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Economic valuation of the environmental impact of anaerobic degradation of rice straw in the national park of the Albufera of Valencia, Spain

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Abstract

Straw rice cultivation in the area of the "Tancats" in the Natural Park of Albufera may suffer anaerobic degradation in humid conditions affecting water quality, impacting negatively on the lake's ecosystem. To perform the impact valuation, during the 2013–2014 season, we first enumerate ecosystem goods and services generated by the Natural Park of the Albufera. Once the services are defined we proceed by using a multi-criteria analysis (AMUVAM) based on experts to evaluate how each of the services are affected by straw anaerobic fermentation. Finally, once hierarchical relevance of impacts is settled, we obtain the total economic impact by using AMUVAM analysis.
Keywords: rice straw, anaerobic fermentation, ecosystem services, AHP, economical valuation, environmental impact, AMUVAM.

1 Introduction

The Albufera Natural Park is considered one of the most important wetlands of the Iberian Peninsula and the Mediterranean, both for its size and for the valuable biodiversity that it hosts (Colmenar [1]). For centuries it has been subjected to anthropogenic exploitation and transformation. This process of agricultural transformation, converting marshes and salt marshes into paddy fields, and the regulation of the hydrological functioning of the wetland to promote cultivation, has been the major cause of the modification of the original landscape of the Albufera (Ferrando and Dies Jambrino [2]).

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Rice production is the main economic use of the territory of the Albufera. It is one of the pillars that sustains the local economy, moreover agriculture is also an essential factor in maintaining the wetland ecosystem that has developed in symbiosis with it. On the one hand the cultivation ensures the maintenance of flood levels and is directly linked to both marsh and aquatic plant and animal communities, and on the other hand it maintains an agricultural landscape, rich in tradition (Díaz *et al.* [3]).

Every year, at the end of the cycle of rice cultivation after its harvest, the straw is left lying on the fields. Traditionally straw was removed and used for other purposes, however since the late 60s such uses were no longer profitable and straw had been eliminated by burning it on the same fields. This practice produced huge amounts of smoke throughout the surrounding areas, emitting CO_2 accumulated in plants and causing public health problems (Sanchís-Jiménez [4]).

In recent years, economical aid promoted by the EU for farmers benefiting from agro-environmental payments of the Common Agricultural Policy (CAP), prohibits the burning of straw as standard practice admitting exceptions for extraordinary cases only, such as phytosanitary emergencies. That is, farmers comply not to burn the rice straw in order to collect the EU aid (Estruch-Guitart and Planells-Valles [5]). This limitation has forced researching new ways of managing straw as pilot projects for the LIFE program of the European Commission SOST-RICE and ECO-RICE carried out by the Valencian Institute of Agricultural Research (IVIA) in collaboration with the Polytechnic University of Valencia (UPV), amongst others, where they study alternatives to burning straw. Regarding the different models for straw management, some focus on the removal from the field and subsequent revaluation of biomass waste, whilst others approach this problem by in-situ treatment and management. The latter may consist in pre-crushing straw for posterior burial or scattering of said straw on the field surface before the winter flooding. This last practice results, during the rainiest years, in the environmental impact analysed in the present work.

When the straw remains on the field and this is subsequently flooded during the winter months (October to January), this leads to the decomposition of this material by heterotrophic microorganisms that live in the water. Thus, even before the straw is completely degraded, the microbial activity will significantly reduce the concentration of dissolved oxygen in the water. This phenomenon of hypoxia/anoxia due to organic matter degrading activity by heterotrophic and aerobic microbial communities, has been widely reported even in natural aquatic environments (Hoch *et al.* [6]). Once in the absence of oxygen, the degradation of the rice straw will progress through the activity of anaerobic heterotrophic microorganisms, which are able to live without oxygen. These microorganisms will decompose rice straw by two main processes; fermentation or anaerobic respiration. This "anoxic" degradation of rice straw involves a greater variety of microbial types, and therefore also a diversity of end products from their metabolism (Nealson and Scott [7] and Madigan *et al.* [8]). However, among them, those who will have a negative effect on the overall value of the habitat, are methane (CH_4) and hydrogen sulphide (H_2S). In fact, these concentrations of hydrogen sulphide together with the absence of oxygen in water have proved seriously damaging in certain areas of the "tancats" park causing mass death of fish and other aquatic organisms damaging the fisheries and prejudice to the neighbouring population.

