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Fuzzy Analytic Hierarchy Process Utilization in Government Projects

A Systematic review of Implementation Processes

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ABSTRACT :

Uncertain assessments challenge the aggregation of expert knowledge in the field of decision-making. Valuable, yet sometimes hesitant, insight of expert decision makers needs to be converted into numerically comparative form in the age of information management. . Fuzzy Analytic Hierarchy Process (FAHP) enables the comparison of decision elements through expert judgements, even when the information at hand is uncertain.

The present study explores Fuzzy Analytic Hierarchy Process (FAHP) implementation in government projects in a systematic literature review. Theoretical framework for Analytic Hierarchy Process (AHP), Fuzzy Set Theory (FST) and their combination, namely Fuzzy Analytic Hierarchy Process (FAHP) is provided.

The systematic literature review categorizes research results under three categories and examines each paper by utilizing review questions. Three main application purposes rise from the literature review; policy planning and assessment, project selection and project and performance evaluation. Overall implementation processes of the three application areas are discussed. The conclusion provides comprehensive evaluation of the approach and considerations for practitioners.

KEYWORDS: Decision-making, Analytic Hierarchy Process, Fuzzy Set Theory, Fuzzy Analytic Hierarchy Process

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TIIVISTELMÄ :

Asiantuntijanäkemysten epävarmuus vaikeuttaa tiedon keräämistä päätöksenteossa. Päätöksentekoprosessin kannalta arvokkaat, vaikkakin joskus epävarmat, asiantuntijanäkemykset tulee voida muuttaa numerollisesti vertailtavaan muotoon tietojohtamisen aikakautena. Sumea Analyyttinen Hierarkiaprosessi mahdollistaa päätöksenteossa käytettävien elementtien vertailun asiantuntija-arviointien avulla, jopa silloin kun käytettävissä oleva tieto on epävarmaa.

Opinnäytetyössä tutkitaan systemaattisen kirjallisuuskatsauksen keinoin Sumean Analyyttisen Hierarkiaprosessin, eng. Fuzzy Analytic Hierarchy Process (FAHP), implementointia julkishallinnon hankkeissa. Tutkimus sisältää teoreettisen viitekehyksen Analyyttisen Hierarkiaprosessin, Sumean joukko-opin, eng. Fuzzy Set Theory (FST) ja niiden yhdistelmän, Sumean Analyyttisen Hierarkiaprosessin, eng. Fuzzy Analytic Hierarchy Process (FAHP), ymmärtämisen tueksi.

Systemaattisen kirjallisuuskatsauksen myötä valittu aineisto luokitellaan kolmeen kategoriaan ja jokaista tutkimusta tarkastellaan ennalta määrättyjen kysymysten avulla. Systemaattisen kirjallisuuskatsaukseen myötä valittujen tutkimusten kolme olennaisinta käyttötarkoitusta ovat; käytännön suunnittelu ja arviointi, hankevalinta sekä hankkeiden ja suoritusten arviointi. Aineiston luokittelun jälkeen tutkimus etenee tarkastelemaan erilaisiin käyttötarkoituksiin suunnattujen Sumean Analyyttisen Hierarkiaprosessi -metodin implementointiprosesseja. Johtopäätös -osio tarjoaa pohdintaa ja huomioita siitä, miten päätöksentekijät voivat suhtautua Sumean Analyyttisen Hierarkiaprosessin hyödyntämiseen julkishankkeiden yhteydessä.

AVAINSANAT: Päätöksenteko, Analyyttinen Hierarkiaprosessi, Sumea joukko-oppi, Sumea Analyyttinen Hierarkiaprosessi

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1. Introduction

While decision-making tools and applications develop rapidly and become ever more nuanced, it remains crucial to discuss their applicability prior to implementation. Vast technological progress and data availability in recent years support scientific decision-making in government and enterprise activities. Yet, the challenge of utilizing experts' valuable insight in situations where the information at hand is vague, imprecise or challenging to address, prevails.

The process of governmental decision-making is fundamentally different from private enterprises. Transparency of administration, high ethical standards, social and environmental sustainability are only a few examples of intangible values that governmental decision-making should systematically consider. Multiple stakeholders, decision attributes and desirable outcomes add layers of complexity, making decision processes hard to navigate without proper approaches.

Despite the challenges, decision makers and managers are expected to perform their duties in an effective and concise manner. While comparing decision-making methods in order to obtain the most feasible approach, the decision makers should remain educated about the direction of recent developments.

According to literature, one of the most frequently used Multi Criteria Decision Making (MCDM) method in recent years has been the Analytic Hierarchy Process (AHP). Analytical Hierarchy Process (AHP) is a decision-making theory that was developed in the 1970' to organize complex decision problems into easily accessible hierarchical structure. Hierarchical approach enables the decision criteria to be compared pairwise, which creates a unique opportunity for decision makers to define the bilateral degree of importance by pairs. The method produces a ranking of alternatives based on the weighting of decision criteria.

An extension to the Analytic Hierarchy Process was developed to capture the innate uncertainty of human judgements through the utilization of Fuzzy Set Theory (FST). Fuzzy Set Theory (FST) is an extension of traditional Set Theory. The main concept of FST is that an element may only partially belong to a set. The belongingness of an element in a set can be presented by a membership function instead of using crisp numerical values.

Integration of Fuzzy Set Theory (FST) and the Analytic Hierarchy Process (AHP), namely the Fuzzy Analytic Hierarchy Process (FAHP), enables the researchers and practitioners to aggregate experts' preferences and evaluate elements in the decision-making processes despite the inherent uncertainty of statement values.

Operational research literature utilizes the Fuzzy Analytic Hierarchy Process -method extensively because of its flexibility to handle complex and uncertain decision problems. FAHP modeling has been used in various applications in different fields, e.g. risk management, sustainability, transportation, healthcare, construction, education, tourism and R&D projects.

The present study is exploring how the Fuzzy Analytic Hierarchy Process (FAHP) has been employed in research literature considering government activities in recent years. Such activities consider planning and assessment of policy implementation, project selection and project and performance evaluations. The decision to investigate applications of the FAHP in the public sector was because it opens possibilities to examine one dimension of the complexity of public decision-making a little closer, that is, uncertainty.

Practitioners who decide to implement the FAHP approach for decision-making purposes in government projects, should possess sufficient understanding about the operations of the method. Interpreting the results of the FAHP method are not limited to the final product of ranking order of the alternatives. The method has been used in various advantaged approaches that integrate hybrid methods or utilize the FAHP method only partially in practical decision-making problems. The method is seen as a powerful approach in the field of decision-making; a foundation that is applicable for multiple purposes.

First section of the thesis introduces the topic to the readers. Second topic establishes the study objectives and declares the chosen methodological approach. Section number three unfolds the history and backgrounds of FST, AHP and FAHP methods. Section four discusses the complexity of multi criteria decision making through the entrenched concept of wicked problems. Section number five provides a theoretical framework for both approaches, AHP and FST, first separately and then together as FAHP. Sixth section proceeds to systematically categorize and review relevant research considering the FAHP utilization in government projects. 38 document results via Scopus database search are examined using five separate review questions.
Lastly, section number seven concludes the research by discussing the application purposes, considerations, strengths and weaknesses of the FAHP method.

2. Study objectives and methodology

The objective of the study is to identify aspects that affect Fuzzy Analytic Hierarchy Process (FAHP) implementation in government projects. Another goal of the research is to outline the theoretical side of the FAHP method in order to support the implementation of the method in practice. The outcome of the thesis is to serve practitioners, who operate outside of the scientific community of FAHP research, to better understand the possibilities and pitfalls of the FAHP implication. Research questions that the paper is aiming to answer are:

RQ 1 : How does the FAHP method work?
RQ 2 : What are the key considerations in FAHP implementation in government projects?

The motivation to explore FAHP applications in government projects started from the recognition that general expectations towards optimizing decision-making methods are high. Despite the developing field of decision-making models providing ever more options to choose from, practitioners should not blindly rely on computer run algorithms to solve their decision problems. Multi staged approaches require attention in all phases of the process. Thus a considerable amount of the thesis is dedicated to familiarize with the theory.

The analysis part of the research is conducted as systematically reviewing the content of Fuzzy Analytic Hierarchy Process (FAHP) research literature in government project applications. The literacy for the analysis was generated through SCOPUS database search. For the search, following keywords were selected; ''*Fuzzy analytic hierarchy process*'' and ''*government*'' and ''*application*''. The search, last conducted on 1.4.2023, resulted in a total of 69 documents. After filtering the results based on their

correspondence to the topic and accessibility, a total of 38 results were reviewed systematically.
The documents were considered to typify the field of FAHP literature sufficiently for the purpose of the thesis because of the versatile representation of multiple domains, such as sustainability, renewable energy sector, computer science, technology sector, industrial engineering, management science and urban science.

The systematic review approach was chosen to assemble the literature findings and to discover the elements that affect the FAHP implementation in the government sector. There is no previous literature analyzing what kind of factors affect the FAHP implementation in the public sector. Closest single study regarding the theme was conducted by Fountzoula and Aravossis (2021, pp. 1–15). They reviewed AHP applications in the public sector between 2010 and 2020. Their paper ''*Analytic hierarchy process and its applications in the public sector: a review''* concentrates on evaluating the approaches along with exploring the sector-wise distribution of AHP implementation. (Fountzoula and Aravossis, 2021, pp. 1–15)

The analysis in the thesis is executed by categorizing the literature findings into three main utilization purposes; i) *Policy planning and assessment*, ii) *Project selection* and iii) *Project and performance evaluation*.
In addition to these three categories, iv) Theoretical literature was distinguished in the review process, but not further examined, since the contribution of these documents was solely theoretical.

The documents are then viewed with the intention to answer five questions designed to discover the factors that affect FAHP method implementation. Those questions are:

1) What are the characteristics of the implementation environment?
2) Why was the AHP method employed?
3) Why was FST employed?

4) Why were possible hybrid methods employed?
5) Was the FAHP method and obtained results feasible for researchers purposes or not?

