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Selecting a small run-of-river hydropower plant by the analytic hierarchy process (AHP): A case study of Miño-Sil river basin, Spain

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ABSTRACT

Hydroelectric power is obtained by harnessing the potential energy of a mass of water flowing along a river bed to convert it first into mechanical and then into electrical energy. The system is therefore both clean and autonomous and has a high potential for development.

A small hydropower plant has an installed power capacity of below 10 MW and is considered run-of-river when it diverts part of a river flow to generate its electricity.

The use of multicriteria techniques in environmental decision making, including selecting between various alternatives, is important when it involves complex decisions in a number of disciplinary fields. The most widely used of these techniques is the analytic hierarchy process (AHP).

This work proposes an application of the AHP method to select the best alternative for the installation of a small run-of-river hydropower plant. The systemization of the process, together with its mathematical rigor, means the best project will be selected from the available technical, economic and environmental alternatives.

The main criteria identified in this study for the selection of RoR plant are: protected fauna, fish population, water quality, landscape quality, flow regime and vegetation. Finally, the best alternative was the project of the company Energia of Galicia.

1. Introduction

Hydroelectric power is obtained by harnessing the potential energy of a mass of water flowing along a river bed to convert it first into mechanical and then into electrical energy. It is one of the most important renewable energies and is characterized by being a clean and autonomous source of power (IDAE 2010).

Worldwide, about 3000 TWh of hydroelectric power is generated each year, or about 20% of the world's total energy production, the main producers being Canada, the US and China, although the unused potential of this resource is enormous, especially in the developing countries. At the present time only about 17% of the global resources are harnessed, a figure which is reduced to 8% in the Third World (UNESCO, 2012).

Europe generated 31,680 Kilotons of oil equivalent (KTOE) of hydroelectric energy in 2013 (Eurostat, 2015), with Norway, Sweden, France, Austria and Italy being the principal producers. Spain, in sixth position, generated 3162 KTOE, which made up 9.24% of the country's total energy production.

Hydropower is a general term that covers a broad range of installations. There are some classifications: into water head, storage capacity or size (IHA et al., 2000). Other classification is by facility type: run-of-river (RoR), storage and pumped-storage hydropower (Gaudard and Romerio, 2014). In Europe, hydropower plants are classified according to their installed hydroelectric power capacity; those with an installed power capacity below 10 MW are considered to be small hydropower plants (SHP) (ESHA, 2012). SHP is one of the most common technologies used for electricity generation for rural population in both developed and developing countries (Chang et al., 2010; Okot, 2013; Kumar and Katoch, 2015; Li et al., 2015) and their importance are due to their having relatively low construction and running costs and can they be built in far shorter times than a large hydroelectric plant (Egre and Milewski, 2002; Oud, 2002; Bakis and Demirbas, 2004; Hosseini et al., 2005; Panic et al., 2013).

The SHPs themselves can be divided into two main types: those with a storage reservoir, and the run-of-river type. The former are built under a dam to take advantage of the fall created by the dam

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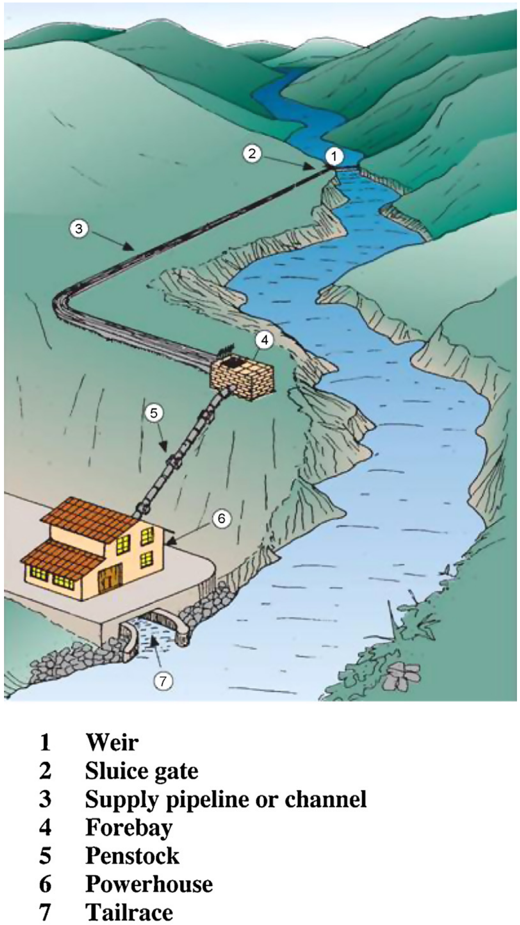

Fig. 1. Scheme of a run-of-river hydropower. Adapted by authors from energialternativaitm.blogspot.com.

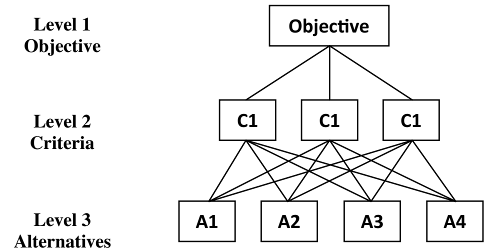

Fig. 2. Scheme of the analytic hierarchy process. Prepared by authors.

itself. In RoR type (Fig. 1) only part of the river flow is diverted to a forebay through channels or pipes, from which it falls down a penstock to enter an electricity-generating turbine. After this process the water is returned to the river via a tailrace. These plants depend directly on natural water cycles, since their water supply is variable and cannot be controlled. The water head is practically constant, so that the power generated by the power plant will depend on the mass of water flowing along the river or stream.

