A COMPARATIVE STUDY OF AHP, ELECTRE III & ELECTRE IV BY EQUAL OBJECTIVE & SHANNON'S ENTROPY OBJECTIVE & SAATY'S SUBJECTIVE CRITERIA WEIGHTING IN A PRIVATE SMALL HYDROPOWER PLANTS INVESTMENTS SELECTION PROBLEM

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ABSTRACT

Private small hydropower plant investments are more challenging than medium and large private hydropower plant investments when considering engineering analysis. One of the necessary tasks is the selection of the most appropriate private small hydropower investment amongst several alternatives. Brokerage, consultancy and private investor activities are a few examples of these kinds of real world activities. There are many multi-criteria decision making (MCDM) or multiple-criteria decision analysis (MCDA) methods, and different researchers prefer different methods This research study investigates three methods at once for the same problem: Analytic Hierarchy Process (AHP), Elimination and Choice Translating Reality (ELECTRE) III and ELECTRE IV. A comparative investigation is conducted on one simple unique selection model for all three methods. This unified model has seven objective factors (catchment area, project runoff, net head, flow rate, firm energy, secondary energy, investment cost). An additional comparison is also made on the criteria weighting amongst equal objective, Shannon's Entropy objective and Saaty's subjective criteria weighting. The simplistic unified model is structured in three levels. There are seven alternatives in the pre-development investment stage. The Super Decisions software and the ELECTRE III-IV software are implemented in this study. The pairwise comparisons of factors results in an inconsistency value of 0,09511 which is 7th in the Saaty's AHP weighting. The Shannon's Entropy objective weighting represents a difference in the rate of the expert decision maker's evaluations ranging between -67% and 671%. The equal weighting represents a rate change between -64% and 626%. Both approaches can't represent human judgments (here only one expert decision maker) well in this model. Fortunately, the same

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alternative (Alternative 3) ranks first. These findings promise that further studies on this subject can give some clues for the development of an autonomous computer based intelligent decision support system. Some observed pros and cons of these methods are also presented in this study. The observations and critical issues are presented during modeling, application, evaluation and analysis to help researchers, consultants, and readers in the small hydropower investments research and practical fields.

Keywords: AHP; Carrot^2; ELECTRE III; ELECTRE IV; investment; Shannon's Entropy; small hydropower plant

1. Introduction

The importance and effectiveness of renewable energy in solving climate change and economic growth problems have been accepted by governing bodies in many countries in the world today. The Renewable Energy Policy Network for the 21st Century (REN21), which is an international non-profit association at the United Nations Environment Programme (UNEP), has recorded that 145 countries in the world have renewable energy support policies and 164 countries have renewable energy targets set by early 2015 (Figure 1). Accordingly, this research study aims to contribute to scientific studies and developments in this field.

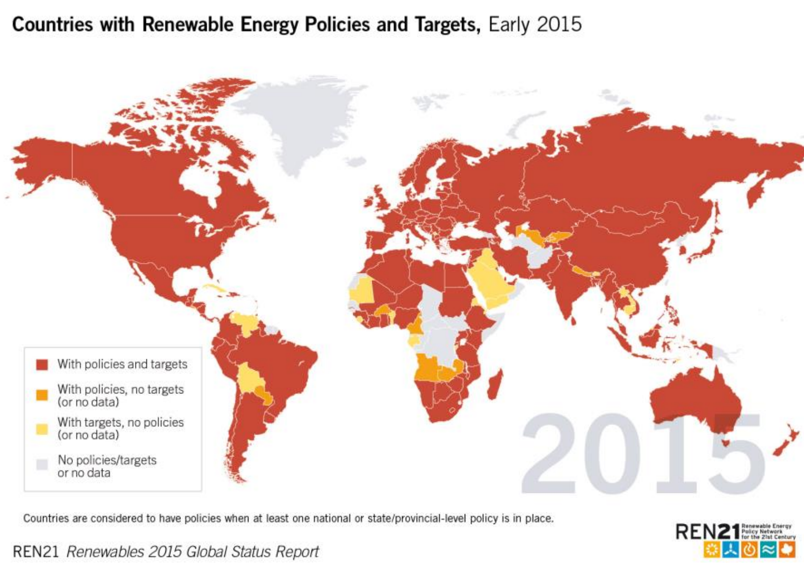

Figure 1. Countries with renewable energy policies and targets (Source: REN21, 2015)

There are various renewable power generation types that produce clean energy, such as concentrating solar thermal, geothermal, hydro, photovoltaics, and wind (REN21, 2015). Today, hydropower is the most widely installed renewable energy type.

The history of hydroelectric power plants started in the Cragside country house in Northumberland, England in 1878. In those days, this technology could only power a single lamp. The first hydropower plant, generating 12,5 kilowatts (kW) in a private and

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commercial customer system (equivalent 250 lights), was commissioned on the Fox River in Wisconsin, USA in 1882 (IEA Hydropower, 2015; IHA, 2015; NHA, 2015; Schmidt & Denny, 2004). This long history has placed hydropower technology in an advantageous position amongst the other renewable energy technologies. Technical and technological maturity, very long lifespan and economic competitiveness are some of these advantages (Hall, 2003; IHAICLD, 2000; Lako et al., 2003). Thus, hydropower technology should always be on the radar of private investors (power plant portfolio) throughout the world.

Hydropower plants are usually classified according to their installed capacities. One of the detailed classification approaches splits the installed capacities into the categories large, medium, small, mini, micro and pico. The upper limits and lower limits of these groups differ in several regions. For instance, the upper limit (25.000 kW) and the lower limit (1.000 kW) are common for the small hydropower plants in India. In the United States of America, these limits are presented as 1.000 kW and 30.000 kW (Bajaj et al., 2007; Berakovic et al., 2009; Dragu et al., 2010; EREC, 2012; Kurien & Sinha, 2006; Moreire & Poole, 1993; Saxena, 2007). In this study, the small hydropower plants are accepted as 1 MW < P ≤ 10 MW. This range was chosen based on the installed capacities in the electricity generation licensing procedures in Turkey by the Electricity Market Law 6446, the Regulation on the Unlicensed Electricity Generation in the Electricity Market, and the Communication Concerning the Application of Regulation on the Unlicensed Electricity Generation on the Electricity Market of the Republic of Turkey (Official Gazette 28603, 2015; Official Gazette 28783, 2015), and the definition of small hydropower plants supported by the European Commission (EC) and the European Small Hydropower Association (ESHA) (EC, 2014; ESHA et al., 2008).

Small hydropower plants are more challenging than large and medium hydropower plants, because they have little or no storage reservoir. Their investment analysis and decisions regarding them are more difficult than others. Consequently, this study focuses on private small hydropower plant investment decisions. Two private small hydropower plants are presented in Figure 2.

Figure 2. Two private small hydropower plants in Norway: Vassvik 3.100 kVA (left), Ytre Alsaker 5.490 kVA (right)
(Source: Småkraft AS http://www.smaakraft.no/)

This research study concentrates on Turkey and is conducted there for three main reasons. The first reason is that it is the homeland of the author. The second reason is the

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level of interest and the excitement of private investors (foreign and domestic) about small hydropower plants in Turkey demonstrated by the number of license applications. There are more than 200 private small hydropower plant license applications as of September 2013 according to the official website of the EMRA (Republic of Turkey Energy Market Regulatory Authority) (EMRA, 2013). The final reason is the characteristics of the private investors' in Turkey. Simple observations made before this study show that these investors have very different organizations, management approaches, and capabilities. However, similar research studies on this core subject can be organized and performed in different countries because of the existence of small hydropower plants in 148 countries or territories (total 75 GW in 2011/2012: Asia 65%, Europe 16%, Americas 13%, Africa 5%, Oceania 1%) worldwide (UNIDO and ICSHP, 2013). In short, this research study isn't particular, specific and unique to Turkey, but the comparative case is performed in Turkey.

Another important issue is the knowledge creation, the knowledge acquisition, and the problem statement and scope of this study. There is only one expert decision maker or "intellectual capital" in this application. The declarative, the procedural, the causal, the conditional, the relational, and the pragmatic knowledge types are based on the knowledge created by several resources and the ones acquired as shown in Figure 3. The research scope focuses on the second hand tasks such as the brokerage, the consultancy and the private investors' activities.

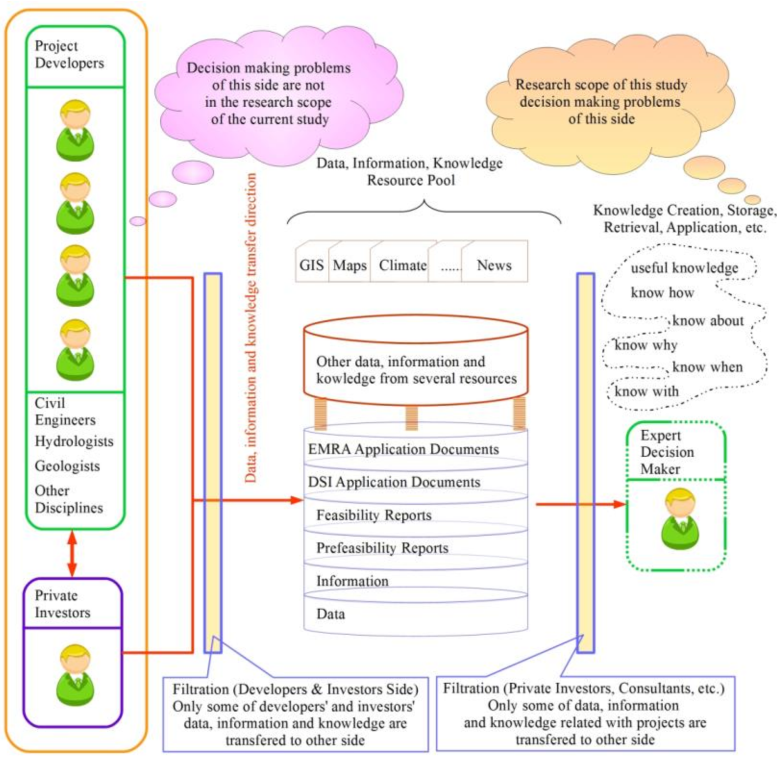

Figure 3. Data, information, knowledge environment and model in this study (Icon: signore_green, 2015; see terms for knowledge: Alavi & Leidner, 1999) (GIS: geographic information system, EMRA: Republic of Turkey Energy Market Regulatory Authority, DSI: General Directorate of State Hydraulic Works)

Finally, this research study was inspired by previous research studies by Saracoglu (2015a,b,c) on decision making and small hydropower plant investments. In these studies, ELECTRE III (ELECTRE: Elimination and Choice Translating Reality/Elimination Et Choix Tradusiant la Realite), ELECTRE IV, Shannon's Entropy, AHP (Analytic Hierarchy Process), and DEXi (Decision EXpert for Education) were implemented in the investment selection of small hydropower plants. Moreover, research by Saaty and Daji (2015), and Zanakis et al., (1998) inspired the idea for this research.

The main research aim of this study is very well described by a quote: "Good decisions come from experience, and experience comes from bad decisions" (possibly by Mark Twain, American novelist and journalist).