Ideally, the reader would gain a new perspective to manage complex multi-criteria decisions through the understanding of practical examples on knowledge formulation and implementation.

3. Literature overview

In this section, the history, generalizations and applications of Fuzzy Set Theory and Analytic Hierarchy Process are discussed. After individually examining the two theories, the similarities and differences of the traditional AHP and integrated method, namely the FAHP, are discussed. It is crucial to understand the theoretical aspects of the methods first independently. Since the integrated model (FAHP) is only one of the various possible combinations of different techniques the MCDM literature has suggested.

3.1 Fuzzy set theory

In 1965, Zadeh introduced Fuzzy Set Theory as an answer to include fuzzy description to mathematical modeling. (Zadeh, 1965, pp. 338–353) The core of the theory is that elements in a set have a membership degree. The gradual degree of each element portrays the belongingness to a given set. While Boolen logic offers elements either to belong (1) or not (0) to a set, the fuzzy set theory allows partial membership. (Zadeh, 1965, pp. 338–353) Gradual degree can be seen to mimic human reasoning, as a lot of times, humans rely on their experience of the system dynamics in addition to the crisp information at hand.

Context-driven conceptualization of information processing affects human judgements. For example, if asked ′′is today Thursday?′′ the answer will most probably be yes or no. When asked ′′Is it cloudy today?′′ The question becomes trickier and the respondent might be tempted to say ′′It is a little cloudy today′′ or ′′It is nearly cloudy′′. Zadeh's theory provided a frame to convert linguistic variables into calculable form for further processing. (Zadeh, 1965, pp. 338–353) This approach provided a significant leap for scientists and researchers handling situations that dealt with reasoning from vague, uncertain and imprecise information occurring in natural language and expressions.

Since 1965, the theory has gained broad attention and has been utilized through branches of science as well as prompted various extensions in different fields.
One of the earliest applications of fuzzy logic in real life was used to create an automatic control system for bullet trains in Japan. (Yasunobu et al., 1983, pp. 33–39) A predictive fuzzy control system operated based on a set of rules conditioned by the experience of skilled human operators. Simulations showed that the newly developed system was able to adjust the train's automatic stop control while taking into account passenger comfort, stopgap and running time, thus optimizing the system performance in a desirable manner. (Yasunobu et al., 1983, pp. 33–39)

One of the extensions of Zadeh's theory is Atanassov's Intuitionistic fuzzy sets (Atanassov, 1986, pp. 87–96). Atanassov extended Zadeh's fuzzy sets by proposing that the membership degree of each element should be paired with a nonmembership degree of the element in question. (Atanassov, 1986, pp. 87–96)

3.2 Analytic Hierarchy Process

The Analytic Hierarchy Process method was developed by Saaty and presented to the world in 1990. (Saaty, 1990, pp. 9–26) The Analytic Hierarchy Process technique was developed to support decision-making in complex multi-criteria situations capturing expert knowledge by comparing the criteria pairwise. The pairwise comparison yields relative importance for each criteria (and sub-criteria) considering the goals and given alternatives. (Saaty, 1990, pp. 9–26) Setting priorities may help the decision makers to evaluate their data and determine the best decision. (Ho and Xin, 2018, pp. 399–414)

According to Saaty's theory, these preference evaluations can then be used to find the desired ranking of the alternatives as well as exposing the underlying dynamics of the experts' perceptions. Saaty's theory has been studied and redefined extensively in the literature since its inception. Analytic hierarchy process has been applied to engineering, government, management, industry, political and social systems and even sports. (Ho and Xin, 2018, pp. 399–414) The method is applicable for various problems since it is based on the innate human tendency to compare problem attributes. (Bertolini et al., 2006, pp. 422–430)

Other widely used multicriteria decision-making methods in public projects are Analytic Network Process (ANP) by Saaty, Technique of Order Preference by Similarity to Ideal Solution (TOPSIS) by Hwang and Yoon, Elimination and Choice Translating Reality (ELECTRE) by Roy, Decision-Making Trial and Evaluation Laboratory (DEMATEL) by the Geneva Research Centre of the Battelle Memorial Institute, Data Envelopment Analysis (DEA) by Charnes, Cooper and Rhodes, Preference Ranking Organization Method for Enrichment Evaluations /PROMETHEEs) and Multicriteria optimization and compromise solution method (VIKOR) by Opricovic. (Fountzoula and Aravossis, 2022, pp. 1–13)

Fountzoula and Aravossis (2021, pp. 1–15) explored the use of AHP applications in decision-making in the public sector. The authors stated in the beginning of their paper, that AHP is a widely used multi-criteria decision-making tool that is employed practically in every decision-making application, but that in the public sector it is most commonly used in transportation, energy, health and technology driven projects. AHP can be used in various ways such as in planning, choosing the best alternative, resource allocation, conflict resolution, optimization etc. (Fountzoula and Aravossis, 2021, pp. 1–15) One of the first contributions to extend the Analytic hierarchy process to a fuzzy environment were

Ruoning and Xiaoyan (1992, pp. 251–257) in their paper ''Extensions of the analytic hierarchy process in fuzzy environments'' in 1992.

3.3 Fuzzy Analytic Hierarchy Process

The fusion of Fuzzy Set Theory and Analytic Hierarchy Process, namely Fuzzy Analytic Hierarchy Process, started gaining attention among researchers who wanted to examine multi criteria decision-making situations including conflicting and incommensurable objectives. (Hwang and Yoon, 1981, pp. 58–191) The Fuzzy AHP method is used according to the principles of the original AHP method, but in addition the fuzzy numbers are added to the process to better portray evaluators preferences through reasonable intervals in uncertain situations. (van Laarhoven and Pedrycz, 1983, pp. 229-241)

Fuzzy numbers handle subjective perceptions effectively and allow appropriate expressions of human judgements by using linguistic variables. Van Laarhoven and Pedrycz (1983) were the first ones to propose the combination of AHP and fuzzy set theory, as they incorporated fuzzy triangular numbers (TFNs) in the pairwise comparison matrix. (van Laarhoven and Pedrycz, 1983, pp. 229-241)
Ruoning and Xiaoyan (1992, pp. 251–257) constructed the fuzzy judgment matrix by using continuous judgment scale and emphasizing that every element of this matrix can be presented by a positive bounded closed fuzzy number.
Kubler et al. (2016, pp. 398–422) conducted a state-of-the-art survey and reviewed 190 papers considering FAHP applications. Their review shows that FAHP is mostly used in manufacturing, industry and government activities.

Various applications in the government cover areas like environmental impact assessment, health care, public transportation and education (Kaya and Kahram, 2011, pp. 6577-6585; Büyüközkan et al., 2011, pp. 9407–9424.; Azam et al., 2017, pp. 83–120; Arslan, 2009, pp. 97-112; Alkharabsheh et al. 2022, pp. 110-120; Ruiz-Padillo et al., 2016, pp. 8–18;Tan et al., 2014, pp. 467-475).

Many of the papers and studies that include FST in the field of public sector and management, have used novel approaches that have been designed to each unique research problem. This emphasizes the flexibility of the FAHP method as it is possible to combine a range of techniques for distinct purposes. (Govindan et al. 2015, pp. 603–626; Lima Junior et al., 2014, pp. 194–209)

Disadvantages of the Fuzzy AHP method are its computational requirements; the calculation process often including several large matrices is lengthy and preference ratios need to be consistent. (van Laarhoven and Pedrycz, 1983, pp. 229-241; Buckley, 1985, pp. 233–247) The criteria in both, the AHP and FAHP approach, is considered to be independent. This reduces the complexity of the decision problem, but leaves an important dimension of complexity essentially unrecognized by the used model. On the other hand, the complexity of a decision problem is already considered by human practitioners who are expressing their preferences through pairwise comparison of the set of criteria. Another widely agreed challenge for the FAHP method is that it does not allow zero weights to be used in the comparison matrix. Zero weight on criteria might lead to a wrong output and thus wrong outcome of a decision-making process. (Chang, 1996, pp. 649–655)

4. Complexity in decision-making and choosing the right approach

Complexity in decision-making can be interpreted as a state or condition of a situation that has multiple elements and connections between them. Dynamic relationships between the elements of the system hampers the order and predictability of the events taking place causing fully linear proceedings to become impossible to maintain in the decision-making process. Decision-making in the landscape that is a compound of intertwined and interdependent relationships, entangled patterns and feedback loops, requires a strategy that is unique in each and every situation observed. Characteristic to complex situations is that the emergent phenomena will rise from the various and ever changing entries of data that causes the disequilibrium of the perceived environment. Decision-making solutions in complex environments thus do not have clear boundaries and might not be understood as complete but ''adequate''. (Bennet and Bennet, 2008a, pp. 72–94)

According to Cairney (2012, pp. 346–358), six main themes that arise from the behavior of complex systems can be identified as follows;

First, complex systems consist of parts that are interdependent, that is why the functions can not be broken into smaller pieces. The parts are highly influenced by the motion of each other and are systematically capable of putting that leverage to account. Secondly, the behavior of the system remains unpredictable because of the lack of linearity within the system. Inconsistent feedback loops dampen or accelerate the action taken within the complex systems.
Thirdly, the clout of the initial conditions is remarkable for the system. The concept of path dependency suggests that past events constrain subsequent events and decisions as well as affecting the long-term equilibrium of the system.

Fourth, the flux of information and variating entries cause the system to produce emergencies on a local level instead of being able to pin the ''efforts'' to produce focused, centroidal, outcomes. Lack of control over the system leads us to explore the rules of the interaction within the complex system.

Fifth, the periodical stability of the system most likely will not accurately indicate the fitness of the entire system. Strange attractor simulations are one attempt to model the radical changes as well as the active regularities in a complex system.
Finally, complexity theory admits that the challenge to address and solve the complex problems in real life, such as climate change related questions, behavior of social and political systems and functioning of a human brain requires interdisciplinary research that pivots the efforts into something tangible. (Cairney, 2012, pp. 346–358; Bovaird, 2008, p. 320; Geyer and Rihani, 2010, p. 39; Mcdowell, 2013, pp. 234–244)

Rittel and Webber (1973, pp. 155–169) were the first ones to use the concept ''wicked problems'' in their social planning research in 1973. Their analogue about contrasting ''wicked'' and ''tame'' situations in the decision-making context has been adopted and further developed by various authors in complexity research. Rittel and Webber (1973, pp. 155–169) distinguished ten characters that arise from the problematic nature of ambiguous contexts of organizations and their environments. Those characters unfold as follows.

