AN AHP APPLICATION IN THE INVESTMENT SELECTION PROBLEM OF SMALL HYDROPOWER PLANTS IN TURKEY

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ABSTRACT

Turkey is a country that has had to deal with high electricity consumption due to its rapid growth and development. Attempts have been made to address this increase in demand by increasing the electricity supply by means such as boosting resources by privatization. The electricity generation sector has been privatized in Turkey; hence investors have been looking for the most appropriate electricity generation projects for a long while. Therefore, researchers and practitioners should focus on how the most suitable small hydropower plant project (SHPP) investments can be selected. In this study, the Analytic Hierarchy Process (AHP) was applied to make the most appropriate and satisfying decision according to the decision makers, experts or investors for a SHPP investment from amongst some alternative SHPP investments in Turkey. All of these SHPPs were assumed to be in the pre-development investment stage, which indicated that their pre-feasibility and feasibility studies had not been presented or taken into consideration until this study was performed. This main constraint forced the researchers to obtain the data and information from the information forms such as the application document to the General Directorate of State Hydraulic Works during the data and information gathering process. The AHP model of this study was structured in four levels with five main criteria, seventeen basic criteria and five alternatives on the Super Decisions Software. The results indicated that Alternative 1 and Alternative 5 should be primarily investigated in detail in subsequent SHPP investment investigation steps.

Keywords: Analytic Hierarchy Process; investment; pre-development investment stage; small hydropower plant project; Turkey

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1. Introduction

The researchers focused on two important indicators or variables for the electricity demand projections today. One of the important indicators is population growth and the other is income growth (Chandran et al., 2010; Cook, 2011; Dalgaard and Strulik, 2011). As a rule of thumb, with today's technical and technological capabilities, constraints and conditions, it can be said and expressed as a cliché that, when both the population and the income increases the electricity demand will also increase.

Turkey is one of the growing economies in the Caucasus (Azerbaijan, Georgia, etc.), the MENA (Middle East and North Africa: Egypt, Lebanon, United Arab Emirates, Morocco, Tunisia etc.) and the WANA (West Asia and North Africa) regions. Turkey's population also increases from year to year. The GNI (gross national income) per capita, which is one of the basic indicators for the growth and standard of living, and the total population in Turkey are presented in Figure 1. The average population growth (annual %), arithmetic mean from 1980 to 2014, and the average GNI growth (annual %), arithmetic mean from 1988 to 2014, is respectively 1,64 and 4,07 in Turkey (World Bank, 2015) (for formula see Abramowitz and Stegun, 1972). Under these conditions, the electricity demand can easily be estimated to steadily increase.

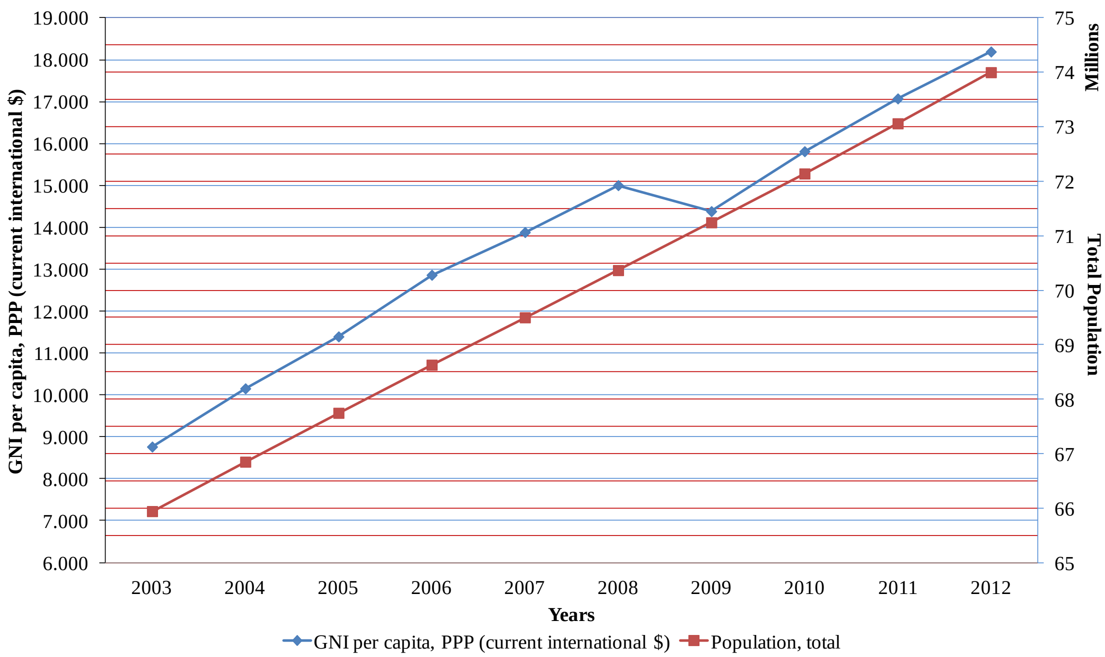

Figure 1. GNI per capita and total population in Turkey, GNI (gross national income), GNI per capita: PPP (purchasing power parity), $: United States dollar sign (World Bank, 2013).

Turkish electricity generation sector players are very diversified in their capabilities, capacities, sizes, organization, management styles etc. Therefore, the decision making process of each of these players differs. The Turkish electricity generation sector players can select either fossil fuels (oil, coal etc.) or renewable energy sources (RESs) to increase the electricity supply to compensate the demand. If they select the RESs, they

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have some alternative sources such as hydro, wind, geothermal, biomass, biogas, and solar (Demirbas, 2002; Topcu and Ulengin, 2004).

Hydropower technology has its own advantages such as being technically and technologically mature, having a very long lifespan, and being economically competitive (Hall, 2003; IHA, 2000; Lako et al., 2003). Hence, some of the private investors have been interested in the hydropower industry in Turkey.

The classification of hydropower plants (large, medium, small, mini, micro and pico) by the installed power or capacity (P) shows that there is not any agreed upon classification for the hydropower plants (see Table 1) (Moreira and Poole, 1993; Kurien and Sinha, 2006; Bajaj et al., 2007; Saxena, 2007; Beraković et al., 2009; Dragu et al., 2010; EREC, 2012).

In this study, SHPPs were defined as 1 MW < P ≤ 10 MW. The lower limit (1 MW) of this installed capacity was chosen by the author due to the almost total consensus of the research (see Table 1). It was also chosen due to the upmost limit of the unlicensed electricity generation activities from the renewable energy sources (without a license or establishing a company or electricity generation license exemptions) 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. The upper limit (10 MW) of this installed capacity was chosen by the author due to the definition of SHP (small hydropower plant) supported by the European Commission (EC) and the European Small Hydropower Association (ESHA) (see EC, 2014; ESHA et al., 2008).

Table 1
Small hydropower plant classification by installed power (kW: kilowatt)

	India	United States	China	Croatia
EREC	<30.000	≤25.000		
Dragu et al.	1.000< ≤25.000	1.000< ≤30.000	500< ≤25.000	
Beraković et al.				50< ≤10.000
Saxena	2.000< ≤25.000			
Bajaj et al.	<25.000	<30.000	<25.000	
Kurien & Sinha	1.000< ≤25.000	1.000< ≤30.000	500< ≤25.000	
Moreire & Poole	1.000< ≤25.000	1.000< ≤30.000	500< ≤25.000	

(Source: Moreire and Poole, 1993; Kurien and Sinha, 2006; Bajaj et al., 2007; Saxena, 2007; Beraković et al., 2009; Dragu et al., 2010; EREC, 2012)

The EMRA's (Republic of Turkey Energy Market Regulatory Authority) official website) was regularly visited while this study was conducted (EMRA, 2013. 212 SHPPs were found under the investigation and evaluation stage of the license application procedure of EMRA. The total installed electrical power of these 212 SHPPs was 1.048 MW_e (MW_e: the electrical installed power in megawatts on the granted license by EMRA). The SHPPs' applications to EMRA have been summarized in Figures 2 and 3 to make the actual private sector license applications status in Turkey clear.

The relatively small to midsized investors can easily prefer to invest in the SHPPs, because of very well-known advantages such as having a small capital requirement, being decentralized, and having a great number of potential projects in Turkey. The large size investors also prefer to invest in the SHPPs, and usually own them in several bunches. They have shares of many of them during the same period according to different strategic investment principles. Each investor has their own strategy or approach due to their different attributes and qualities. With the SHPPs availability and electricity generation market conditions in Turkey, some private investors have been looking for ways to find projects in which they can be shareholders (or whole owner of the project). Also, some of the projects have been waiting for private investors to supply enough capital to continue and finalize the construction and procedural activities to connect to the national grid.

