Analytic network process vs. Benjamin Franklin's rule to select private small hydropower plants investments

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Author Profile

Burak Omer Saracoglu as a researcher in the renewable energy industry. He holds a Doctor of Philosophy (PhD.) degree from the Institute of Science and Technology of Istanbul Technical University (ITU) (http://www.itu.edu.tr/), a Master of Science (MSc.) degree from the Industrial Engineering Program, ITU (http://www.itu.edu.tr/) and a Bachelor of Science (BSc.) degree from the Faculty of Naval Architecture and Ocean Engineering Program, ITU (http://www.itu.edu.tr/). He worked as a planning engineer, a project manager and a logistics manager of some chemical and container vessels and launch way gates. He also worked as a research and development (R&D) engineer and manager of some special purpose vehicles. He was a team member of some strategic, master and regional plans of countries and also a team member of some business and investment plans of companies, international sales and purchase expert of firms in several sectors.

Abstract

The real world investments are problematic, hence their analysis is difficult. Private small hydropower plant investments' (PSHPPI) need attention in this respect. Applying as many multi-criteria decision making (MCDM) methods as possible shall help to take satisfactory decisions. Accordingly, this research study presents mainly the findings of two methods: Analytic Network Process (ANP) and Benjamin Franklin's Rule. The current weightings are only based on the subjective weighting with pair wise approach (Saaty's). These findings in this study (2016) are compared with the previous ones (AHP, DEXi, ELECTRE, PROMETHEE) (2013-2015). There are 5 alternatives and 17 factors in the current models like the predecessor studies. The ANP model is built on the Super Decisions Software. The Benjamin Franklin's Rule model is presented on the Microsoft Office Excel and the Apache Open Office Calc. The ANP ranking is Alternative 1 (1st), Alternative 5, Alternative 4, Alternative 2 and Alternative 3 (5th). The Benjamin Franklin's Rule ranking is Alternative 5 (1st), Alternative 4, Alternative 1, Alternative 2 and Alternative 3 (5th).

Keywords: analytic network process, ANP, benjamin franklin, investment, pros and cons, small hydropower plant, tradeoff, economy, machine learning, possibility, probabilistic, game theoretic, multi criteria

Introduction

PSHPPI decision analysis is a difficult task (see Saracoglu[1] for a PSHPP). Amongst all real sector investments, agriculture and renewable power investments are crucial for the life. Private investments differ from public investments. When only installed costs of small hydro power plants are considered the importance of these decisions will easily be understood by healthy pragmatic rational ordinary people. They also have very serious effects on economies. Moreover, almost all countries' economies are interrelated with each other in today's global conditions. For instance, the Turkish economy is affected negatively by some occasions (e.g. invasion of Iraq, Arab Spring, pro–Russian insurgency) in Iraq, Egypt, and Ukraine; likewise, Israeli–Palestinian conflict.[2] Similarly, the interview with the U.S. General Wesley Clark in March 2007[3] and the U.S. Vice President Joe Biden in June 2016[4] cautions the bloodshed. This research is a part of continuing effort for developing an autonomous or semi–autonomous computer based intelligent decision support system (ACBIDSS) with some integrated artificial intelligence, machine learning, possibility, probabilistic, game theoretic, multi criteria decision making and multi objective optimization approaches[5–11] (Figure 1). The ACBIDSS is still in its research stages. For instance, constraints' categories (e.g. financial–economic, political, external by Nijkamp, et.al.[12] Saracoglu et al.[13]) have been studied for almost 6 years. It has been designed based on honest, fair, healthy and ordinary people's judgments and decisions with all languages for personal and hybrid computers, smart phones and tablets. The ACBIDSS's learning process will be designed for free of biasness (unbiased), dishonesties (honest), unfairness (fair), unjustness (just), partisan (nonpartisan) and illness (healthy). For instance, the ACBIDSS will not take into account any judgments of people with the "posttraumatic stress disorder" and the "traumatic brain injury"[14], "Schizophrenia", "Cognitive Dysfunction in Depression", "Major depressive disorder".[15] It is designed for both ex ante (forward looking) (before the event) and ex post (backward looking) and for both monetary and non–monetary evaluations.[12] Some of the key terms related with it are data information[16], knowledge by Gamble and Blackwell,[17] by Aristotle,[18] wisdom by Gamble and Blackwell,[17] by Aristotle,[18] emotion,[19] investment,[20] intelligence,[21] by Joint Chiefs Of Staff, Dictionary Of Military And Associated Terms, by Kirkpatrick,[22] by Anderson.[23] The knowledge development main structures of the ACBIDSS will have several modules, units, items and sub–units. These units and sub–units are principally generic, flexible and expandable. There are many methods for the multi–criteria decision making (MCDM), multiple–criteria decision analysis (MCDA), multiple criteria decision aiding (MCDA) part/module/unit of it. In this study, a comparison is first made on the findings of the current model of the Analytic Network Process (ANP) and Benjamin Franklin's Rule methods. The second comparison is made with the preceding studies of this research (AHP, DEXi, ELECTRE, and PROMETHEE). The factors and alternatives are kept same with the preceding studies. The differences with individual or group MCDM and model structures are clearly studied and presented for next research studies. This study is a very important step to understand the methods better in this problem field.

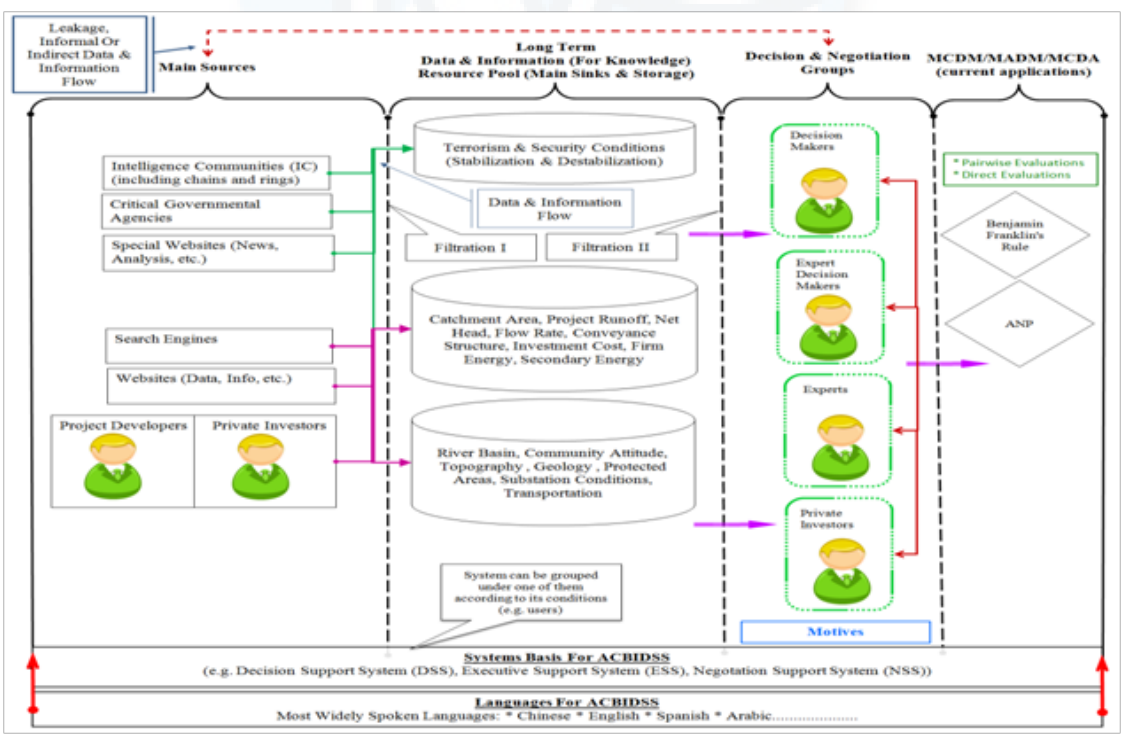


Figure 1 ACBIDSS[8,9]. (Icon: signore_green, 2015). (generated by Microsoft Office Excel & Paint.NET) (Figure1.xlsx, Figure1 Supplementary.xlsx).