In section 2 the objective of the work is proposed and the methodology used, the expert selection and the selection of affected Ecosystem Services (ES) is justified. In point 3 we analyse the first expert consultation by which we defined the ES affected by the environmental impact. In point 4 we proceed to the second phase of the interviews where experts apply a multi-criteria analysis, this data is studied in Section 5. In Section 6 the economical valuation assessment is performed by applying the AMUVAM. Section 7 is the conclusion of this work.

2 Objective and methodological framework

The purpose of this paper is to present a methodology to economically assess the environmental impact generated by rice straw decomposition, under anaerobic conditions, on the ecosystem services. First the information about ecosystem services from the park will be collected and those which were affected by the impact will be identified by a first group of experts. Then through a second consultation with experts, using the methodology of Analytic Hierarchy Process (AHP) (Saaty [9]), the relevance each expert attributes to the impact on each of the services is obtained, and subsequently through an aggregation of all the values we obtain an interval of Economic Value for the Environmental Impact. There are precedents in the field of application of the AHP and updating of rents to reach an Indicator of Total Economic Value of Environmental Assets (Aznar and Estruch [10]).

2.1 Expert selection

To proceed with the assessment, two groups of experts have been selected. The first group is composed by experts in the park's ecosystem and pertains mainly to academic and research backgrounds. The second group is composed by the experts from the first group with the addition of professional organizations from farmers and fishermen, administration representatives, park technics and representatives of ecologist groups, all of which are listed below:

- Polytechnic University of Valencia (UPV).
- University of Valencia (UV).
- Fishermen Community Catarroja.
- Fishermen Community of El Palmar.
- Technical Management Office Albufera.
- Recovery Center Fauna and Flora (GVA).
- Interpretation Centre Raco l' Olla (GVA).
- Acció Ecologista.
- Tancat de la Pipa.
- AVA-ASAJA Cooperative.

- Assut Foundation – Sat Rice Growers Pinedo Valencia.
- Piscifactoria the Palmar (LIFE).

2.2 Ecosystem services definition

The concept of ecosystem services and its consideration for environmental economic valuation has been the result of intense debate on different fronts, but it is possible to define within a particular conceptual framework to define and analyse reality from within it (Boyd and Banzhaf [11]). For this analysis we will take as an ecosystem service those aspects of the ecosystem used directly or indirectly to generate human well-being (Fisher and Turner [12]). Also we consider the differentiation between ecosystem services that we will value and benefits of these services in order to avoid possible double counting when making economic valuation, considering and accounting for only the final ecosystem services (Boyd and Banzhaf [11]). Similarly, we consider that another defining characteristic for these to be considered as ES is to be ecological processes in nature, considering also the Cultural Services as a component of the SE (Wallace [13] and MA [14]).

2.3 Analytic Hierarchy Process (AHP)

The AHP (Saaty [9]) is a method which helps decision making, widely used in various professional and business fields. Allowing to prioritise a set of alternatives by a paired comparison between components through a fundamental scale designed for this purpose (Table 1).

Table 1: Scale of comparison (Saaty [9]).

Intensity of Importance	Definition	Explanation
1	Equal importance	Two activities have equal contribute to the objective
3	Moderate importance	Experience and judgment slightly favor one activity over another.
5	Strong importance	Experience and judgment strongly favor one activity over another
7	Very strong on demonstrated importance	An activity is favored very strongly over another
9	Extreme importance	The evidence favoring one activity over another is of the highest possible order of affirmation
2,4,6,8	For compromise between the above values	Sometimes one needs to interpolate a compromise judgment numerically

Comparing two by two alternatives based on one criteria, and using the scale box of pairwise comparison we obtain square matrices $A = a_{ij}$ that meet the properties of reciprocity, homogeneity and consistency.

The eigenvector v_{ai} of the proposed matrix indicates the importance or weight of each alternative based on that criterion.