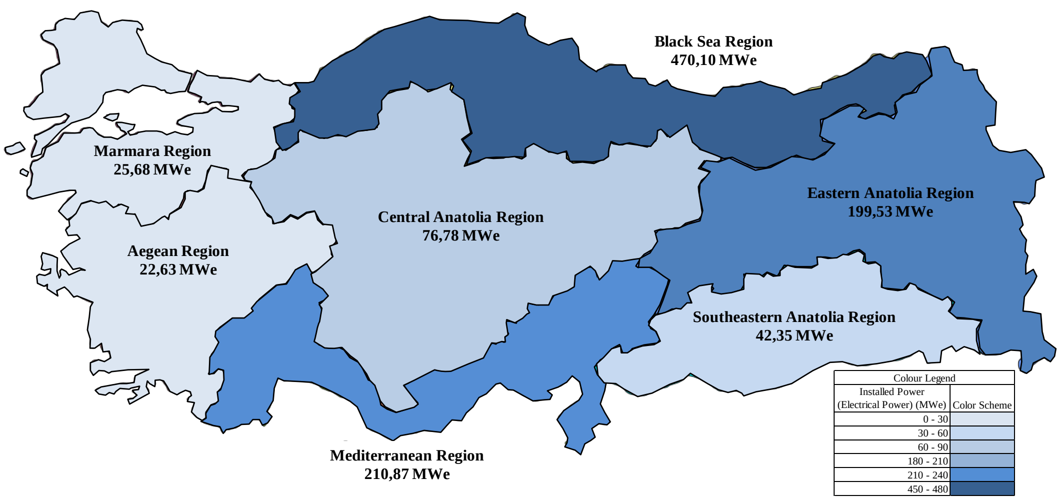

Figure 2. SHPPs' applications to EMRA by region (Installed Power (Electrical) (MW_e) (Latest 2012 September) (EMRA, 2012, Basemap: Wikipedia, 2014).

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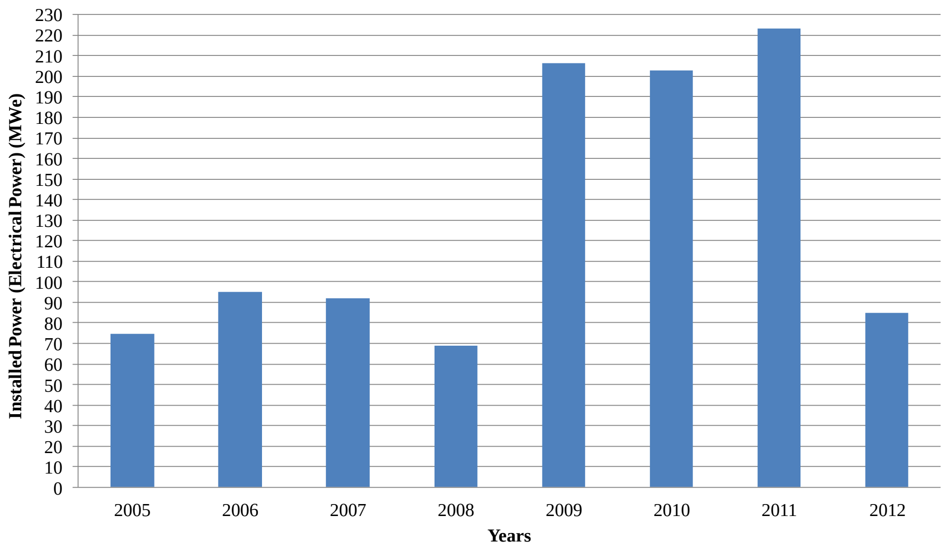

Figure 3. SHPPs' applications to EMRA by year (Installed Power (Electrical) (MW_e) (Latest 2012 September) (EMRA, 2012).

In this paper, a part of a real life case study was presented. In this real life case study, the investors wanted to invest in one or more SHPPs from the available SHPPs on the projects' radar. They asked to find some alternative projects and their related data and information. Moreover, an evaluation and recommendation study about the projects was also requested. All requested and related activities were performed, and afterwards the AHP methodology was applied for five SHPPs on the investor's radar. Due to the concern of the commercially sensitive information involved, the titles or names of these projects were not given in this paper; however all of the necessary and required data and information relevant to these projects is supplied in the following sections.

2. Literature review

The review of previous research was carried out at two separate times. The first review was carried out until 05/09/2013 in the original manuscript. The second one was until 05/04/2015 in the second round revision of this manuscript. The previous studies were reviewed on scientific online database websites with the help of three key phrases. These phrases were *Analytic Hierarchy Process* & *small hydro* (A), *AHP & small hydro* (B), *small hydro* (C). The unlimited truncation option was selected on the search preferences of these database websites. Henceforth, all types of documents in all types of sources such as books, journals, proceedings, transactions, magazines, and newsletters were searched based on the anywhere on the document rule. As a result, titles, abstracts, main texts, references and all other documents on these database websites were searched in this study. The subjects of these sources were not limited so that all of the subjects such as agricultural sciences, business and management, computer sciences, decision sciences, energy and power were directly reviewed in the current study. The literature review was summarized in Table 2.

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Table 2
Summary of literature review

Scientific publisher	A	B	C
ACM Digital Library	0	0	49
ASCE Online Research Library	0	0	46
Cambridge Journals Online	0	0	66
DOAJ	0	0	29
Emerald Insight	0	0	20
Google Scholar	130	197	18.900
IJAHP	0	0	0
Science Direct	44	45	2.512
Taylor & Francis Journal	2	2	310

Source: (ACM Digital Library, 2015; ASCE Online Research Library, 2015; Cambridge Journals Online, 2015; DOAJ, 2015; Emerald Insight, 2015; Google Scholar, 2015; *International Journal of the Analytic Hierarchy Process (IJAHP),* 2015; Science Direct, 2015; Taylor & Francis Journal, 2015).

There were quite a remarkable number of papers that had considered or focused on small hydro power in a manner (economy, finance, planning etc.) in the scientific journals until 05/04/2015. None of these studies adopted AHP or modeled AHP in the scope and subject of the current study, with only two studies in the literature being close.

Mladineo et al. (1987) selected some SHPP locations using the PROMETHEE method (PROMETHEE: Preference Ranking Organization METHod for Enrichment Evaluations). The most critical criterion in their study was the unit cost (the lower, the more preferable). Saracoglu (2015) presented an experimental research study on the selection of private small hydropower plant investments. His main research aim was to build up an intelligent autonomous decision making system for SHPPs. He used the ELECTRE III (ELECTRE: Elimination and Choice Translating Reality) and the ELECTRE IV methods for the ranking of actions. The voting power of criteria was modeled by three different approaches as the objective weighting by Shannon's Entropy, the subjective weighting by Saaty's AHP pairwise comparison, and the equal weighting. The experimental research study was applied based on the group decision making model. In short, there were only a few relevant papers in an enlarged view as given in Table 3.

Table 3
Summary of literature review

Paper	**Subject/topic**	**Method**
Mladineo et al., 1987	SHPP location selection	PROMETHEE
Saracoglu, 2015	private SHPP investment selection	ELECTRE III/IV, Shannon's Entropy Objective Weighting, Saaty's AHP Subjective Weighting

This extensive literature review showed that this paper would be one of the first studies looking at the selection problem of the SHPPs' investments. The AHP methodology that

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was developed by Thomas L. Saaty was preferred for the solution of the problem because of the general advantages of the AHP method (Saaty, 1980; Saaty, 1990). These advantages include the ability to model daily real life problems with ease and simplicity; ability to reflect the reality of the problems in a true and easy manner; giving experts the ability to express their thoughts in a free, correct and almost perfect manner due to their experiences; giving people with little or no knowledge about decision making methods the opportunity to understand the method; having simple and easy mathematical calculations, which helps the experts concentrate on the problems rather than the difficult mathematical calculations; having the pair-wise comparisons, which helps the experts and decision makers compare one by one each criteria and alternative with respect to the goal and with respect to the alternatives (Coyle, 2004; Saaty, 2008; Saaty, 2010; Saaty, 2011; Yoon and Hwang, 1995).

3. AHP application in the case study

There were five SHPP investment alternatives (Alternative$_{1 \text{ to } 5}$: Alt$_{1 \text{ to } 5}$) in this case study. They were available for sale (like sales in other markets such as agricultural, art, automotive, banking, housing, shipping, and sport). Also, some shares (stocks) of them could be bought (exchanged/purchased) in the SHPP portfolio market (search for acquisition, asset, joint venture, merger, portfolio, share, and stock terms on the Investopedia (Investopedia US, 2014)). These SHPPs were assumed to be in the pre-development investment stages (see Table 4 for the details of these SHPPs according to the factors). There were seventeen SHPPs' investment selection factors in this study, which were determined based on the available data and information.