As in utilization of other renewable energy sources, RoR plants also have effects on natural environment. The main negative environmental impacts are: lack of proper fish and wildlife passages, inadequate quantity of environmental flow and monthly distribution, mortality of fish due to the turbines, lack of control over environmental flow, high-voltage power lines, inadequate rehabilitation and restoration of habitat, illegal hunting, waste accumulation, dust and noise pollution (Čada, 2001; Trussart et al., 2002; Kucukali and Baris, 2009; Rojanamon et al., 2009; Valero, 2012; Karunarathna, 2013; Kucukali, 2014; Kumar and Katoch, 2014; Vowles et al., 2014).

The tool to check the effects and the importance of the impacts on the environment is the Environmental Impact Assessment (EIA) process. It is a set of systematic technical studies that provide an estimate of the effects on the environment of a given project, work or activity (European Union, 2014).

In Spain, all projects included in the activities in Annex I of the current legislation (Spain, 2013) are subjected to EIAs, as are those included in Annex II, should the environmental authority so decide. All small hydropower plant projects must be subjected to EIA processes, since they could belong to *Group 7, Section a, Hydraulic Engineering Projects and Water Management, Dams and other installations designed to retain or store water when the additional volume of stored water is in excess of 10 Hm^3*, or because the part referring to the transmission of electrical power belongs to *Group 3, Section g, Electrical Installations, power transmission lines with voltages at or above 220 kV over a distance greater than 15 km.* In Annex II, at the discretion of the environmental authority, they would be included in *Group 4, Power Generating Plants, Section b, construction of power transmission lines (projects not included in Annex I) with voltages equal to or higher than 15 kV over distances greater than 3 km, and in Section d, hydroelectric power-generating stations.*

Decisions that impinge on the environment, including EIA, are frequently large, complex and recourse must be made to specialists from multidisciplinary fields, including natural sciences, physics, politics and ethics (Huang et al., 2011; Alonso-Tristán et al., 2011; Panic et al., 2013; Kumar and Katoch, 2014).

Multi criteria decision analysis techniques (MCDA) are highly suited to solving this type of problem. The term MCDA is used generically to describe different methods that use diverse criteria either individually or in groups to solve a problem or take a decision on a given situation (Belton and Stewart, 2002).

One of these techniques is the analytic hierarchy process (AHP), *which* is a multicriteria decision-making system proposed by Saaty (1980, 1994, 1996). This method constitutes a theory of the relative measurements of intangible criteria for decision analysis. The decision problem is broken down into different levels in such a way that establishes a hierarchy with one-way relationships between each level. The highest level of the hierarchy contains the desired objective and the lowest the alternatives. The intermediate levels contain the criteria, and if necessary sub-criteria, which are used as the basis for taking the decision (Fig. 2).

The application of this method in the area of "ecological engineering" is helpful as the target or even the criteria reflect environmental issues which allow the development or preservation of ecosystems (Mitsch, 1992).

Huang et al. (2011), in their bibliometric study on the use of multicriteria decision techniques in the environmental field, found that in the last decade approximately 48% of the selected articles used the analytic hierarchy process (AHP) and the analytic network process (ANP) and that 17% of these included an EIA. If the analysis is by area, 62% of the articles used ANP–AHP techniques for the EIA.

A correctly performed EIA can clarify many environmental alternatives and in conjunction with tools such as AHP–ANP will help to identify the best alternatives as regards the siting of a projected plant or technological process. Examples can be found in infrastructures for waste water management (Martin et al., 2007; Iwanejko, 2007), urban development (Gómez-Navarro et al., 2009), urban industrial land (Aragonés-Beltrán et al., 2008), waste disposal (Contreras et al., 2008; Aragonés-Beltrán et al., 2010a), photovoltaic solar power plant (Aragonés-Beltrán et al., 2010b), solar–thermal power plant (Aragonés-Beltrán et al., 2014), power stations (Chatzimouratidis and Pilavachi, 2008) and for natural wastewater treatment alternatives (Ouyang et al., 2015).

This work proposes an application of the AHP method to select the best alternative for the installation of a small RoR hydropower plant from three technologically and environmentally viable alternatives.

2. Method

This section is divided into two sub-sections: the first defines the method followed in the study and the second deals with the mathematical basis of the AHP used to select the best alternative for the siting of a RoR hydropower plant.

2.1. Development of the method

The work was divided into stages as shown in Table 1. The INITIAL STAGE includes the definition of the general objective of the decision problem and the different alternatives and the creation of the team to take part in the study. This team was given the job of solving the decision problem after being provided with all the available information on the objective and the alternatives.