- Wicked problems can not be sharply defined but may appear different in times and situations.
- There is no single solution or decision that would make an end of a wicked problem.
- The solutions to wicked problems can not be categorized into true or false -ones but rather good or bad -ones.
- Solutions to wicked problems can not be tested

- Each attempt to solve a wicked problem will change the dynamics of the wicked situation, and consequently trial-and-error methods are not seen as a sustainable approach to solve wicked problems.
- The set of feasible solutions or permissible operations within the decision-making process in wicked situations can not be exhaustively described.
- Even if similarities and connecting patterns occur, each wicked problem is unique.
- Wicked problems are built around the previous demeanor of the system. Wicked problems indicate imbalance.
- Wicked problems can not be sharply defined, but the standpoint of attempting to explain the phenomenon determines the orientation of the problem's resolution.
- *''The planner has no right to be wrong''* Means that the decision-makers are accountable for the decisions they make as they heavily impact on other people's lives. This refers to the ethical and moral haze that hovers around complex social issues. (Rittel and Weber, 1973, pp. 155–169)

Choosing a right kind of approach for decision-making requires careful preparation; distinguishing the decision objectives and alternatives, criteria and possible sub-criteria, identifying the relevant stakeholders along with gathering adequate information to draw conclusions from is not an obvious nor linear process. Oftentimes decision-making is bound by rules and conditions. Abstract values, like social and environmental sustainability are enormous trends in scientific research, yet, quantifying these values remains challenging. Locating the decision-making situation according to Rittel and Weber's (1973, pp. 155–169) proposed approach helps the decision-makers to identify the nature of the forthcoming decision-making process as well.

5. Theory

This section provides a conceptual framework and theoretical background of Fuzzy Set Theory (FST) and Analytic Hierarchy Process (AHP). FST is introduced first, since chronologically, the theory was introduced before AHP. After thoroughly describing the principles of both theories, the section discussed the unification of the two methods, namely the Fuzzy Analytic Hierarchy Process

5.1 Fuzzy Set Theory

In 1965, Zadeh (1965, pp. 338–353) proposed his theory about fuzzy sets, which is a generalization of Classical Set Theory (CST). In Classical Set Theory, two requirements are essential; the elements of each set need to be distinguishable. Secondly, an element either belongs to a set or not; ‘’a is a member of A’’ statement can be either true or false. (Bĕlohlávek et al., 2017, pp. 1–10)

The essence of fuzzy set theory, on the other hand, is to express the degree of an element belonging to a set by gradual membership degree. Fuzzy membership is given in a degree between 0 and 1. 0 equals an element not being part of a (fuzzy) set and value 1 equals a full membership. (Zadeh, 1965, pp. 338–353; Bĕlohlávek et al., 2017, pp. 1–10; Kahraman, 2008, p. 3)

5.1.1 Fuzzy logic

Opposite to classical logic, that only uses Boolen-valued functions, Fuzzy Logic is a form of reasoning that takes into consideration intermediate values between truth and false statements. Fuzzy logic rejects the second requirement of Classical Set Theory and thus the fuzzy set boundaries are not inherently sharp. (Zadeh, 1965, pp. 338-353; Bělohlávek et al., 2017, pp. 1–10)

By enabling the element's condition being other than true or false, Zadeh's theory provided a new and flexible mode for reasoning; a mode that is able to take into account inaccuracies and uncertainties. The pursuit of resembling human reasoning is based on the principle that the rules of reasoning are set in natural language. This emulates the way humans perform decision-making in their daily life. (Dernoncourt, 2011, pp. 1–12)

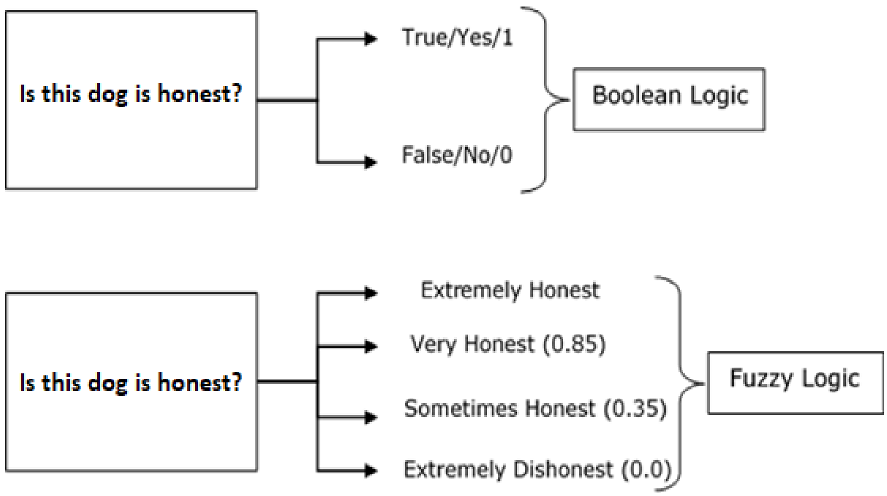

Figure 1. Example of truth values in Boolean logic and Fuzzy logic (Vijaysinh, 2022)

Figure 1. demonstrates the difference between Classical Logic, that only uses Boolean-valued functions, and Fuzzy Logic that permits also intermediate values to be used in the reasoning process. (Vijaysing, 2022)

Before fuzzy logic, uncertain situations were primarily encountered through probability theory in sciences, technology and common situations. Probability Theory, that is based on principles of bivalence, links uncertainty to randomness but fails to explain situations associated with imprecise and ambiguous information. (Athanassopoulos and Voskoglou, 2020, p. 52) Ataei et al. (2012, 83–93) noted that, although probability theory is a helpful tool in portraying some phenomena, it falls short when applied to human-kind reasoning as the vagueness in natural language is neither random nor stochastic.

Zadeh (1995, p. 271) himself suggests that probability theory and fuzzy logic could enhance the effectiveness of the latter, if used together. This view implies that rather than being competitive approaches to model uncertainties, the theories should be combined to complement each other. (zadeh, 1995, p. 271)

Fuzzy logic is emerging as a desirable approach for modeling complex situations, as it enables decision-making based on the qualitative attributes of dynamic and intricate systems. (Wikström, 2014, p.17) It presents a promising alternative for the study of governance due to its ability to address the complexity and non-linear behavior inherent in subjective estimates of available information, as well as the expertise and experience of those who manage it. Fuzzy logic provides simple conclusions that can be attributed to ambiguous, inaccurate, or incomplete information. Its primary advantage lies in its use of linguistic variables, rather than solely numerical data to mirror human thinking.

Compared to other statistical methods, fuzzy logic eliminates the need for complicated mathematical expressions and provides solutions that combine linguistic expressions with numerical data. Lozano and Fuentes suggest that fuzzy logic is well-suited to procedures based on intuitive rules that are otherwise difficult to express in mathematical terms. (Mancilla-Rendón et al., 2021)

Fuzzy logic can be used to overcome problems like incomplete and uncertain information as it allows labeling of intermediate values to define estimates between true and false, black and white, hot and cold, little and much, close and far among others that would otherwise distort scoring methods and thus the results of analyses. In an attempt to integrate subjective elements to a formal model, fuzzy logic can be applied. (Vinodh and Aravindraj, 2022, 1186–1195; Mancilla-Rendón et al., 2021)

5.1.2 Membership function

Let X depict a universe of points. A generic element of the universe X is noted by x. A denotes a set in a universe X. For any element x of universe X, membership function μA(x) equals the degree to which x is an element of set A. This degree, a value between 0 and 1, represents the degree of membership, also called membership value, of element x in set A.

The membership function of fuzzy set A in the universe X: μ_A: X → [0, 1]. Thus the closer the membership value is to number one, the unity, the higher the grade of membership x has in the set A. The lower the membership value is, the lesser the grade of membership x has in the set A. Similarly to Classical Logic, 0 denotes x not belonging to set A. (Zadeh, 1965, pp. 338–353)

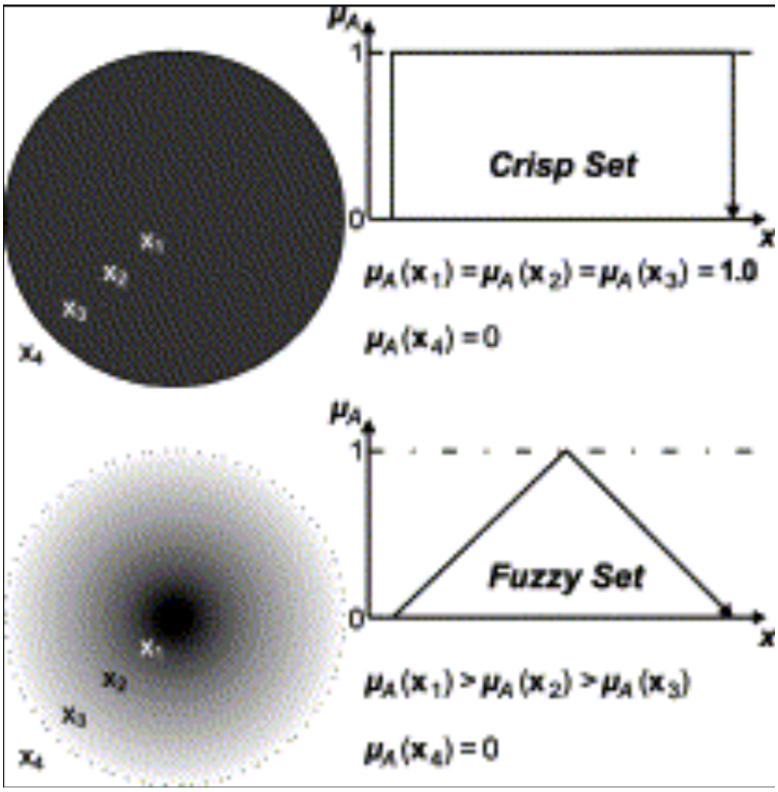

Figure 2. Differences between bivalent logic and fuzzy logic. Fuzzy set depicted as a triangular fuzzy set. (Aydin, 2004)