The main structures of a SHPP must be considered in order to understand the factors well. These main structures are the diversion weir, the de-silting tank, the channel, the tunnel, the headpond/forebay, the penstock, the powerhouse, the tailrace, and the substation. Moreover, the electrical installed capacity (in Watts) of a SHPP should be kept in mind (Formula/Equation 1).

$$P = \eta_{tr} \times \eta_g \times \eta_t \times \rho_w \times g \times Q \times H_{net} \quad (1)$$

(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 basic SHPPs investment selection factors (subjective and objective) in the current study were found, defined, identified, described, determined and selected by the experts from a pool of selection factors of the SHPPs. These factors were gathered from this study and the other studies of the author due to the selection factors' ability, competence, capability, effectiveness, and help analyzing the alternatives in a very quick, rapid, fast, appropriate, and applicable manner for this so-called the pre-development investment stage. The data and information availability for each factor was also considered.

The basic SHPPs investment selection factors in this study include (see also Saracoglu, 2015 for complementary, supportive and supplementary information):

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C_1: River Basin (subjective criteria): This factor was for the evaluation of the main river basin of the project amongst other alternatives' main river basins with the knowledge and experience of the experts (01 Meric-Ergene, 02 Marmara, 03 Susurluk, 04 Kuzey Ege, 05 Gediz, 06 Kucuk Menderes, 07 Buyuk Menderes, 08 Batı Akdeniz, 09 Antalya, 10 Burdur, 11 Akarcay, 12 Sakarya, 13 Batı Karadeniz, 14 Yesilırmak, 15 Kızılırmak, 16 Konya Kapalı, 17 Dogu Akdeniz, 18 Seyhan, 19 Ası, 20 Ceyhan, 21 Dicle-Fırat, 22 Dogu Karadeniz, 23 Coruh, 24 Aras, and 25 Van Golu) in Turkey. It is important to not misunderstand the river basin term, and not to confuse it with the geographical regions (Aegean, Black Sea, Central Anatolia, Eastern Anatolia, Marmara, Mediterranean, and Southeastern Anatolia) of Turkey (for this term visit (EIA, 2013)) (EIA: United States Energy Information Administration).

C_2: Catchment Area (objective criteria, km^2) (more is better ↑ ↑): The catchment area was evaluated by the approximate values presented in the information form (DSI, 2013) (DSI: The General Directorate of State Hydraulic Works) of the SHPP (for this term visit (EIA, 2013)).

C_3: Project Runoff (objective criteria, hm^3) (more is better ↑ ↑): The project runoff was considered as the mean yearly total runoff and evaluated by the approximate values presented in the information form of the SHPP (USGS, 2013) (USGS: United States Geological Survey). The runoff is normally generated by rainfall and the melting of snow.

C_4: Conveyance Structure (subjective criteria): In this factor, the conveyance structure type, the length of conveyance structure and other properties of the conveyance structure were evaluated with knowledge and experience of the experts. For instance, the conveyance structure could be a long tunnel or a short tunnel, or an open channel, or a short tunnel and an open channel, that would make the project complex or simple and difficult to construct or easy to construct and to operate (for this term visit (IWA, 2013)).

C_5: Net Head (objective criteria, m) (more is better ↑ ↑): The net heads of the SHPPs were compared with each other (for this term visit (EIA, 2013)). Wherever there was more than one net head in the projects, the equivalence of these net heads based on the electrical installed power formula of SHPPs had been calculated and the equivalence net head was written in the input file. This approximation and assumption could be easily agreed upon by the experts. The technically perfect conditions were assumed such as perfect efficiency.

C_6: Flow Rate (objective criteria, m^3/s) (more is better ↑ ↑): The flow of the SHPPs was compared with each other (for this term visit (EIA, 2013)). Wherever there was more than one flow rate in the projects, the equivalence of these flow rates based on the electrical installed power formula of SHPPs had been calculated and the equivalence flow rate was written in the input file. This approximation and assumption could be easily agreed upon by experts. The technically perfect conditions were assumed such as perfect efficiency.

C_7: Firm Energy (objective criteria, GWh) (more is better ↑ ↑): The approximate firm energy of the SHPPs was compared. ESHA (2004) defined the firm energy as "the power delivered during a certain period of the day with at least 90 – 95% certainty".

C_8: Secondary Energy (objective criteria, GWh) (more is better ↑ ↑): The approximate secondary energy of the SHPPs was compared with each other. The secondary energy is the energy which can be generated by the SHPP and this energy is added to the firm energy to reach the total energy.

C_9: Investment Cost (objective criteria, USD) (less is better ↓ ↑): The approximate total estimated investment cost of the SHPPs was compared with each other. The investment cost data in Turkish Lira currency was gathered from the information forms. The foreign-exchange rate data (1 USD = apprx. 2,06 TL) was taken from the official webpage of the Central Bank of the Republic of Turkey (TCMB) visited on September 8,2013 (TCMB, 2013). Some other issues such as the escalation, the inflation etc. were not taken into consideration because of the subject of the current study.

C_{10}: Community Attitude (subjective criteria): The public opinion of the local people in the SHPPs' locations can be either in positive (giving support and participating) or negative (showing opposition and protesting). If there is some opposition and protests against the SHPPs by the local people, then there will be a high possibility of the construction work being stopped or blocked, and this will cause some legal cases in the courts. The activities during the construction period and the operation period will be performed in difficult conditions, if there are oppositions and protests. The community attitude was evaluated based on these conditions and principles in this study.

C_{11}: Transportation (subjective criteria): This factor was for the evaluation of all modes (air, rail, road, water, and cable) of transportation in the view of availability, flexibility, quality, and general conditions of the SHPPs. During the construction period of the SHPPs, all kinds and sizes of equipments such as the water or hydropower turbines and generators, materials etc. are transported by means of various transportation modes. The road transportation may be the most important one, because the SHPPs have to be reached by road by the equipment, materials and people. If the road to SHPP site is available and good quality this will be an advantage for the site, otherwise new roads such as the access roads have to be built. In addition, the air transportation is very important because the staff, supervisors, managers and owners will want to reach the SHPP site in the short duration, so that the availability of good quality air transportation will be preferable. In the current case study, this factor was evaluated by all means of transportation at once.

C_{12}: Topography (subjective criteria): This factor was for the evaluation of natural and artificial surface shapes and features of the SHPPs. The appropriate topography for the construction and operation of the SHPP was evaluated during the current study. Wherever necessary, the related maps were investigated.

C_{13}: Geology (subjective criteria): This factor was for the evaluation of general geological conditions and properties of the location of the SHPPs. The appropriate geology for the construction and operation of the SHPP was evaluated during the current study. Wherever necessary, the related data, maps and information were investigated. This factor also includes the natural hazards such as earthquakes, landslides etc.

C_{14}: Security Conditions (subjective criteria): This factor was for the evaluation of the perceived security risks, threats and so forth in the areas of human security, public security, and infrastructure security etc. (see Front Line, 2005). Theft, burglary etc. were considered during the comparisons of the alternatives. The terrorism related issues were not evaluated in this scope under this criteria, they were evaluated under the C_{15} (Terrorism Conditions) criteria.

C_{15}: Terrorism Conditions (subjective criteria): This factor was for the evaluation of the perceived terrorism risks, threats, effects and so forth in any type of terrorism (all internationally accepted types such as civil disorder, political, non-political, quasi, ideological, official or state or religious etc.) (visit United Nations, 2013) for the definition of terrorism) in the location or nearby locations of the SHPP. The experts compared the alternatives based on this factor which was actually a whole group of the types of this factor. (visit UNODC, 2013) (UNODC: United Nations Office on Drugs and Crime) to read and understand this factor).

C_{16}: Protected Areas (subjective criteria): This factor considered all of the protected areas such as natural parks, ecological values (important bird areas, rainforests), cultural values, regional values etc. Wherever, there are some protected areas in the SHPP site or nearby it, there will be the possibility of some additional procedural work and permissions needed. Some of the necessary permissions often can't be obtained in the protected areas, so that the SHPP can't be built up in those regions.

C_{17}: Substation Conditions (subjective criteria): Substation network is very important for the national or international electricity networks. The national or international substation network is a constraint function for the whole electricity system. The generation sources have to connect to the grid by the substations. This factor was for the evaluation of the possibility, capability and conditions of connection to the national grid by the substation. This factor was very critical on the financing, construction, and operation of the utility-scale SHPPs in Turkey.

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Table 4
SHPP investment alternatives (see also Saracoglu, 2015 for additional information)

Alternatives	C_1	C_2	C_3	C_4	C_5	C_6	C_7	C_8	C_9
$Alternative_1$	08	79	47	Channel Closed Rectangular 3900	369	3	26	15	11.429.000
$Alternative_2$	23	61	48	uPVC pipe 3300	388	3	6	31	7.783.000
$Alternative_3$	21	329	131	Channel Open Rectangular 9600	172	8	16	38	16.551.000
$Alternative_4$	22	130	133	Tunnel Modified horseshoe 8800	135	10	14	29	24.052.000
$Alternative_5$	22	553	701	Tunnel Circular 5900	97	19,5	29	23	27.878.000

In short, there were ten subjective factors C_1: River Basin, C_4: Conveyance Structure, C_{10}: Community Attitude, C_{11}: Transportation, C_{12}: Topography, C_{13}: Geology, C_{14}: Security Conditions, C_{15}: Terrorism Conditions, C_{16}: Protected Areas, C_{17}: Substation Conditions, and seven objective factors C_2: Catchment Area, C_3: Project Runoff, C_5: Net Head, C_6: Flow Rate, C_7: Firm Energy, C_8: Secondary Energy, C_9: Investment Cost.

