between the production of rice —a private good— and the supply of a public good (biodiversity). In this particular case, a variety of waterfowl feed on the rice that remains in the soil after the harvest and on small fish and crustaceans that depend on the continuation of rice production. Economic competitiveness, allowing the continuation of rice cultivation, also influences water quality (C22), because the rice fields act as natural sedimentation basins for urban residual waters flowing into the lake and for waters that seasonally circulate between the lake and the rice fields.

The environmental cluster also exerts an influence on the social and cultural cluster. For instance, biodiversity protection in the rice fields (C21) induces job creation (C33), because the mechanical control of weeds, which substitutes the use of chemical products, is more labour intensive. Furthermore, more labour is also required for maintenance work in order to counteract the damage caused on rice field edges by some small crustaceans, like the red swamp crayfish that, once again, cannot legally be fought with chemical products.

The relationship between the economic cluster and the social and cultural cluster stems from the impact that rice cultivation has on the four criteria included in the latter. If rice farming is not economically viable, it will be abandoned, leading to a change in the current landscape (C32). Moreover, considering there is no farming alternative in the area under study, if rice cultivation were abandoned, the remaining three criteria would also be affected, as the rest of links to the local production system through the supply of output and the demand for labour, inputs and services would be broken (C33, C34) and the incentives to maintain the hydrological system (C31) ready for use would disappear.

The social and cultural cluster is related to the economic cluster through the impact that the presence of labour and small firms specialised in traditional jobs and farm management in the area has on cultivation costs (and therefore on economic indicators C11 and C12).

Likewise, the three cultivation technologies (A1, A2, and A3) influence the economic cluster, because income and costs will be different and, therefore, so will the economic indicators. Differences in cost are the direct result of the type of cultivation tasks carried out. In the case of income, differences are due to subsidies, which depend on the technology used, and to different market revenue derived from changing yields and sale prices.

Moving on to the description of the loops connecting elements belonging to the same cluster, one example concerning the social and cultural cluster is the conservation of hydrological heritage (C31), which influences job creation (C32) and fosters economic activity (C34), as labour and machinery are being employed to clean the beds of irrigation channels and labour is used to mow the weeds at the margins. Hydrological heritage also affects the maintenance of the landscape (C33). The other cluster in which criteria are interrelated is the environmental cluster. A decrease in water quality (C22), due to pollution by nitrates, phytosanitary products and herbicides, directly affects the trophic chain and, consequently, the biodiversity of the ecosystem in both the rice fields and neighbouring areas. Likewise, changes in the state of the rice fields (C21) and in adjacent areas (C24) influence each other as they are part of one sole ecosystem.

The interdependences described above allowed for the construction of the corresponding interfactorial domination matrix. Then, the interfactorial domination matrix was used to obtain the supermatrix, built up with the eigenvectors obtained from the pairwise comparison matrices proposed by the group of experts. The following procedure was used: the whole group of experts was asked to establish the outer dependences in both directions between the alternative (A), environmental (C2) and sociocultural (C3) clusters by means of pairwise comparisons using Saaty's Fundamental Scale (1980). A subgroup of 12 experts was asked, using the same methodology, to determine the outer and inner dependences between the economic (C1), environmental (C2) and sociocultural (C3) clusters. The subgroup was chosen according to experts' profile of specialisation. In both cases, the opinions expressed by the experts were put together in order to obtain an aggregate result for each subgroup. As a result of the outer dependences between the alternatives (A) and the cluster of economic criteria (C1) being quantitatively defined, the eigenvector was determined directly in this case by means of normalisation (Saaty, 1980).

Table 2. Limit supermatrix

		Economic C1		**Environmental C2**				**Social & cultural C3**				**Alternatives A**		
		C11	**C12**	**C21**	**C22**	**C23**	**C24**	**C31**	**C32**	**C33**	**C34**	**A1**	**A2**	**A3**
C1	C11	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024	0.024
	C12	0.142	0.142	0.142	0.142	0.142	0.142	0.142	0.142	0.142	0.142	0.142	0.142	0.142
C2	C21	0.059	0.059	0.059	0.059	0.059	0.059	0.059	0.059	0.059	0.059	0.059	0.059	0.059
	C22	0.119	0.119	0.119	0.119	0.119	0.119	0.119	0.119	0.119	0.119	0.119	0.119	0.119
	C23	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015	0.015
	C24	0.146	0.146	0.146	0.146	0.146	0.146	0.146	0.146	0.146	0.146	0.146	0.146	0.146
C3	C31	0.122	0.122	0.122	0.122	0.122	0.122	0.122	0.122	0.122	0.122	0.122	0.122	0.122
	C32	0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042	0.042
	C33	0.029	0.029	0.029	0.029	0.029	0.029	0.029	0.029	0.029	0.029	0.029	0.029	0.029
	C34	0.065	0.065	0.065	0.065	0.065	0.065	0.065	0.065	0.065	0.065	0.065	0.065	0.065
A	A1	0.093	0.093	0.093	0.093	0.093	0.093	0.093	0.093	0.093	0.093	0.093	0.093	0.093
	A2	0.104	0.104	0.104	0.104	0.104	0.104	0.104	0.104	0.104	0.104	0.104	0.104	0.104
	A3	0.039	0.039	0.039	0.039	0.039	0.039	0.039	0.039	0.039	0.039	0.039	0.039	0.039

Finally, the limit supermatrix (Table 2), which lists the weightings of the criteria (C11,…,C34) and alternatives (A1, A2, A3) under study, was obtained by raising the supermatrix, previously transformed into a stochastic matrix, to consecutive powers. Aggregation of individual preferences was performed using the method of the geometric mean.