The CRITERIA PHASE establishes certain steps. First, each evaluator is asked to compose a personal list of proposals for the evaluation criteria; in this case, environmental factors that will determine the selection of the alternative. Secondly, a group session is organized to analyze the individual proposals and select the evaluation criteria for the problem under study. Finally, applying the pair-wise comparisons of the AHP method, the criteria are given different priorities. In this phase the local weights of the criteria are obtained from pair-wise comparisons of the criteria at each level, after which the overall weights are obtained.

In the third or ALTERNATIVES phase the assessors set the priorities between the alternatives for each of the criteria. The final or EVALUATION stage involves the mathematical treatment of the data by means of Saaty's proposal with the help of Expertchoice computer software. The results of this phase will give the overall priorities for each alternative and will facilitate the final decision.

2.2. The analytic hierarchy process (AHP)

The AHP method presents a decision problem in the form of a hierarchy which contains the objective at the first level, with the alternatives at the next level, and the decision criteria and sub-criteria (if applicable) at the intermediate levels. In order to determine the priorities of the alternatives on the basis of the selected criteria, this method uses pair-wise comparisons to assign weights to the elements at each level by measuring their relative importance by means of ratios or scales (Table 2). Preference ratios are defined (when comparing alternatives) and importance ratios (when comparing criteria).

The **A** matrix of pairwise comparisons is an $n \times n$ squared matrix in which a_{ij} expresses the preference as a numerical value of the element in row i when it is compared with the element in column j, i.e. $a_{ij} = w_i/w_j$. If there are n elements to be compared, the comparison matrix **A** is defined as:

$$\mathbf{A} = \left\langle \begin{matrix} \boldsymbol{w}_1/\boldsymbol{w}_1 & \boldsymbol{w}_1/\boldsymbol{w}_2 & \dots & \boldsymbol{w}_1/\boldsymbol{w}_n \\ \boldsymbol{w}_2/\boldsymbol{w}_1 & \boldsymbol{w}_2/\boldsymbol{w}_2 & \dots & \boldsymbol{w}_2/\boldsymbol{w}_n \\ \boldsymbol{w}_n/\boldsymbol{w}_1 & \boldsymbol{w}_n/\boldsymbol{w}_2 & \dots & \boldsymbol{w}_n/\boldsymbol{w}_n \end{matrix} \right\rangle$$

$$= \begin{bmatrix} 1 & a_{12} & \dots & a_{1n} \\ a_{21} & 1 & \dots & a_{2n} \\ \dots & \dots & \dots & \dots \\ a_{n1} & a_{n2} & \dots & 1 \end{bmatrix}$$

where $\boldsymbol{w}_1/\boldsymbol{w}_2$ expresses the preference of the element in row 1 compared with the element in column 2, and its value is called a_{12} and $\boldsymbol{w}_2/\boldsymbol{w}_1$ expresses the preference of the element in row 2 compared with the element in column 1, and its value is called a_{21}.

After all the pairs have been compared, the priority weight vector ($\boldsymbol{w}$) is calculated as the only solution to $\mathbf{A}{\cdot}\mathbf{A} = \lambda_{max}{\cdot}\boldsymbol{w}$, in which λ_{max} is the highest eigenvalue in matrix **A** and $\boldsymbol{w}$ is its eigenvector.

The consistency index (CI) and consistency ratio (CR) of the pairwise matrix can be calculated by $CI = (\lambda_{max} - n)/(n-1)$ and $CR = CI/RCI$, in which RCI is the Random Consistency Index

Table 1
Method used in the selection process. Prepared by authors.

ID	Phase	ID	Subphase
A	Initial stage	A1	Definition of the general objective of the decision problem
		A2	Definition of the alternatives
		A3	Creation of the team study
B	Criteria	B1	Composition of personal list of proposals for the evaluation criteria
		B2	Group session
		B3	Pair-wise comparison of the criteria
C	Alternatives		Assess the priorities between the alternatives for each criteria
D	Evaluation		Mathematical treatment with Expertchoice and Conclusions

Table 2
Saaty's comparison scale.

Numerical scale	Definition	Explanation
1	Equal importance	Two elements contribute equally to the objective
3	Moderate importance of one element over another	Experience and judgment moderately favor one element over another
5	Strong importance of one element over another	One element is strongly favored
7	Very strong importance of one element over another	One element is very dominant
9	Extreme importance of one element over another	One element is favored by at least a difference of one order of magnitude
2, 4, 6, 8	Intermediate values between two adjacent judgments	Used as a compromise between two judgments

Table 3
RCI values. Adapted by authors from Saaty.

n	1	2	3	4	5	6	7	8	9	10
RCI	0	0	0.58	0.89	1.11	1.24	1.32	1.40	1.45	1.49

determined by Saaty, which depends on the number of elements in the comparison (n) (Table 3).

In general, if the CR index is less than 0.1, the judgment can be taken as consistent.

This process is repeated with the alternatives in order to establish the priorities for each criterion. Finally, the overall priorities of each alternative are determined as a total value that is the sum of the value of each criterion multiplied by its weight.