AHP also evaluates the inconsistency of the decider when making judgments by calculating the so-called consistency ratio (CR). Overall, inconsistencies are accepted below 10% for matrices of rank n> 4 (5% for n = 3 and 8% for n = 4) (Saaty [9]). If these conditions are not met, the judgments should be revised or the matrices discarded.

In this paper, unlike a classic model of AHP and previous work on assessment, prioritization is performed by taking into account a single criterion, so that the paired comparison is used only to answer the question "between these two ecosystem services affected by the environmental impact, which is considered to be most affected, and with what intensity". The resulting matrix corresponding to the eigenvector of this process indicates the weighting or relative importance of all the ES considered.

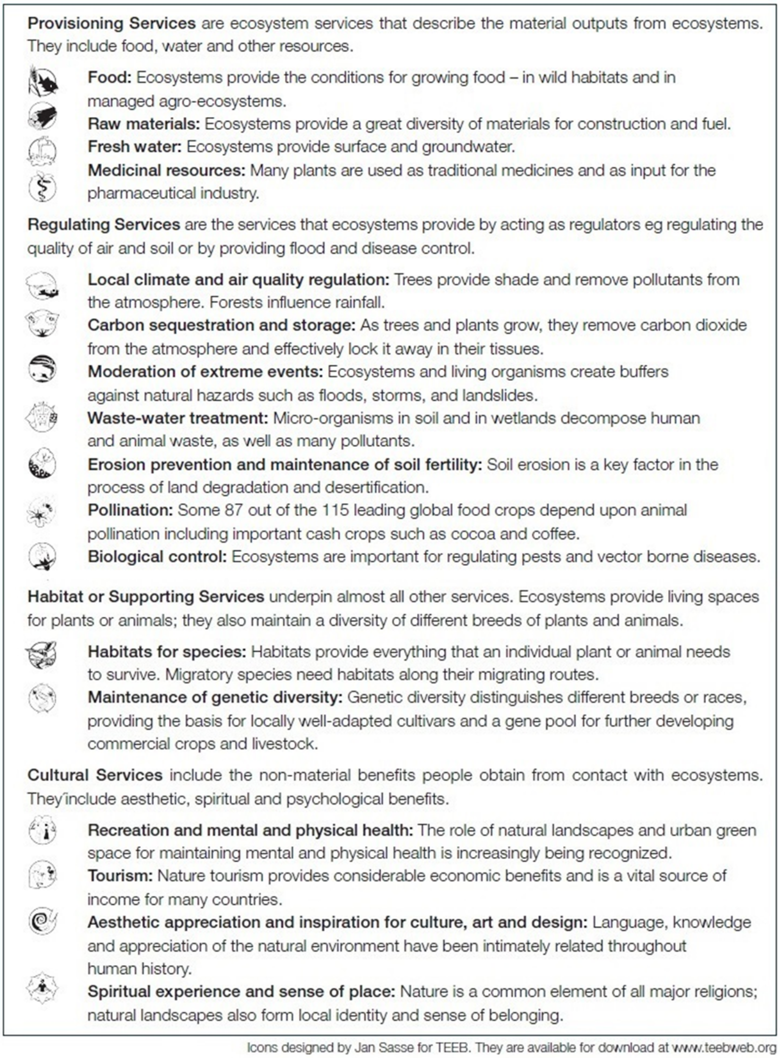
3 Environmental impact on ecosystem services

During the first phase of the study, individual interviews with a group of experts were conducted in order to determine which ecosystem services were directly affected by the impact produced due to the anaerobic fermentation of straw. For this, the following procedure was followed:

- Subjects were exposed to the definition of ES spelled out in 2.2, differentiating between intermediate services, final services and benefits derived from them (Boyd and Banzhaf [11]).
- Then the different strategies of the rice straw management in the park and the physical and chemical processes of anaerobic fermentation were explained to them (Hoch *et al.* [6]) (as mentioned at the end of section 1 of this work).
- Afterwards, these experts were presented with a categorization of ecosystem services to provide a basis from which to perform the valuation (Figure 1), "The Economics of Ecosystems and Biodiversity" [15].
- Once presented with the diagram the experts were asked to list those ES which they judged were directly affected by the impact.