According to the author's point of view, these kinds of studies are very important for understanding small hydropower plants, their investments and the decision making methods. Researchers and practitioners in this field can learn from this approach and take into account the critical success and failure issues based on the outcomes and findings of this study in the short and long term.

In this paper, a comparison is made on the findings of the combination of ELECTRE III, ELECTRE IV, and AHP methods with Shannon's Entropy, Saaty's AHP, and equal weighting approaches. The comparison is based on a unique model, and therefore no model differences exist to be investigated. Moreover, the alternatives are taken from real life applications and are the same for each combination of methods, and therefore no alternative differences exist to be investigated. Above all, this comparative study will hopefully contribute to the previous studies in the literature (Saracoglu, 2015a,b,c) in order to develop an autonomous computer based intelligent decision support system for the real world cases.

2. Previous research in the literature

Key terms were defined in order to get the best hit rates on online scientific databases and journal websites. Moreover, the search activity was performed only on titles, abstracts and keywords at first. This preference eliminates all of the inappropriate documents and will hopefully only show documents where both methods were discussed in the same document. The full text search option has produced widely dispersed articles in previous studies. The selected key terms with operators in this review were very close to the current subject (search queries in Table 1). The search terms and queries were defined according to the advanced search tips such as, "choose search terms that are specific or closely related to the topic of interest", "use the singular form of the word", "use connectors" and basic search strategies (ScienceDirect®, 2015a,Van Rijsbergen, 1979).

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Table 1
Search queries (until 25/07/2015)

Search Number(#)	Search Queries
#1	"AHP" AND "ELECTRE III" AND "hydro"
#2	"AHP" AND "ELECTRE IV" AND "hydro"
#3	"Analytic Hierarchy Process" AND "ELECTRE III" AND "hydro"
#4	"Analytic Hierarchy Process" AND "ELECTRE IV" AND "hydro"
#5	"AHP" AND "ELECTRE III"
#6	"AHP" AND "ELECTRE IV"
#7	"AHP" AND "ELECTRE"
#8	"Analytic Hierarchy Process" AND "ELECTRE"
#9	"Analytic Hierarchy Process" AND "Elimination and Choice Translating Reality"

Books, chapters, journals, proceedings, transactions, magazines, and newsletters were all searched during this review until 25/07/2015. The titles and the abstracts were reviewed one by one and the full text of studies, the author viewed as important, were reviewed. Some of these documents (according to abstract and full text review) were presented in the following paragraphs in this section. The search results of this literature review were also summarized in Table 2 for other researchers and following studies.

Table 2
Summary of literature review (until 25/07/2015)

Scientific publisher	#1	#2	#3	#4	#5	#6	#7	#8	#9
ACM Digital	0	0	0	0	2	0	5	2	0
ASCE Online	0	0	0	0	0	0	1	1	0
American Society	0	0	0	0	0	0	29	16	0
Cambridge Journals	0	0	0	0	0	0	4	3	1
Directory of Open	0	0	0	0	6	0	15	3	1
Emerald Insight	0	0	0	0	0	0	3	1	0
Google Scholar	95	16	87	11	1.030	201	3.940	3.490	220
Hindawi Publishing	0	0	0	0	2	0	2	3	0
Inderscience	0	0	0	0	0	0	3	0	0
IJAHP	0	0	0	0	0	1	1	0	0
Science Direct	0	0	0	0	4	0	22	9	0
Science Publishing	0	0	0	0	0	0	0	0	0
Springer	12	2	10	1	145	35	619	469	26
Taylor & Francis	0	0	0	0	2	0	6	5	0
Wiley-Blackwell	0	0	0	0	0	0	3	3	0
World Scientific	0	0	0	0	0	0	2	2	0

There were some papers that presented comparative studies in scientific journals until the date of 25/07/2015; however none of these studies were in real world investments within small hydropower plants. There were only 18 studies in the literature that were close to the current study. Lootsma & Schuijt (1998), Raju & Pillai (1999), Mahmoud & Garcia

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(2000), Akpinar et al. (2005), Gilliams et al. (2005), Grau et al. (2010), Sawicka et al. (2010), Geldermann & Schobel (2011), Ozcan et.al. (2011), Shaverdi et.al. (2011), Phogat & Singh (2013), Ur-Rehman & Al-Ahamri (2013), Janiak & Zak (2014), Massei et al. (2014), Samaras et al. (2014), Zak et.al. (2014), Sabzi & King (2015), and Sanchez-Lozano et al. (2015) applied several MCDM methods. In short, there were 18 comparative studies discussing AHP and ELECTRE methods in the literature. These studies were in varying fields such as solar power, transportation, hydropower, production and manufacturing, banking, logistics, painting, and agricultural. The hydropower (water, river, etc.) related studies were by Raju and Pillai (1999), Mahmoud and Garcia (2000), and Samaras et al. (2014), and none of these studies looked at private investments and small hydropower plants. Therefore, to our knowledge this paper is the first study in the private small hydropower plant investment selection problem of this scope (AHP, ELECTRE III, ELECTRE IV, and Shannon's Entropy).

The ELECTRE (ELimination Et Choix Traduisant la REalite: ELimination and Choice Expressing the REality) methods family was born with ELECTRE I (electre one) in the 1960s. It was mentioned in many studies that Bernard Roy was the father of these methods. Govindan and Jepsen (2014) wrote:

> "*The first ELECTRE method was presented by Benayoun et al. (1966) who reported on the works of the European consultancy company SEMA with respect to a specific real world problem. But the first journal article did not appear until 1968, when Roy (1968) described the method in detail. Later, it was renamed to ELECTRE I.*"

The ELECTRE methods were grouped under the outranking approach (the European school of multicriteria decision analysis, the European school approach, the French school of multicriteria decision analysis) (Huang & Chen, 2005; Lootsma, 1990). Detailed information and studies on the ELECTRE methods can be found on the official websites of the LAMSADE (Laboratoire d'Analyse et Modélisation de Systèmes pour l'Aide à la DEcision: http://www.lamsade.dauphine.fr/) in France, the EURO Working Group Multicriteria Decision Aiding (http://www.cs.put.poznan.pl/ewgmcda/), and Professor Dr. Bernard Roy (http://www.lamsade.dauphine.fr/~roy/). The ELECTRE III (electre three) was developed for use with pseudo-criteria and the fuzzy binary outranking relations for ranking actions (Roy, 1991; Lair et al., 2004, Damaskos & Kalfakakou, 2005). The ELECTRE IV (electre four) was recommended for use when working without the relative criteria importance coefficients (Roy, 1991; Bashiri & Hejazi, 2009; Figueira et al., 2010). The "decision aiding" term was preferred to the term "decision support", "decision making", and "decision analysis" (Figueira et al., 2010). For more details about the principles and the equations of the ELECTRE III and the ELECTRE IV methods see Saracoglu (2015a), Ishizaka & Nemery (2013) and Figueira et al. (2005).

Several weighting methods such as the rating method, the utility function method, the extreme weight approach and the entropy method have been presented in scientific studies (Tzeng et al., 1998). The weighting methods could be grouped by subjective and objective weight assessment methods (Lotfi & Fallahnejad, 2010). In the literature, the subjective weight assessment was typically based on the decision maker's preferences; on the other hand the objective weight assessment was often based on hard data. However, there were some occasions when the objective factors were evaluated by the decision maker. Moreover, there were also some occasions where the subjective factors

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evaluations by the decision makers were treated with the objective weight assessment approaches (Akyene, 2012; Lotfi & Fallahnejad, 2010; Safari et al., 2012; Saracoglu, 2015a; also OnlineStatBook, 2015 for the statistical basis on this respect). As a result, it was tricky to classify the subjective weight assessment and objective weight assessment methods for our study. In this study, the subjective weight assessment term was used when the decision maker had the discriminative power (e.g. Saaty's AHP subjective criteria weighting) and the objective weight assessment was preferred when hard data had the discriminative power (e.g. Shannon's Entropy objective criteria weighting). In other words, when the criteria weights were calculated based on the criteria values of the alternatives, the objective weight assessment term was used. Entropy methods are one of the applied objective weight assessment methods (Tzeng et al., 1998). Some studies support entropy methods, however others do not. (Lesne, 2011; Logan, 2012; Zhou et al., 2013). There were several entropy methods developed in the information and decision analysis research field such as the Kullback-Leibler divergence (Kullback & Leibler, 1951), the Renyi Entropy (Bromiley et al., 2004), the De Luca and Termini, Szmidt and Kacprzyk (Hung & Chen, 2009) and the base method as the Shannon's Entropy (Shannon, 1948; Crooks, 2015). There were several applications of the Shannon's Entropy in many research fields in the literature (Akyene, 2012; Fu et al., 2015; Safari et al., 2012; Saracoglu, 2015a, Zou et al., 2006). Akyene (2012) presented a solution based on the Shannon's Entropy and TOPSIS methods for the mobile phone selection problem where twelve factors (dimensions, weight, screen size, memory, RAM, speed, blue tooth, camera, operating system, CPU, battery, price) were taken into account. The weights of these factors were calculated by the Shannon's Entropy method, and the selection process was performed by the TOPSIS method. Fu et al. (2015) recommended a new publishing index for the scientific institution rankings. The corrected count and number of articles criteria were used for the proposed method, and a comparison of the current and proposed approaches for the Asia-Pacific ranking of the Nature Publishing Index was given. Safari et al. (2012) used the Shannon's Entropy and the PROMETHEE methods for the supplier selection based on 6 factors (capacity, delivery, quality, shipment accuracy, warranty policies, availability of raw materials). Saracoglu (2015a) conducted an experimental research study to understand how private small hydropower plant investments could be selected by two ELECTRE methods with different weighting approaches. The weighting approaches were the Shannon's Entropy, the equal weighting and the Saaty's AHP criteria weight assignment. The ELECTRE III and the ELECTRE IV methods were used for the evaluations of the actions based on 17 factors. Some of these factors were first evaluated by the expert decision makers, according to the verbal statements (very good to very bad according to the Likert 5 type scale. Then the ordinal data were used as the interval data for the objective weight assignments. Zou et al. (2006) worked on the Three Gorges reservoir water quality assessment problem where water quality monitoring data for 4 indicators were used. They compared the results with the traditional method. The Shannon's Entropy objective weighting method was presented according to the previous studies in the literature as below (Abdullah & Otheman, 2013; Akyene, 2012; Zou et al., 2006; Shannon, 1948; Saracoglu, 2015a):

Initialized decision matrix: $X=(x_{ij})_{n \times m}$
i represents the criteria $(1 \leq i \leq n)$
j represents the alternative $(1 \leq j \leq m)$
Normalized matrix: $R=(r_{ij})_{n \times m}$
$0 \leq r_{ij} \leq 1$ (normalized matrix elements r_{ij} are between 0 and 1)

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where

maximization criterion

$$r_{ij} = \frac{x_{ij} - \min_i\{x_{ij}\}}{\max_i\{x_{ij}\} - \min_i\{x_{ij}\}} \quad (1)$$

minimization criterion

$$r_{ij} = \frac{\max_i\{x_{ij}\} - x_{ij}}{\max_i\{x_{ij}\} - \min_i\{x_{ij}\}} \quad (2)$$

entropy: e_i (other representations as H, H(p(x) or H(A))) of the i^{th} criterion $e_i = -k \sum_{j=1}^{m} f_{ij} \ln(f_{ij})$,

where $f_{ij} = \frac{r_{ij}}{\sum_{j=1}^{m} r_{ij}}$, k=1/ln(m), when $f_{ij}=0 \Rightarrow f_{ij} \ln(f_{ij})=0$. (3)

weight of entropy of i^{th} criterion

$$w_i = \frac{1-e_i}{n-\sum_{i=1}^{n} e_i}$$

where $0 \leq w_i \leq 1$, $\sum_{i=1}^{n} w_i = 1$ (4)

The AHP methodology was developed and first presented in the 1980s by Thomas L. Saaty (Saaty, 1980, 1987, 1990). The description and definition of this method are given as:

> "*In its general form the AHP is a nonlinear framework for carrying out both deductive and inductive thinking without use of the syllogism by taking several factors into consideration simultaneously and allowing for dependence and for feedback, and making numerical tradeoffs to arrive at a synthesis or conclusion.* " (Saaty, 1987).