3. Case study: selecting the optimal site for a run-of-river plant on the River Couso in Galicia

A river basin is an area of terrain whose entire surface runoff drains into the sea at a single river mouth, estuary or delta via a series of streams, rivers and lakes, and is considered to be an indivisible unit as regards water resource management (European Union, 2000; Spain, 2001). The hydroelectric plant under study in the present case is located in the Miño-Sil river basin (Fig. 3) in the Autonomous Community of Galicia (Spain) on the banks of the Couso River in the municipal area of Avión in the province of Ourense.

The Couso river runs through a valley with steep slopes, where there are no major infrastructure: a road and some power lines. The soils are acidic and have poorly developed profiles given its high slope. The vegetation is characterized by three main units: the riparian forest, meadows and crops and scrubland. The riparian forest is mainly composed of *Betula alba*, *Salix* sp., *Quercus robur* and *Alnus glutinosa*. The scrubland, located in the highest areas of the valley, has populations of pinus and eucalyptus. The river has a stable population of trout and a small population of otters.

One stretch of the River Couso is a protected area for its environmental interest (Plan Hidrológico Norte I), which implies that the natural quality of its waters must be kept up to standard and that any actions within the basin that might affect its fauna must be avoided. Three alternatives were proposed for the hydropower plant involving different designs, layout of the components and power capacity. All of the projects were technically and environmentally feasible (Spain, 2014). These alternatives are described below and are identified by the names of the firms that submitted the proposals.

3.1. Alternative A1: Cortizo Hidroeléctrica

This project proposes to supply a 2080 kW installed power plant with a flow of 2500 l/s under a 103 m head of water.

The weir would be situated on the Couso 70 m downstream from the OR-212 road bridge (Fig. 4). The weir is the gravity type, equipped with a 37 m long fish ladder on its left side composed of ten hollow steps. The outlet to the settling channel is on the right-hand side. The settling channel is covered over by concrete slabs, is 13.2 m long with a rectangular cross section and joins the supply channel that runs alongside the right bank of the river. It empties into a 6 m × 3 m × 1.25 m forebay with a capacity of 22.5 m^3. A 1000 mm penstock feeds water to the power plant from the forebay over a distance of 320 m. The plant itself is built on the right-hand bank of the river 1300 m upstream from where it joins the River Avia at the village of Pascais. The powerhouse is 20 m long and 10 m wide and houses a Francis-type horizontal axis turbine with a power output of 2080 kW coupled to a synchronous generator and a 2277 kVA transformer plus auxiliary machinery. The circuit is completed by a tailrace that returns the water back into the river. The access roads to the plant and weir would need to be improved. The electric power generated could be connected to the national grid by a 10 kV overhead power line.

Table 4
Abstract of the alternatives. Prepared by authors.

Alternative	Power plant (kW)	Water head (m)	Weir	Flow (l/s)	Setting channel	Forebay	Penstock	Powerhouse	Turbine	Generator (kVA)
A1: Cortizo Hidroeléctrica	2080	103	Gravity type	2500	Concrete slabs; 13.2 m length	22.5 m^3	Diameter of 1000 mm and a length of 320 m	20 m × 10 m	Francis type	2277
A2: Energía of Galicia	4100	125.5	Gravity type	4000	Concrete slabs	11 m of length, 2.2 m of wide and variable depth	Diameter of 1300 mm and a length of 280 m	25 m × 10 m	Francis type	5000
A3: Hidroeléctrica of Avión	2035	122.5	Gravity type	2000	Carbon steel pipeline of 1118 mm diameter and a length of 1734 m	–	Diameter of 1067 mm and a length of 353 m	19.50 m × 11.20 m	Francis type	2500

Fig. 3. Miño-Sil river basin location. Area study of the river Couso (left-bottom) and a photograph of river Couso (right-top). Adapted by authors.