Figure 2. visualizes the dissimilarity of the membership function in Classical Logic and Fuzzy Logic. Classical bivalent sets (above) are called ʻʻcrisp setsʼʼ in Fuzzy Set Theory. A membership score of 1 indicates complete membership in a set while a score close to 1 (e.g., 0.8 or 0.9) indicates strong but partial membership, and scores less than 1 indicate weaker membership. (Zadeh, 1995, 338–353)

In the above example, the membership degree of elements x1, x2 and x3 is 1 which means that they are all part of a set. In the example below, x1 has a greater membership degree than the element x2, which has a greater membership degree than x3. In both cases, the element x4 imposes a membership degree 0 and is not considered to be part of the set. (Zadeh, 1995, 338–353)

5.1.3 Fuzzy numbers

Fuzzy number refers to an interval within a real number R representing a set of possible values of the truth statement. The benefit of this is that truth statements may be presented as intermediate values between 0 (not true) and 1 (absolutely true). The interval of possible values is thus a fuzzy set itself. (Chapter, Fuzzy Number. In: First Course on Fuzzy Theory and Applications. Advances in Soft Computing, 2015, p.130)

The boundaries of the interval are imprecise but generally presented by two possible ending points; a1 and a3 along with the descriptor of a highest value. In figure 3., the peaking point where the membership of an element equals to 1 (absolutely true) exists at point a2 on the x-axis. Thus fuzzy number A = [a1, a2, a3] represents the membership function of an element x belonging to a set. (Chapter, Fuzzy Number. In: First Course on Fuzzy Theory and Applications. Advances in Soft Computing, 2015, p. 130; Dijkman et al. 1983, pp. 301–341)

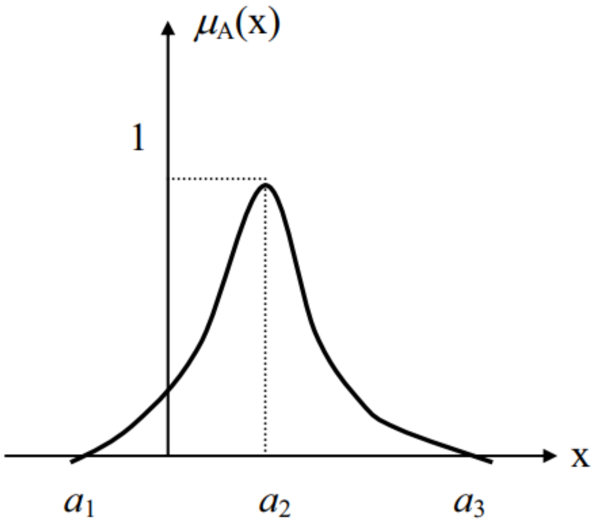

Figure 3. Fuzzy number A = [a1, a2, a3]. The highest value on a convex is recognized by Alpha cut (α-cut). (Dijkman et al., 1983)

Membership function can be represented in multiple ways. Kreinovich et al. stated that most commonly used fuzzy number shapes in the literature and practical applications are triangular and trapezoidal fuzzy numbers because they are simple to use and intuitively clear. Kreinovich et al. added that if participants have difficulties in understanding a concept of a complex membership function, they end up relying on the formulas rather than their intuition and thus results are affected in a negative way. (Kreinovich and Stylios, 2015, pp. 1–10; Le et al., 2008, 438–448)

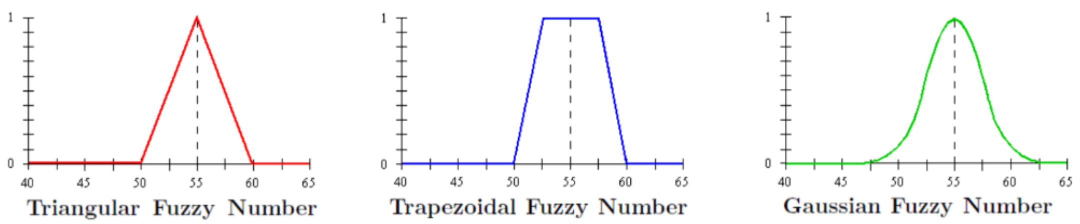

Figure 4. Fuzzy numbers; Triangular, Trapezoidal and Gaussian Fuzzy Numbers (Quevedo, 2017, p.75)

Choosing an optimal shape that reflects the case depends on factor like sampling size, employed inference system and practicality (e.g. calculations) (Jiang and Ruan, 2009, 324-331; Kreinovich and Stylios, 2015, pp. 1–10)

The concept of fuzzy numbers is important for the further comprehension about how the linguistic expressions are converted into fuzzy numbers and analyzed as a part of the FAHP method. Fuzzy numbers allowing the utilization of intermediate truth values is an essential part of this process. Fuzzy numbers serve as a tool for managing ambiguity in decision-making processes by handling the vagueness of available information. When the mathematical model or input data is considered to be incomplete or unknown, fuzzy logic can enhance the process of criteria weighting by allowing the aforementioned intermediate values.(Quevedo, 2017, pp. 57–88; Zadeh, 1965, pp. 338–353)

5.1.4 Extensions of the FST

In some cases, the actual shape of a membership function is uncertain. This is due to the membership function taking its values in other forms than in the unit interval. Bebe (2013, pp. 193–199) stated that in situations where models are imprecise and expert subjectivity can not be captured through the original theory, higher order extensions are being introduced.

A subcategory of the extensions to the original FST are Lattice Valued Fuzzy Sets (L-sets). L-sets make use of partially ordered sets that are able to depict the membership function in algebraic or structural form. (Bělohlávek, 2004, pp. 277-298)

Often used extension in the literature is Intuitionistic Fuzzy Set Theory (IFS) by K. Atanassov (1986). Atanassov proposed the idea that fuzzy sets should be described by combination of membership function and non-membership function of the variable x. (Bělohlávek, 2004, pp. 277-298)

Other extensions include Lattice Valued Fuzzy Sets (L-sets), Interval Type II Fuzzy Sets among others. (Bede, 2013) Extensions can be integrated with further optimization methods in the same way as the original theory, thus the flexibility attracts researchers to test different approaches for their specific purposes (Chang et al., 2022; Meniz and Özkan, 2023)

5.2 Analytic Hierarchy Process

The Analytic Hierarchy Process (AHP) was developed to leverage expert knowledge in estimating the relative importance of elements in decision-making. Analytic Hierarchy Process is a method that employs pairwise comparisons of qualitative (subjective) and quantitative (objective) elements in a hierarchical structure (Saaty, 1987, 161–176). The hierarchy models the decision process at hand by breaking the intricate process to easily comprehended sections. The structured technique helps decision-makers to organize and analyze complex processes using aggregated expert assessments as a weighting method. (Fountzoula and Aravossis 2021, pp.1–15)

The process follows the following sequence:

1) Define the problem.
2) Determine the criteria and sub-criteria (if any) to evaluate.
3) Develop decision hierarchy; decision goal on the top level followed by evaluation criteria in the middle. On the bottom of the hierarchy are the decision alternatives.

4) Perform the analysis; compare the decision elements on the same hierarchical level pairwise to determine their priorities.
5) Calculate the weights and consistency
6) Evaluate the alternatives (Fountzoula and Aravossis, 2021, p. 3)

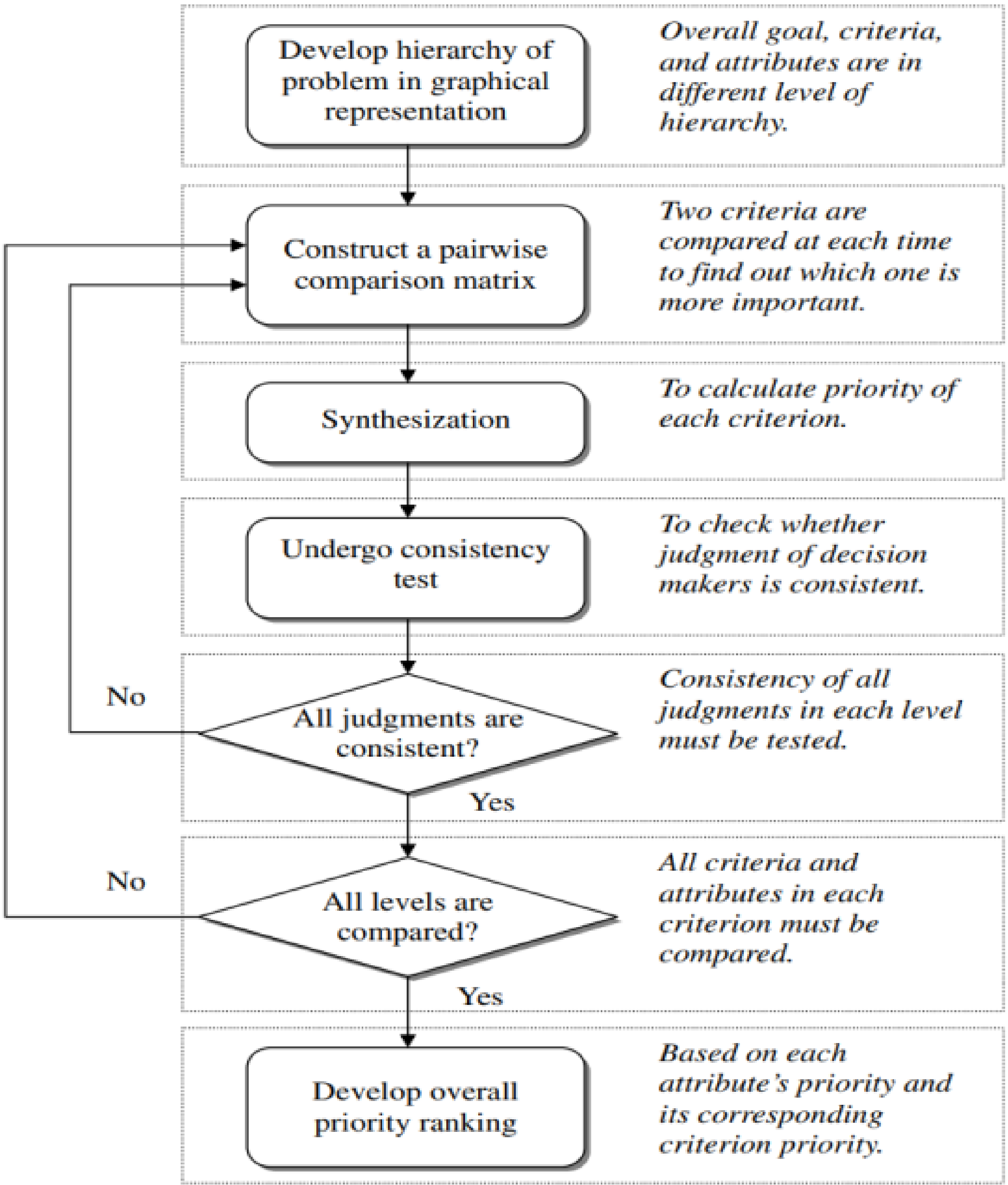

Figure 5. The flowchart of AHP (Fountzoula and Aravossis, 2021, p. 3)