In this definition, some possible difficult and important terms were "deductive thinking", "inductive thinking", and "syllogism"; for definitions please visit IEP (2015) and Wikipedia (2015a) for deductive thinking, and inductive thinking, and Cambridge University Press (2015) and LDOCE (2015) for syllogism.

The AHP method was grouped under the American school of multicriteria decision approach (Pomerol & Barba-Romero, 2012; Lootsma, 1990). This method has been applied in many different research fields such as health, transportation-railway project strategic investment decisions, and shipbuilding-new shipbuilding yards investment location selection in countries master plans (Andreichicova & Radyshevskaya, 2009; Macura and Selmic, 2015, Saracoglu, 2013). As usual for any scientific research subject some studies supported the AHP method in the literature while others were opposed (Barzilai, 1998; Saaty, 2004; Saaty et.al., 2009). For more details about the principles and the equations of the AHP method see Brunelli (2015), Saaty (2004) and Saaty & Sodenkamp, (2010).

The scope of this work is to understand, analyze, investigate and compare the findings of one of the American school methods (AHP) and two of the European school methods (ELECTRE III and ELECTRE IV) with objective and subjective weighting methods (equal, Shannon's Entropy, Saaty's AHP, and no weighting approaches) on a simplistic unified small hydropower plant investment selection model in the pre-development investment stages. This research study will hopefully contribute to the main aim of building up an intelligent autonomous decision or executive support system (human like computer reasoning and modeling) in the renewable energy field.

3. Comparative research model, case, results, and discussion

The comparative research model and its case study were built on the pillars of the methods (ELECTRE III, ELECTRE IV, AHP, and Shannon's Entropy) and the cognitive limitations of humans (long term and short term memory). The simplistic unified and unique research model and its case study have to satisfy all requirements of these methods; hence it must be developed very carefully under the restrictions of these methods.

Modeling constraints and guidance in this research study (please read the original documents cited in this text to avoid any conceptual, pragmatic, and semantic change or shift).

These pillars are found in this study as:

1) Apply ELECTRE II, ELECTRE III, or ELECTRE IV for ranking problems (Figueira et al., 2010, Ishizaka & Nemery, 2013)
2) Use ELECTRE III when expressing the relative importance of the pseudo-criteria are possible (Dias et al., 2006)
3) Use ELECTRE IV under three conditions (not able, does not want, cannot express the relative importance). "Using ELECTRE IV is only valid if the following two conditions are satisfied: no criterion is either preponderant or negligible when compared to any subset of half of the criteria" (Dias et al., 2006)
4) Use more than five criteria up to twelve or thirteen in ELECTRE methods (Figueira et al., 2005)
5) Use a maximum of 9 factors in each level in the AHP method (Gawlik, 2008; Kruger & Hattingh, 2006; Saaty, 1980)
6) Preferable to apply ELECTRE methods in problems with large number of alternatives (Pohekar & Ramachandran, 2004; Soncini-Sessa et al., 2007)
7) Preferable to apply ELECTRE methods when at least one criterion can be evaluated by an ordinal scale or a weakly interval scale (Figueira et al., 2005)
8) Preferable to apply ELECTRE methods when criteria have a strong heterogeneity (Figueira et al., 2005)
9) Build AHP model that is complex enough for capturing the situation and nature of the problem, but small and easy enough for handling changes (Saaty, 1987)
10) Take into account the principles of sensory information storage (SIS), short-term memory (STM) and long-term memory (LTM) in the decision analysis. "Sensory information storage holds sensory images for several tenths of a second after they are received by the sensory organs. The functioning of SIS may be observed if you close your eyes, then open and close them again as rapidly as possible. As your eyes close, notice how the visual image is maintained for a fraction of a second before fading" (Heuer, 1999). "Information passes from SIS into short-term memory, where again it is held for only a short period of time—a few seconds or minutes. Like SIS, short-term memory holds information temporarily, pending further processing. This processing includes judgments concerning meaning, relevance, and significance, as well as the mental actions necessary to integrate selected portions of the information into long-term memory" (Heuer, 1999). "Some information retained in STM is processed into long-term memory. This information on past experiences is filed away in the recesses of the mind and must be retrieved before it can be used. In contrast to the immediate recall of current

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experience from STM, retrieval of information from LTM is indirect and sometimes laborious" (Heuer, 1999).
11) Take into account the principles of working memory by obeying the magical number 7, and the 7±2 rule to guarantee the trustworthiness (Miller, 1956; Shiffrin & Nosofsky, 1994).
12) Choose realistic threshold values in the ELECTRE methods (Rogers & Bruen, 1998; Saracoglu, 2015a).

- the indifference threshold of a criterion (*q*) has to be the highest value which beyond it the difference is perceptible
- the preference threshold of a criterion (*p*) may be easily selected as at least twice as the indifference threshold (*p*) where symmetrical about the mean value
- the veto threshold of a criterion (*v*) may be easily defined as at least three times as the preference threshold
- for maximization criteria $v \geq p \geq q$, for minimization criteria additive inverse (Rogers & Bruen, 1998; Saracoglu, 2015a)

Under these rules and guidelines, a simple and unified model is built in this study, because it makes it easier to do the following:

1) Understand AHP, ELECTRE III, ELECTRE IV, Shannon's Entropy weighting, equal weighting, Saaty's AHP weighting methods and approaches
2) Compare the findings
3) Find, collect, and process data and information
4) Evaluate factors (e.g. avoid difficulty and too much complexity of evaluating or pairwise comprising of some subjective and objective factors as such Ganser, 2001; Ganser, 2005; McDaniel et al., 2015; Zukauskas & Vveinhardt, 2015)
5) Take small steps and open new doors for the development of a human like intelligent autonomous support system

Based on this, the model criteria were first studied based on three research studies in this specific field (Saracoglu, 2015a, b, c). Only seven factors were selected and used. During this selection process, the electrical installed capacity (in Watts) of a small hydropower plant is intentionally taken into consideration (Equation 5) because the plan is to use this equation as an objective function or a constraint in the future combined multi objective optimization and multi criteria decision making research studies.

$$P = \eta_{tr} \times \eta_g \times \eta_t \times \rho_w \times g \times Q \times H_{net} \tag{5}$$

(η_{tr}: efficiency of transformer, η_g: efficiency of generator, η_t: efficiency of turbine, ρ_w: density of water (kg/m^3), g: gravity (m/s^2), Q: rated discharge (m^3/s), H_{net}: net head (m))
(for extraction of this formula/equation see Eliasson and Ludvigsson, 2000; ESHA, 2004; ESHA, 2005)

The wisdom, "let first the data speak", is followed in this study, therefore the objective factors are first selected for this simplistic unified comparative model (Jorba et al., 2008). These attributes are also investigated using the help of Carrot^2. "Carrot^2 is an open source software project that includes several text clustering algorithms which include bisecting K-means, Suffix Tree Clustering and Lingo algorithm" (Carrot^2, 2015; Zamir & Etzioni, 1999; Osinski & Weiss, 2005). The documents are clustered for each factor on the

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Carrot^2 desktop and studied one by one on some preferred clusters. The basic private small hydropower plant investment selection factors (criteria/attributes) in this study are as follows:

C_1: Catchment Area (drainage basin, catchment, catchment basin, drainage area, river basin, water basin) (objective criteria, km^2) (more is better ↑ ↑). The catchment area is defined as, "The land area where precipitation falls off into creeks, streams, rivers, lakes, and reservoirs. It is a land feature that can be identified by tracing a line along the highest elevation between two areas on a map" (USGS, 2015). Georges River (2015) defines it as, "An area of land where water collects when it rains, often bounded by hills. As the water flows over the landscape it finds its way into streams and down into the soil, eventually feeding the river. Some of this water stays underground and continues to slowly feed the river in times of low rainfall. Every inch of land on the Earth forms part of a catchment". Langbein & Iseri (1995) define the drainage area as, "A stream at a specified location is that area, measured in a horizontal plane, which is enclosed by a drainage divide", and drainage basin as, "A part of the surface of the earth that is occupied by a drainage system, which consists of a surface stream or a body of impounded surface water together with all tributary surface streams and bodies of impounded surface water". The European Small Hydropower Association or ESHA (2004) defines it as, "The whole of the land and water surface area contributing to the discharge at a particular point on a watercourse". When the catchment area of a small hydropower plant is calculated by any means, the location of weirs (diversion dam, diversion weir) is taken into account. If there is more than one weir in the project, the total catchment area as an equivalent catchment area is calculated by the sum of all catchment area values in the evaluation of this study. When two catchment areas of small hydropower plants are compared or evaluated, the large one is preferred to the smaller one in this study. The properties of catchments are not used and considered in this simplistic unified decision aiding (decision making) model. The data of the small hydropower plant investments are directly taken and tabulated in this study. This criterion is a site and design specific factor. The Carrot^2 is used for gathering additional information for better perception in an easy and fast way as shown in Figure 4. Further details of this criterion are discussed in Saracoglu (2015a, b, c).