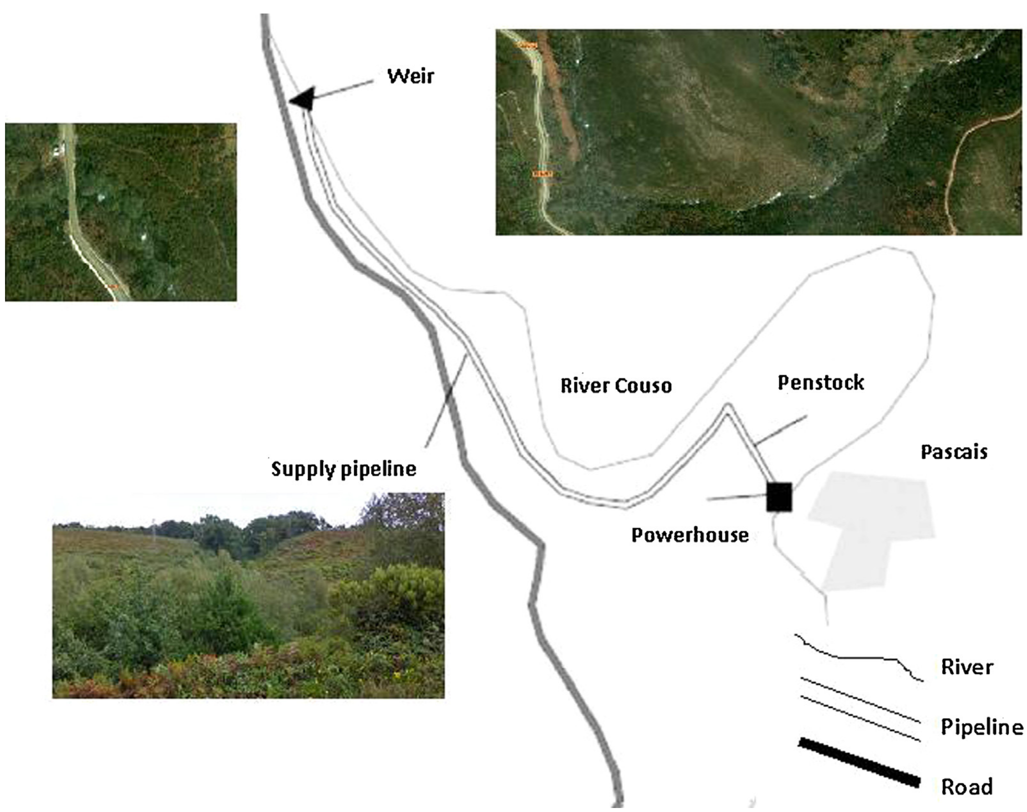

Fig. 4. Scheme of Alternative No. 1. Prepared by authors.

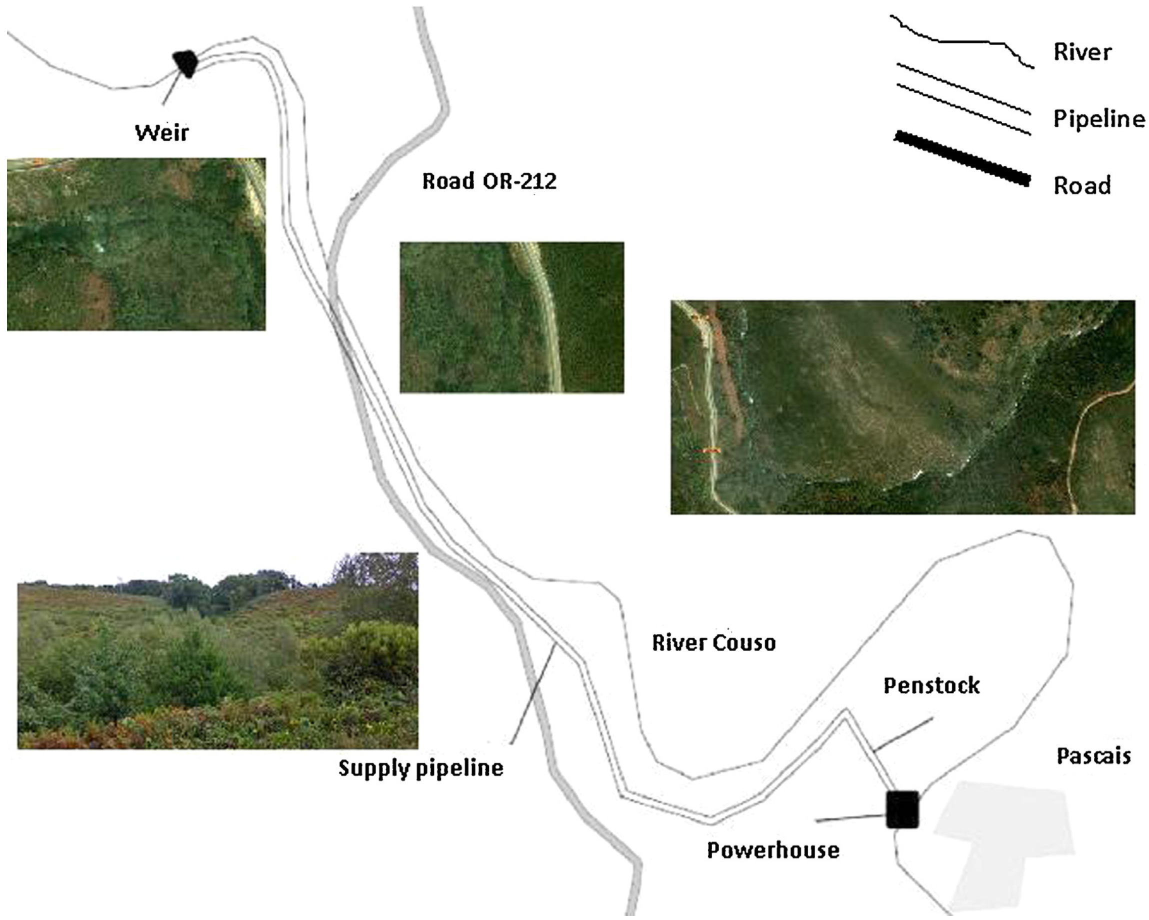

Fig. 5. Scheme of Alternative No. 2 and No. 3. Prepared by authors.

3.2. *Alternative A2: Energía of Galicia*

This project proposes a feed water flow rate of 4000 l/s with a total head of 125.5 m for an installed power plant able to generate 4100 kW.

The weir would be placed 500 m upstream from the OR-212 road bridge over the river (Fig. 5). The weir is the gravity type 37 m long and would have an eight-step fish ladder on its right-hand side. The water intake would also be on the right-hand side (composed of an energy-dissipating basin and a settling and transition basin before the supply channel).