Results

Table 3 was obtained from the data in Table 2 and presents the aggregate score for the set of criteria that make up each cluster. The table shows that, taking aside the three cultivation options; the experts consider the environmental cluster to be the most important (44.4%), followed by the social and cultural cluster (33.8%) and the economic cluster (21.7%).

Table 3 also presents the normalised weightings for the criteria used, four of which account for almost 70% of the total: the effect of rice cultivation on the biodiversity of nearby ecosystems in the Park (C24); the indicator of long term competitiveness (C12), which is related to the viability of maintaining the Park's rice surface area in production, the impact that the cultivation alternatives have on the preservation of traditional hydrological heritage (C31) and the impact of cultivation on water quality (C22). This suggests that experts most value the criteria that directly affect the biodiversity of the existing ecosystem in the Park outside the specific areas where rice is cultivated.

The normalised weighting of the alternatives of rice cultivation technology (A) are also displayed in the Table. Ecological cultivation (A2) receives the highest weighting (44.4%), followed by agroenvironmental cultivation (A1) (39.5%) and some distance behind, unrestricted traditional cultivation (A3) (16.4%).

Table 3. Element weightings

		Weighting	**Normalised weighting**
Cluster			
C1	Economic	0.166	0.217
C2	Environmental	0.339	0.444
C3	Social & Cultural	0.258	0.338
Criteria			
C24	Effect on nearby ecosystems	0.146	0.191
C12	Long term competitiveness	0.142	0.186
C31	Preservation of hydrological heritage	0.122	0.160
C22	Water quality	0.119	0.156
C34	Fostering of economic activity	0.062	0.086
C21	Biodiversity proteccion	0.059	0.078
C32	Landscape	0.042	0.056
C33	Job creation	0.029	0.038
C11	Short term competitiveness	0.024	0.031
C23	Air quality	0.015	0.019
Alternative rice production technologies			
A1	Agroenvironmental	0.093	0.395
A2	Ecological	0.104	0.441
A3	Unrestricted tradicional	0.039	0.164

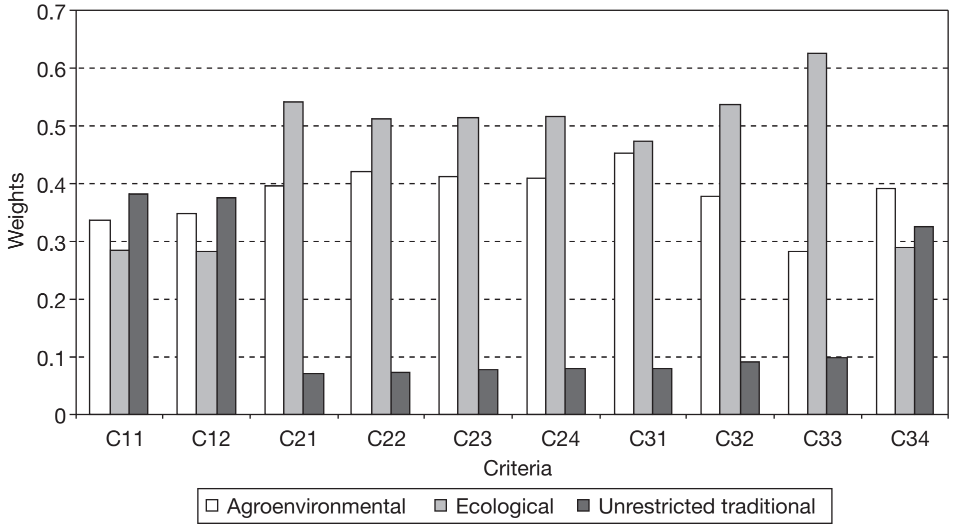

Figure 2. Criteria weightings by alternative.

Figure 2 displays the weightings assigned to each criterion for each alternative. Unrestricted traditional cultivation is only superior to the other two when economic criteria alone (C11, C12) are considered. However, when considering the remaining criteria, the alternatives of agro-environmental and ecological cultivation are considered substantially more sustainable than unrestricted traditional cultivation, except in relation to fostering farming-related economic activity (C34), where weightings are more evenly balanced. The reason why ecological and agro-environmental cultivation are more valued is that they are more respectful of the natural ecosystems near the rice fields, they have less of a negative impact on water quality and they guarantee the preservation of hydrological heritage.