After discussing the results obtained the group of experts agreed on the ES affected by the environmental impact. These services were:

- S1. Fishing (provisioning service).
- S2. Water quality (provisioning service).
- S3. Habitat for species (habitat service).
- S4. Maintenance of genetic diversity (supporting service).
- S5. Cultural services.



Provisioning Services are ecosystem services that describe the material outputs from ecosystems. They include food, water and other resources.

Food: Ecosystems provide the conditions for growing food – in wild habitats and in managed agro-ecosystems.
Raw materials: Ecosystems provide a great diversity of materials for construction and fuel.
Fresh water: Ecosystems provide surface and groundwater.
Medicinal resources: Many plants are used as traditional medicines and as input for the pharmaceutical industry.

Regulating Services are the services that ecosystems provide by acting as regulators eg regulating the quality of air and soil or by providing flood and disease control.

Local climate and air quality regulation: Trees provide shade and remove pollutants from the atmosphere. Forests influence rainfall.
Carbon sequestration and storage: As trees and plants grow, they remove carbon dioxide from the atmosphere and effectively lock it away in their tissues.
Moderation of extreme events: Ecosystems and living organisms create buffers against natural hazards such as floods, storms, and landslides.
Waste-water treatment: Micro-organisms in soil and in wetlands decompose human and animal waste, as well as many pollutants.
Erosion prevention and maintenance of soil fertility: Soil erosion is a key factor in the process of land degradation and desertification.
Pollination: Some 87 out of the 115 leading global food crops depend upon animal pollination including important cash crops such as cocoa and coffee.
Biological control: Ecosystems are important for regulating pests and vector borne diseases.

Habitat or Supporting Services underpin almost all other services. Ecosystems provide living spaces for plants or animals; they also maintain a diversity of different breeds of plants and animals.

Habitats for species: Habitats provide everything that an individual plant or animal needs to survive. Migratory species need habitats along their migrating routes.
Maintenance of genetic diversity: Genetic diversity distinguishes different breeds or races, providing the basis for locally well-adapted cultivars and a gene pool for further developing commercial crops and livestock.

Cultural Services include the non-material benefits people obtain from contact with ecosystems. They include aesthetic, spiritual and psychological benefits.

Recreation and mental and physical health: The role of natural landscapes and urban green space for maintaining mental and physical health is increasingly being recognized.
Tourism: Nature tourism provides considerable economic benefits and is a vital source of income for many countries.
Aesthetic appreciation and inspiration for culture, art and design: Language, knowledge and appreciation of the natural environment have been intimately related throughout human history.
Spiritual experience and sense of place: Nature is a common element of all major religions; natural landscapes also form local identity and sense of belonging.

Icons designed by Jan Sasse for TEEB. They are available for download at www.teebweb.org

Figure 1: TEEB [15] "The Economics of Ecosystems and Biodiversity: Mainstreaming the Economics of Nature: A synthesis of the approach, conclusions and reccomendations of the TEEB".

4 Interviews: multicriteria application

During the second phase of the study, experts were interviewed individually in sessions, for an average of 30 minutes, during which they were presented with a series of descriptive questions about the professional reality of these and their general views of the context in which the park is circumscribed. Once these questions were answered, they were asked to fill in the matrix of pairwise comparisons multi-criteria on which once the consistency ratios where verified, ruling or restating those inconsistent, the eigenvectors corresponding to each ES (Table 2) were calculated.

Table 2: Eigenvectors and consistency ratio.