Figure 4. Carrot^2 workbench clustering results for "drainage basin" on 29/07/2015, Source: Wiki, Algorithm: Lingo, Visualization: FoamTree (generated by the Carrot^2 http://carrot2.org & the Paint.NET)

ISSN 1936-6744
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C_2: Project Runoff (objective criteria, hm^3) (more is better ↑ ↑) The project runoff is the mean annual total runoff of the catchment area in this study. This term can also be used as only runoff. Langbein & Iseri (1995) define it as, "part of the precipitation that appears in surface streams". There are also a few important terms that help to understand the meaning of project runoff for mall hydropower plants. Langbein & Iseri (1995) define streamflow as, "The discharge that occurs in a natural channel. Although the term discharge can be applied to the flow of a canal, the word streamflow uniquely describes the discharge in a surface stream course. The term "streamflow" is more general than runoff, as streamflow may be applied to discharge whether or not it is affected by diversion or regulation". Langbein & Iseri (1995) define overland flow as "the flow of rainwater or snowmelt over the land surface toward stream channels. After it enters a stream, it becomes runoff". USGS Water Science School (2015a) discusses surface runoff as, "Many people probably have an overly-simplified idea that precipitation falls on the land, flows overland (runoff), and runs into rivers, which then empty into the oceans. That is "overly simplified" because rivers also gain and lose water to the ground. Still, it is true that much of the water in rivers comes directly from runoff from the land surface, which is defined as surface runoff. When rain hits saturated or impervious ground, it begins to flow overland downhill. It is easy to see if it flows down your driveway to the curb and into a storm sewer, but it is harder to notice it flowing overland in a natural setting". The ESHA (2004) defines it as, "The rainfall, which actually does enter the stream as either surface or subsurface flow". When the project runoff of a small hydropower plant is calculated by any means, the location of weirs (diversion dam, diversion weir) is taken into account. If there is more than one weir in the project, the total project runoff as equivalent total project runoff is calculated by the sum of all total project runoff values in the evaluation of this study. Moreover, the environmental flow runoff (for ecosystems and human livelihoods) isn't included in this total. When two project runoff values of small hydropower plants are compared or evaluated, the larger one is preferred to the smaller one in this study. The data on the small hydropower plant investments are directly taken and tabulated in this study. This criterion is a site and design specific factor. The Carrot[2] is used for gathering additional information for better perception in an easy and fast way as shown in Figure 5. Further details of this criterion are discussed in Saracoglu (2015a, b, c).

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Figure 5. Carrot^2 workbench clustering results for "runoff" on 29/07/2015 Source: Wiki, Algorithm: Lingo, Visualization: Circles (generated by the Carrot^2 & the Paint.NET)

C_3: Net Head (objective criteria, m) (more is better ↑ ↑) The net head is defined as, "The gross head minus all hydraulic losses except those chargeable to the turbine" (EIA, 2015). The head is sometimes called the water pressure. The ESHA (2004) defines it as, "The gross head minus the sum of all the losses equals the net head, which is available to drive the turbine". The losses are generally caused by trash racks, pipe friction, bends and valves. The gross head is defined as, "A dam's maximum allowed vertical distance between the upstream's surface water (headwater) forebay elevation and the downstream's surface water (tailwater) elevation at the tail-race for reaction wheel dams or the elevation of the jet at impulse wheel dams during specified operation and water conditions" (EIA, 2015). ESHA (2004) defines the gross head as, "The vertical distance that the water falls through in giving up its potential energy (i.e. between the upper and lower water surface levels)". Here, the turbine type is important because some types of turbines discharge the water to the atmosphere. If there are multiple net heads in the project (cascade group projects or other clustered projects), the equivalence of these net heads according to the electrical installed power equation is calculated and used in the evaluation. This equivalent net head is an approximation and assumption of this study. Some detailed technical conditions such as total efficiencies of turbines, generators and transformers are assumed to be the same for all alternatives and actions. When two project net head values of small hydropower plants are compared or evaluated, the larger one is preferred to the smaller one in this study. The data on the small hydropower plant investments are directly taken and tabulated in this study. This criterion is a site and design specific factor. The Carrot^2 is used for gathering additional information for better perception in an easy and fast way as shown in Figure 6. Further details of this criterion are discussed in Saracoglu (2015a, b, c).

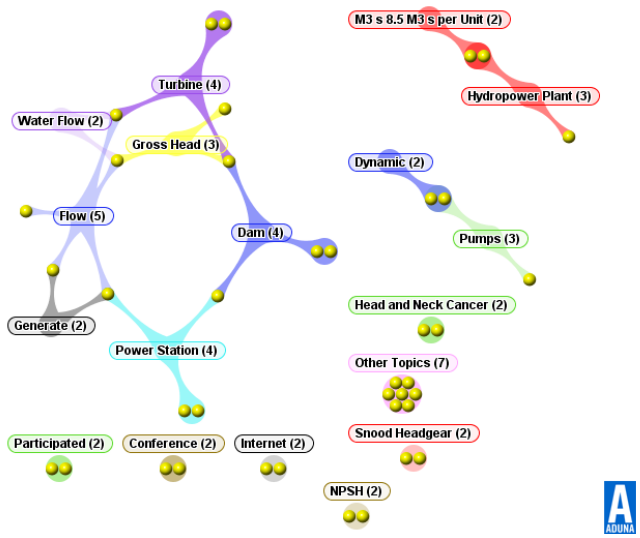

Figure 6. Carrot² workbench clustering results for "net head" on 31/07/2015 Source: Wiki, Algorithm: Lingo, Visualization: Aduna Cluster Map (generated by the Carrot² & the Paint.NET)

C_4: Project Design Discharge (capacity, discharge, flow, flow rate, rate of flow) (objective criteria, m^3/s) (more is better ↑ ↑) USGS Water Science School (2015b) defines discharge as, "The volume of water moving down a stream or river per unit of time, commonly expressed in cubic feet per second or gallons per day. In general, river discharge is computed by multiplying the area of water in a channel cross section by the average velocity of the water in that cross section". Here, the maximum project design discharge of the turbined water is taken into account. If there are more than one project design discharges in the project (several weirs, several turbines, cascade group projects or other clustered projects), the equivalence of these discharges according to the electrical installed power equation is calculated and used in the evaluation of this study. This equivalent discharge is an approximation and assumption of this study. Some detailed technical conditions such as total efficiencies of turbines, generators and transformers are assumed to be same for all alternatives and actions. When two project discharge values of small hydropower plants are compared or evaluated, the large one is preferred to the smaller one in this study. The data on the small hydropower plant investments are directly taken and tabulated in this study. This criterion is a site and design specific factor. Further details of this criterion are discussed in Saracoglu (2015a, b, c).

C_5: Firm Energy (objective criteria, GWh) (more is better ↑ ↑) ESHA (2004) defines this as, "The power delivered during a certain period of the day with at least 90 – 95% certainty". When two project firm energy values of small hydropower plants are compared or evaluated, the larger one is preferred to the smaller one in this study. The data on the small hydropower plant investments are directly taken and tabulated in this study. This criterion is a site and design specific factor. Further details of this criterion are discussed in Saracoglu (2015a, b, c).

C_6: Secondary Energy (objective criteria, GWh) (more is better ↑ ↑) The secondary energy is the remaining part of the total energy generated after the deduction of the firm energy of a small hydropower plant (Equation 6). Further details of this criterion are discussed in Saracoglu (2015a, b, c).

$$E_{total} = E_{firm} + E_{secondary} \tag{6}$$

(E_{total}: total electricity generation (kWh), E_{firm}: firm energy (kWh), $E_{secondary}$: secondary energy (kWh), kilowatt hour unit is for this study, the unit can be megawatt hour, gigawatt hour, etc.)

C_7: Investment Cost (objective criteria, USD) (less is better ↓ ↑) This includes the total estimated investment cost of the private small hydropower plants. The construction cost of the small hydropower plant structures such as the diversion weir, the de-silting tank, the channel, the tunnel, the headpond, or in other words the forebay, the penstock, the powerhouse, the tailrace, and the substation are also taken into account. Moreover, all related costs for the electromechanical equipment such the turbines, the generators, the transformers, the control systems, the diesel generators, the cooling systems, and the dewatering systems are all taken into account. Transmission lines and their related costs, all of the engineering studies and their related costs, supervision tasks and related costs are all taken into account. Moreover, the contingency, the financial costs, the expropriation costs, the insurance costs are all taken into account in this item. In addition to these cost items, the operational costs of the private small hydropower plants are also calculated. The data of small hydropower plant investments are directly taken and tabulated in this study. Henceforth, there isn't any design study and cost estimation performed in the current study. It is assumed that the investment costs of private small hydropower plants are the same items for all small hydropower plants. Moreover, it is assumed that the investment cost of private small hydropower plants contains all of the cost items of a small hydropower plant. Here, the only calculation made is for the currency exchange and time value of money change (Investopedia, 2015a). We attempt to find the investment cost calculation date, then the foreign-exchange rate data (USD: United States Dollar to TL: Turkish Lira or TL to USD) is taken from the official webpage of the Central Bank of the Republic of Turkey and used for the currency exchange (TCMB, 2015) of the investment cost (Equation 7).

$$IC_{USD\ date} = IC_{TL\ date} \times CR_{TL\ to\ USD\ date} \tag{7}$$

($IC_{USD\ date}$: investment cost of private small hydropower plant on the investment cost calculation date in USD, $IC_{TL\ date}$: investment cost of private small hydropower plant on the investment cost calculation date in TL, $CR_{TL\ to\ USD\ date}$: official currency rate of TCMB from TL to USD on the investment cost calculation date)

The time value of money change is calculated by the future worth or the future value equation based on the compounded annual interest rate in this study (Investopedia, 2015b) (Equation 8). The present value and the future value equations, and the detailed information about these terms can be found in Gitman et al. (2014), Known et al. (2004), Panneerselvam (2012), and several other engineering economics, financial management and financial accounting books.

$$IC_{small\ hydropower\ plant\ investment\ today} = IC_{small\ hydropower\ plant\ investment\ initial\ value} \times (1+i)^n \tag{8}$$

($IC_{small\ hydropower\ plant\ investment\ today}$: investment cost of private small hydropower plant today for this study in USD, $IC_{small\ hydropower\ plant\ investment\ initial\ value}$: investment cost of private small hydropower plant on the investment cost calculation date in USD, i: interest rate,

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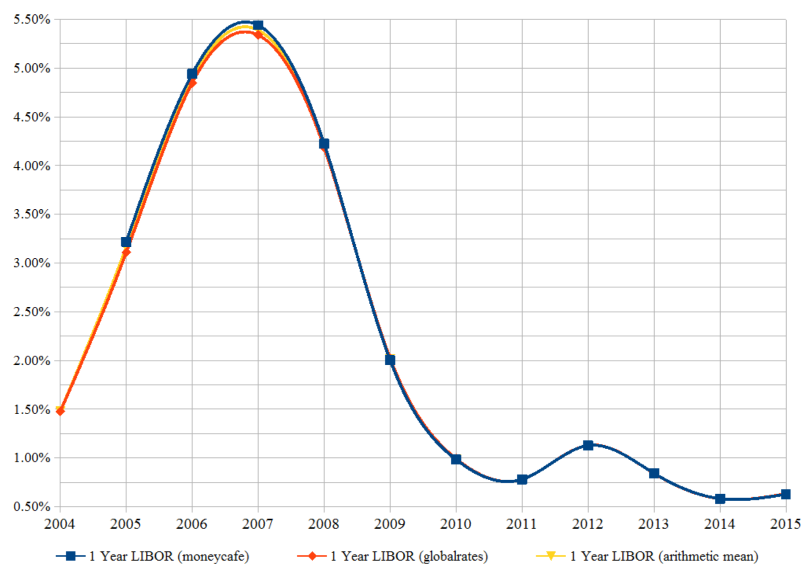
approximation as the arithmetic mean of USD annual LIBOR rates in this study, n: years counted from the initial value of year to today as year 2015).