Previous research in the literature

This literature review was structured in the way of previous studies.[5–11] The scientific online database and journals' websites with low search hit rates were eliminated in this review. The current literature review aimed mainly to find the comparative studies of ANP and Benjamin Franklin's Rule in this industry. Hence, the key terms were narrowed according to the websites' guidelines.[24] The review was performed with "ANP" "Benjamin Franklin" "hydro" (#1), "Analytic Network Process" "Benjamin Franklin" "hydro" (#2), "ANP" "Benjamin Franklin" (#3), "Analytic Network Process" "Benjamin Franklin" (#4) search queries on the scientific publisher websites (#A: Directory of Open Access Journals, 2016; #B: Google Scholar, 2016; #C: Hindawi Publishing Corporation, 2016; #D: Inderscience Publishers, 2016; #E: International Journal of the Analytic Hierarchy Process, 2016; #F: Science Direct®, 2016; #G: Science Publishing Group, 2016; #H: Springer, 2016) until 04/06/2016. There weren't any documents found on the #A to #H. This situation presented that this study would contribute to the scientific literature very well. Accordingly, four additional search queries were determined "ANP" "small hydro" (#5), "Analytic Network Process" "small hydro" (#6), "ANP" "small hydropower" (#7), "Analytic Network Process" "small hydropower" (#8). These key terms were searched on the same websites until 05/06/2016. There weren't any documents found on any websites. This literature review study showed that this study would probably be the first comparative Analytic Network Process and Benjamin Franklin's Rule study with also their preceding studies by the Analytic Hierarchy Process (AHP), the Decision Expert for Education (DEXi), the Elimination and Choice Translating Reality (ELECTRE) and the Preference Ranking Organization Method for Enrichment Evaluations (PROMETHEE).

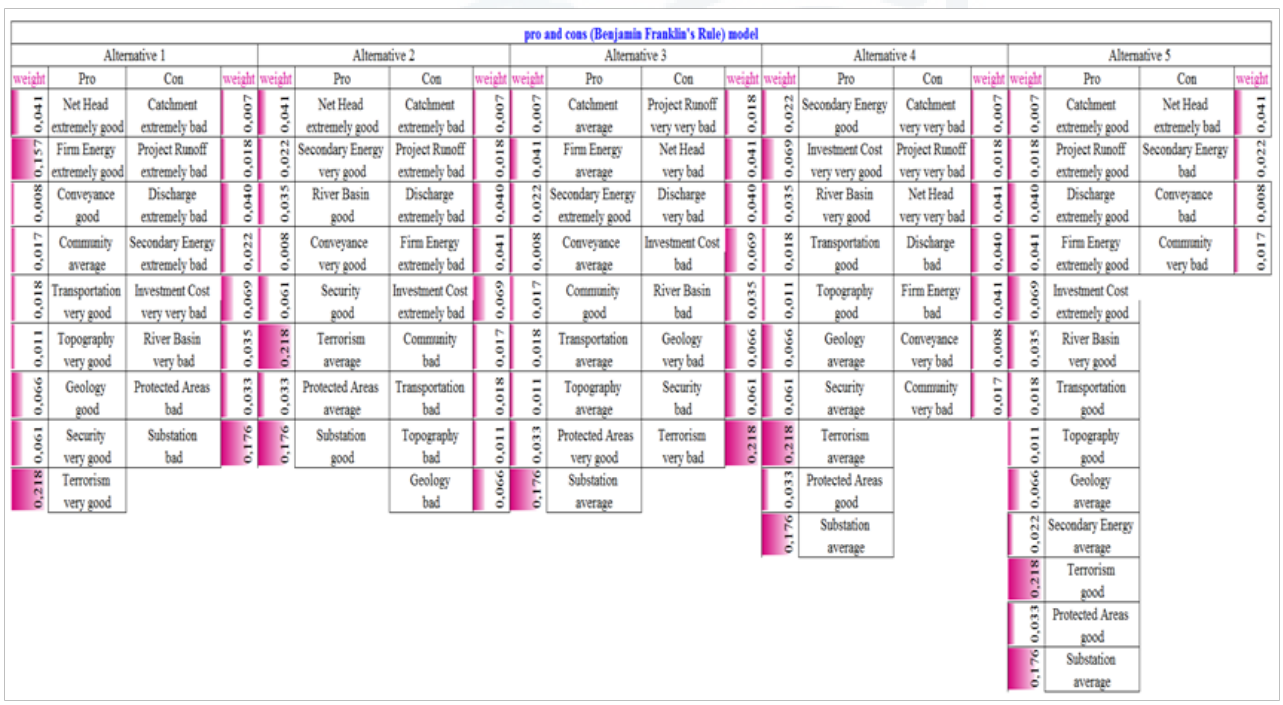
The development and publication information on the historical basis are shortly as follows: MCDM/MADM Theory; pro and con,[25] U.S.A, Benjamin Franklin, 1772; AHP, U.S.A., Thomas L. Saaty, 1971; ANP, U.S.A., Thomas L. Saaty, 1974; ELECTRE III, France, Bernard Roy, 1978; DMP (Decision Making Process), Slovenia, Janet Efstathiou & Vladislav Rajkovic, 1979; DECMAK, Slovenia, Marko Bohanec & Ivan Bratko & Vladislav Rajkovic, 1981; ELECTRE IV, France, Bernard Roy & Jean–Christophe Hugonnard, 1982; PROMETHEE I, PROMETHEE II, Belgium, Jean–Pierre Brans & Bertrand Mareschal, 1982; PROMETHEE GAIA, Belgium, Jean–Pierre Brans & Bertrand Mareschal, 1983; DEX, Slovenia, Marko Bohanec & Vladislav Rajkovic, 1988; DEXi, Slovenia, Eva Jereb & Marko Bohanec & Vladislav Rajkovic, 2000; application in PSHPPI selection: AHP, Turkey, Burak Omer Saracoglu, 2013; ELECTRE III & IV, PROMETHEE I & II & GAIA, DEXi, Turkey, Burak Omer Saracoglu, 2014; this study, 2016 (confirmation: Thomas L. Saaty, Marko Bohanec, Bertrand Mareschal, Bernard Roy, Jose Rui Figueira, Burak Omer Saracoglu). Although, MCDM's foundations were dated back to the early pairwise comparisons on the world,[26] the International Society on MCDM defined the beginning with Benjamin Franklin's studies (International Society on MCDM[27]). Benjamin Franklin's Rule was presented by his letter (ProCon, 2016; Founders Online, 2016). Some of its several different applications with original or sophisticated developed versions were by Brady,[28] Nickol,[29] Hammond et.al.,[30] Shipp.[31]