Expert	Service 1	Service 2	Service 3	Service 4	Service 5	Consistency ratio (%)
1	0.44	0.22	0.14	0.04	0.16	8.69
2	0.37	0.18	0.18	0.13	0.13	9.65
3	0.04	0.55	0.15	0.13	0.13	5.90
4	0.06	0.22	0.04	0.30	0.38	5.83
5	0.38	0.09	0.04	0.06	0.43	9.01
6	0.45	0.26	0.11	0.15	0.03	9.43
7	0.38	0.38	0.10	0.11	0.03	8.83
8	0.28	0.28	0.05	0.28	0.12	3.48
9	0.05	0.58	0.14	0.19	0.05	7.86
10	0.03	0.29	0.24	0.38	0.06	8.94
11	0.53	0.25	0.04	0.06	0.11	9.65
12	0.08	0.24	0.37	0.28	0.03	8.88
13	0.28	0.52	0.08	0.07	0.05	9.25
14	0.33	0.29	0.03	0.26	0.09	8.95
15	0.03	0.28	0.06	0.08	0.55	8.49
16	0.21	0.55	0.08	0.08	0.08	3.39
17	0.09	0.45	0.11	0.32	0.04	8.41
18	0.49	0.26	0.07	0.11	0.08	8.99
19	0.20	0.20	0.20	0.20	0.20	0.00
20	0.39	0.40	0.05	0.13	0.03	7.78
21	0.10	0.27	0.37	0.20	0.05	4.11
22	0.07	0.47	0.19	0.19	0.07	1.25
23	0.08	0.30	0.27	0.27	0.09	0.71
24	0.06	0.49	0.20	0.21	0.03	9.13
25	0.34	0.06	0.40	0.15	0.06	5.68

As shown in table 2, the distribution of the values of the eigenvectors within each ES, we observe that the values given are quite heterogeneous at intervals. Service S1 with an average=0.23 and std.deviation=0.16, and S2 with average=0.32 and std.deviation=0.14, are both the services that present more variability. For this reason and in order to obtain a weighted aggregation of eigenvectors according the methodology of aggregation of the geometric mean, we perform a statistical data analysis to identify trends within the group of experts (Aczél and Saaty [16], Forman and Peniwati [17], Gass and Rapcsák [18]).

5 Conglomerate analysis: ANOVA application

By a multivariate cluster analysis technique, we established three groups over which we have conducted an analysis of variance (ANOVA) and a post- hoc test to establish existing patterns between groups framed within each ES (Table 3).

Table 3: Post-hoc Scheffé test (source: own elaboration).

Scheffé							
Variable dependiente	(I) Average Linkage (Between Groups)	(J) Average Linkage (Between Groups)	Diferencia de medias (I-J)	Error típico	Sig.	Intervalo de confianza al 95%	
						Límite inferior	Límite superior
s1	1	2	,2837273*	0,0431352	0	0,170529	0,396925
		3	,2248182*	0,0658902	0,009	0,051906	0,397731
	2	1	-,2837273*	0,0431352	0	-0,396925	-0,170529
		3	-0,0589091	0,0658902	0,675	-0,231822	0,114004
	3	1	-,2248182*	0,0658902	0,009	-0,397731	-0,051906
		2	0,0589091	0,0658902	0,675	-0,114004	0,231822
s2	1	2	-,1737273*	0,047037	0,005	-0,297164	-0,05029
		3	0,0565758	0,0718502	0,737	-0,131978	0,245129
	2	1	,1737273*	0,047037	0,005	0,05029	0,297164
		3	,2303030*	0,0718502	0,015	0,04175	0,418856
	3	1	-0,0565758	0,0718502	0,737	-0,245129	0,131978
		2	-,2303030*	0,0718502	0,015	-0,418856	-0,04175
s3	1	2	-0,0757273	0,0427723	0,231	-0,187973	0,036518
		3	0,078303	0,0653358	0,499	-0,093155	0,249761
	2	1	0,0757273	0,0427723	0,231	-0,036518	0,187973
		3	0,1540303	0,0653358	0,084	-0,017427	0,325488
	3	1	-0,078303	0,0653358	0,499	-0,249761	0,093155
		2	-0,1540303	0,0653358	0,084	-0,325488	0,017427
s4	1	2	-0,0665455	0,0387072	0,25	-0,168123	0,035032
		3	-0,0012727	0,0591263	1	-0,156435	0,15389
	2	1	0,0665455	0,0387072	0,25	-0,035032	0,168123
		3	0,0652727	0,0591263	0,553	-0,08989	0,220435
	3	1	0,0012727	0,0591263	1	-0,15389	0,156435
		2	-0,0652727	0,0591263	0,553	-0,220435	0,08989
s5	1	2	0,0320909	0,0216281	0,35	-0,024667	0,088848
		3	-,3585152*	0,0330374	0	-0,445214	-0,271817
	2	1	-0,0320909	0,0216281	0,35	-0,088848	0,024667
		3	-,3906061*	0,0330374	0	-0,477305	-0,303908
	3	1	,3585152*	0,0330374	0	0,271817	0,445214
		2	,3906061*	0,0330374	0	0,303908	0,477305