The fundamental principle of AHP is based on human judgment. Human decision maker or expert assesses the importance of elements in a hierarchy by comparing them pairwise. The aggregation of relative importance assessments transforms the preference evaluations into numerical form, facilitating the ranking of the alternatives. AHP can accommodate vague and sometimes immeasurable information in the decision-making process, due to the complementary judgments provided by experts. (Saaty, 2001, pp.15–35; Fountzoula and Aravossis, 2022, pp.1–13)

AHP applications encompass a range of functions, such as determining the priority of assessment models, selecting optimal method, decision analysis and risk assessment, resource allocation, evaluating managerial performance, analyzing conflict issues and solutions, predicting incident result and providing reference for decision-making support. (Hsueh and Yan,, 2011, pp.135–144) The method is widely used in various fields, such as governmental decision-making, sustainability, construction, business, education and healthcare. Characteristic aspects of application purposes is that there are multiple agents, criteria, alternatives and perceptions to reconcile. Each agent comes from a specialized area and most likely utilize particular terminology to assess their perceptions. The method eases communication between participants because the actual preference assessments (linguistic expressions) remain same through the process and are same for everyone. Despite the advantages of the method, AHP has shown its inefficiency when applied to problems considering uncertain information, e.g. vagueness in expert assessments. (Forman and Gass, 2001, pp. 469–486)

5.2.2 Building the hierarchy

The Analytic Hierarchy Process starts from identifying and defining the decision problem. Then, the structure of the hierarchy will be assessed.

On the top of the hierarchy is the decision goal, followed by a set of criteria that relate the alternatives to the decision goal. Criteria is followed by possible subcriteria and sub-subcriteria. On the bottom of the criteria are the decision alternatives (Fountzoula and Aravossis, 2021, pp. 1–13). The extent of the structure depends on the decision and can be flexibility managed (Zio, 1996, pp.311–336). It is suggested that the pairwise comparison is not an effective means to produce a ranking if there are more than nine alternatives. Problem with more than nine alternatives is that comparison becomes time consuming, consistency of comparisons is challenging to preserve, and differences in final scores shrink. The number of criteria should be considered carefully as well. Russo and Camanho (2015, pp. 1123–1132) reviewed 41 studies that were using the AHP method. They observed that, among the reviewed studies, the average number of criteria was 4,76 and the average number of sub-criteria around five. (Russo and Camanho, 2015, pp. 1123–1132)

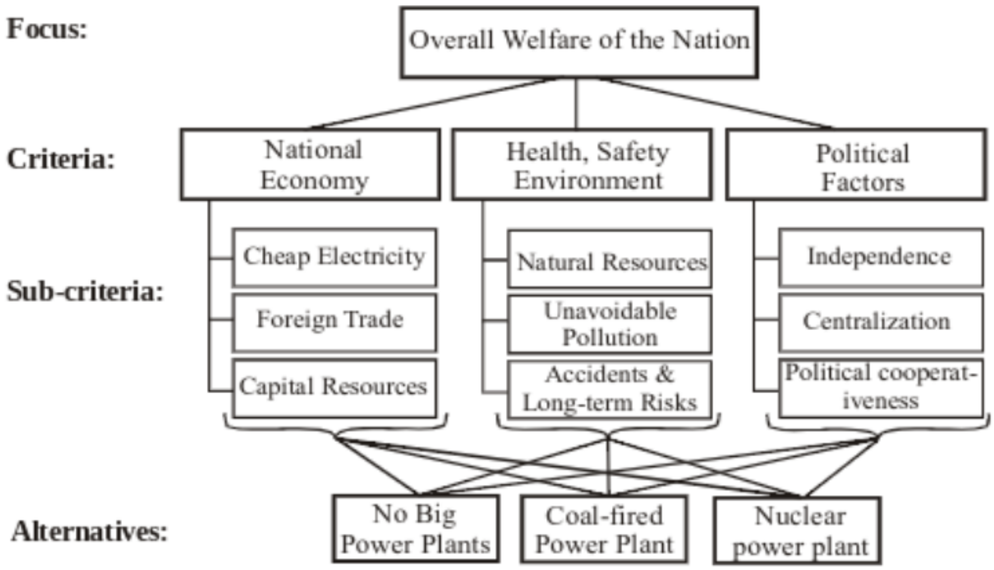

Figure 6. An example of AHP hierarchy considering Finland's energy policy. (Cabala, 2010, p. 7)

The model is flexible to consider new elements or comparisons to be added throughout the process. The AHP method involves numerous mathematical synthesis of judgements that are usually calculated using specified programs.

5.2.3 Pairwise comparison

Kahneman and Tversky (1982, pp. 32–47) suggests that when someone is faced with the same choice of options repeatedly, they do not always choose the same way. This may lead one to question whether the decision maker is consistent with their preferences. An important distinction must be drawn, however, between two possible meanings of inconsistent preference. Preferences could be inconsistent because they vary from time to time, that is, because the decision maker does not want the same thing at all times. This kind of inconsistency can be perceived as variability. On the other hand, preferences could be inconsistent because they are logically incompatible with the assumptions (known as axioms) of expected utility theory. (Carreño, 2020, p. 13)

The priority weights of the criteria are derived from the pairwise comparison of the criteria or equivalent decision variants. The comparison involves pairwise evaluation of all the elements that exist in the same hierarchical level. The evaluation takes place in a reciprocal matrix *A*. Pairwise comparison allows all the possible combinations of the criteria being compared by determining the preference ratio between two elements. The comparison is performed in relation to a reference point that exists in a higher level in the hierarchical structure. E.g. the importance of criteria is compared in relation to the decision goal; subcriteria is compared to the descriptive criteria above etc. (Cabala, 2010, 1–23)

Pairwise comparison methods have been found to be effective in decision-making problems where criteria and alternatives are strongly interrelated. This way the decision-makers are compelled to consider all the elements of the problem thoroughly (Hajkowicz, 2007, pp. 177–184). According to Herrera-Viedma et al. (2004, 98–109), preference relation is a useful tool to model decision-making processes especially when expert knowledge is used to aggregate group preferences.

MCDM methods that involve the direct rating of criteria and alternatives may cause the procedure for determining weight coefficients being less accurate for interactions, than methods that derive the weights using an indirect approach. (Hajkowicz, 2007, 177–184; Konidari and Mavrakis (2007, pp. 6235-6257) In AHP, decision-makers focus on two elements at a time, which should, in theory, provide precise evaluations. (Cavallo et al., 2018, pp. 1–9) According to Konidari and Mavrakis (2007, pp. 6235–6257) the standard AHP method is suitable for determining weight coefficients, as it allows decision-makers to understand the relative importance of interacting alternatives and criteria (Konidari and Mavrakis, 2007, pp. 6235-6257).

In the pairwise comparison, participants compare two elements using the so-called Saaty scale. The method of pairwise comparison can be conducted using various relative importance scales, with the scale proposed by Saaty (2001, 15–35) being the most commonly used. This scale assigns values ranging from 1 to 9 to assess the relative importance of each element, thus enabling the contrast of two elements to be represented in a comparable form. The structure of the pairwise comparison matrix does not directly provide the priority ranking. (Cabala, 2010, pp.1–23)

Identical elements can not be differentiated by preference, thus the preference ratio is expressed by the number 1. The choice of this particular scale in AHP literature can be attributed to its widespread use and acceptance in the field. (Triantaphyllou and Mann, 1995, pp. 35–44; Saaty, 2001, pp. 15–35)

Intensity of Importance	*Definition*	*Explanation*
1	Equal Importance	Two activities contribute equally to the objective
2	Weak or slight	
3	Moderate importance	Experience and judgement slightly favour one activity over another
4	Moderate plus	
5	Strong importance	Experience and judgement strongly favour one activity over another
6	Strong plus	
7	Very strong or demonstrated importance	An activity is favoured very strongly over another; its dominance demonstrated in practice
8	Very, very strong	
9	Extreme importance	The evidence favouring one activity over another is of the highest possible order of affirmation
Reciprocals of above	If activity *i* has one of the above non-zero numbers assigned to it when compared with activity *j*, then *j* has the reciprocal value when compared with *i*	A reasonable assumption
1.1–1.9	If the activities are very close	May be difficult to assign the best value but when compared with other contrasting activities the size of the small numbers would not be too noticeable, yet they can still indicate the relative importance of the activities.

Figure 7. Saaty's scaling for pairwise comparison of relevant importance. (Saaty, 2008, p.86)

After the decision hierarchy is built, systematic evaluation of elements takes place. While making comparisons, the participants may use concrete data to assess the importance of elements, or use their own expertise in judgements. Linguistic assessments are then converted into numerical values as demonstrated in the above picture of Saaty's scale. Numerical values are used to derive a priority, i.e. the weight for each element of the hierarchy. Example of the weighting and ranking process is provided in section 5.2.5.