The ANP methodology was developed and first presented in 1974 by Thomas L Saaty. The description of it was given as "ANP provides a general framework to deal with decision without making assumptions about the independence of higher level elements from lower level elements and about the independence of the elements within a level. In fact the ANP uses a network...".[32] The ANP models could be explained as "a system of N components (which may be part of a cluster of components) that forms a network where every component (C_n) can interact or have an influence on itself or some or all of the other components of the system. The network, N, equals..." Niemira et al.[33] The relations described as the inner dependence, when elements in a component are connected to others in the same component, and the outer dependence, when elements in a component are being connected to elements in other components.[34] Instead of asking the question "What is more preferred or more important?" in the AHP method, "What has greater influence?", "Which of two elements being compared with respect to it has greater influence (is more dominant) with respect to that parent element?" or "Which is influenced more with respect to that parent element?" was asked in the ANP method[35,36]. The AHP and ANP methods were the American school of multi criteria decision approaches.[37] The readers could find the definitions, details and axioms of the ANP and its 12 application steps (e.g. "If a control criterion or sub criterion has a global priority of 3% or less, you may consider carefully eliminating it from further consideration.") in Niemira et al.,[33] Blair et.al.[38] Saaty[32,34,39,40]). The ANP method was already applied in many subjects. Aghilone et al.[41] selected the best feasible mini wind plant with 4 clusters of 19 factors. Aragones–Beltran et.al.[42] applied the ANP at their proposed Level 3 stage for a Spanish company's solar–thermal power plant investment project portfolio selection process. Bottero et al.[43] & Chung et.al.[44] presented some models respectively in the problems of waste incinerator plants in Italy, and semiconductor factory product mix selection in Taiwan.

The main aim of this research is to build, understand and analyze the findings of the pros and the cons method (Benjamin Franklin's Rule) (1772 Benjamin Franklin) and the Analytic Network Process (ANP) method (1974 Thomas L. Saaty), which is the successor of the Analytic Hierarchy Process (AHP) method (1971 Thomas L. Saaty), on a PSHPPI selection problem in the pre–development investment stages. The subsidiary objective of the current study is to understand, analyze, investigate and compare the findings of Benjamin Franklin's Rule and ANP with the predecessor applications (AHP, ELECTRE III and IV, DEXi, PROMETHEE). The quote "Knowing is not enough; we must apply. Willing is not enough; we must do." by Johann Wolfgang von Goethe informs readers about the core competence of this research study very well.

Comparative research model, case, results, and discussion

The current comparative research is built upon the previous studies' foundations for a fare and good comparison basis. Saracoglu at al.[5] presents an ELECTRE III & IV study with 17 basic factors (catchment area, project runoff, net head, flow rate, firm energy, secondary energy, investment cost, river basin, conveyance structure, community attitude, transportation, topography, geology, security conditions, terrorism conditions, protected areas, substation conditions) for the pre–development investment stage. Saracoglu[6,7,11] applies these criteria with an AHP model, a DEXi model and a PROMETHEE model. 7 of these factors (catchment area: drainage basin, catchment, catchment basin, drainage area, river basin, water basin; project runoff; net head; project design discharge: capacity, discharge, flow, flow rate, rate of flow; firm energy; secondary energy; investment cost) are used in Saracoglu.[8] As a result, these 17 basic factors are used in the current pros and cons (Benjamin Franklin's Rule) (see all transformation and model construction on Benjamin Model.xls/ods) and ANP models are structured as shown in Figure 2 & Figure 3. The detailed explanations of these factors are given in Saracoglu.[5–11] The reader should also be aware that many other factors such as multi composite (multi factorial: several factors integrated measures) financial measures (e.g. Earnings before Interest, Taxes, Depreciation and Amortization) can be used in the development investment stages. This study can be grouped under the satisfying behavior amongst the optimizing, satisfying and justifying behavioral paradigms given by Nijkamp et al.,[12] like the preceding studies of this research. The short description and source information about these factors and some equations (in the way of factors and equations pool), that are considered during this study and can be used in the mid to long term multi–objective optimization (MOO) studies with the MCDM, are given below:



pro and cons (Benjamin Franklin's Rule) model

Alternative 1				Alternative 2				Alternative 3				Alternative 4				Alternative 5			
weight	Pro	Con	weight	weight	Pro	Con	weight	weight	Pro	Con	weight	weight	Pro	Con	weight	weight	Pro	Con	weight
0,041	Net Head extremely good	Catchment extremely bad	0,007	0,041	Net Head extremely good	Catchment extremely bad	0,007	0,007	Catchment average	Project Runoff very very bad	0,018	0,022	Secondary Energy good	Catchment very very bad	0,007	0,007	Catchment extremely good	Net Head extremely bad	0,041
0,157	Firm Energy extremely good	Project Runoff extremely bad	0,018	0,022	Secondary Energy very good	Project Runoff extremely bad	0,018	0,041	Firm Energy average	Net Head very bad	0,041	0,069	Investment Cost very very good	Project Runoff very very bad	0,018	0,018	Project Runoff extremely good	Secondary Energy bad	0,022
0,008	Conveyance good	Discharge extremely bad	0,040	0,035	River Basin good	Discharge extremely bad	0,040	0,022	Secondary Energy extremely good	Discharge very bad	0,040	0,035	River Basin very good	Net Head very very bad	0,041	0,040	Discharge extremely good	Conveyance bad	0,008
0,017	Community average	Secondary Energy extremely bad	0,022	0,008	Conveyance very good	Firm Energy extremely bad	0,041	0,008	Conveyance average	Investment Cost bad	0,069	0,018	Transportation good	Discharge bad	0,040	0,041	Firm Energy extremely good	Community very bad	0,017
0,018	Transportation very good	Investment Cost very very bad	0,069	0,061	Security good	Investment Cost extremely bad	0,069	0,017	Community good	River Basin bad	0,035	0,011	Topography good	Firm Energy bad	0,041	0,069	Investment Cost extremely good		
0,011	Topography very good	River Basin very bad	0,035	0,218	Terrorism average	Community bad	0,017	0,018	Transportation average	Geology very bad	0,066	0,066	Geology average	Conveyance very bad	0,008	0,035	River Basin very good		
0,066	Geology good	Protected Areas bad	0,033	0,033	Protected Areas average	Transportation bad	0,018	0,011	Topography average	Security bad	0,061	0,061	Security average	Community very bad	0,017	0,018	Transportation good		
0,061	Security very good	Substation bad	0,176	0,176	Substation good	Topography bad	0,011	0,033	Protected Areas very good	Terrorism very bad	0,218	0,218	Terrorism average			0,011	Topography good		
0,218	Terrorism very good					Geology bad	0,066	0,176	Substation average			0,033	Protected Areas good			0,066	Geology average		
												0,176	Substation average			0,022	Secondary Energy average		
																0,218	Terrorism good		
																0,033	Protected Areas good		
																0,176	Substation average		

Figure 2 Benjamin Franklin's Rule model (Benjamin Model.xls/ods).