From these analyses we establish that these three subgroups within the surveyed experts differ significantly, especially regarding their value judgments as to the significance of the considered impact on fishing, water quality and cultural services. Of these three groups both 1 and 2 represent 44% of the sampled population each, while group 3 only represents 12%. Another significant factor observed is a differentiation between groups 1 and 2; while group 1 is made up almost entirely of components within the research and university's context, group 2 instead consists predominantly of representatives of the fisheries sector, agriculture and park technicians. This fluctuation is probably due to the different conceptions of reality and the experience between groups. While the first group has intervened in various studies and previous interventions in the park repeatedly over time, the second group has experienced a more direct, day-to-day, relationship with the reality of the park. This is probably reflected in an accentuation of what they consider as the most affected service by the anaerobic fermentation of straw, the fishing service.

Because of this fluctuation as to the ratings of each service and in order to get the economic value of the impact, we obtain the eigenvectors (Table 5) of each of these to calculate, according to the methodology aggregation of the geometric mean the weighted aggregation eigenvectors (Aczél and Saaty [16], Forman and Peniwati [17], Gass and Rapcsák [18]).

6 Economic value of the environmental impact

In order to calculate the economic value of the environmental impact we start from a pivot value, which in this case is the fishing service, because the impact effects can be directly correlated economically to losses and declines in catches, which are easily documented. To get such data, we have consulted the databases of the Fishing Community of El Palmar and have used as reference the season before and after the environmental problem took place during the year 2013. We have considered the losses in eel catches, since they are the specie that has been most significantly affected in these periods during which the problem of straw fermentation has been considerable (Table 4).

Table 4: Eel catches (source: Comunidad de Pescadores del Palmar).

Year	Anguila maresa (kg)	Anguila pasturenca (kg)	Total (kg)	Stock Price (eur.)	Total (eur.)
2012-13	3628	1911	5539	8	44312
2013-14	2473	363	2836	7	19852
				Estimated Losses	24460

Table 5: AMUVAM (source: own elaboration).

Group 1			Group 2		
Service	Value (eur.)	Eigenvector	Service	Value (eur.)	Eigenvector
S1	24460,00	0,3606	S1	24460,00	0,0912
S2	19631,85	0,2894	S2	117080,55	0,4366
S3	7629,68	0,1125	S3	53436,89	0,1993
S4	10321,71	0,1522	S4	56544,78	0,2108
S5	5787,71	0,0853	S5	16654,96	0,0621
Total Value	67830,95		Total Value	268177,19	

Group 3		
Service	Value (eur.)	Eigenvector
S1	24460,00	0,1024
S2	48973,50	0,2051
S3	12270,89	0,0514
S4	30839,20	0,1291
S5	122258,52	0,5120
Total Value	238802,11	

Having the economical estimated losses of 24,460 Euros, and the eigenvectors of the fishing service (S1), we estimate through the multi-criteria valuation methodology AMUVAM (Aznar and Estruch [10]) the total value of the environmental impact according to each of the subgroups of experts (Table 5). Doing so we can assess that the value of the environmental impact occurring on the year of 2013 has fluctuated in a range between 67.380,85 and 268.177,19 Euros.

7 Conclusions

The proposed assessment method allows us to estimate a range of economic value generated in the park as a result of the impact produced by the anaerobic decomposition of the straw that occurred between the seasons of 2012–13 and 2013–14. It has the advantage of considering only those experts who are consistent in their views. It sets a value interval, for although the impact on services that have a market is the same, the importance attached to the other services that have no market differs depending on the different existing positions. This difference in the importance given by the experts can be seen in the degree of the interval amplitude obtained. It should be noted that this valuation methodology consists of an anthropocentric approach because it is based on judgments that may differ more or less depending on the reality and context of each of the individuals interviewed. This factor allows the representation of the plurality of judgments and opinions inherent human reality. That is why we believe that this methodology may serve well as a very interesting tool to apply in assessing environmental impacts where there is a significant convergence of disparate interests between governments, corporations, unions and other groups, therefore serving as a starting point in managing environmental impacts.

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