5.2.4 Transitivity and consistency check

Transitivity refers to the logic of preference. The property of transitivity is that if an expert prefers the option x over y and y over z, then they should also prefer x over z to be consistent. When dealing with humans with a large number of alternatives, inexperience in preference elicitation, numeric quantifications and obscurity in the dimensions of the problem attributes, the judgements may end up inconsistent. (Liu et al. 2017, pp-128-147; (Islam and Raihan, 2019, pp. 521)

The consistency assessment of the subjective judgements in the overall model means that a consistency ratio of each matrix needs to be evaluated independently. Saaty suggested that the consistency of a matrix should be discovered through consistency index (CI):

$$CI = \frac{\lambda_{max} - n}{n - 1}$$

Formula 1. The formula of consistency index. (Franeka and Kresta, 2014, p. 164)

The CI formula where *λmax* refers to maximum eigenvalue of the pairwise comparison matrix and *n* represents the number of elements being compared in the square matrix (figure 5). Consistency index assesses the degree of deviation between the eigenvalue of the pairwise comparison matrix and random index (RI) of an identical size matrix (figure 6). RI is a predetermined benchmark value that depends on a matrix size. Consistency index ranges from 0 to 1. 0 indicates perfect consistency whereas 1 indicates complete inconsistency.

Consistency threshold CI of the matrix A is then compared to random index (RI) that results in the consistency ratio (CR). Random index depends of the size of a matrix. (Franeka and Kresta, 2014, pp. 164–173)

Consistency ratio:

$$CR = \frac{CI}{RI}$$

Formula 2. The formula of consistency ratio. (Franeka and Kresta, 2014, p. 164)

In Saaty's approach, a consistency ratio that equals or is less than 0,1, is considered acceptable. Any matrices that exceed the consistency threshold 0,1 are considered inconsistent and should be adjusted. (Saaty, 2008, 83–98)

5.2.5 Example of the AHP method

The following section will provide a practical example of the AHP to illustrate the overall process. The example will help to build a foundation for understanding the comparison between implication purposes that are introduced later in section 6.

Cabala (2010, pp. 1–23) offered a clear demonstration about AHP method in their paper ''Using the Analytic Hierarchy Process in evaluating decision alternatives''. The process starts from constructing the hierarchy with overall goal, criteria, (possible sub-criteria) and alternatives. In the example, the project goal was to evaluate and choose the strategy for project implementation. Each variant (I, II and III) represents an alternative way of project implementation. Seven criteria were chosen to be evaluated in the pairwise comparison.

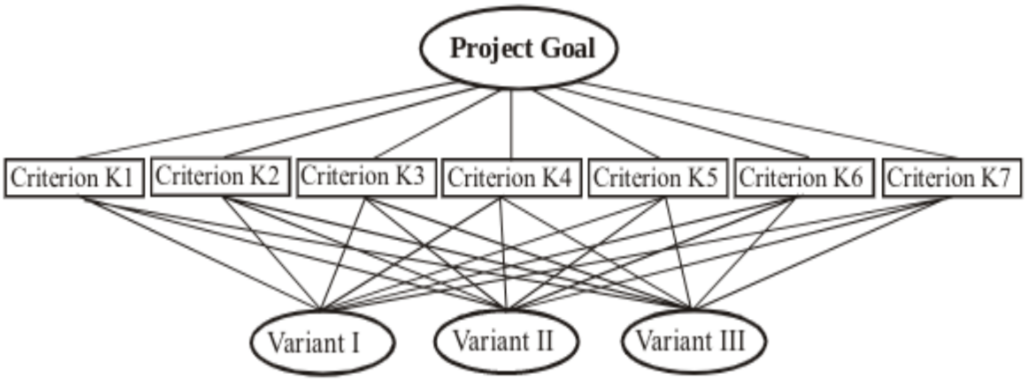

Figure 8. Structured hierarchy (Cabala, 2020, p. 17)

In the pairwise comparison, the preferences are set in relation to the element that is located above the compared elements in the hierarchy. In the comparison of criteria and alternatives, the preferences are determined in the relation of the project goal. The process continues to form a matrix of the pairwise comparison of all the seven criteria (*K1-K7*). The example process used the 9-point Saaty's scale to determine the preference ratios:

Table 1. Pairwise comparison of the evaluation criteria. (Cabala, 2010, p. 17)

Goal	K1	K2	K3	K4	K5	K6	K7
K1	1	2	1/5	1/5	2	1/9	3
K2	1/2	1	1/5	1/5	2	1/8	2
K3	5	5	1	1	4	1/5	6
K4	5	5	1	1	3	1/4	5
K5	1/2	1/2	1/4	1/3	1	1/7	1
K6	9	8	5	4	7	1	8
K7	1/3	1/2	1/6	1/5	1	1/8	1

The resulting 49 comparisons were then converted into corresponding numeric values. Eigenvector *w* that agrees with the maximum eigenvalue *λmax* of the comparison matrix A represents the final expression of the preferences between elements. Three methods to determine the eigenvector according to Cabala (2010) are Saaty's method, power method and geometric mean method. Saaty's method in determining the priority vectors is the most frequently used in the literature considering AHP modeling and applications. (Cabala, 2010, pp. 1–23; Ahmed et. al., 2017; Pendharkar, 2003, 199–212) Utilizing the Saaty method, the values were then normalized and maximum eigenvector determined:

Table 2. Normalized pairwise comparison matrix with the principal eigenvector *w*. (Cabala, 2010, p. 17)

	K1	K2	K3	K4	K5	K6	K7	w_i
K1	0.047	0.091	0.026	0.029	0.100	0.057	0.115	0.0664
K2	0.023	0.045	0.026	0.029	0.100	0.064	0.077	0.0520
K3	0.234	0.227	0.128	0.144	0.200	0.102	0.231	0.1810
K4	0.234	0.227	0.128	0.144	0.150	0.128	0.192	0.1720
K5	0.023	0.023	0.032	0.048	0.050	0.073	0.038	0.0411
K6	0.422	0.364	0.640	0.577	0.350	0.512	0.308	0.4531
K7	0.016	0.023	0.021	0.029	0.050	0.064	0.038	0.0344

Each element is divided by the sum of its column to obtain the normalized relative weight of the element. Maximal eigenvector w, i.e the priority vector or preference vector, is determined by averaging across the rows. The vector values represent the preference order of the criteria. The priority weights are organized from the highest value to the lowest, thus in the example the preference order of the criteria is:

K6 > K3 > K4 > K1 > K2 > K5 > K7 .

After establishing the preference order, it is necessary to run a consistency check of the previous comparisons. The consistency check starts from calculating the maximal eigenvalue of the maximal eigenvector w:

$$\lambda_{\max} = \frac{1}{n}\sum_{i=1}^{n} \frac{(\mathbf{Aw})_i}{w_i} = 7.4671$$

Formula 3. Maximal eigenvalue. (Cabala, 2010)

The maximal eigenvalue is then used to calculate the consistency index CI:

$$\mathrm{CI} = \frac{\lambda_{\max} - n}{n-1} = 0.07785$$

Formula 4. Consistency index (Cabala, 2010)

Calculations can be interpreted consistent, since the consistency threshold (0.1) is not exceeded.

5.2.6 Integration of FST and AHP

In 1987, van Laarhoven and Pedrycz (1983, pp. 229-241) combined Fuzzy Set Theory (FST) with Analytic Hierarchy Process (AHP). The combination, namely Fuzzy Analytic Hierarchy Process (FAHP), considers the uncertainty of linguistic assessments. There are different fusions of combining FST and AHP method; Noor et al. (2017, 139–154) listed the most frequently used ones being Triangular AHP, Trapezoidal AHP and both Fuzzy TOPSIS and VIKOR.

Traditional AHP uses crisp numbers (as suggested in Saaty's scale) to assess the preference between two elements. In the FAHP method, on the other hand, the evaluation of the elements is conducted by fuzzifying the values of the linguistic expressions (Hsu et al., 2010)

Linguistic Variables	Triangular Fuzzy Scale	Triangular Fuzzy Reciprocal Scale
Equally strong	(1, 1, 1)	(1, 1, 1)
Moderately strong	(2, 3, 4)	(1/4, 1/3, 1/2)
Strong	(4, 5, 6)	(1/6, 1/5, 1/4)
Very strong	(6, 7, 8)	(1/8, 1/7, 1/6)
Extremely strong	(9, 9, 9)	(1/9, 1/9, 1/9)
Intermediate values	(1, 2, 3)	(1/3, 1/2, 1)
	(3, 4, 5)	(1/5, 1/4, 1/3)
	(5, 6, 7)	(1/7, 1/6, 1/5)
	(7, 8, 9)	(1/9, 1/8, 1/7)

Table 3. Fuzzified scale of linguistic variables (Kannan et al. 2013, pp. 355–367).

The notable difference in AHP and FAHP processes is how the priority weights are derived from the fuzzified numbers. The extent analysis method was proposed by Chang in 1996 to obtain a crisp priority vector from a triangular fuzzy comparison matrix. Chang's technique has remained as the most commonly used approach in the literature (Chang, 1996, pp. 649–655).

To understand the fuzzifying process, let 2 describe 'moderate importance' of one criterion over another in AHP. In the fuzzy AHP the number 2 is replaced by the set of fuzzy numbers. Whether the series of numbers is representing a triangular, trapezoidal or intuitionistic fuzzy set, the AHP method is still able to calculate priority weights for the criteria and address the ranking of the alternatives. Including a series of numbers addresses the problems that experts in some cases are unable to assign an exact number to the judgment. Their memberships indicate to what extent the experts are sure about the numbers to be used for the judgment. (Zimmermann, 2001).