C_1: River Basin (subjective) (machine or human evaluation: human evaluation state of science),

C_2: Catchment Area (drainage basin, catchment, catchment basin, drainage area, river basin, water basin) (objective, km^2: square kilometer) (more is better ↑↑) (machine or human evaluation),[45]

C_3: Project Runoff or Inflow (objective, hm^3: cubic hectometer) (more is better ↑↑) (machine or human evaluation),[45,46]

C_4: Conveyance Structure (subjective) (human evaluation state of science),

C_5: Net Head (objective, m: metre) (more is better ↑↑) (machine or human evaluation) (see IFC, 2015),

C_6: Project Design Discharge (capacity, discharge, flow, flow rate, rate of flow) (objective, m^3/s: cubic metre per second) (more is better ↑↑) (machine or human evaluation),[45,46]

C_7: Firm Energy (objective, GWh: Gigawatt Hour) (more is better ↑↑) (machine or human evaluation),

C_8: Secondary Energy (objective, GWh) (more is better ↑↑) (machine or human evaluation),

C_9: Investment Cost (objective, USD: United States Dollar) (less is better ↓↑) (machine or human evaluation),[45] C_{10}: Community Attitude (subjective) (human evaluation state of science) (see IFC, 2015),

C_{11}: Transportation (subjective) (human evaluation state of science),[45]

C_{12}: Topography (subjective) (human evaluation state of science) (see IFC, 2015),

C_{13}: Geology (subjective) (human evaluation state of science) (fault zones, earthquake gaps such as "a gap that has not been filled for 250 years" IFC,[45] Bohnhoff et al.[47]),

C_{14}: Security Conditions (subjective) (human evaluation state of science) (for example: financial, internet and high–tech crime not related with terrorism[48,49]),

C_{15}: Terrorism Conditions (subjective) (human evaluation state of science) (for instance: facts; nation's wars; special warfare and welfare; mass atrocities, falsification, forgery, fabrication, de facto and chaos creation/generation; hostile operations and plans presented in the documents based on the analysis, counterintelligence, human, measurement and signature, and open–source intelligences, see DIA;[50] Morgan et.al.[51]),

C_{16}: Protected Areas (subjective) (human evaluation state of science),[45] C_{17}: Substation Conditions (subjective) (human evaluation state of science).[45]

Flow–Duration Curve (FDC): "flow–duration curve is a cumulative frequency curve..."[52]

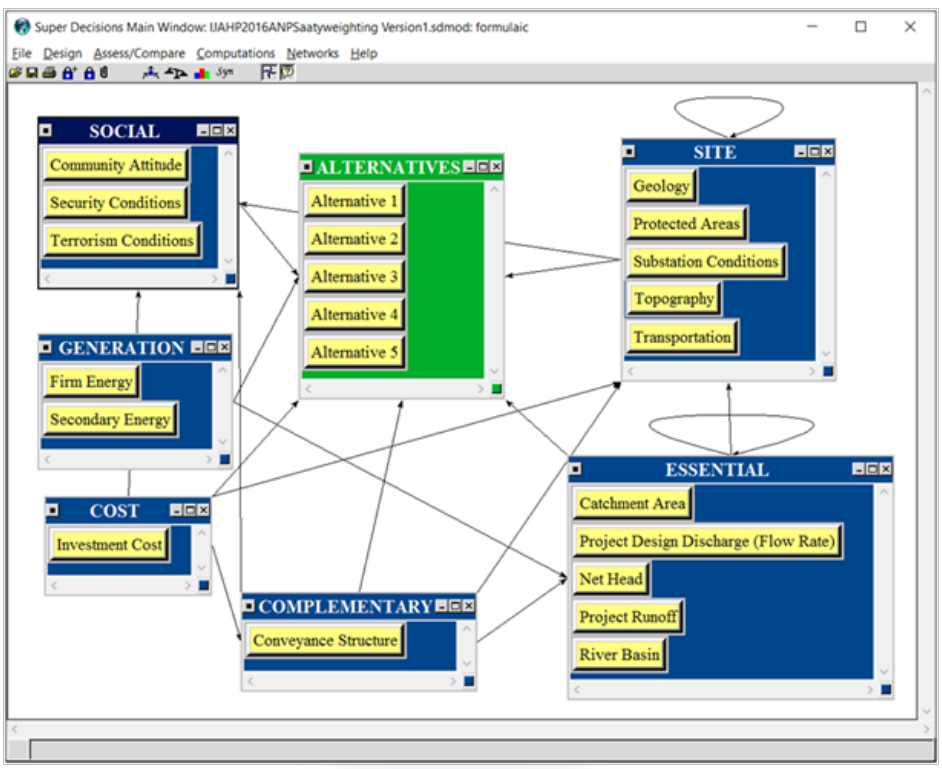


Figure 3 Screen view of ANP model on Super Decisions (ANP Model.sdmod) (simple network: all clusters and nodes in a single window).

Small Hydropower Power Plant Installed Capacity:[45]

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

η_{tr} :Efficiency of transformer 98−99,5%;

η_g : Efficiency of generator 90−98%,

η_t : Efficiency of turbine,

ρ_w : Density of water (kg/m^3),

g: gravity (m/s^2) approx: 9,81 m/s^2,

Q: rated discharge (m^3/s),

H_{net} : net head (m)Total Energy (see IFC, 2015; RETScreen®, 2005):

$$E = P \times t \quad (2)$$

$$E = P \times 8760 \times \text{capacity factor} \quad (3)$$

"Given that the flow–duration curve represents an annual cycle, each 5% interval on the curve is equivalent to 5% of 8,760 hours (number of hours per year)"

$$E = \sum_{i=1}^{20} \left(\frac{P_{5(k-1)} + P_{5k}}{2} \right) \frac{5}{100} 8760 \left(1 - I_{dt}\right) \quad (4)$$

E: generated energy MWh,

P: power produced MW,

t: period of time h,

capacity factor (%): typically 50 % to 60 %,

I_{dt} : Annual downtime losses

Internal Rate Of Return – IRR:[51]

$$0 = \sum_{t=1}^{T} \frac{C_t}{\left(1 + IRR\right)^t} - C_o \quad (5)$$

C_t:net cash inflow during the period t,

C_o:total initial investment costs, r: discount rate, t: number of time periods

Initial Capital Cost Estimate (US$, 2011):[53]