The London Interbank Offered Rate (LIBOR) data are taken directly as 1 year/ 12 month rates from moneycafe.com (2015) and globalrates.com (2015). The arithmetic mean of the values from these two different web pages is calculated for each year (Equation 9). When only one data point exists, then this data is taken as the LIBOR value in its year. Next, the interest rate for a period is calculated by the arithmetic mean of LIBOR values in this period. This interest rate is a good approximation for the calculation of the time value of money change in the investment cost (Equation 10). By this approach, the complexity of the inflation in Turkey, the redenomination (removal of six zeros in Turkish Lira) in Turkey, and the exchange rates in Turkey are eliminated. The LIBOR data and the interest rates are presented in Figure 7.

$$LIBOR_{\text{year i}} = (LIBOR_{\text{year i moneycafe}} + LIBOR_{\text{year i globalrate}}) / 2 \tag{9}$$

$$i_{year\ j\ to\ year\ k} = \frac{1}{(year\ k - year\ j)} \times \sum_{year\ k}^{year\ j} LIBOR_{year\ i} \tag{10}$$

When two investment costs of small hydropower plants are compared or evaluated, the smaller one is preferred to the larger one in this study. This criterion is a site and design specific factor.



Years	i	Years	i	Years	i
2004-2015	2,18%	2005-2015	2,24%	2006-2015	2,15%
2007-2015	1,84%	2008-2015	1,40%	2009-2015	1,00%
2010-2015	0,83%	2011-2015	0,79%	2012-2015	0,80%
2013-2015	0,69%	2014-2015	0,61%	2015-2015	-

Figure 7. LIBOR 1 year or 12 month LIBOR (January) (Data: moneycafe.com, 2015; globalrates.com, 2015) (Calculation: arithmetic mean) (generated by the Apache OpenOffice 4.1.1 Calc http://www.openoffice.org/ & the Paint.NET)

The current simplistic unified model structure for AHP, ELECTRE III and ELECTRE IV has three levels (Figure 8). There are seven private small hydropower plant investment alternatives or actions (Alternative$_{1\text{ to }7}$/Action$_{1\text{ to }7}$) (Table 4). There is only one expert decision maker who builds the model and presents his thoughts on the factors and alternatives. The objective factors aren't evaluated due to the alternatives because their approximate values are directly taken in several ways (Figure 3). The threshold values (indifference, preference, veto) in the ELECTRE methods are chosen based on the opinion of the expert decision maker. The criteria weights are calculated by the equal weighting, the Shannon's Entropy, and the Saaty's AHP approaches. While assigning the criteria weights by the pairwise comparisons of the expert decision maker, the linguistic, or verbal evaluation labels are used based on the Fundamental Scale of the AHP (Saaty, 1980; Saaty, 2008) and the Likert type scale (Likert, 1932: extension 1 to 9 of original work 5 point scale) (Saracoglu, 2015b). The expert decision maker judgments are made with the help of the Super Decisions version 2.2 software (http://www.superdecisions.com/) for the Saaty's AHP weighting. The inconsistency of the matrix is directly calculated by the Super Decisions software and recorded. The equal weighting and the Shannon's Entropy weighting calculations are made directly in a Microsoft Excel spreadsheet.

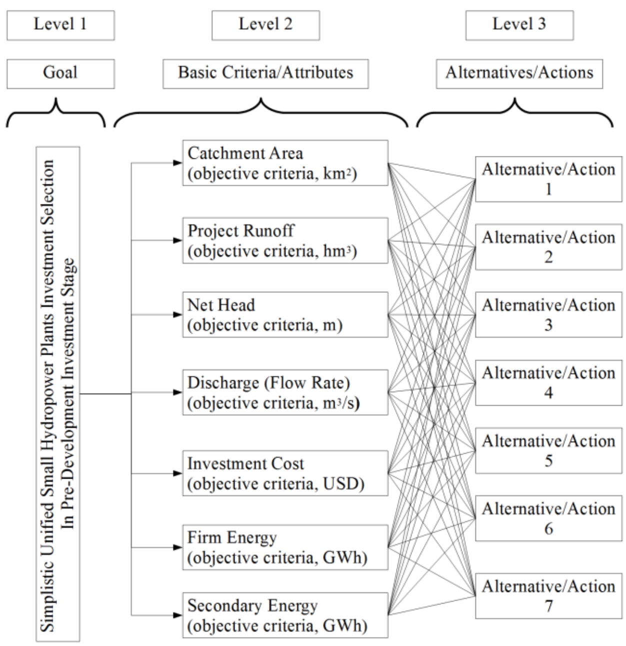


Figure 8. Simplistic unified model structure for AHP, ELECTRE III and ELECTRE IV

ISSN 1936-6744
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Table 4
Private small hydropower plant investment actions/alternatives

Actions/ Alternatives	P	C_1	C_2	C_3	C_4	C_5	C_6	C_7
$Alternative_1$	6,56	470,00	302,90	31,54	24,00	0,85	18,45	10.069.000
$Alternative_2$	1,91	36,00	26,79	76,36	2,80	0,00	5,12	4.534.000
$Alternative_3$	8,55	4.550,00	589,22	19,58	50,00	4,58	24,49	22.054.000
$Alternative_4$	5,43	1.243,31	193,71	54,03	12,64	0,00	18,62	17.757.000
$Alternative_5$	3,91	352,00	103,20	60,28	7,50	1,25	10,56	3.948.000
$Alternative_6$	6,52	1.763,50	274,76	36,00	20,82	0,00	8,83	12.653.000
$Alternative_7$	9,23	1.945,00	301,62	59,14	18,00	0,00	30,01	26.654.000

P: Installed Power (MW: megawatt), C_1: Catchment Area (km^2), C_2: Project Runoff (hm^3), C_3: Net Head (m), C_4: Discharge (m^3/s), C_5: Firm Energy (GWh/year), C_6: Secondary Energy (GWh/year), C_7: Investment Cost (USD)

The equal weighting, the Shannon's Entropy weighting, and the Saaty's AHP weighting approaches for voting power or weight of the criteria on this simplistic unified small hydropower plant investment selection model in the pre-development investment stages are evaluated, calculated and compared. The equal weighting is 0,1429 per criteria, that sums to a total of 1,000 for seven factors. The Shannon's Entropy weighting is calculated according to its equations and the criteria weights are: catchment area 0,1517, project runoff 0,0979, net head 0,0858, discharge 0,1207, firm energy 0,3573, secondary energy 0,1019, investment cost 0,0847. The Saaty's AHP weighting, that is the pairwise comparisons of the expert decision maker, starts with an inconsistency of 0,22171. The inconsistency reaches 0,09511 at the 7^{th} evaluation. At this level, there aren't any additional pairwise evaluations made because the desired inconsistency level in the AHP method is less than 0,10 (Saaty, 1990). The inconsistency value per evaluation in the Saaty's AHP weighting is presented in Figure 9. The recommendations of the Super Decisions software aren't taken into account when the evaluations are performed again. The number of pairwise comparisons is 21 for 7 factors with respect to the goal. There are 7 evaluations, making the total number of pairwise comparisons 147 in this study. It is observed that the evaluations of the expert decision maker fit a logarithmic trendline with a good R squared (coefficient of determination) value (Figure 9). This observation is recorded for future studies. The Shannon's Entropy objective weighting representation difference rate (performance) of the evaluations of the expert decision makers ranges between -67% and 671% (Figure 10). The equal weighting representation difference rate ranges between -64% and 626% (Figure 10). These criteria weight findings show that neither of these objective weighting (equal and Shannon's Entropy) approaches are helpful in predicting the expert decision maker judgments and behavior on the criteria weights. The criteria weights and their representational capabilities of the Saaty's AHP weighting are shown in Figure 10. The equal weighting approach doesn't have the capability of discriminating the differences between the factors (Figure 10). Henceforth, this objective weighting approach can only predict the human judgments on the criteria weights well when the decision maker doesn't know anything about the factors and their details or when the factors being investigated don't have any major differences between themselves. For instance, an ordinary person can't decide or make any judgments on the weights of the factors of the firm energy and the secondary energy because he or she doesn't know what these factors mean and which one is more important and so on (Figure

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10). Although the Shannon's Information Theory (Shannon's Entropy) strictly depends on the probability of events (probability theory), its representation capability is still questionable and needs very detailed and long term research studies for the criteria weight assignments in the human decision making research field (Carter, 2014; Shannon, 1948; Shannon, 1951). One of the important aspects of the Shannon's Entropy is that it is based on large quantities of information. Further research studies need to investigate this issue with more hard data. The Shannon's Entropy objective weighting approach predicts fairly well the firm energy criteria weight (Figure 10). The performance of the Shannon's Entropy weighting in predicting the Saaty's AHP weighting for other factors is poor in this study. In short, the firm energy, the secondary energy and the investment cost factor weights are all predicted less than the Saaty's AHP weighting (Figure 10). The discharge, the net head, the project runoff and the catchment area criteria weights are all predicted more than the Saaty's AHP weighting (Figure 10). It is important to remember what William Bruce Cameron said, "Not everything that can be counted counts, and not everything that counts can be counted". Also, Edward Gibbon was wise when he stated, "The laws of probability, so true in general, so fallacious in particular". These two weighting approaches can't represent the expert decision maker judgments in this study because both the Shannon's Entropy and the equal objective weighting approaches are based only on the hard data of the alternatives. However, Saaty's AHP subjective weighting assessment is based only on the expert knowledge. This observation is also recorded for future studies.

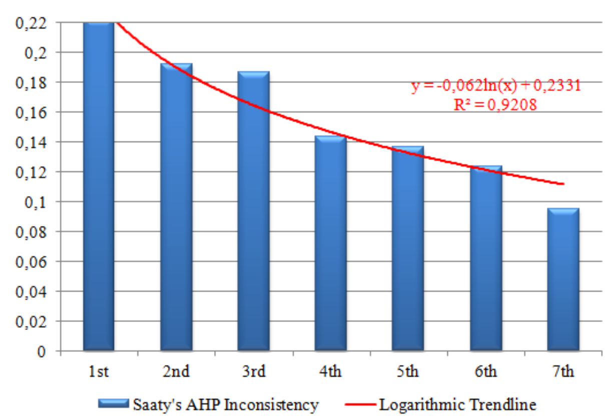
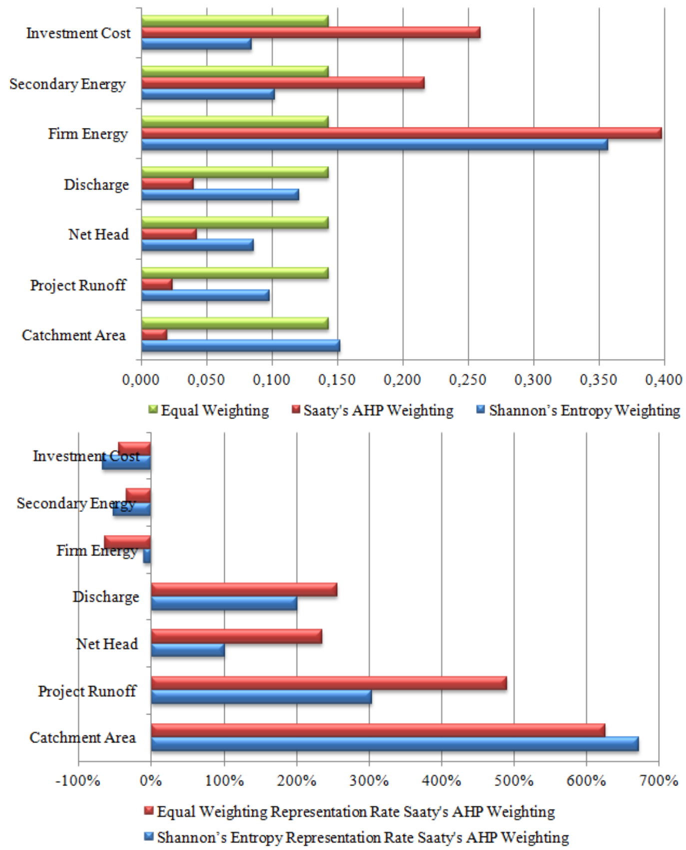