Chang's technique defuzzifies the fuzzy weights by calculating the fuzzy synthetic extents $\tilde{S}\ x$ of the comparison matrix. The technique considers the lower bound, middle bound and the upper bound of a fuzzy triangular number. The technique compares fuzzy weights pairwise, and the result of this comparison is a degree of possibility that one fuzzy weight is greater than another fuzzy weight. After this, the minimum degree of possibility of the weight vector *W'* is determined. The minimum possibility represents the overall score of the criterion. (Chang, 1996, pp. 649–655).

The process of FAHP generally conforms the flow of AHP method:

1) Define the problem
2) Establish the fuzzy pairwise comparison matrix
3) Synthesize the judgements
4) Calculate the fuzzy weights of the criteria
5) Defuzzify the weights
6) Check the consistency (Cavallo et al., 2014, pp. 842–850)

6. Systematic literature review

After becoming familiar with the theoretical side of Analytic Hierarchy Process (AHP), Fuzzy Set Theory (FST) and their combination, the Fuzzy Analytic Hierarchy Process (FAHP), the thesis proceeds to systematically examine relevant research literature. Systematic review methodology was chosen because it allows to present the research results in a concise form and to evaluate their consistency. The methodology can reveal the shortcomings of previous research and contribute to future research needs. (Salminen, 2011)

The purpose of the examination is to identify the key factors that practitioners and decision makers should consider to affect the utilization of the Fuzzy Analytic Hierarchy Process before, during and after its implementation in government projects. The identification of affecting factors is conducted through analyzing the content of relevant research articles through review questions that are introduced later in paragraph 6.1. The dispersion of the search results suggests that the FAHP method is a plausible approach in several different areas of science as well as operational development and management.

List of research considering fuzzy AHP applications in government projects was created based on search results on SCOPUS database using search combination ''Fuzzy analytic hierarchy process'' AND ''government'' AND ''application''. The search was last conducted on 5th of April 2023 and yielded 69 document results.
Search results that i) were written in a language other than english, ii) were not accessible, iii) did not include both the AHP and fuzzy set theory, iv) were other than scientific articles or book chapters and v) did not have government connection, were eliminated from the listing. After screening and excluding aforementioned documents, a total of 47 articles were then examined again for their suitability. A total of nine (9) research papers were exploring solely theoretical aspects of the FAHP method and

thus not included in the following analysis. Resulting 38 documents were considered to be sufficient scope of relevant literature for systematic review. Documents were published between 2008 and 2023 and represent a wide range of discipline areas in multiple countries.

The categorization of the literature is based on the utilization purposes that were identified after the first round of review. Three application purposes arose from the research literature in addition to theoretical literature.

Categories of application purposes are:

i) Policy planning and assessment
ii) Project selection
iii) Project and performance evaluation

A total of 11 research papers were aiming at *policy planning and assessment* by utilizing the FAHP method in their approach. A total of 11 papers used the FAHP method for *project selection* by ranking the set of alternatives. Most of the research used the method for evaluative purposes; 16 research applied the FAHP method for project and performance evaluation. A total of nine (9) research papers were exploring solely theoretical aspects of the FAHP method and thus not included in the following analysis.

The categorization of the search results was not a straightforward task. Especially the terms ‘’assessment’’ and ‘’evaluation’’ were used, in some cases, as synonyms among authors. Thesis makes a clear distinction between these two terms; ‘’assessment’’ represents research that was aiming to develop a set of criteria based on an individual's understanding prior to assessing the weights used in further calculations. Studies under the category of ‘’Project planning and assessment’’ were generally exploring the possibilities and developmental aspects of government projects prior to their implementation. Risk assessment studies also read to the aforementioned category. Studies that focused on establishing plausible evaluation and ranking models for future policy implementations were also part of this category.

''Project evaluation'', on the other hand, represents research approaches that utilize either a standardized or formerly established set of criteria for analysis purposes (Guan and Zhao, 2022; Peng et al., 2021; Gao et al., 2011) Cho et al. (2015) drafted the criteria and factors used in their research based on preceding research and presurvey by an expert group. Hsu et al. (2010) established their set of criteria based on consulting academics, government sectors and industries. Evaluative studies, in the most part, used the FAHP method and its hybrid forms to review already implemented projects and related performances. (Zhou et al., 2021; Xu et al., 2020)

Research in the category of ''Project selection'' utilized the FAHP framework mainly for ranking purposes. Intention of these studies was to produce conclusions about the most suitable alternative or set of alternatives or approach for the research selection problem. (Ocampo et al., 2019)

Some of the authors preferred to call their research method an AHP rather than FAHP. Using a fuzzy approach in assessing the criteria weights didn't automatically mean they would call the overall approach as FAHP. (Ocampo et al. 2019; Kahraman et al., 2008) This linguistic detail did not affect categorization. Another notable point is that application areas did not affect the categorization; in almost all areas of operational analysis found within the SCOPUS database search (e.g risk management, sustainability issues, transportation, land use etc.) research was conducted to assess, select and evaluate government linked activities.
In some cases the research objectives were multi-fold or multi-stage and thus challenging to place under a single category. (Zhang et al., 2015).

Table 4. List of review literature (Scopus.com)

				Category		
	Authors	Year	Title	Policy planning and assessme	Project selection	Project and performance evaluation
1	Meniz & Özkan	2023	Vaccine selection for COVID-19 by AHP and novel VIKOR hybrid approach with interval type-2 fuzzy sets		x	
2	Tadić, Krstić & Kovač	2023	Assessment of city logistics initiative categories sustainability: case of Belgrade	X		
3	Tuyet, Wang & Thanh	2022	Multicriteria Decision Making and Its Application in Geothermal Power Project		x	
4	Guan & Zhao	2022	A Two-Step Fuzzy MCDM Method for Implementation of Sustainable Precision Manufacturing: Evidence from China			x
5	Chang, Chen & Kung	2022	Evaluating a Business Ecosystem of Open Data Services Using the Fuzzy DEMATEL-AHP Approach			x
6	Nguyen & Chaysiri	2022	Spherical Fuzzy AHP-VIKOR Model Application in Solar Energy Location Selection Problem: A Case Study in Vietnam		x	
7	He & Sun	2022	Index Construction and Application of School-Enterprise Collaborative Education Platform Based on AHP Fuzzy Method in Double Creation Education Practice	X		
8	Hsueh et al.	2021	Using ai-mcdm model to boost sustainable energy system development: A case study on solar energy and rainwater collection in guangdong province	X		
9	Peng et al.	2021	An Application of Fuzzy Analytic Hierarchy Process in Risk Evaluation Model			x
10	Bahrami et al.	2021	Key challenges in big data startups: An exploratory study in iran	X		
11	Zhou, Wang & Zhang	2021	Evaluation of community tourism empowerment of ancient town based on analytic hierarchy process: A case study of Zhujiajiao, Shanghai			x
12	Mian, Hongqi & Tianyi	2020	Research on the development level of regional science and technology service industry			x
13	Dai et al.	2020	Establish of fuzzy synthetic evaluation model and China coal mine safety risk analysis system	X		
14	Xu, Yu & Gupta	2020	Evaluating the performance of the government venture capital guiding fund using the intuitionistic fuzzy analytic hierarchy process			x
15	Shete, Ansari & Kant	2020	A Pythagorean fuzzy AHP approach and its application to evaluate the enablers of sustainable supply chain innovation	X		
16	Wahyuni et al.	2020	Analysis on vocational high school teacher competency gaps: Implication for VHS teacher training needs			x
17	Altintas et al.	2020	An extended GRA method integrated with fuzzy AHP to construct a multidimensional index for ranking overall energy sustainability performances			x
18	Haryanta, Azhari & Mustofa	2020	Model for Measuring benefit of government IT investment using fuzzy AHP			x
19	Noori, Pradhan & Ajaj	2019	Dam site suitability assessment at the Greater Zab River in northern Iraq using remote sensing data and GIS		x	
20	Chen & Zhang	2019	Research on Security Evaluation of Government Cloud Platform Based on Fuzzy Analytic Hierarchy Process			x
21	Calabrese et al.	2019	Integrating sustainability into strategic decision-making: A fuzzy AHP method for the selection of relevant sustainability issues	X		
22	Islam & Raihan	2019	Fuzzy AHP-based study of barriers to the implementation of cleaner production in textile industry	X		
23	Ocampo et al.	2019	A novel multiple criteria decision-making approach based on fuzzy DEMATEL, fuzzy ANP and fuzzy AHP for mapping collection and distribution centers in reverse logistics		x	
24	Li & Wei	2018	A hybrid approach based on the analytic hierarchy process and 2-tuple hybrid ordered weighted averaging for location selection of distribution centers		x	
25	Ligus	2017	Evaluation of economic, social and environmental effects of low-emission energy technologies development in Poland: A multi-criteria analysis with application of a fuzzy analytic hierarchy process (FAHP)			x
26	Agarwa	2016	Fuzzy application to the analytic hierarchy process for institute ranking		x	
27	Zhang et al.	2015	Geo-environmental impact assessment and management information system for the mining area, Northeast China	X		
28	Ren & Lützen	2015	Fuzzy multi-criteria decision-making method for technology selection for emissions reduction from shipping under uncertainties		x	
29	Cho, Kim & Heo	2015	Application of fuzzy analytic hierarchy process to select the optimal heating facility for Korean horticulture and stockbreeding sectors		x	
30	Gao et al.	2011	Evaluation system for reliability of grid-connected wind farms based on fuzzy analytic hierarchy process			x
31	Chen	2011	Exploring digital capital of automated cargo clearance business websites	X		
32	Markaki, Charilas & Askounis	2010	Application of fuzzy analytic hierarchy process to evaluate the quality of e-government web sites			x
33	Hsu, Lee & Kreng	2010	The application of Fuzzy Delphi Method and Fuzzy AHP in lubricant regenerative technology selection		x	
34	Mosadeghi et al.	2009	Coastal management issues in queensland and application of the multi-criteria decision making techniques	X		

35	Zhou & Huang	2009	Evaluation on financing environment of attracting private capital into government projects			x
36	Fei, Yao & Yu	2008	Fuzzy analytic hierarchy process application to E-government performance evaluation			x
37	Huang, Chu & Chiang	2008	A fuzzy AHP application in government-sponsored R&D project selection		x	
38	Kahraman et al.	2008	A SWOT-AHP application using fuzzy concept: E-Government in Turkey			x

6.1 Review questions

The next section will offer analysis of distinctive research approaches under each of the three categories; *Policy planning and assessment; Project selection* and *Project and performance evaluation.* The search results under the category of ''*Theoretical literature*'' are left unexamined because they do not provide direct input for the purpose of analyzing operational approaches including the FAHP method.