$$C_P = 566,9 \times H^{0,01218} \times P^{1,1452} \quad (6)$$

C_P cost of overall project,

P: installed capacity in kW,

H: hydraulic head in m

There are five PSHPP alternatives in this study from Saracoglu.[5–8] As a consequence, the decision (Benjamin Franklin's Rule and ANP) is to select the best PSHPP alternative. The evaluations and judgments of subjective factors are adopted and directly taken from the previous studies (2012–2015 evaluations). In this study, there is only one expert decision maker. The evaluations from the previous studies are due to the group decision making by the geometric mean calculation. They are very close to the expert decision maker's individual evaluations. The differences in the group and individual decision making are also tried to be analyzed (how judgments distribute and differentiate in this unique problem?). The objective factors are directly taken with their data. The criteria weights (voting power) are taken from the previous studies (Saaty's AHP/ANP). The pair wise comparisons of the ANP (this study) is the same as the AHP (previous one), with the same principles such as the Fundamental Scale,[54] the Likert type scale,[55] the magical number 7, and the 7±2 rule.[56,57] The other items of the models (ANP and Benjamin Franklin) are according to their own methodological principles (e.g. ANP factors relations, new evaluations due to ANP, Benjamin Franklin alternative evaluations). The calculations and presentations are made by Super Decisions version 2.2 (http://www.superdecisions.com/), Microsoft Office Excel 2007 (http://www.microsoft.com) and Apache Open Office Calc 4.1.2 (https://www.openoffice.org/). The tradeoffs can't exactly be made according to Benjamin Franklin's letter in this study, because the objective factors are evaluated by the numerical values. The total number of alternatives and factors are over the cognitive capacity of the decision maker, according to the decision maker's point of view (too much/many data, information, alternatives and factors make confusion and trouble during evaluation and tradeoffs). The pro and con can be defined and tradeoffs can be made without any difficulty with words only. Hence, the tradeoffs in the Benjamin Franklin's rule in this study are made as described, in order, in the following steps: 1–) The minimum, average, maximums are found for each objective factor, 2–) The range is calculated for each objective factor, 3–) The scale discrimination is calculated (9 point scale) for each objective factor, 4–) The transposition of the objective factors evaluations from numbers to words are performed (computing with words), 5–) The minimum, maximums are found for each subjective factor (evaluations from previous studies), 6–) The whole evaluations are presented by only words (see all on Benjamin Model.xls/ods Transposition Sheet), 7–) The alternatives and the factors are organized as in a pro and con matrix (Figure 2) ("divide half a Sheet of Paper", "one Pro, and over the other Con"), as explained in Benjamin Franklin's letter (ProCon, 2016)). 8–) The voting power ("their respective Weights") is also presented on this matrix (left & right) (for simplicity Saaty's AHP/ANP), 9–) The tradeoffs are made by considering weights (approx.) ("I put down under the different Heads short Hints of the different Motives that at different Times occur to me for or against the Measure", as explained in Benjamin Franklin's letter (ProCon, 2016)) for each alternative ("that seem equal, I strike them both out", "I strike out the five") (e.g. Alternative 1: net head (pro) and catchment, project runoff, secondary energy (con) strike out at the same time). In short, the balance on each alternative by factors are found at first, 10–) The tradeoffs are made by considering weights and evaluations of the remaining factors amongst all alternatives. The balance amongst alternatives is found at second. The evaluations are colored (aim: ergonomic visual display) (Benjamin Model.xls/ods) (Figure 4). In this study, the ranks and the preference order of the alternatives are respectively found as Alternative 5 (no cons, 11 pros such as good terrorism, extremely good firm energy, extremely good investment cost), Alternative 4 (no cons, 8 pros such as very good investment cost, good secondary energy), Alternative 1 (no cons, 1 pro very good terrorism), Alternative 2 (no cons, average terrorism, average protected areas), and Alternative 3 (no pros, two cons). Hence, it should be recommended to the experts (investors, etc.) to investigate, negotiate, make agreements and buy Alternative 5, because this alternative is the best in tradeoffs amongst all alternatives (choose Alternative 5!). If this PSHPP option can't be bought during the investigation and negotiation period, Alternative 4, Alternative 1, Alternative 2 and Alternative 3 can be taken into account respectively for further detailed studies and investigations.

In this ANP model, the connections are found according to following questions: What has an influence on Alternative 1? What has an influence on Investment Cost? etc. Moreover, the priorities at feedbacks are derived according to following questions: For the Alternative 1, which do you like better, its Investment Cost or its Firm Energy?, Its Investment Cost or its Catchment Area?[33] (ANP Evaluations. xlsx). There are totally 225 pair wise comparisons of nodes such as 10 for conveyance structure factor on alternatives cluster (same for all factors on alternatives cluster), 1 on essential cluster, 6 on site cluster, 3 on social cluster, 10 for investment cost factor on site cluster, 10 on site cluster, 3 on social cluster. There are totally 19 pair wise comparisons of clusters such as 6 for complementary cluster. The inconsistency checks are made during the matrix evaluations. For instance, "Comparisons with respect to "River Basin" node in "ALTERNATIVES" cluster" has an inconsistency of 0,05212 (ANP Evaluations.xlsx). Although this study aims to reach an inconsistency lower than 0,10 on each pair wise comparison matrix, the maximum inconsistency (0,26516) is observed in "Comparisons with respect to "Community

Attitude" node in "ALTERNATIVES" cluster". This pair wise comparison exactly reflects the expert true beliefs due to the data and information from the previous studies (learning/gaining experience). The inconsistencies range between 0,00000 and 0,26516 in this study. The priorities of factors and alternatives are taken directly as the limiting values from the priorities button on the computations tab of Super Decisions (Computations>Priorities>Limiting). These values are respectively: Alternative 1 (0,112848), Alternative 2 (0,062817), Alternative 3 (0,045372), Alternative 4 (0,086622), Alternative 5 (0,098668), conveyance structure (0,025051), investment cost (0,00000), catchment area (0,052284), net head (0,083484), project design discharge (flow rate) (0,06425), project runoff (0,055847), river basin (0,089096), firm energy (0,00000), secondary energy (0,00000), geology (0,031455), protected areas (0,011196), substation conditions (0,004715), topography (0,084357), transportation (0,006535), community attitude (0,010082), security conditions (0,018793), and terrorism conditions (0,056529). It is noticed that the factors are in the following order of priority: river basin, topography, net head, project design discharge (flow rate), terrorism conditions, project runoff, catchment area, geology, conveyance structure, security conditions, protected areas, community attitude, transportation, substation conditions, investment cost, firm energy, and secondary energy. This finding is surprising at the first look; however, when Creative Decisions Foundation (2012) is read again, it becomes more reasonable and logical. The priorities of factors are determined by the feedbacks in the ANP models, so that the information about the factors is also taken from the alternatives and other factors. For instance, the information about firm energy is taken from the factors (catchment area, flow rate, net head, project runoff, river basin) and the alternatives. In this study, the ranks and the preference order of the alternatives are, respectively: Alternative 1 (0,277727), Alternative 5 (0,242828), Alternative 4 (0,213183), Alternative 2 (0,154598), and Alternative 3 (0,111663). Hence, it should be recommended to the experts (investors, etc.) to investigate, negotiate, make agreements and buy Alternative 1 and Alternative 5, because these alternatives have the highest priorities amongst all the alternatives (choose Alternative 1!). If these PSHPP options can't be bought during the investigation and negotiation period, Alternative 4, Alternative 2 and Alternative 3 can be taken into account respectively for further detailed studies and investigations.