Figure 9. Inconsistency values of pairwise comparisons in this study



Code	Criterion	equal	Shannon's	Saaty's AHP
C_1	Catchment Area	0,1429	0,1517	0,0197
C_2	Project Runoff	0,1429	0,0979	0,0242
C_3	Net Head	0,1429	0,0858	0,0426
C_4	Discharge	0,1429	0,1207	0,0401
C_5	Firm Energy	0,1429	0,3573	0,3982
C_6	Secondary Energy	0,1429	0,1019	0,2163
C_7	Investment Cost	0,1429	0,0847	0,2590
	Sum Of Weights	1,0000	1,0000	1,0000

Figure 10. Criteria weights comparison (on top), objective weighting representation rate of Saaty's AHP weighting (on bottom) in this study

The indifference threshold (q), the preference threshold (p), and the veto threshold (v) of criteria for the ELECTRE methods are chosen by the expert decision maker according to item 10 of the modeling constraints and guidance in Section 3 (Rogers & Bruen, 1998; Saracoglu, 2015a) (Table 5). All of these evaluations are totally subjective judgments. The ELECTRE III-IV software version 3.x is used in this study, so that the parameters and inputs are organized according to the software standards. This software defines the thresholds by two coefficients α and β as such:

$$(q \text{ or } p \text{ or } v)_j = \alpha_j \times g_j + \beta_j \tag{11}$$

(q: indifference threshold, p: preference threshold, v: veto threshold, j: criteria number or criteria, g_j: value or evaluation of the action or the alternative on the j^{th} criterion, α_j and β_j: coefficients of q, p, or v)

In this study, the threshold values are decided as the constant values by the expert decision maker, so that the values in Table 5 are entered as β values on the ELECTRE III-IV software. This evaluation approach is simpler for the expert decision maker than defining two coefficients α and β. Instead of deciding these two coefficients, the expert decision maker directly decides the threshold values. The direct threshold preference is selected on the software. (Dias et al., 2006)

Table 5
Threshold values*

Criterion	Direction Of Preferences	Indifference (q_j)	Preference (p_j)	Veto (v_j)
Catchment Area	Max	500	1.000	3.000
Project Runoff	Max	200	400	1.200
Net Head	Max	40	80	240
Discharge	Max	10	20	60
Firm Energy	Max	0,9	1,8	5,4
Secondary Energy	Max	15	30	90
Investment Cost	Min	5.000.000	10.000.000	30.000.000

* α values are taken as zero and β values are taken as threshold values

The AHP model calculations are performed in the Super Decisions version 2.2 (see Figure 11 for the AHP model screen view) for the equal weighting, the Shannon's Entropy weighting, and the Saaty's AHP weighting approaches. The direct data input table is used for entering the data from Table 4 into Super Decisions. The zero values aren't accepted by the software, hence instead of zero values, values very close to zero are entered (0,00 ≈ 0,00001). Moreover, the values on the table are automatically changed to approximate values by the software (e.g. 1.243,31 ≈ 1243.3093; 4.534.000 ≈ 4534000.09397). These values are checked one by one and it is assumed that there will not be any major effect on the results of the calculations in this subject. The matrices for the alternatives with respect to the objective factors aren't studied for their inconsistency because they are the objective factors. In this study, the priorities of the factors and the alternatives are taken by their normalized cluster values in Super Decisions. The preference orders of the alternatives by the equal weighting approach are Alternative 1 (0,1247) (3rd rank), Alternative 2 (0,0509) (7th rank), Alternative 3 (0,3314) (1st rank), Alternative 4 (0,1177) (4th rank), Alternative 5 (0,0918) (6th rank), Alternative 6 (0,1128) (5th rank), and Alternative 7 (0,1708) (2nd rank). The preference orders of the alternatives by the Shannon's Entropy weighting approach are Alternative 1 (0,1228) (3rd rank), Alternative 2 (0,0324) (7th rank), Alternative 3 (0,4348) (1st rank), Alternative 4 (0,0855) (6th rank), Alternative 5 (0,1118) (4th rank), Alternative 6 (0,0872) (5th rank), and Alternative 7 (0,1255) (2nd rank). The preference orders of the alternatives by the Saaty's AHP weighting approach are Alternative 1 (0,1274) (3rd rank), Alternative 2 (0,0325) (7th rank), Alternative 3 (0,4120) (1st rank), Alternative 4 (0,0973) (5th rank), Alternative 5 (0,1159) (4th rank), Alternative 6 (0,0678) (6th rank) and Alternative 7

(0,1472) (2nd rank). The findings show that Alternative 3 is ranked first for all methods, Alternative 7 is ranked second for all methods, and Alternative 1 is ranked third for all methods. These findings represent that the first three ranks match for each weighting approach on the AHP method even though their criteria weights aren't the same. The 4th rank is occupied by Alternative 4 in the equal weighting, Alternative 5 in the Shannon's Entropy weighting, and Alternative 5 in the Saaty's AHP weighting approaches. The 5th rank is occupied by Alternative 6 for equal weighting, Alternative 6 in the Shannon's Entropy weighting, and Alternative 4 in the Saaty's AHP weighting approaches. The 6th rank is occupied by Alternative 5 in the equal weighting, Alternative 4 in the Shannon's Entropy weighting, and Alternative 6 in the Saaty's AHP weighting approaches. Alternative 2 is ranked seventh for all methods. These findings show that the rankings of alternatives promise to be the same or very similar without any major disturbance with these weighting approaches. Hence, it is possible to represent human subjective evaluations by some objective weighting approaches when only considering the final ranks of the AHP method (only considering these factors in private small hydropower plant investments). Under these conditions, it is recommended that an investigation be started (review data, feasibility studies, etc.) into Alternatives 3, 7, and 1 for private small hydropower plant investment options.

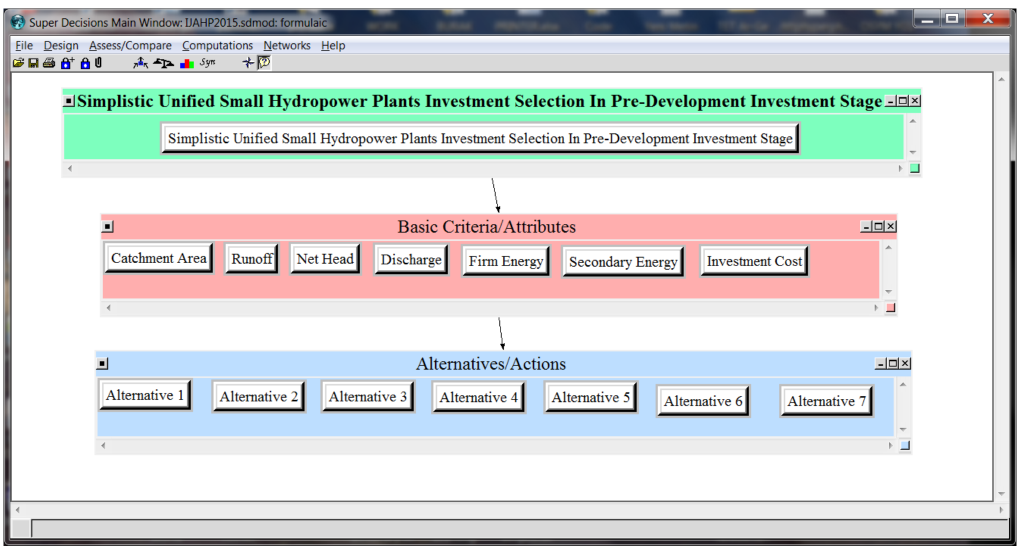


Figure 11. The AHP model on the Super Decisions software (open the electronic supplementary material: IJAHP2015SaatyAHPweighting.sdmod)

The ELECTRE III and ELECTRE IV model calculations are performed on the ELECTRE III-IV version 3.x for the equal weighting, the Shannon's Entropy weighting, and the Saaty's AHP weighting approaches. The direct data input tables are used for entering the data from Table 4 into the ELECTRE III-IV. The descending and ascending distillations for both ELECTRE III & IV models are taken from the menu Results/Distillations on the software. The ranks of the actions in the final pre-order for both ELECTRE III & IV models are taken from the menu Results/Ranks in Final Preorder on the software. The complete results for both ELECTRE III & IV models are taken from the menu Results/Final Graph on the software. The descending and ascending distillations (left), the final pre-orders (middle), and the final graph (right) are presented

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in Figures 12 to 17. Other important results (Concordance Matrix, Credibility Matrix, Ranking Matrix) are also taken from the menus and presented in the electronic supplementary material (IJAHP2015 Electronic Supplementary.pdf). It is helpful to be reminded that "descending distillation selects at first the best actions to end the process with the worst ones", oppositely "the ascending distillation selects first the worst actions to end the process with the best ones" (Dias et al., 2006). Moreover, "an action which is incomparable to a group of others will be ranked at the end of this group in the descending distillation and at the top in the ascending distillation. The actions which are considered equal (equivalence classes) in a distillation are displayed in the same box" (Dias et al., 2006). The final pre-orders should be understood as "any action which has no better action will have rank 1 (even if it is incomparable to many others), the actions of ranks 2 are those whose better actions are only of rank 1...." (Dias et al., 2006). The final graph is a good representation of the final rankings. In Figure 12 (left), Alternative 5 is the best action in the ELECTRE III with the Saaty's AHP weighting. It is at the first (top of the figure) of the selection process in the descending distillation. Alternative 3 follows Alternative 5 in the ELECTRE III with the Saaty's AHP weighting in the descending distillation. Alternative 7 is the worst action in the descending distillation. It is the last (bottom of the figure) of the selection process in the descending distillation (left in Figure 12). Alternative 3 is the worst action in the ELECTRE III with the Saaty's AHP weighting in the ascending distillation (top of the figure). Alternative 1 and Alternative 5 (in the same box) follow Alternative 3 (bottom of the figure). Alternative 7 is the best action in the ascending distillation. It is at the last (bottom of the figure) of the selection process in the descending distillation (left in Figure 12). Alternative 3 and Alternative 5 are ranked first in ELECTRE III with the Saaty's AHP weighting (middle and right in Figure 12). Alternative 1 follows these two alternatives, and Alternative 7 is the worst preferred action (middle and right in Figure 12). Under these conditions, it is recommended that an investigation be started (review data, feasibility studies etc.) on Alternative 3 and Alternative 5 first, and then Alternative 1 for private small hydropower plant investment options.