The supply channel would run along the right-hand river bank, would be covered with slabs and would empty into a forebay, from which the water would drop down a 280 m long × 1300 mm diameter penstock to the turbine. The powerhouse would be built on the right bank of the river about 1200 m upstream from where it joins the Avia at the village of Pascais. The building is 25 m long and 10 m wide and contains two electric generators consisting of two Francis-type horizontal axis turbines with a power output of 1400 and 2700 kW coupled to synchronous generators and a 5000 kVA transformer plus auxiliary machinery. The circuit is completed by a tailrace that returns the water back into the river. The access roads to the plant and weir would need to be improved. The electric power generated could be connected to the national grid by a 20 kV overhead power line.

3.3. *Alternative A3: Hidroeléctrica of Avión*

This project involves a feed water flow of 2000 l/s with a total water head of 122.5 m for an installed power of 2035 kW.

The weir would be on the Couso 290 m upstream of the OR-212 bridge (Fig. 5) and would be a 20 m long gravity type with an eight-step fish ladder on the left and a 20 m long × 4 m wide × 1.4 m high rectangular cross-section settling channel on the left. The 1118 mm diameter × 1734 m long carbon steel supply pipeline would run along the right river bank and would empty directly into a 1067 mm diameter × 353 m long carbon steel penstock also situated on the right bank.

The powerhouse would be built to the right of the river 1200 m upstream from its joining the River Avia at Pascais, with dimensions of 19.50 m long × 11.20 m wide. Generating power would be provided by two Francis-type horizontal axis turbines with a power output of 1474 and 632 kW coupled to synchronous generators and a 2500 kVA transformer plus auxiliary machinery. The circuit is completed by a tailrace that returns the water back into the river. The access roads to the plant and weir would need to be improved. The electric power generated could be connected to the national grid by an underground 20 kV power cable.

Table 4 shows an abstract of the characteristics of the three alternatives of the study.

4. Results

Section 3 dealt with the definition of the objective and the alternatives in the Initial Phase. This phase defines the team involved in the study, which was composed of 14 selected evaluators qualified and experienced in industry-related technologies and the environment, led by an expert in the evaluation of environmental impact and multicriteria decision analysis techniques. The meeting called to deal

Table 5
Individual criteria proposed during the criteria selection phase.

Criteria proposed by the evaluators	No.
Protected fauna (no. of species and population)	12
Fish population	11
Water quality	11
Flow regime	10
Ichthyofauna and macroinvertebrates	9
Landscape quality	9
Ground fragility	7
Vegetation (all types)	6
Public opposition to the project	6
River bank vegetation	6
Accumulation or synergy with other projects	4
Protected vegetation	4
Hillside erosion	4
Fertility of ground	3
Acoustic impact of works	3
Visual impact	3
Water temperature	2
Low levels of nutrients	1
Trout migration	1
Access infraestructures	1
Habitats of special interest	1
Water fauna	1
Soil erosion	1

with the CRITERIA phase drew up a list of 23 possible criteria as shown in Table 5, which also gives the number of times these criteria were suggested by the evaluators as a measure of their importance.

After a joint analysis by all the evaluators, nine decision criteria were selected (Table 6).

Table 7
Weighting of evaluation criteria.

Id	Criterion	Weight
C1	Protected fauna	0.273
C2	Water quality	0.200
C3	Fish population	0.172
C4	Landscape quality	0.066
C5	Vegetation	0.085
C6	Flow regime	0.089
C7	Soil fragility and erosion	0.052
C8	Public opposition to project	0.042
C9	Accumulation or synergy with other projects	0.022

Table 8
Normalized mean of evaluators' scores.

	C1	C2	C3	C4	C5	C6	C7	C8	C9
A1	0.87	1.00	0.96	0.63	1.00	0.94	0.80	1.00	0.90
A2	1.00	0.98	0.89	1.00	0.82	1.00	1.00	0.91	1.00
A3	0.79	0.74	1.00	0.79	0.77	0.90	0.89	1.00	0.90

As the final step in the CRITERIA phase, each evaluator decided the weight of each criterion using pairwise comparisons. The average of the comparisons was then calculated and the weight of each criterion was determined by the AHP method (Table 7). The consistency ratio (CR) was 0.05, less than 0.1, so the judgment can be taken as consistent.

In the ALTERNATIVES phase, each of the alternatives was analyzed in the light of the selected criteria. The evaluators' scores were then normalized, the arithmetic mean was worked out and the decision matrix was obtained, as can be seen in Table 8.

Table 6
Definitive criteria established in the criteria phase.