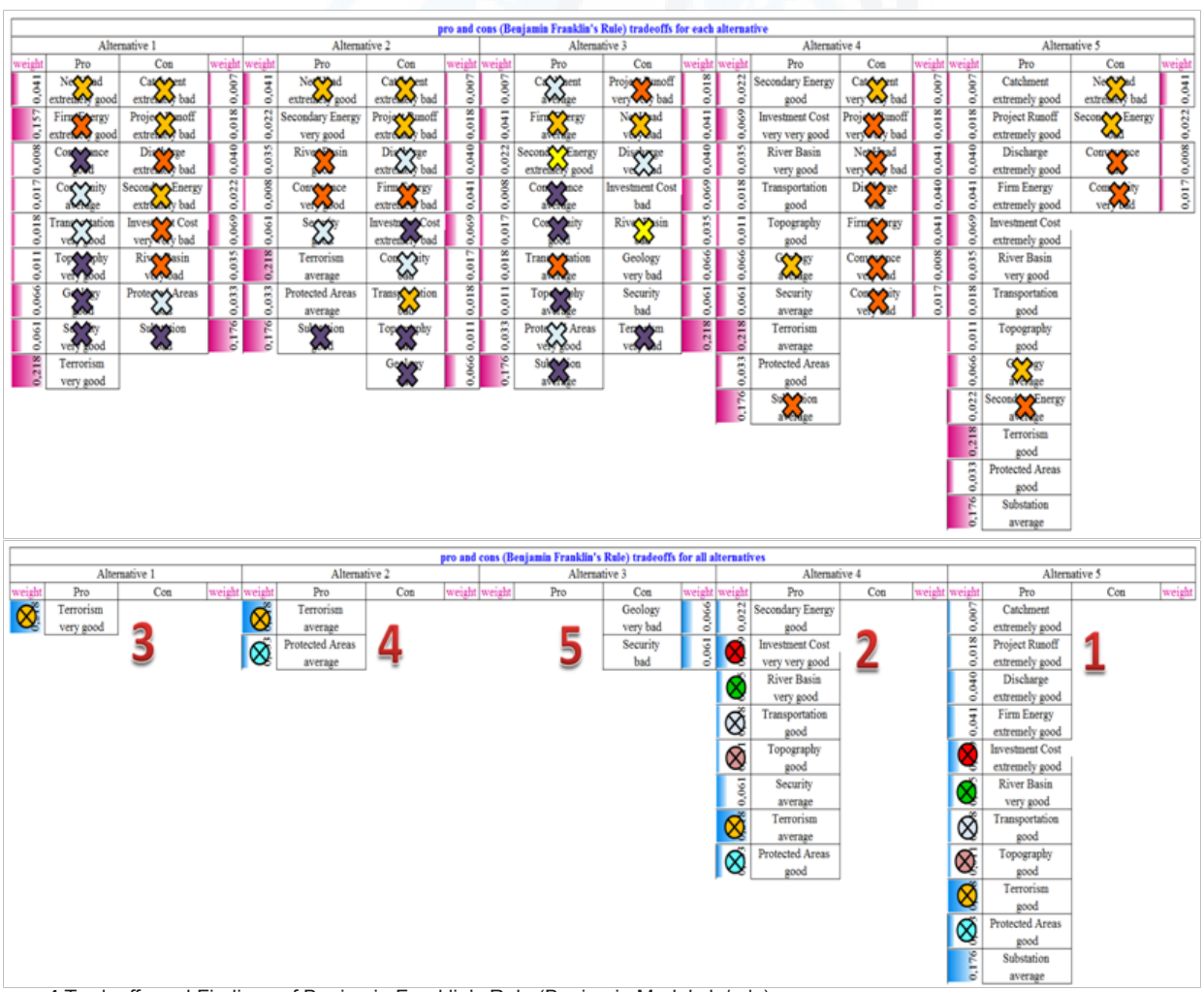


Figure 4 Tradeoffs and Findings of Benjamin Franklin's Rule (Benjamin Model.xls/ods).

The sensitivity analyses are performed by the Super Decisions software. The first sensitivity analysis is the node sensitivity. However, there are some important issues with sensitivity analysis of the ANP by Super Decisions. For instance "In the ANP setting (with feedback, and/or nodes having multiple destination clusters) the equivalent sensitivity on a particular judgment set yields either no sensitivity at all, or at the best, very minimal sensitivity.", "AHP defined method of sensitivity analysis and translating to the ANP setting leads to essentially no sensitivity (when using the "with respect to node" method),.....which by–passes all of the limit matrix calculations, thereby skipping over the essential ANP structure" "However, the "with respect to node" calculation shows miniscule or non–existent sensitivity in networks with feedback (unless the sensitivity node happens to be an alternative, and in that case it is trivial linear sensitivity or a skewed curve because of the renormalization)." and "Lastly the ANP Row Sensitivity graphs with smart p_0 allow us to see quickly how changes to the importance of a given node affect the overall alternative scores whether we are in a single level network, or in multiple level networks.[58] On the basis of these clauses and comments, the node sensitivity is presented in this study. The lines (red, green, blue, orange, yellow) represents the priorities of the alternatives with respect to the priority of the factors (terrorism conditions, substation conditions, project design discharge, and net head) (Figure 5) (x–axis: priority of the parameter value, such as terrorism conditions). The black dots indicate the synthesized priorities of the alternatives for a priority of 0,3–0,5 for terrorism conditions, 0,0–0,1 for substation conditions, 0,0–0,6 for project design discharge (flow rate), 0,3–0,4 for net head. Alternative 1 increase it's prefer ability as the priority of terrorism conditions increases from 0 to 1. Alternative 5 is almost the same as the priority of terrorism conditions increases from 0 to 1. Alternative 2, Alternative 3, and Alternative 4 decrease their preferabilities as the priority of terrorism conditions increases from 0 to 1. Similar findings are gathered for the others (Figure 5) (ANP Model. sdmod for all).

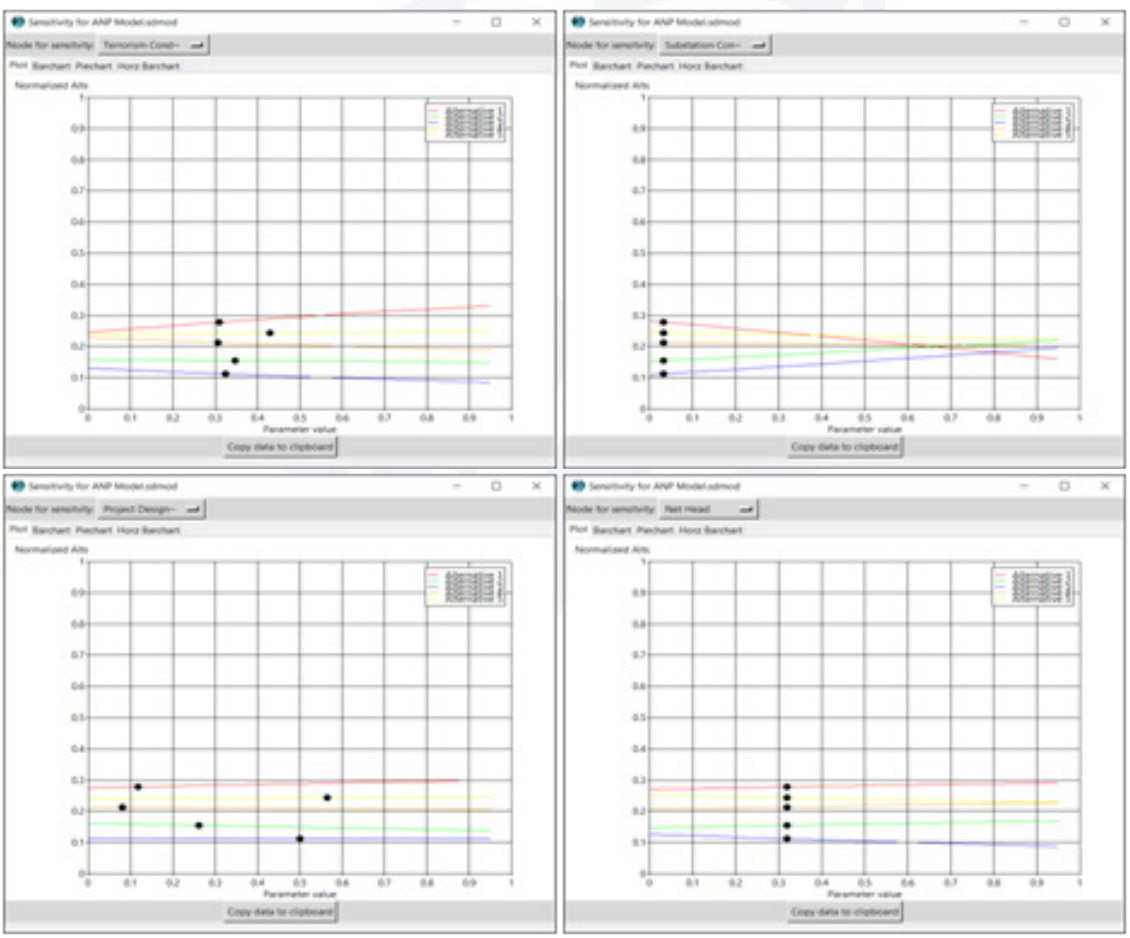


Figure 5 Node Sensitivity with sensitivity parameter to Smart P0 setting for four factors (left: terrorism, midleft: substation, midright: project design discharge, right: net head).