In the AHP analysis, an evaluation of a total of 9 factors has been recommended (Gawlik, 2008; Kruger and Hattingh, 2006; Saaty, 1980). This basic principle was based on the magic number 7, and the 7±2 rule, which was built upon research studies on the human psychological limit, human cognition and short term memory capacity. Moreover, the magic number 7, and the 7±2 rule was suggested for all of the cognitive studies to ensure the reliability and the trustworthiness of the attendances (Miller, 1956; Shiffrin and Nosofsky, 1994).

Henceforth, the basic factors in the current study were grouped under the aggregate factors. After strictly obeying the maximum limit of the magic number 7, and the 7±2 rule, the problem was modeled by a multi-layer structure with five main criteria (MC_1: Essential Features of the SHPP, MC_2: Complementary Features of the SHPP, MC_3: Electricity Generation Features of the SHPP, MC_4: Social Features of the SHPP's Site/Location, and MC_5: Essential Features of the SHPP's Site/Location) and seventeen sub-criteria as presented in Figure 4.

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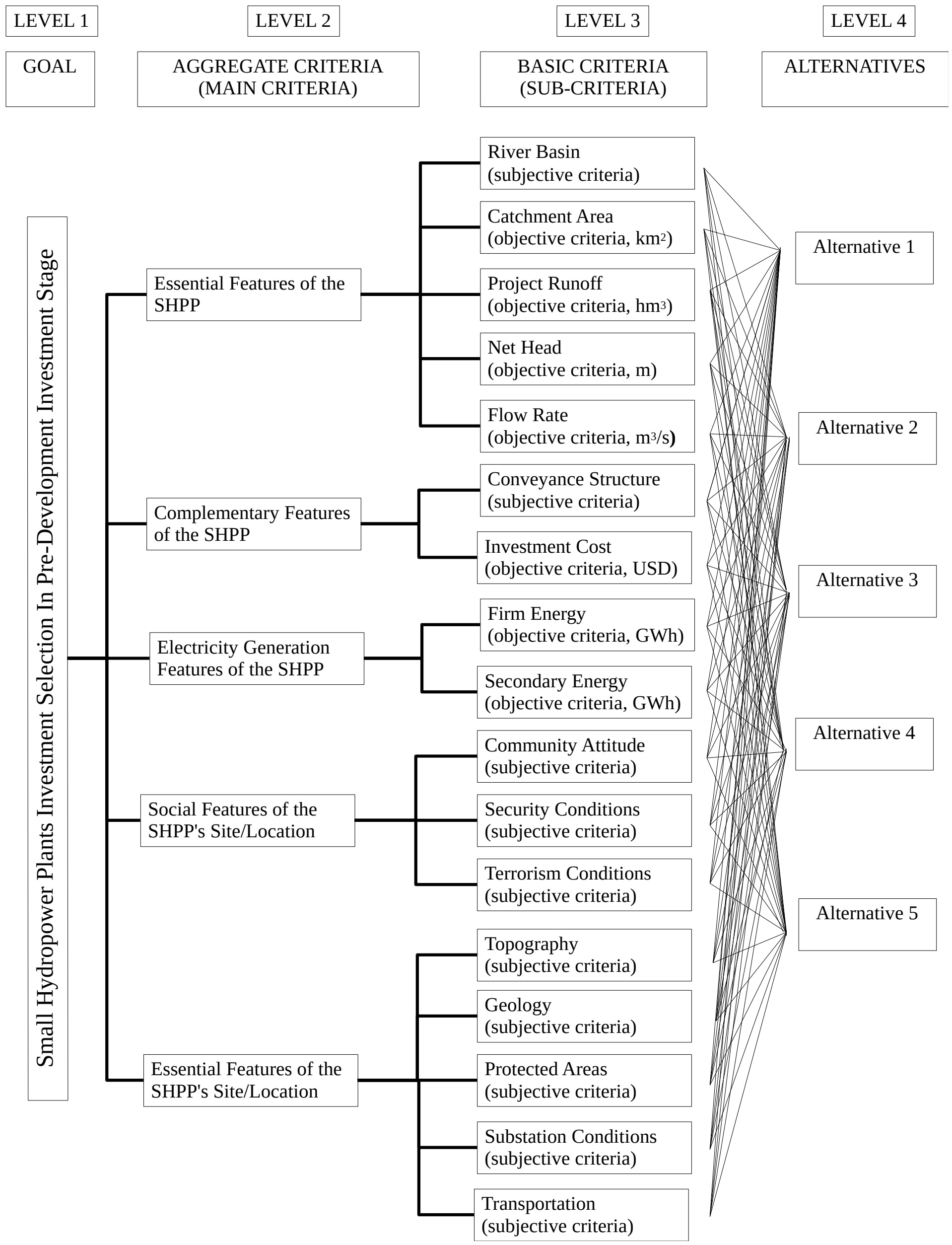

Figure 4. The structure of the AHP model in the case study

Calculations for the AHP model can be performed on some specific AHP software such as the Decision Lens, Expert Choice, and Super Decisions. In addition to these choices of software, spreadsheet software such as Microsoft Excel and Apache OpenOffice Calc can be used to formalize the AHP models. Moreover, any mathematical calculation and numerical computation software can be used to code for these kinds of studies such as Octave, R, and Scilab.

In the current study, some of the calculations were performed on the spreadsheet software and some were performed with the help of Super Decisions (see Figure 5 for the screen

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view of the AHP model of this study). The mathematical calculation and numerical computation software were also used whenever the calculations needed to be checked.

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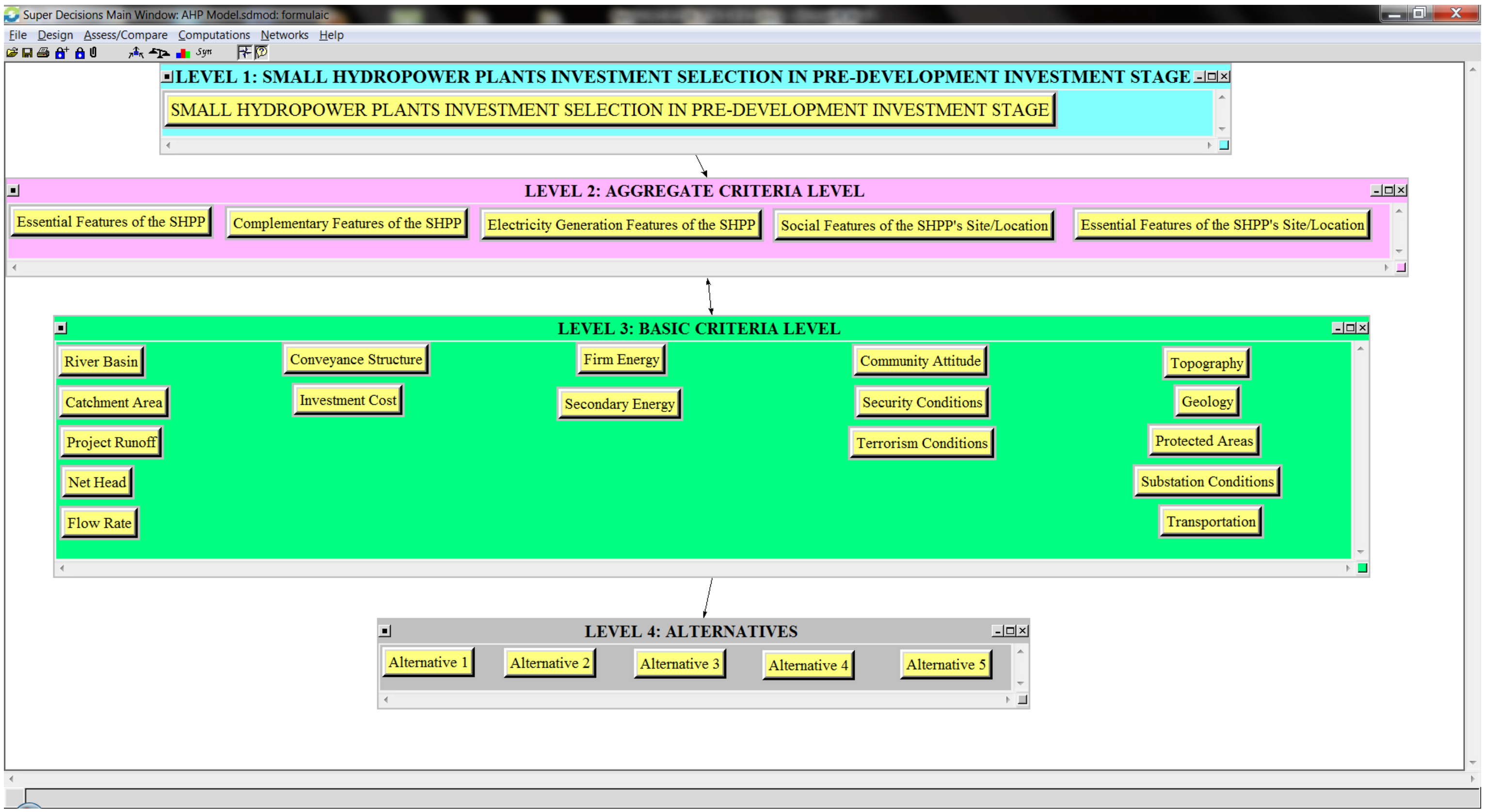

Figure 5. Screen view of the current AHP model on Super Decisions software (open the electronic supplementary material: AHP Model.sdmod)

In the current case, there were two experts who gave their input on the factors and alternatives. One of the experts has a Bachelor's degree in Naval Architecture and Marine Engineering, a Master's degree in Industrial Engineering, a multi-disciplinary doctorial educational background, and also work experience in the shipbuilding and energy industries. The other expert has a Bachelor's and Master's degree in Civil Engineering (both in design and construction), and practical work experience in the construction and energy industries. Hence, the experts were capable of coping with these kinds of problems and their powerful properties (advantage of the multi-disciplinary expert group) and could support each other.