Id	Criteria	Description
C1	Protected Fauna	Determine the lowest effect on protected fauna including icthyofauna
C2	Water quality	Determine the lowest effect on water quality, including parameters such as suspended solids, temperature, low levels of nutrients, etc.
C3	Fish population	Determine the lowest effect on quantity and quality of fish population
C4	Landscape quality	Determine the lowest effect of the different components of the hydropower plant on the landscape
C5	Vegetation	Determine the lowest effect on vegetation in general, including river bank and protected vegetation
C6	Flow regime	Determine the lowest effect on river regime according to the flow through the hydropower plant, including seasonal effects
C7	Soil fragility and erosion	Determine the lowest effect on soil erosion in hillsides and river banks
C8	Public opposition to project	Determine the highest degree of opposition of the local population by their participation in demonstrations against the project, both in the EIE process and press and other media
C9	Accumulation or synergy with other projects	Determine the lowest effect caused by the installation due to the accumulation or synergy with other related projects (access roads, power lines, etc.) or other projects in the area that could participate in the work

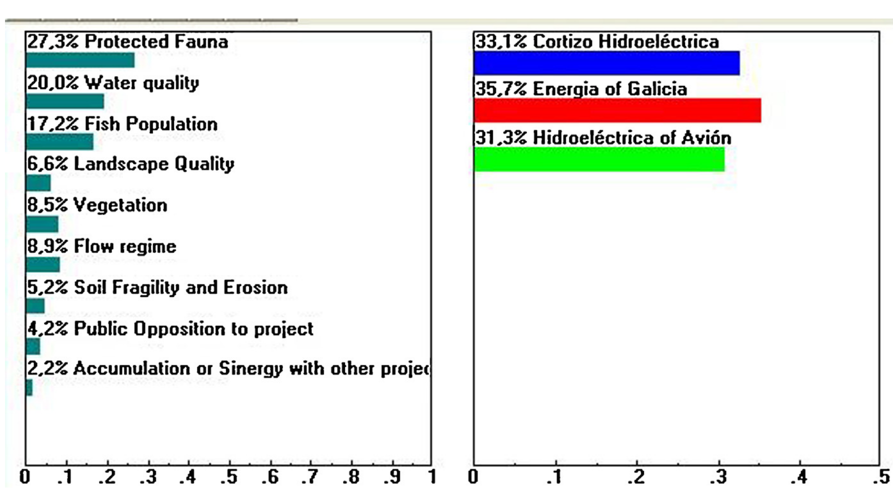

Fig. 6. Results of the evaluation by Expertchoice. Prepared by authors.

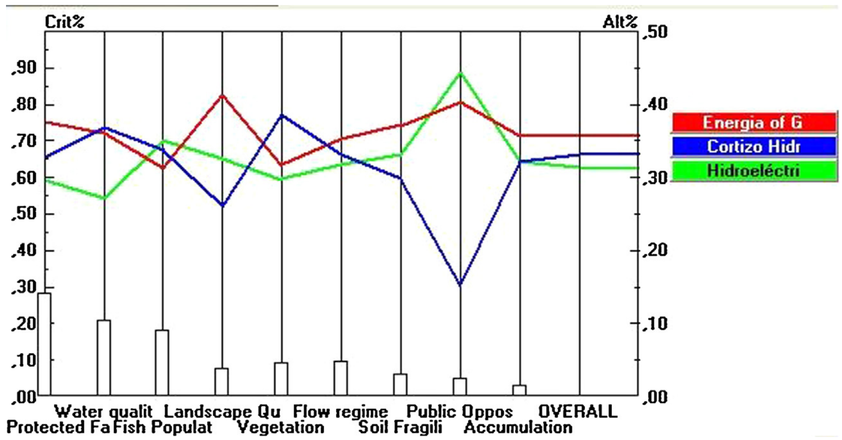

Fig. 7. Performance sensitivity analysis of the solution obtained. Prepared by authors.

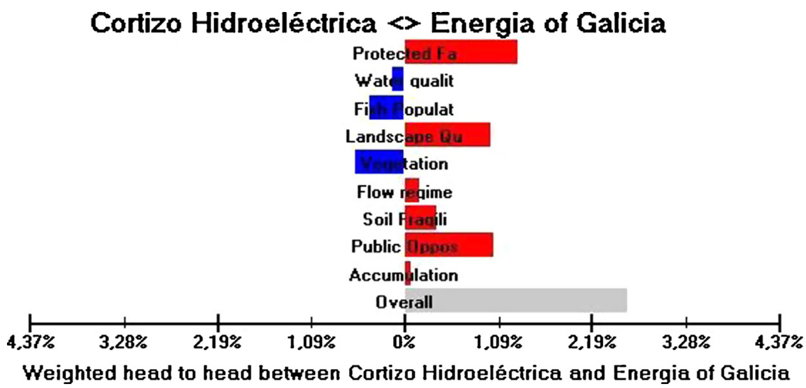

Fig. 8. Head-to-head sensitivity analysis of Alternatives A1 and A2. Prepared by authors.

The priority of the different alternatives was then obtained from these evaluations (Fig. 6). In this case the highest score, 0.357, was obtained by Alternative A2: Energía of Galicia, followed by A1: Cortizo Hidroeléctrica with 0.331, and A3: Hidroeléctrica of Avión with 0.313.

The results show that all three alternatives were given very similar scores (there is only a 4.4% difference between the first, A2, and the last, A3). This can be explained by the fact that all the projects were technically and financially viable and were drawn up by private companies to harness the hydroelectric potential of the river. The alternatives were also environmentally acceptable as they had been subjected to EIA and had obtained a positive Record of Decision (Spain, 2008).