The second sensitivity analysis, which is explained and presented in Adams et al.[59] Creative Decisions Foundation [37] & Saaty,[11] is the what–if sensitivity analysis (ANP Row Sensitivity Adams et al.[60,61]) for the networks (also clauses and comments Adams[58]). The colored lines (red, blue, black, green, yellow) show the importance of the alternatives according to the super matrix row of topography, net head, project design discharge (flow rate) (Figure 6) (x–axis:

super matrix row of the independent variable). The black dotted line on the graph indicates the importance of the node and the interceptions with the slanted lines indicate the importance of the alternatives (there is the possibility to move and drag the dotted line). Alternative 1 increases its importance as the importance of the topography, considering all its connections (super matrix row) increases from 0 to 1. Alternative 5 and Alternative 2 decrease their importance as the importance of the topography considering with all its connections (super matrix row) increases from 0 to 1. Alternative 4 has almost the same importance as the importance of the topography considering with all its connections (super matrix row) increases from 0 to 1. Similar findings are gathered for the other nodes (Figure 6). When the independent variables (topography, net head, project design discharge) are analyzed at the same time, the importance of alternatives is learnt by dragging the dotted line as such super matrix rows: topography: 0,11672471387248798; net head: 0,83326670000000003; project design discharge: 0,1667333 then Alternative 1:0,235; Alternative 2:0,195; Alternative 3:0,093; Alternative 4:0,228; Alternative 5:0,249 (ANP Model. sdmod).

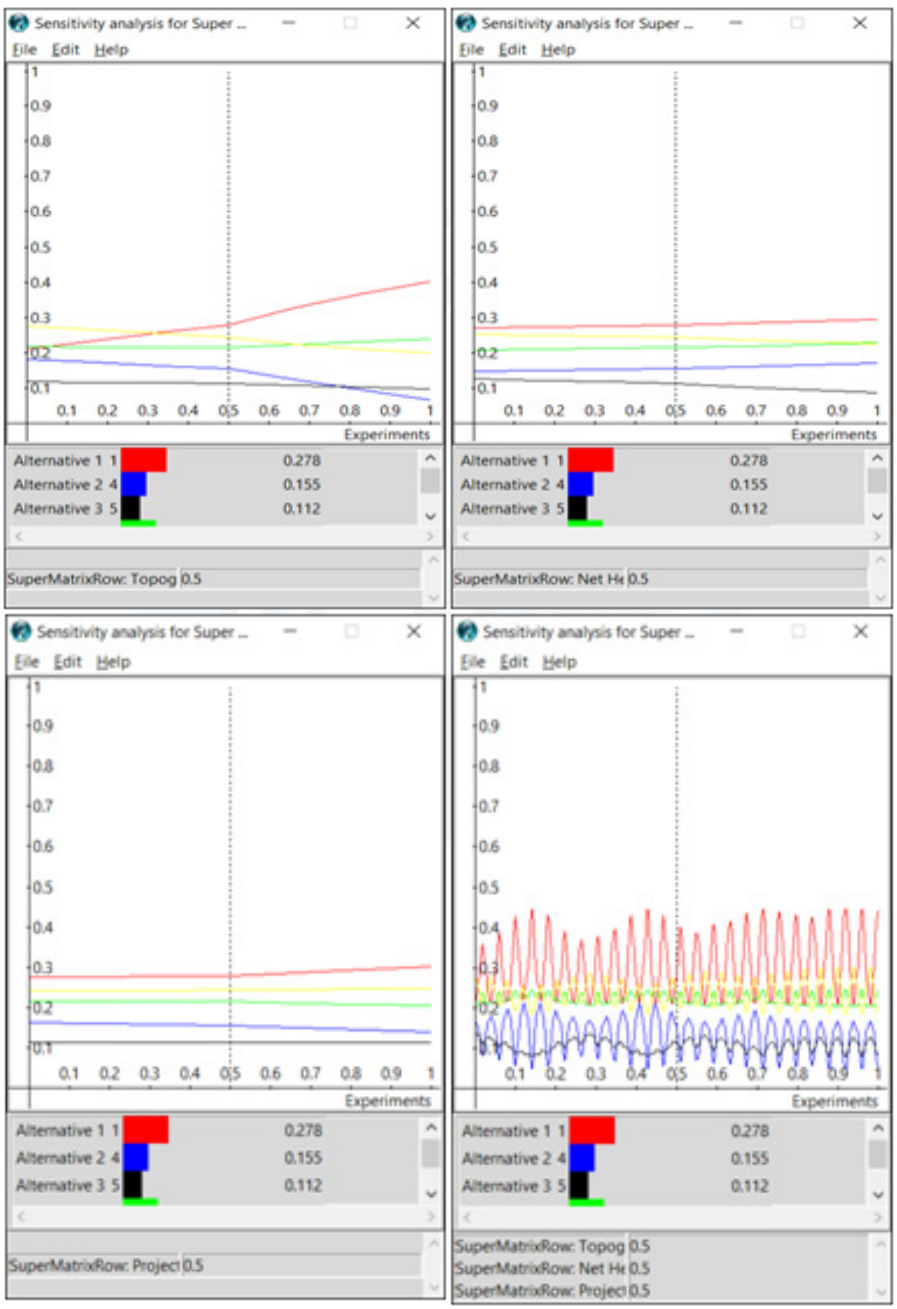


Figure 6 Sensitivity analysis by selecting the parameter type as "SuperMatrixRow", Wrt node ("with respect to" node) as "topography" (left), "net head" (middle left), "project design discharge (flow rate)" (middle right), all together (right).

The overall findings of this PSHPP selection problem (Figure 7) show that Alternative 1 is ranked as the first for AHP, ELECTRE IV, PROMETHEE and ANP approaches. It gets the second rank in ELECTRE III mainly and the third rank in DEXi and Benjamin Franklin's Rule methods. Alternative 2 is ranked as the first in ELECTRE IV, the second in ELECTRE III, the third in ELECTRE III, DEXi and PROMETHEE, the fourth in AHP, Benjamin Franklin's Rule and ANP methods. Alternative 3 is ranked as the first in ELECTRE IV, the second in ELECTRE III and DEXi, the third in AHP and ELECTRE III, the fourth in ELECTRE III and the fifth in PROMETHEE, Benjamin Franklin's Rule and ANP methods. Alternative 4 is ranked as the first in ELECTRE IV, the second in ELECTRE III, DEXi and Benjamin Franklin's Rule, the third in ELECTRE III and ANP, the fourth in ELECTRE III and PROMETHEE, the fifth in AHP and ELECTRE III methods. Alternative 5 is ranked as the first in ELECTRE III, ELECTRE IV, DEXi and Benjamin Franklin's Rule, the second in AHP, PROMETHEE, and ANP. Moreover, Alternative 1 gets mainly the first and the second ranks. Alternative 2 gets mainly the third and the fourth ranks. Alternative 3 gets mainly the fourth and the fifth ranks. Alternative 4 gets mainly the third rank. Alternative 5 gets mainly the first rank. Under these conditions, Alternative 5 and Alternative 1 can be recommended for detailed investigations. Afterwards, Alternative 4, Alternative 2 and Alternative 3 should be studied in detail. In this specific problem, it is observed that the group judgments and the individual judgments do not affect the final results very much. Moreover, it is thought that when the models for each method (AHP, ELECTRE, DEXi, PROMETHEE, and ANP) are reviewed in a detailed and organized manner and some revisions of models are made comparatively, the same findings can be gathered from each revised model on each method with the same evaluations.