On the other hand, if the agro-environmental (A1) and ecological (A2) alternatives are compared, we can see how the latter is better considered than the former in all criteria except those in the economic cluster and C34. Ecological cultivation achieves the greatest advantage over agro-environmental cultivation with regards to criteria C33 (job creation), C32 (landscape), and C21 (biodiversity protection).

Consequently, it has been verified that the best alternative depends on the clusters being considered and the weightings that each has received. Therefore, if only economic criteria were taken into account, unrestricted traditional cultivation would be the preferred alternative. However, when all sustainability criteria are contemplated, each with its corresponding weighting, ecological cultivation is the highest valued alternative, followed closely by agro-environmental cultivation, while unrestricted traditional cultivation is the least valued alternative, at a substantial distance behind the other two.

Discussion

Considerable research has been devoted in the last few years to go deeply into the concept of sustainability and its measurement. It has been generally agreed that agricultural sustainability is best understood at farming system scale and from a quantitative approach (Hansen, 1996). This paper adopts this characterization of agricultural sustainability, dealing with the construction of sustainability indicators for rice cultivation technologies operated at local farming system level. We propose the use of the Analytic Network Process, a multicriteria decision method, to rank locally-applied cultivation technologies.

Facing the difficult issues of aggregation and weighting, some researchers have preferred not to aggregate individual indicators selected to evaluate different facets of sustainability (*i.e.* Rasul and Thapa, 2004). Others have opted for a variety of methods to construct composite indicators of sustainability, including the use of multicriteria decision methods. One stream of the literature using multi-criteria decision methods has focused on the assessment of sustainable development or the evaluation of agricultural practices using the Analytical Hierarchy Process (Krajnc and Glavic, 2005; Karami, 2006; Parra *et al.*, 2008). But we believe that the relative performance of a set of technologies in terms of sustainability does not always lend itself to be modelled as a linear bottom-up hierarchic process, as in AHP. We show instead how ANP is able to deal with feedback and interdependence relationships between different clusters of environmental, social and economic variables operating in local farming systems. We empirically illustrate the use of ANP in assessing the sustainability of cultivation technologies through an application to rice farming in a site of great ecological value, the wetlands of the Albufera Natural Park of Valencia (Spain).

Rice cultivation in Mediterranean wetlands, like the Albufera Natural Park (Valencia, Spain) is a system of land management that performs important non-marketable functions, such as protecting biodiversity and shaping highly valued landscapes. That is the reason why rice farming in this area qualifies as a multifunctional cultivation system. But, sustainability is a much more policy-oriented concept than multifunctionality. Ranking alternative cultivation technologies according to sustainability contributes an input for public policy making and can shed light on the discussions concerning the legitimacy of public interventions grounded on the multifunctionality discourse (OECD, 2001b; Brouwer, 2004).

This paper undertakes a comparative analysis of the economic, environmental and socio-cultural sustainability of three alternative rice cultivation technologies in the Albufera rice fields: the current system, that we call agro-environmental, a conventional production system, with no environmental restrictions attached and an ecological cultivation system. All three technologies have been submitted to evaluation, using the following criteria: short and long term economic competitiveness, impact on air and water quality, impact on landscape and biodiversity, cultural heritage with regards to the hydrological system and ability to foster job creation and economic activity in the area. These criteria were grouped in three clusters, namely economic, environmental and socio-cultural sustainability.

The ANP was used to rank the three aforementioned technologies according to their relative sustainability, implicitly building up a composite sustainability indicator. Using this methodology, we found that the ecological cultivation system is the most sustainable technology (weighted value of the sustainability indicator of 0.441). The current agro-environmental system ranks second (0.395), while the conventional unrestricted system ranks last (0.164), at a substantial distance behind the first two. Our computations also showed that if only the economic dimension of sustainability were considered, the order would be reversed, with conventional and ecological technologies changing places and the current system remaining in second place.

The singly most important criteria for analysing sustainability was the effect of the three cultivation alternatives on the ecosystems nearby the rice fields (C24, 0.191), the long term competitiveness indicator (C12, 0.186), the preservation of hydrological heritage (C31, 0.160) and conservation of water quality (C22, 0.156). Only under the second of these criteria, which belongs to the economic cluster, is unrestricted conventional cultivation superior to the other two alternatives. This illustrates the importance of including not only economic criteria, but also environmental and socio-cultural criteria when it comes to ranking the sustainability of different cultivation technologies. It is also evident that biases can arise in the weighting of different criteria from experts' subjective judgment. Even if it is an unavoidable feature of this methodology, we have done our best in this paper to minimise this risk by choosing a balanced group of experts, widely representative of different views.

We conclude that multi-criteria methods, like ANP, should be seriously considered to enhance the use of sustainability analysis for farm and agro-environmental policy making, because they grant the due attention to the multiple facets of the concept of sustainability and reinforce its practical relevance. Ranking alternative farming technologies according to multiple economic, social and environmental criteria leads to an improved assessment of the public and private costs and benefits of farming, and allows for a more rational design of public interventions directed to the correction of environmentally-related market failures.

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