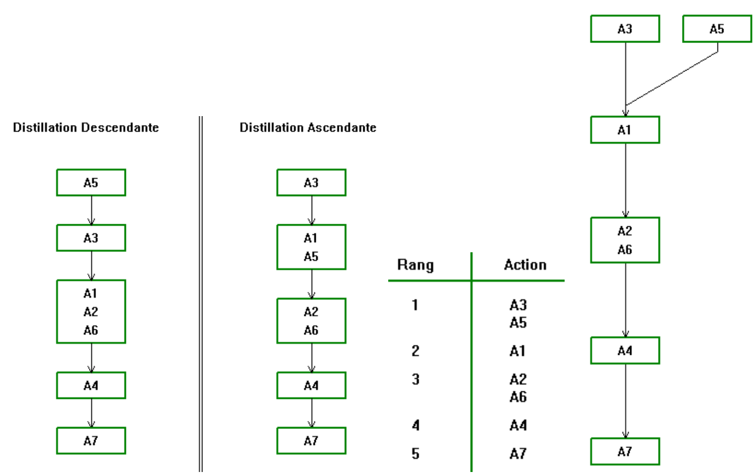

Figure 12. The ELECTRE III model results on the ELECTRE III-IV Version 3 software (open the electronic supplementary material: ijahpsa.elp) by the Saaty's AHP weighting, distillations (on left), ranks in final preorder (on middle/center), final graph (on right)

In Figure 13 (left), Alternative 3 is the best action in the ELECTRE IV with the Saaty's AHP weighting. It is first (top of the figure) in the selection process in the descending distillation. Alternative 6 follows Alternative 3 in the descending distillation. Alternative 2, Alternative 4, and Alternative 7 are the worst actions in the descending distillation. They are last (bottom of the figure) in the selection process in the descending distillation. Alternative 1 and Alternative 3 are the least actions in the ascending distillation (top of the figure). Alternative 4 is the best action in the ascending distillation. Alternative 3 is ranked first in ELECTRE IV with the Saaty's AHP weighting (middle and right in Figure 13). Alternative 1, Alternative 5, and Alternative 6 follow this alternative, and Alternative 4 is the least preferred action. Under these conditions, it is recommended that an investigation be started (review data, feasibility studies, etc.) into Alternative 3 first, then Alternative 1, Alternative 5, and Alternative 6 for private small hydropower plant investment options.

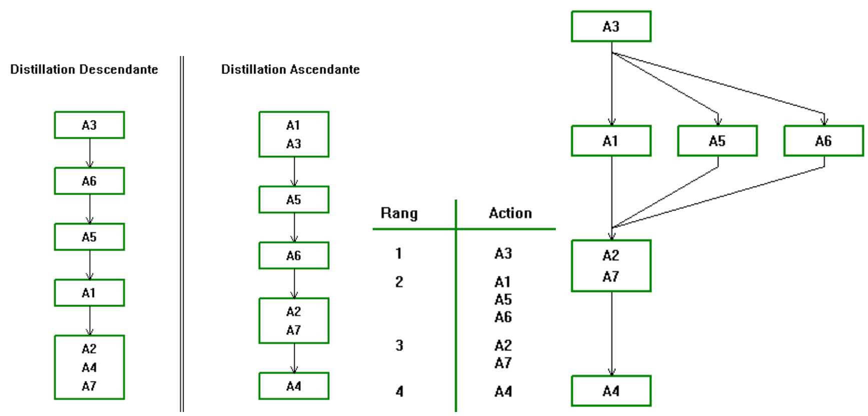

Figure 13. The ELECTRE IV model results on the ELECTRE III-IV Version 3 software (open the electronic supplementary material: ijahpsa.elp) by the Saaty's AHP weighting, distillations (on left), ranks in final preorder (on middle), final graph (on right)

In Figure 14 (left), Alternative 3 is the best action in the ELECTRE III with the equal weighting. It is first (top of the figure) in the selection process in the descending distillation. Alternative 1, Alternative 6, and Alternative 7 follow Alternative 3 in the descending distillation, and Alternative 2, Alternative 4, and Alternative 5 are the worst actions in the descending distillation. They are last (bottom of the figure) in the selection process in the descending distillation. Alternative 3 is the worst action in the ascending distillation (top of the figure). Alternative 2 is the best action in the ascending distillation. Alternative 3 is ranked first in ELECTRE III with the equal weighting (on middle and right in Figure 14). Alternative 1, Alternative 6, and Alternative 7 follow this alternative, and Alternative 2 is the least preferred action. Under these conditions, it is recommended that an investigation be started (review data, feasibility studies, etc.) of the Alternative 3 first, then Alternative 1, Alternative 6, and Alternative 7 for private small hydropower plant investment options.

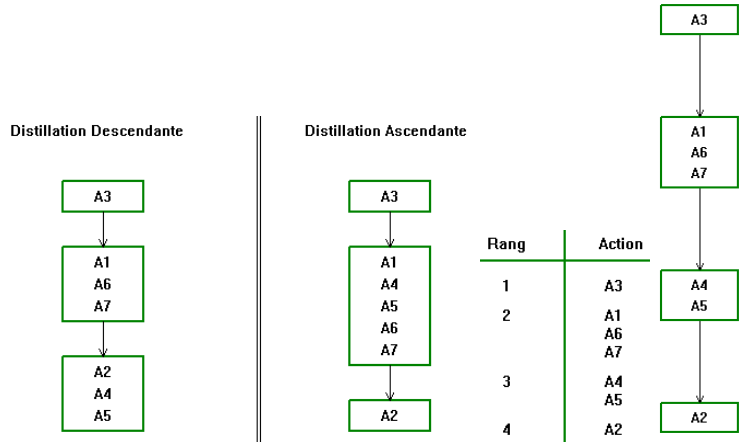

Figure 14. The ELECTRE III model results on the ELECTRE III-IV Version 3 software (open the electronic supplementary material: ijahpew.elp) by the equal weighting, distillations (on left), ranks in final preorder (on middle), final graph (on right)

In Figure 15 (left), Alternative 3 is the best action in the ELECTRE IV with the equal weighting. Alternative 6 follows Alternative 3 in the descending distillation. Alternative 2, Alternative 4, and Alternative 7 are the worst actions in the descending distillation. Alternative 1 and Alternative 3 are the worst actions in the ascending distillation. Alternative 4 is the best action in the ascending distillation. Alternative 3 is ranked first in ELECTRE IV with the equal weighting (middle and right in Figure 15). Alternative 1, Alternative 5, and Alternative 6 follow this alternative. Alternative 4 is the least preferred action. Under these conditions, it is recommended that an investigation be started (review data, feasibility studies, etc.) of Alternative 3 first, then Alternative 1, Alternative 5, and Alternative 6 for private small hydropower plant investment options.

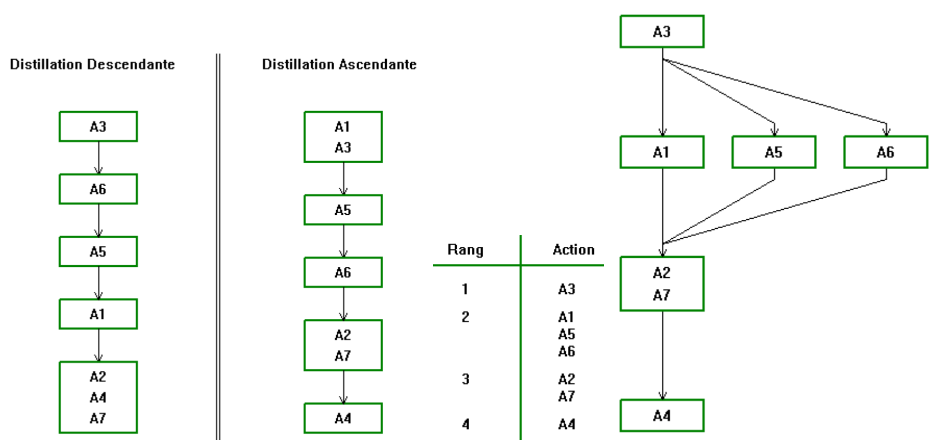

Figure 15. The ELECTRE IV model results on the ELECTRE III-IV Version 3 software (open the electronic supplementary material: ijahpew.elp) by the equal weighting, distillations (on left), ranks in final preorder (on middle), final graph (on right)

ISSN 1936-6744
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In Figure 16 (left), Alternative 3 is the best action in the ELECTRE III with the Shannon's Entropy weighting. Alternative 5 follows Alternative 3 in the descending distillation. The others are the worst actions in the descending distillation. Alternative 3 is the worst action in the ascending distillation. Alternative 4 is the best action in the ascending distillation. Alternative 3 is ranked first in ELECTRE III with the Shannon's Entropy weighting (on middle and right in Figure 16). Alternative 5 follows this alternative. Alternative 4 is the least preferred action. Under these conditions, it is recommended that an investigation be started (review data, feasibility studies, etc.) for Alternative 3 first, then Alternative 5 for private small hydropower plant investment options.

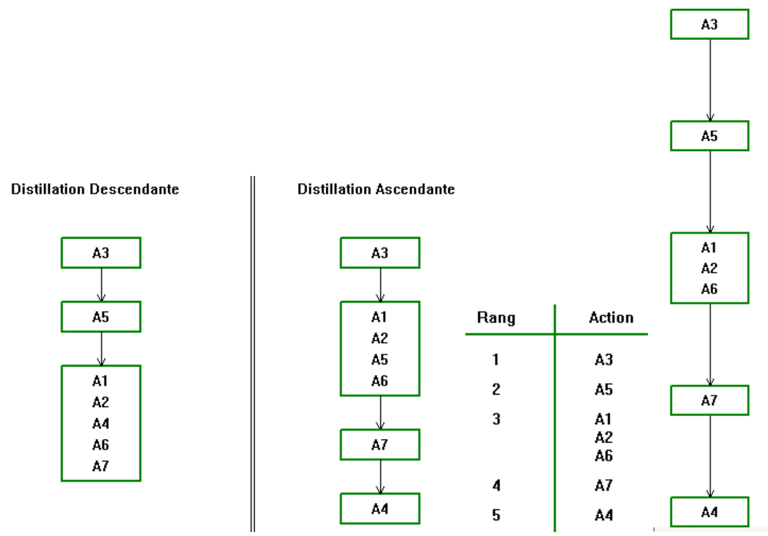


Figure 16. The ELECTRE III model results on the ELECTRE III-IV Version 3 software (open the electronic supplementary material: ijahpse.elp) by the Shannon's Entropy weighting, distillations (on left), ranks in final preorder (on middle), final graph (on right)

In Figure 17 (left), Alternative 3 is the best action in the ELECTRE IV with the Shannon's Entropy weighting. Alternative 6 follows Alternative 3 in the descending distillation. Alternative 2, Alternative 4, and Alternative 7 are the worst actions in the descending distillation. Alternative 1 and Alternative 3 are the worst actions in the ascending distillation. Alternative 4 is the best action in the ascending distillation. Alternative 3 is ranked first in ELECTRE IV with the Shannon's Entropy weighting (on middle and right in Figure 16). Alternative 1, Alternative 5, and Alternative 6 follow this alternative. Alternative 4 is the least preferred action. Under these conditions, it is recommended that an investigation be started (review data, feasibility studies, etc.) for Alternative 3 first, then Alternative 1, Alternative 5, and Alternative 6 for private small hydropower plant investment options.