The Expertchoice Sensitivity Graph tool was used to carry out an analysis of the sensitivity of the results obtained. If the vertical bars (criteria for selecting the RoR) are modified, the evaluators' scores of the three alternatives are modified and it permits to see the variability of the priority of the alternatives. Fig. 7 shows the performance analysis with the preference of the alternatives according to the weights of the criteria for the solution obtained. In this case

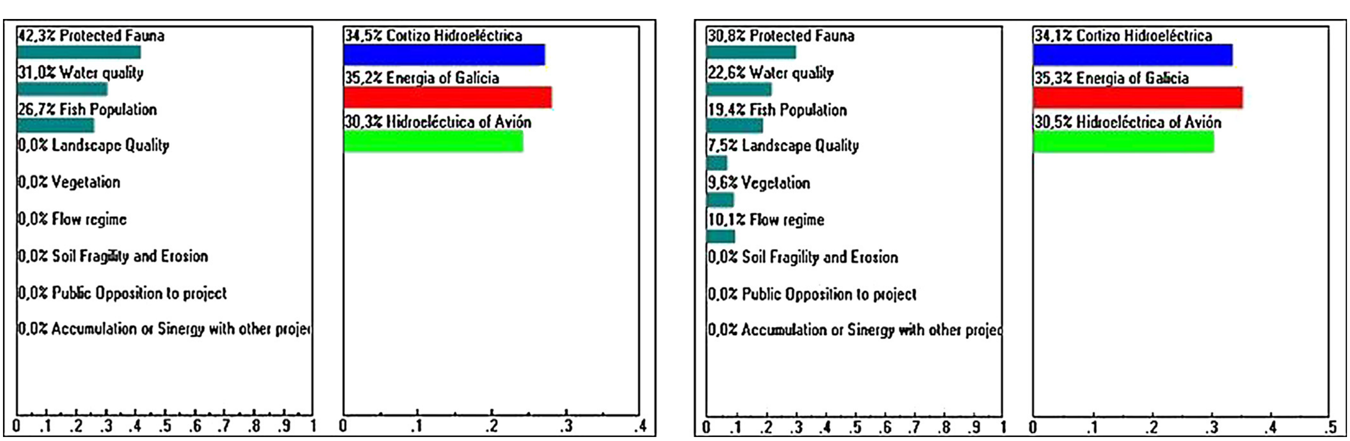

Fig. 9. Dynamic sensitivity analysis. Prepared by authors.

the maximum dispersion of the evaluators' scores is for the criterion "public opposition", but its importance in the final evaluation is low, so there is not any variation for the rank priority of the alternatives.

The two highest scoring alternatives, A2 Energía of Galicia and A1 Cortizo Hidroeléctrica, show a difference of 2.6%. If the scores of both alternatives are analyzed head-to-head (Fig. 8) it can be seen that the criteria that had the greatest influence on making A2 the winner were the protected fauna, the landscape quality and the public opposition.

An analysis of the decision criteria shows that the three most heavily weighted criteria (C1: protected fauna, C2: water quality and C3: fish population) have an overall weight of 64.5%. Three criteria (C7, C8 and C9) have a weight of less than 5%. Two further analyses were carried out (Fig. 9); firstly supposing that the decision was based solely on C1, C2 and C3, and secondly eliminating C7, C8 and C9. The dynamic analysis shows that the selected alternative would not have been changed.

5. Discussion and conclusions

There is still a lot of room for growth in hydropower from small generating plants around the world. However, the complexity of the technical and administrative processes could put a brake on their expansion (Huang et al., 2011; Alonso-Tristán et al., 2011; Panic et al., 2013; Kumar and Katoch, 2014).

The administrative requirements for hydropower plants in Spain include an EIA process to ensure the environmental compatibility of the site chosen for their installation. Selecting from the alternatives is a complex problem from any point of view and requires the use of scientific and mathematically sound tools of proven worth that convert the task into a systematic process. The present paper proposes an application of the AHP method for the selection of the best alternative for the siting of a small run-of-river hydropower plant.

In this case study the decision process is between technically, financially and environmentally viable alternatives, since they were planned to be run by private companies and all the projects were subjected to environmental impact assessment and obtained a positive Record of Decision. These characteristics are reflected in the small differences between the final scores obtained by the three alternatives involved.

The main criteria identified in this study for the selection of RoR plant are: protected fauna, fish population, water quality, landscape quality, flow regime and vegetation. These criteria, with the particularities of the Couso river basin, are similar to the criteria used in other countries as Serbia (Panic et al., 2013), Sri Lanka (Karunarathna, 2013), Turkey (Kucukali, 2014), India (Kumar and Katoch, 2014) or China (Li et al., 2015). The best alternative for the RoR hydropower plant of the case study was the project of the company Energia of Galicia.

In spite of these slight differences between the three alternatives, when the results were subjected to a sensitivity analysis, no variations were found in the preferences of the alternatives due to the robustness of the study carried out, since the selection of the criteria, their weighting and evaluation were carried out by a large group of experts in a systematic and structured process. One of the main factors to avoid the uncertainty and the variability of the application of the AHP method is the creation of the study team. If the study team is designed with technicians and experts who cover all the aspects of the facility and the environment, the addition or change of one technician does not suppose variation in the final rank.

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