The objective factors were not compared due to the alternatives by the experts because their approximate values were taken directly from the information forms. The alternatives were compared only due to the subjective factors on the cognitive, linguistic, or verbal evaluation labels or statements modeled with the help of the Fundamental Scale of the AHP and the Likert type scale (Saaty, 1980; Saaty 2008; Likert, 1932). The original work by Likert included a 5 point scale from "strongly agree" to "strongly disagree", extensions included 1 to 7, 1 to 9, and 0 to 4. This scale was as follows: indifference (1), little moderately more important (2), moderately more important (3), little strongly more important (4), strongly more important (5), quite a lot strongly more important (6), very strongly more important (7), little absolutely more important (8) and absolutely more important (9) (see also Boone and Boone, 2012; Costa and Correa, 2010; Saaty, 1987; Silva et al., 2009). Figure 6 details the scales and expressions based on Saaty and Likert

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The Fundamental Scale of the AHP		
Intensity Of Importance	Definition	Explanation
1	Equal importance	Two elements contribute equally to the objective
3	Moderate importance	Experience and judgment slightly favor one element over another
5	Strong importance	Experience and judgment strongly favor one element over another
7	Very strong importance	An activity is favored very strongly over another
9	Absolute importance	The evidence favoring one activity over another is of the highest possible order of affirmation
2, 4, 6, 8	Used to express intermediate values	

The Verbal Statements & Expressions In This Study

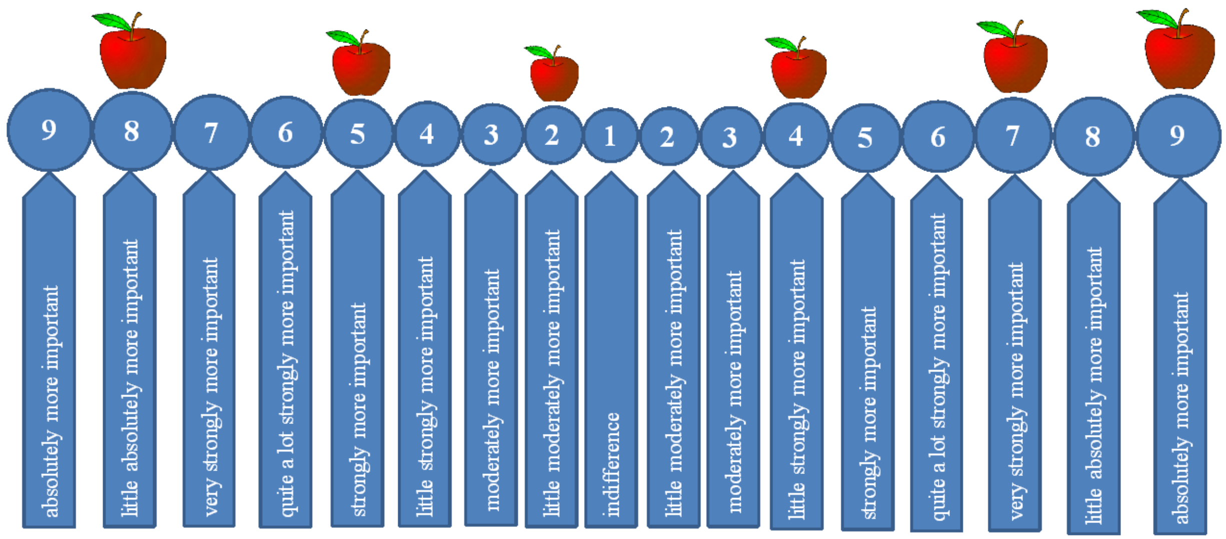

Figure 6. The verbal statements and expressions of this study and the fundamental scale of the AHP (scale & expressions based on Saaty's and Likert's research studies)

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The experts' opinions or judgments were very carefully recorded with the help of the spreadsheet calculation software Microsoft Excel and Apache OpenOffice Calc (see Figure 7).

EXPERT 1: The relative importance of the factors with respect to "Essential Features of the SHPP"

	absolutely more important	little absolutely more important	very strongly more important	quite a lot strongly more important	strongly more important	little strongly more important	moderately more important	little moderately more important	indifference	little moderately more important	moderately more important	little strongly more important	strongly more important	quite a lot strongly more important	very strongly more important	little absolutely more important	absolutely more important	
	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	
River Basin							3											Catchment Area
River Basin									1									Project Runoff
River Basin					5													Net Head
River Basin					5													Flow Rate
Catchment Area													5					Project Runoff
Catchment Area													5					Net Head
Catchment Area													5					Flow Rate
Project Runoff															7			Net Head
Project Runoff															7			Flow Rate
Net Head									1									Flow Rate

The number of pairwise comparisons is 10

EXPERT 2: The relative importance of the factors with respect to "Essential Features of the SHPP"

	absolutely more important	little absolutely more important	very strongly more important	quite a lot strongly more important	strongly more important	little strongly more important	moderately more important	little moderately more important	indifference	little moderately more important	moderately more important	little strongly more important	strongly more important	quite a lot strongly more important	very strongly more important	little absolutely more important	absolutely more important	
	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	
River Basin							3											Catchment Area
River Basin							3											Project Runoff
River Basin									1									Net Head
River Basin									1									Flow Rate
Catchment Area													5					Project Runoff
Catchment Area															7			Net Head
Catchment Area													5					Flow Rate
Project Runoff													5					Net Head
Project Runoff													5					Flow Rate
Net Head									1									Flow Rate

The number of pairwise comparisons is 10

The total number of pairwise comparisons is 20

Figure 7. Data of the relative importance of the factors with respect to "Essential Features of the SHPP" by experts on Microsoft Excel or Apache OpenOffice Calc

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In all of the pair-wise comparison matrices that were dependent on human cognition and decision, the consistency ratios (look at Consistency Index: Dave, Desai, and Raval, 2012; Kong and Liu, 2005) were calculated by Super Decisions Software. Whenever the inconsistency (Consistency Ratio: CR > 0,1, Inconsistency < 0,1) was too high, the suggested judgments by Super Decisions were examined and the evaluations were reviewed to improve and settle the inconsistency value (see Figure 8).

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Goal: SHPP Investment Selection In Pre-Development Investment Stage

EXPERT 1					EXPERT 2					EXPERTS' GROUP				
0,04	MC_3	MC_1	MC_5	MC_4	0,02	MC_3	MC_1	MC_5	MC_4	0,01	MC_3	MC_1	MC_5	MC_4
MC_2	1	2	5	4	MC_2	2	2	4	4	MC_2	1,41	2,00	4,47	4,00
MC_3		2	4	4	MC_3		3	3	3	MC_3		2,45	3,46	3,46
MC_1			3	3	MC_1			2	2	MC_1			2,45	2,45
MC_5				1	MC_5				1	MC_5				1,00

Complementary Features of the SHPP

EXPERT 1		EXPERT 2		EXPERTS' GROUP	
0,00	C_9	0,00	C_9	0,00	C_9
C_4	9	C_4	9	C_4	9,00

Electricity Generation Features of the SHPP

EXPERT 1		EXPERT 2		EXPERTS' GROUP	
0,00	C_8	0,00	C_8	0,00	C_8
C_7	9	C_7	5	C_7	7,00

Essential Features of the SHPP

EXPERT 1					EXPERT 2					EXPERTS' GROUP				
0,05	C_6	C_5	C_3	C_1	0,08	C_6	C_5	C_3	C_1	0,05	C_6	C_5	C_3	C_1
C_2	5	5	5	3	C_2	5	7	5	3	C_2	5,00	5,92	5,00	3,00
C_6		1	2	1	C_6		1	5	1	C_6		1,00	3,16	1,00
C_5			2	1	C_5			5	1	C_5			3,16	1,00
C_3				2	C_3				3	C_3				2,45