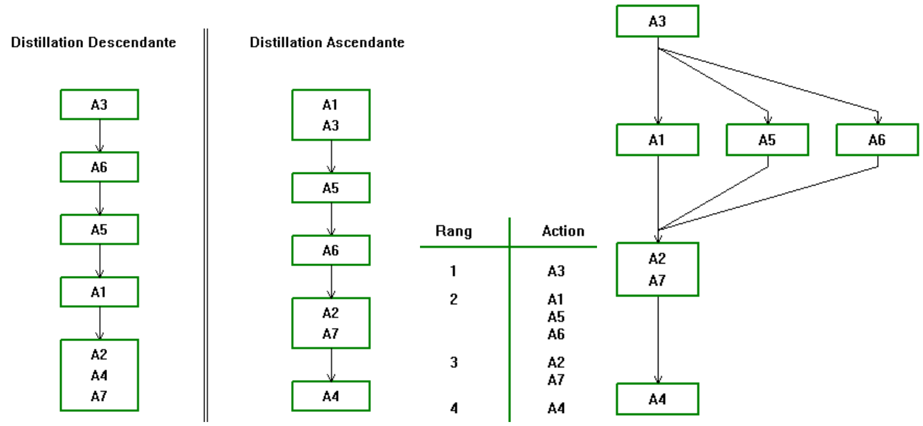
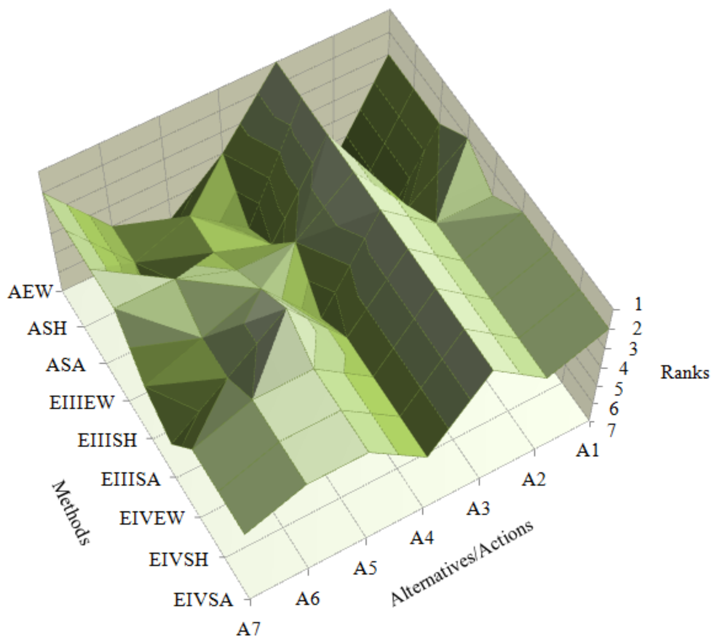


Figure 17. The ELECTRE IV model results on the ELECTRE III-IV Version 3 software (open the electronic supplementary material: ijahpse.elp) by the Shannon's Entropy weighting, distillations (on left), ranks in final preorder (on middle), final graph (on right)

The findings show that Alternative 3 is ranked first for all ELECTRE III approaches. These findings represent that the first rank matches for each weighting approach on the ELECTRE III method even though their criteria weights aren't the same. Alternative 1 ranks second for the equal weighting and Saaty's AHP weighting. Alternative 1, Alternative 6 and Alternative 7 rank second in the equal weighting. This study shows that ELECTRE III can't discriminate much between the alternatives based on the similar findings. Even in the Saaty's AHP weighting, Alternative 3 and Alternative 5 rank first. However, these findings show that the rankings of alternatives still promise to be similar with minor disturbance with these weighting approaches in ELECTRE III. Hence, there is hope that it is possible to represent human subjective evaluations by some objective weighting approaches when only considering the final ranks on ELECTRE III method (only considering these factors in private small hydropower plant investments) (Figure 18). In contrast and more importantly, similar results in the rankings don't necessarily mean that the way of thinking is similar. Therefore, future research should focus not only on just the ordinal rankings, but also its degree of dominance (Garuti, 2012).

The findings show that Alternative 3 is ranked first, Alternative 1, Alternative 5, and Alternative 6 are ranked second, Alternative 2 and Alternative 7 are ranked third, and Alternative 4 is ranked fourth for all ELECTRE IV approaches. These findings show that all ranks match for each weighting approach on the ELECTRE IV method even though their criteria weights aren't the same. Alternative 1, Alternative 5, and Alternative 6 occupy the same rank, while Alternative 2 and Alternative 7 also occupy the same rank. This study shows that ELECTRE IV can't discriminate the alternatives as ELECTRE III and AHP can. Even in the Saaty's AHP weighting Alternative 1, Alternative 5 and Alternative 6 rank second. However, these findings show that the rankings of alternatives promise to be the similar with no disturbance with these weighting approaches in ELECTRE IV. Hence, it is possible to represent human subjective evaluations by some objective weighting approaches with only considering the final ranks on ELECTRE IV method (only considering these factors in private small hydropower plant investments) (Figure 18). In contrast and more importantly, similar results in the rankings don't necessarily mean that the way of thinking is similar. Therefore, future research should focus not only on just the ordinal rankings, but also its degree of dominance (Garuti, 2012).

It is observed that Alternative 3 ranks first for all of the approaches while other alternatives have several ranks. Hence, it is believed that it is possible to represent the human subjective evaluations by some objective weighting approaches by only considering the final ranks on some multi criteria decision making methods (only considering these factors in private small hydropower plant investments) (Figure 18). If these kinds of findings are found in several studies, some computer based systems which work with very little human efforts can be modeled, designed and developed in the future.



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	AHP			ELECTRE III			ELECTRE IV		
	Equal	Shannon's	Saaty's	Equal	Shannon's	Saaty's	Equal	Shannon's	Saaty's
Alternative 1	3	3	3	2	3	2	2	2	2
Alternative 2	7	7	7	4	3	3	3	3	3
Alternative 3	1	1	1	1	1	1	1	1	1
Alternative 4	4	6	5	3	5	4	4	4	4
Alternative 5	6	4	4	3	2	1	2	2	2
Alternative 6	5	5	6	2	3	3	2	2	2
Alternative 7	2	2	2	2	4	5	3	3	3

Output	Methods	Alternative	Rank	Priority Normal Weight
1	Equal Weight AHP (AEW)	Alternative 1	3	0,1247
		Alternative 2	7	0,0509
		Alternative 3	1	0,3314
		Alternative 4	4	0,1177
		Alternative 5	6	0,0918
		Alternative 6	5	0,1128
		Alternative 7	2	0,1708
2	Shannon's Weight AHP (ASH)	Alternative 1	3	0,1228
		Alternative 2	7	0,0324
		Alternative 3	1	0,4348
		Alternative 4	6	0,0855
		Alternative 5	4	0,1118
		Alternative 6	5	0,0872
		Alternative 7	2	0,1255
3	Saaty's Weight AHP (ASA)	Alternative 1	3	0,1274
		Alternative 2	7	0,0325
		Alternative 3	1	0,4120
		Alternative 4	5	0,0973
		Alternative 5	4	0,1159
		Alternative 6	6	0,0678
		Alternative 7	2	0,1472
4	Equal Weight ELECTRE III (EIIIEW)	Alternative 1	2	-
		Alternative 2	4	-
		Alternative 3	1	-
		Alternative 4	3	-
		Alternative 5	3	-
		Alternative 6	2	-
		Alternative 7	2	-
5	Shannon's Weight ELECTRE III (EIIISH)	Alternative 1	3	-
		Alternative 2	3	-
		Alternative 3	1	-
		Alternative 4	5	-
		Alternative 5	2	-
		Alternative 6	3	-
		Alternative 7	4	-
6	Saaty's Weight ELECTRE III (EIIISA)	Alternative 1	2	-
		Alternative 2	3	-
		Alternative 3	1	-
		Alternative 4	4	-
		Alternative 5	1	-
		Alternative 6	3	-
		Alternative 7	5	-
7	Equal Weight ELECTRE IV (EIVEW)	Alternative 1	2	-
		Alternative 2	3	-
		Alternative 3	1	-
		Alternative 4	4	-
		Alternative 5	2	-
		Alternative 6	2	-
		Alternative 7	3	-
8	Shannon's Weight ELECTRE IV (EIVSH)	Alternative 1	2	-
		Alternative 2	3	-
		Alternative 3	1	-
		Alternative 4	4	-
		Alternative 5	2	-
		Alternative 6	2	-
		Alternative 7	3	-
9	Saaty's Weight ELECTRE IV	Alternative 1	2	-

ISSN 1936-6744
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	(EIVSA)	Alternative 2	3	-
		Alternative 3	1	-
		Alternative 4	4	-
		Alternative 5	2	-
		Alternative 6	2	-
		Alternative 7	3	-

Figure 18. Comparative model in this study

4. Conclusions, future applications and research

In this paper, a comparative study was conducted for three weighting approaches (equal weighting, Shannon's Entropy, Saaty's AHP) with three multi criteria decision aiding methods (AHP, ELECTRE III, ELECTRE IV) on a simplistic unified private small hydropower plant investment selection problem in the renewable energy industry.

One important observation made during this research study concerns the representation capability of the equal and the Shannon's Entropy objective weighting methods. Unfortunately, these methods can't represent the opinions, and the preferences of the expert decision maker on the factors taken by the pairwise comparisons of the Saaty's AHP method. Another important observation is related to the MCDM methods. The preferences of the expert decision maker can be considered very easily by the AHP method however, it is not easy to reach the desired level of consistency. Often, several attempts must be made to reduce the level of inconsistency, and this process is very time consuming. The ELECTRE methods do not have any special way to obtain criteria weights. One of the major disadvantages is perceived while deciding the threshold values which are very subjective for the decision makers. The investigations should be performed well whether or not the thresholds are convincing or unconvincing, however this is very difficult. Moreover, the ELECTRE III and the ELECTRE IV aren't capable of discriminating the actions when compared to the AHP in this study. One of the main advantages of these methods is their capability to split a big problem into smaller pieces and investigate these pieces in detail to solve the larger problem. They are very helpful in understanding real world problems and their possible solutions. Hence, future studies will always recommend to designers and engineers that they gather help and work with these methods in their professional lives. The authors think it is important that lectures on this subject be given at universities in the engineering disciplines. Finally, another surprising observation is made concerning the final ranks. Even though the weights aren't the same, the same alternative was ranked first. This finding gives support for continuing to work on this subject via an autonomous computer based intelligent decision support system.

In the future, we aim to build and investigate data powered decision aiding models. When some statistical methods and approaches are integrated with these weighting methods and multi criteria decision making (AHP, ELECTRE III and ELECTRE IV) methods, the solutions of the small hydropower plant investment selection problem will become easier and more collective. In fact, there are already plans to use these methods in several hydropower plant categories and classes. In addition, plans for the application of these methods in solar power plants and the 100% renewable power grid are already being made by the researcher. We hope that this study and following ones will contribute to the practical research of these methods and to the renewable energy.

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