Reference Study	MCDM/MCDA Method	Model Structure	Factor Weighting	Subjective Criteria Scale	Weight EDM 1	Weight EDM 2	Alternative 1	Alternative 2	Alternative 3	Alternative 4	Alternative 5
Saracoglu, 2015b	AHP	Group	Saaty's	9	0,5	0,5	1	4	3	5	2
Saracoglu, 2015a	ELECTRE III λ cut level 0,67	Group	Equal	N/A	0,4	0,6	2	2	2	2	1
		Group	Shannon's	5	0,4	0,6	2	2	2	2	1
		Group	Saaty's	5	0,4	0,6	2	3	4	3	1
Saracoglu, 2015a	ELECTRE III λ cut level 0,85	Group	Equal	N/A	0,4	0,6	2	3	4	3	1
		Group	Shannon's	5	0,4	0,6	3	2	2	3	1
		Group	Saaty's	5	0,4	0,6	2	3	4	3	1
Saracoglu, 2015a	ELECTRE III λ cut level 0,90	Group	Equal	N/A	0,4	0,6	2	4	3	5	1
		Group	Shannon's	5	0,4	0,6	2	3	2	4	1
		Group	Saaty's	5	0,4	0,6	2	3	4	3	1
Saracoglu, 2015a	ELECTRE IV λ cut level 0,67	Group	N/A	5	0,4	0,6	1	1	1	1	1
Saracoglu, 2015a	ELECTRE IV λ cut level 0,85	Group	N/A	5	0,4	0,6	1	1	1	1	1
Saracoglu, 2015a	ELECTRE IV λ cut level 0,90	Group	N/A	5	0,4	0,6	1	1	1	1	1
Saracoglu, 2015c	DEXi	Individual	N/A	2 to 5	N/A	N/A	3	3	2	2	1
Saracoglu, 2016c	PROMETHEE	Group	Saaty's	5	0,4	0,6	1	3	5	4	2
Current	Benjamin Franklin's	Individual	Saaty's	9	N/A	N/A	3	4	5	2	1
Current	ANP	Individual	Saaty's	9	N/A	N/A	1	4	5	3	2

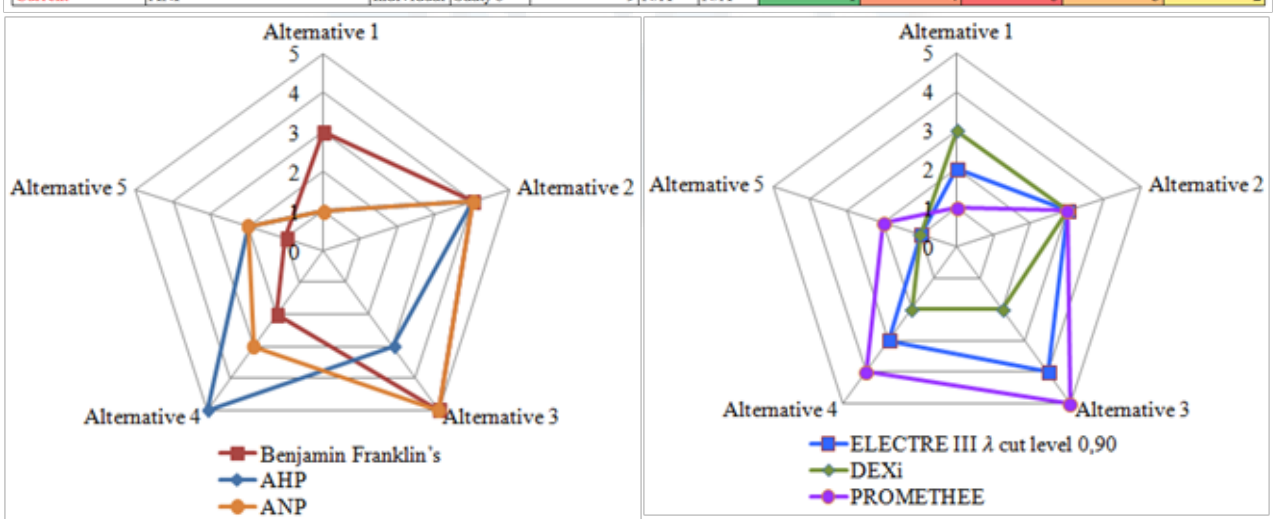


Figure 7 Comparative models in this study.

The whole research study (all of them as one piece) clues the researcher in on all of these methods' difficulties, capabilities, advantages and disadvantages. According to the researcher's experience from all of these studies during the whole research period and from the literature and the previous studies, some crucial observations can be done. The Benjamin Franklin's Rule ("Moral or Prudential Algebra") has a very simple structure. The decision models can even be built by healthy, pragmatic rational ordinary people with some middle degree education (e.g. middle or

high school). It is a very simple methodological approach, but the tradeoff evaluations are very difficult, especially when several alternatives are involved in the problem. Moreover, it has a methodological weakness "Franklin's approach assumes that equivalences–balanced pros and cons – will exist, when in fact they may not.[30] On the other hand, the ANP is very organized and structured, but it's very complex and need expertise in every aspect to build a model. The AHP method is simpler than the ANP method considering the model construction. The ELECTRE III and IV methods are almost same, but the ELECTRE III is more discriminative than the ELECTRE IV. Both the methods are more difficult than AHP method regarding the decisions on the parameters (e.g. thresholds). When the structure and the construction of ELECTRE III and IV models are compared with the AHP models, the latter is more difficult according to the researchers' point of view. However, the ELECTRE III and IV's overall difficulty is higher than the AHP's overall difficulty due to the current experiences of the researcher. The DEXi is more similar to the AHP on the structural basis, but the evaluations of alternatives/options are different. Both these methods are the simplest ones. The PROMETHEE is more difficult than the ELECTRE, because of its additional preference function knowledge and decisions. As a result, the researcher thinks that the methods can be ordered from the easiest to the hardest, according to the current experience and knowledge, as: Benjamin Franklin's Rule, AHP, DEXi, ELECTRE, ANP, PROMETHEE according the current experience and knowledge. It is believed that in practice, many methods should be used concurrently (e.g. ANP, ELECTRE, PROMETHEE), according to these studies common philosophy. Hence, many commonly accepted templates (e.g. ANP Model. sdmod) in the ACBIDSS should be created and presented to the users, otherwise very experienced decision analysts need to be involved in the MCDM process. Especially experts should use these methods together with the investors to better understand the problem and to solve it.

Conclusion, future applications and research

In this paper, a two–step comparative study is presented for Benjamin Franklin's Rule and ANP (first) and Benjamin Franklin's Rule, ANP, AHP, ELECTRE III, ELECTRE IV, DEXi, PROMETHEE (second) multi criteria decision aiding methods on a private small hydropower plant investment selection problem. Personal observations are clearly made and indicated during this study (cases specific). The main advantage of these MCDM methods is their capability to decompose and aggregate huge problems into smaller parts that can be solved by humans. During this decomposition and aggregation period, the real world problems can be understood very well and their possible solutions can be recommended by the experienced people. The decomposition and aggregation studies can be better performed by knowing and having experience on many models of the same problem (e.g. 10, 100, and 1000 models of the current problem). Hence, it is understood that presenting some standard templates for the industries, researchers and academics are very important to develop a knowledge base in a specific problem. In the future, the researcher will try to build a large decision maker's pool (very large number of decision makers) (e.g. 10, 50, 100, 1000) on this specific subject. It is hoped that the decision makers in the large pool will work for understanding and analyzing how the judgments distribute and differentiate in this unique problem. Above all, a research study on the differences of the individual decision making and the group decision making will be conducted in the following year.

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Conflict of interest

The author declares there is no conflict of interest.

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