Essential Features of the SHPP's Site/Location

EXPERT 1					EXPERT 2					EXPERTS' GROUP				
0,11	C_{16}	C_{17}	C_{12}	C_{11}	0,11	C_{16}	C_{17}	C_{12}	C_{11}	0,10	C_{16}	C_{17}	C_{12}	C_{11}
C_{13}	3	5	5	4	C_{13}	4	5	7	5	C_{13}	3,46	5,00	5,92	4,47
C_{16}		5	2	5	C_{16}		7	3	3	C_{16}		5,92	2,45	3,87
C_{17}			9	9	C_{17}			9	9	C_{17}			9,00	9,00
C_{12}				3	C_{12}				4	C_{12}				3,46

Social Features of the SHPP's Site/Location

EXPERT 1			EXPERT 2			EXPERTS' GROUP		
0,11	C_{14}	C_{15}	0,11	C_{14}	C_{15}	0,11	C_{14}	C_{15}
C_{10}	5	9	C_{10}	5	9	C_{10}	5,00	9,00
C_{14}		5	C_{14}		5	C_{14}		5,00

Community Attitude

EXPERT 1					EXPERT 2					EXPERTS' GROUP				
0,38	Alt_2	Alt_3	Alt_4	Alt_5	0,23	Alt_2	Alt_3	Alt_4	Alt_5	0,26	Alt_2	Alt_3	Alt_4	Alt_5
Alt_1	2	2	4	4	Alt_1	1	2	2	2	Alt_1	1,41	2,00	2,83	2,83
Alt_2		2	4	4	Alt_2		1	4	2	Alt_2		1,41	4,00	2,83
Alt_3			2	2	Alt_3			2	2	Alt_3			2,00	2,00
Alt_4				4	Alt_4				4	Alt_4				4,00

Conveyance Structure

EXPERT 1					EXPERT 2					EXPERTS' GROUP				
0,09	Alt_2	Alt_3	Alt_4	Alt_5	0,09	Alt_2	Alt_3	Alt_4	Alt_5	0,09	Alt_2	Alt_3	Alt_4	Alt_5
Alt_1	3	4	7	4	Alt_1	3	4	9	6	Alt_1	3,00	4,00	7,94	4,90
Alt_2		4	7	6	Alt_2		5	9	7	Alt_2		4,47	7,94	6,48
Alt_3			5	3	Alt_3			7	3	Alt_3			5,92	3,00
Alt_4				4	Alt_4				4	Alt_4				4,00

Geology

EXPERT 1					EXPERT 2					EXPERTS' GROUP				
0,08	Alt_2	Alt_3	Alt_4	Alt_5	0,00	Alt_2	Alt_3	Alt_4	Alt_5	0,02	Alt_2	Alt_3	Alt_4	Alt_5
Alt_1	3	3	3	3	Alt_1	1	1	1	1	Alt_1	1,73	1,73	1,73	1,73
Alt_2		3	3	3	Alt_2		1	1	1	Alt_2		1,73	1,73	1,73
Alt_3			3	3	Alt_3			1	1	Alt_3			1,73	1,73
Alt_4				1	Alt_4				1	Alt_4				1,00

Protected Areas

EXPERT 1					EXPERT 2					EXPERTS' GROUP				
0,09	Alt_2	Alt_3	Alt_4	Alt_5	0,09	Alt_2	Alt_3	Alt_4	Alt_5	0,08	Alt_2	Alt_3	Alt_4	Alt_5
Alt_1	4	5	5	5	Alt_1	4	7	5	5	Alt_1	4,00	5,92	5,00	5,00
Alt_2		5	3	3	Alt_2		7	3	3	Alt_2		5,92	3,00	3,00
Alt_3			4	4	Alt_3			4	5	Alt_3			4,00	4,47
Alt_4				1	Alt_4				3	Alt_4				1,73

River Basin

EXPERT 1					EXPERT 2					EXPERTS' GROUP				
0,06	Alt_2	Alt_3	Alt_4	Alt_5	0,09	Alt_2	Alt_3	Alt_4	Alt_5	0,06	Alt_2	Alt_3	Alt_4	Alt_5
Alt_1	7	1	9	9	Alt_1	5	2	5	5	Alt_1	5,92	1,41	6,71	6,71
Alt_2		7	3	3	Alt_2		5	4	5	Alt_2		5,92	3,46	3,87
Alt_3			5	5	Alt_3			7	7	Alt_3			5,92	5,92
Alt_4				1	Alt_4				1	Alt_4				1,00

Security Conditions

EXPERT 1					EXPERT 2					EXPERTS' GROUP				
0,09	Alt_2	Alt_3	Alt_4	Alt_5	0,10	Alt_2	Alt_3	Alt_4	Alt_5	0,11	Alt_2	Alt_3	Alt_4	Alt_5
Alt_1	5	9	3	4	Alt_1	5	9	4	7	Alt_1	5,00	9,00	3,46	5,29
Alt_2		5	5	3	Alt_2		6	4	3	Alt_2		5,48	4,47	3,00
Alt_3			9	9	Alt_3			9	4	Alt_3			9,00	6,00
Alt_4				3	Alt_4				5	Alt_4				3,87

Substation Conditions

EXPERT 1					EXPERT 2					EXPERTS' GROUP				
0,08	Alt_2	Alt_3	Alt_4	Alt_5	0,09	Alt_2	Alt_3	Alt_4	Alt_5	0,08	Alt_2	Alt_3	Alt_4	Alt_5
Alt_1	3	5	5	3	Alt_1	3	5	3	3	Alt_1	3,00	5,00	3,87	3,00
Alt_2		2	3	3	Alt_2		2	3	3	Alt_2		2,00	3,00	3,00
Alt_3			3	3	Alt_3			5	5	Alt_3			3,87	3,87
Alt_4				1	Alt_4				1	Alt_4				1,00

Terrorism Conditions

EXPERT 1					EXPERT 2					EXPERTS' GROUP				
0,07	Alt_2	Alt_3	Alt_4	Alt_5	0,10	Alt_2	Alt_3	Alt_4	Alt_5	0,08	Alt_2	Alt_3	Alt_4	Alt_5
Alt_1	3	9	5	5	Alt_1	3	9	7	5	Alt_1	3,00	9,00	5,92	5,00
Alt_2		7	3	1	Alt_2		5	3	3	Alt_2		5,92	3,00	1,73
Alt_3			7	7	Alt_3			5	7	Alt_3			5,92	7,00
Alt_4				1	Alt_4				3	Alt_4				1,73

Topography

EXPERT 1					EXPERT 2					EXPERTS' GROUP				
0,10	Alt_2	Alt_3	Alt_4	Alt_5	0,09	Alt_2	Alt_3	Alt_4	Alt_5	0,08	Alt_2	Alt_3	Alt_4	Alt_5
Alt_1	5	7	3	3	Alt_1	3	5	3	3	Alt_1	3,87	5,92	3,00	3,00
Alt_2		3	7	7	Alt_2		3	5	5	Alt_2		3,00	5,92	5,92
Alt_3			5	3	Alt_3			3	3	Alt_3			3,87	3,00
Alt_4				3	Alt_4				1	Alt_4				1,73

Transportation

EXPERT 1					EXPERT 2					EXPERTS' GROUP				
0,09	Alt_2	Alt_3	Alt_4	Alt_5	0,09	Alt_2	Alt_3	Alt_4	Alt_5	0,82	Alt_2	Alt_3	Alt_4	Alt_5
Alt_1	3	5	2	3	Alt_1	5	7	3	3	Alt_1	3,87	5,92	2,45	3,00
Alt_2		3	5	3	Alt_2		3	3	3	Alt_2		3,00	3,87	3,00
Alt_3			3	3	Alt_3			5	3	Alt_3			3,87	3,00
Alt_4				3	Alt_4				3	Alt_4				3,00

With Respect To (Comparisons)	EXPERT 1		EXPERT 2	
	Evaluation	Re-evaluation	Evaluation	Re-evaluation
Goal	0,04452	N/A	0,02286	N/A
Complementary Features of the SHPP	0,00000	N/A	0,00000	N/A
Essential Features of the SHPP	0,04936	N/A	0,08001	N/A
Essential Features of the SHPP's Site/Location	0,27329	0,11062	0,19093	0,10626
Social Features of the SHPP's Site/Location	0,53926	0,11260	0,53926	0,11260
Community Attitude	0,75121	0,38035	0,46596	0,23121
Conveyance Structure	0,20973	0,08979	0,17873	0,08829
Geology	0,07799	N/A	0,00000	N/A
Protected Areas	0,11993	0,09409	0,15279	0,09437
River Basin	0,05743	N/A	0,17080	0,09118
Security Conditions	0,28657	0,08867	0,24015	0,09768
Substation Conditions	0,10074	0,07518	0,14943	0,08512
Terrorism Conditions	0,06827	N/A	0,15242	0,09983
Topography	0,20706	0,09595	0,08782	N/A
Transportation	0,15692	0,08552	0,19634	0,09237

Figure 8. Final Super Decisions' matrix mode data (pair-wise comparison matrix and inconsistency) (after re-evaluations) & the inconsistency in the first and the second evaluations (N/A: not applicable, green font color: 0,000 ≤ inconsistency ≤ 0,100, blue font color: 0,100 < inconsistency ≤ 0,150, red font color: 0,150 < inconsistency)

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Despite the fact that the objective of the current study was to reach an inconsistency lower than 0,10 on the pair-wise comparison matrices, it had to be allowed up to 0,15 in the evaluations of the factors and alternatives because of the impossibility of reflecting the experts true beliefs. Although the inconsistency was allowed up to 0,15 in this study, the pair-wise comparison matrix of "the relative importance of the alternatives with respect to community attitude" could not be lower than 0,38035 after almost 50 attempts. The pair-wise comparison matrix of the community attitude due to the alternatives was left at this level (see Figure 8).

The main cause of this was the scale factor (1 to 9, 1 to 7, or 1 to 5) of the current study. If the scale was selected as 1 to 7 or 1 to 5, the inconsistency of the pair-wise matrices would easily be lower than 0,10 in most of the cases. The matrices about the alternatives with respect to objective factors were not analyzed by the consistency ratio, because of their nature, being objective.

The evaluations of the experts could not be directly entered into Super Decisions 2.2 because there is no experts' group option; only one expert's input screen is available. Hence, the group decision outcomes were calculated by the geometric mean formula (see Formula/Equation 2) with Microsoft Excel and Apache OpenOffice Calc according to Saaty's recommendation, and entered into the model on Super Decisions software. "It has been proved that the geometric mean, not the frequently used arithmetic mean, is the only way to do that. If the individuals are experts, they may not wish to combine their judgments but only their final outcomes obtained by each from their own hierarchy. In that case one takes the geometric mean of the final outcomes." (Saaty, 2008).

$G\ (a_1,..,a_n) = (\prod_{i=1}^{n} a_i)^{1/n}$, where ($a_i > 0$) (2)
(for extraction of this formula see Abramowitz and Stegun, 1972; Wolfram Research, 2014)

In the current study, a total of 270 pair-wise comparisons (20, 2, 2, 20, 20, 6, 20, 20, 20, 20, 20, 20, 20, 20, 20, 20 respectively for goal, MC_2, MC_3, MC_1, MC_5, MC_4, C_{10}, C_4, C_{13}, C_{16}, C_1, C_{14}, C_{17}, C_{15}, C_{12}, C_{11}) were performed in the first evaluation. There were approximately 266 pair-wise attempts performed (20, 6, 120, 20, 20, 20, 20, 20, 20 respectively for MC_5, MC_4, C_{10}, C_4, C_{16}, C_{14}, C_{17}, C_{12}, C_{11}) in the second evaluation. Hence, the researchers and practitioners should take into account this challenging and very time-consuming effort before starting any study of this scope.

In the current study, the priorities of the main factors, the sub-factors and the alternatives were normalized by cluster and limiting values from the priorities button on the computations tab of Super Decisions. The importance of the main factors were respectively the essential features of the SHPP's site/location (0,30434), the social features of the SHPP's site/location (0,29716), the electricity generation features of the SHPP (0,1799), the essential features of the SHPP (0,14142) and the complementary features of the SHPP (0,07718). The importance of the factors were respectively found as the terrorism conditions (0,21847), the substation conditions (0,17629), the firm energy (0,15741), the investment cost (0,06946), the geology (0,0661), the security conditions (0,06142), the net head (0,04133), the flow rate (0,04007), the river basin (0,03487), the protected areas (0,03275), the secondary energy (0,02249), the transportation (0,01816),

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the project runoff (0,01799), the community attitude (0,01727), the topography (0,01105), the conveyance structure (0,00772), and the catchment area (0,00717).
When the experts analyzed these results, they concluded that the results were appropriate and reflected the nature and the solution of the current problem. In this study, the ranks and the preference order of the alternatives was respectively found as Alternative 1 (0,23871), Alternative 5 (0,21654), Alternative 3 (0,18563), Alternative 2 (0,18500), and Alternative 4 (0,17413). These results were also analyzed by the experts and agreed upon as satisfactory results.

The findings of the current study recommended to the experts and investors that they should first start investigating Alt_1 (0,23871) and Alt_2 (0,21654) SHPP investment options in detail because these alternatives had very close priorities compared to the other alternatives (Alt_3 (0,18563), Alt_2 (0,18500), and Alt_4 (0,17413)).

These findings provided the opportunity to move on to new investigation steps, such as reviewing the detailed feasibility studies of these two alternatives and verifying and validating the respective data and information on their studies and reports as much as possible. Moreover, the negotiations and discussions on the agreements of these SHPP investments could be started and performed with the help of this study such as performing the detailed earnings, the detailed costs investigations, the shareholder agreements and the business models for these two SHPP investment options. If these SHPP options could not be invested in (no go, no green) for any reason, the other options, Alternative 3 (0,18563), Alternative 2 (0,18500), and Alternative 4 (0,17413) could be taken into account for further detailed investigations because of their close priority values.

In this study, the sensitivity analysis was performed and presented with the help of Super Decisions software. One of the sensitivity analyses was the node sensitivity. The colored lines (red: Alt_1, green: Alt_2, blue: Alt_3, orange: Alt_4, yellow: Alt_5) showed the priorities of the alternatives according to the priority of the terrorism, the substation, the firm energy, and the investment cost (see Figure 9) (the x-axis of the priority of parameter value: the terrorism conditions, the substation conditions, the firm energy, the investment cost). The black dots on the screen view of the Super Decisions software indicated the synthesized priorities of the alternatives for a priority of 0,7 - 0,8 for the terrorism conditions, 0,5 - 0,6 for the substation conditions, 0,8 - 0,9 for the firm energy, 0,9 for the investment cost. The Alt_1 was almost the same as the priority of the terrorism conditions increased from 0 to 1. The Alt_5 increased its preferability as the priority of the terrorism conditions increased from 0 to 1. However, the preference of the Alt_1 on the terrorism conditions never changed as the priority of terrorism conditions increased from 0 to 1.

Similar results were gathered for the other three factors as presented in Figure 9. The Super Decisions model file of this study has been supplied as electronic supplementary material (open AHP Model.sdmod).

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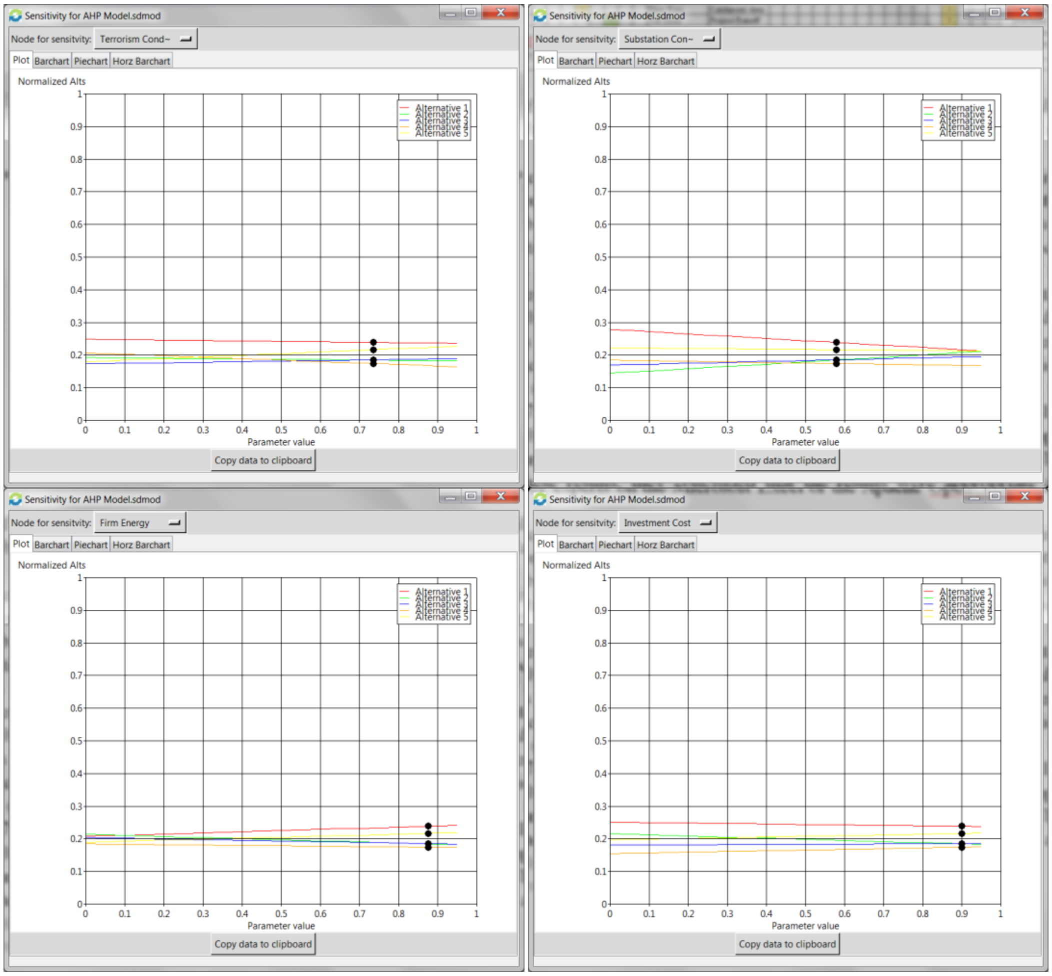

Figure 9. The sensitivity analysis (Node Sensitivity) for the first four highest priority factors (top left: the terrorism conditions (0,21847), top right: the substation conditions (0,17629), bottom left: the firm energy (0,15741), bottom right: the investment cost (0,06946)) by setting the sensitivity parameter to Smart P0 (Computations>Influence/Sensitivity>Options> Smart P0) and selecting the computations tab and the node sensitivity on the Super Decisions Software.

The other sensitivity analysis was the what-if sensitivity analysis for the hierarchies. The colored lines (red: Alt_1, blue: Alt_2, black: Alt_3, green: Alt_4, yellow: Alt_5) showed the priorities of the alternatives according to the priority of the complementary features of the SHPP, the Electricity Generation Features of the SHPP, the Essential Features of the SHPP, the Essential Features of the SHPP's Site/Location and the Social Features of the SHPP's Site/Location (see Figure 10 respectively top left, top middle, top right, bottom left, and bottom right) (the x-axis of the priority of the parameter value of the 1st other node). The black dotted line on the screen view of the Super Decisions software indicated the priority of the 1st other node and the interceptions with the slanted lines indicated the priorities of the alternatives. The priorities of the alternatives for the original synthesized values were found by moving and dragging the dotted line to the priorities of the alternatives presented in the previous paragraphs.

The Alt_1 decreased its preferability as the priority of the complementary features of the SHPP increased from 0 to 1. The Alt_5 increased its preferability under the same conditions. Although the Alt_1 was selected on the original synthesized value of 0,07718 for the complementary features of the SHPP, the preference of the Alt_1 decreased and at the same time the preference of the Alt_5 increased as the priority of the complementary features of the SHPP increased from 0 to 1. At about the synthesized value of 0,22 of this main factor, the Alt_5 had the first rank with 0,227 priority value. Similar findings were gathered for the other three alternatives as presented in the Figure 10. The Super Decisions model file of this study has been supplied as electronic supplementary material (open AHP Model.sdmod).

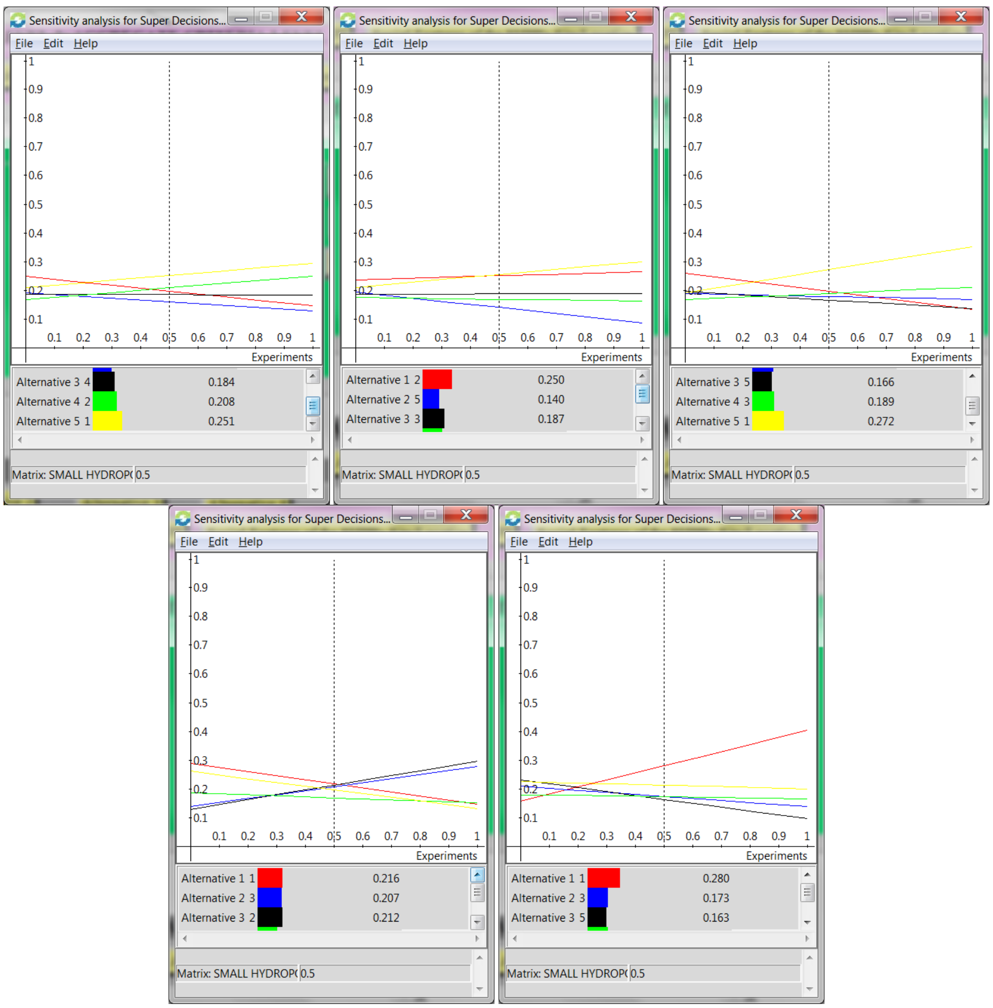

Figure 10. The sensitivity analysis (what-if sensitivity for hierarchies) for the "Goal: Small Hydropower Plants Investment Selection In Pre-Development Investment Stage" by selecting the parameter type as "SuperMatrix", Wrt node ("with respect to" node) as "SMALL HYDROPOWER PLANTS INVESTMENT SELECTION IN PRE-DEVELOPMENT INVESTMENT STAGE", 1st other node as "Complementary Features of the SHPP" (0,07718) (top left), "Electricity Generation Features of the SHPP" (0,1799) (top middle), "Essential Features of the SHPP" (0,14142) (top right), "Essential Features of the SHPP's Site/Location" (0,30434) (bottom left), "Social Features of the SHPP's

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Site/Location" (0,29716) (bottom right), Start as "0,0001", End as "0,99990000000000001", Steps as "7" (open the electronic supplementary material to see these inputs and screen views: AHP Model.sdmod).

4. Conclusions, future applications and research

In this paper, the AHP approach and model was applied to determine a solution for an investment selection problem in the energy industry in the Turkish SHP electricity generation market. The advantages of the AHP method, such as the ease of taking and expressing an expert's opinion were once more very well observed during the current case study. On the other hand, the disadvantages of the AHP method such as the amount of the pair-wise activities and effort required for the number of alternatives or factors was also an issue in the current case study.

The subjective and objective factors were selected by the experts without using any sophisticated method, but mainly due to the data and information availability for each factor in this case study. In general, while selecting the subjective factors, the experts should keep in mind the most challenging issues during the pre-construction, construction and operation phases of the SHPPs in Turkey. The objective factors are related with other scientific areas and methodologies. For instance, the rainfall data should be taken from statistical data tables of the metrological stations. The data and information of the SHPP for this aspect cannot be calculated by the experts, but can only be compared with others on the basis of the rough hard data sets. The design of the SHPP cannot be revised based on this study, because this scientific area is not in the scope of these kinds of problems. However, the compression of the main characteristics and structures of the SHPPs can be performed with the help of the subjective and objective factors.

The mathematics of the AHP method are not too difficult to understand and adopt. Henceforth, the researchers and even the practitioners can easily solve their AHP models. The AHP models can be solved with either the help of computer software or even by hand. Moreover, there are several custom written and off-the-shelf software packages for the AHP such as Super Decisions Software 2.2.

During this study, one of the crucial observations was about the mental process of the human nature. The experts expressed that the decisions on the factors and the alternatives were often affected by other internal and external factors during each evaluation. Henceforth, the evaluations could not be perfect.

In the SHP sector, the investors' happiness and satisfaction with their SHPP investments is very crucial, not only for the attention, and interest on the SHPP investments, but also for the health, the economic growth (real, not fictitious and financial markets) and the wealth of the world. Henceforth, the increasing number of the research studies and analysis based on the AHP method on the SHPP investments will inevitably improve our perception and understanding of the nature of the SHPP investments and SHPP investors. This study was conducted in a specific setting in the SHPP industry in Turkey, therefore the results cannot be directly applied to any other situation.

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