The aim of the analysis is to map the research literature utilizing the FAHP method in order to explore the feasibility of the approach in given circumstances.

The examination is answering the following five questions to identify factors that influence the implementation of the FAHP method in the public sector. The review was not able to find answers to all of the questions in all 28 cases. It was observed that often the answers were similar or close to similar in the research representing the same category. This was taken into consideration and no identical answers from authors were included in the analysis.

1) What are the characteristics of the implementation environment?
2) Why was the AHP/ FAHP method employed?
3) Why was the Fuzzy Set Theory employed?
4) Why were possible hybrid methods integrated with the FAHP?
5) Was the FAHP method and obtained results feasible for the research's purposes?

6.1.1 What are the characteristics of the implementation environment?

Policy planning and assessment: Tadić et al. (2022) evaluated the sustainability of city logistic initiative categories. The authors stated that lack of planning activities and improper approaches to solve the logistical challenges in the past have made the process of finding compromising solutions very difficult. He and Sun (2022) stated that weak implementation of policies, lack of necessary research, differentiating perceptions in used measures and lack of cooperation between stakeholders have all complicated the new school-enterprise collaboration platform to success.

Hsueh et al. (2021) studied solar energy and rainwater collection in China to boost sustainable energy system development. Climate change and recent developments in energy systems are two major issues that affect sustainability world wide.

Bahrami et al. (2021) identified environmental challenges of big data startups in Iran. The authors suggested that lack of relevant laws and regulations, transparency, data mismanagement, financial challenges along with weak technological and educational skills challenge the development of big data startups. Dai et al. (2020) established an evaluation model of coal mine safety risks in order to scientifically manage safety aspects of coal mines in China. The authors uncovered that coal mine disasters are extremely serious and happen frequently.
Shete et al. (2020) examined the enablers of sustainable supply chain innovations; they stated that social and economic sustainability development faces pressure from government bodies, society and organizations. In their case study, managers desired to learn about the relative importance of different SSCI (sustainable supply chain innovation) drivers to better understand the stakeholder’s perceptions.

Calabrese et al. (2019) studied strategic sustainability and wanted to highlight Hahn’s(2013) argument; there is still no accordant understanding about what corporate sustainability should really focus on. Islam and Raihan (2019) studied cleaner production (CP) barriers in developing countries. In their paper, Islam and Raihan (2019) recognized that the CP industry has started to favor preventive strategies. Meeting the materialistic needs of the ever growing population inevitably means the exploitation and deterioration of the environment in developing countries. (Islam and Raihan)

Luy et al. (2018) paper suggested an approach to assess the socio-economic risks during urban development in China. High-stake research conclusions; Luy et al. (2018) were able to pinpoint the possible reason for building collapse incidents in rural areas. Zhang et al. (2015) conducted research about mining activities' environmental impacts. Zhang et al. (2015) narrated that various methodologies have been developed for assessment purposes in this area, yet some of them lack objectivity or are challenging to handle.

Chen (2011) explored digital capital measures of semi-government controlled cargo clearance websites. Chen (2011) revealed that countries that have managed to modernize their custom logistics have boosted their trade tax collection and thus government revenue.
Mosadeghi et al. (2009) reviewed regional coastal plans in south-east Queensland. The coastal management plans need to be reviewed every seven years.

Project selection: Meniz and Özkan (2023) introduced a novel approach for COVID-19 vaccine selection. Their model considers unique characterization of people in various countries. Thus, the definition of ''ideal vaccination'' is vague. Tuyet et al. (2022) proposed a model for determining a suitable place for a geothermal power plant in Vietnam. Energy sector activities are restricted and controlled by the government, which makes it hard to evaluate the interconnected aspects affecting the location selection.

Ngyen et al. (2022) stated that the pressure of shifting to more sustainable energy resources has increased since the latest geopolitical events along with the ever present worry about climate change; the growing interest indicates the need for new research approaches. Growing government support means more subsidies towards renewable energy projects, that the projects are competing over. Noori et al. studied suitable dam location in northern Iraq where people in the area are highly impacted by climate change; long-term drought, water shortage and flood events hamper the lives of locals. The water management of the Greater Zab River requires a dam to be built on carefully selected area.

Ocampo et al. developed a framework for reverse logistic facility location planning. Sustainable practices (e.g. resource depletion, consumer awareness, legislation and government incentives) are a recurrent pursuit in every level of manufacturing that need to be considered in location selection. Li and Wei (2018) narrated that the distribution location process faces new issues for location planning in Chinese megacities; pollution and congestion. Municipal planning departments need new strategies for land use allocation.

Agarwa (2016) proposed a decision support system for solving common institute ranking problems. Agarwa described that institute evaluation should be ''complete, precise and measurable''. Ren and Lützen (2015) study developed a method for technology selection for emission reduction from shipping. Shipping is one of the largest and most important industries in the world; proposals need to achieve compliance with sustainability regulations, including economic issues, environmental performances and social concerns. Cho et al. (2015) conducted research about optimal heating facility selection for the horticulture and stockbreeding sector in Korea. Authors explained that farmers rely on conventional heating that depend heavily on oil and high electricity consumption, while policymakers are trying to encourage the use of renewable resources.

Hsu et al. (2010) provided a systematic approach for lubricant oil recycling technology selection in Taiwan. The authors stated that recycling and regeneration of lubricant oil technologies are government responsibility. Thus the government should provide selection indexes for selection purposes. Huang et al. (2006) research aimed at supporting government-sponsored research and technology (R&D) development project selection in private companies in Taiwan. The authors described that companies may not pursue R&D projects because 1) they are risky and the percentage of the projects to fail are high, 2) companies may not meet the requirements to develop their technology and 3) the incentives to undertake a project that may face difficulties in estimating the benefits of the process are not sufficient.

Project and performance evaluation: Guan et al. (2022) aimed at identifying and ranking the drivers of Sustainable Precision Manufacturing (SPM) that had not been done earlier in the literature. SPM is a huge and strategically important industry for China that should be developed in an environmentally and socially responsible way. Chang et al. (2022) constructed an evaluation scale to measure the business ecosystem's performance of open data services. Government in Taiwan has formulated and implemented an open data policy to promote administrative transparency and economic development. The field has been previously examined mostly by e-government services.

Peng et al. (2021) presented a set of risk assessment indexes for conflicts in land exploration in China. The authors explained that conflicts in land expropriation have caused significant casualties; hindering the urbanization, caused social contradictions as affected social stability and development, vandalism, expulsion and even assassinations. Preventing conflicts in land expropriation has become top priority even though the complex causes are difficult to assemble.

Zhou et al. (2021) combined empirical research and questionnaire to analyze residents' awareness of community empowerment in the ancient town, a tourist attraction, in Zhujiajiao, Shanghai. Lately, ancient towns have experienced coordinated development of both, cultural protection and tourism. Mian et al. (2020) proposed a method to evaluate the development level of the regional science and technology service industry in China. By evaluating the development level, the utilization of resources becomes more effective and innovation guiding and sustainable development are enhanced.

Xu et al. (2020) constructed a performance analysis model for government venture capital guiding fun (GVCGF) in Ningbo City, China. According to the authors, existing literature considering the evaluation of GVCGF performance was conducted solely under an econometric framework. Xu et al. considered four dimensions, namely, standardization development, risk control capability, leverage effect and support effect to propose a comprehensive performance evaluation index system. Wahyuni et al. (2020) analyzed vocational high school teachers competency gaps in Bali Province, Indonesia. The authors stated that vocational training is the foundation in improving and maintaining the competitiveness of companies and the national economy of the country.

Altintas et al. (2020) constructed a multidimensional index for ranking overall energy sustainability performances in 35 OECD member countries. Economic and social development around increasing energy consumption has become a critical concern of governments worldwide. Thus, policy making requires ever new metrics for tracking and tracing the energy sustainability. Haryana et al. (2020) proposed a model to evaluate IT investments after implementation particularly in government organizations. The authors explained that IT investment models generally measure the feasibility of an investment prior to its implementation.

Chen and Zhang (2019) analyzed security problems in the government department's e-government cloud in Shandong, China. Security assessment method that was proposed can be used as a reference for building an e-government cloud in the future. Security of the cloud government platform is a fundamental guarantee. Security evaluations ensure the safety of confidential information in the environment that is otherwise open and public in its nature.

Ligus (2017) evaluated economic, social and environmental effects of low-emission energy technology development in Poland. Poland intends to accomplish multiple sustainable development goals. Gao et al. (2011) constructed an evaluation system considering the reliability of grid-connected wind farms. Systemic reliability is a challenge in rapidly developing grid-connected wind power systems. Markaki et al. (2010) applied FAHP to propose evaluation of e-government websites. The expected performance level of public websites has raised, which leads to the issue of evaluating the usability, information display and services of the e-government websites. Zhou and Huang (2009) analyzed the financing environment for attracting private capital into government projects in Ruian City, China. The authors revealed that during the time of their research China did not have a scientific and comprehensive system to evaluate the financing environments in particular regions.

Fei et al. (2008) utilized the FAHP method to evaluate e-government performance. The authors stated that traditional methods are generally too subjective and thus inaccuracy in the evaluation processes may occur. Kahraman et al. (2008) evaluated alternative e-government strategies in Turkey using SWOT-FAHP analysis. The authors explained that government digitalization in Central Europe, especially in Turkey, offers an opportunity for transparency and efficiency of administration after the collapse of the repressive communist era.

6.1.2 Why was the AHP method employed

Policy planning and assessment: Tadić et al (2023) stated that AHP systematically organizes the criteria and forms an easy-to-follow structure and simple solution. The AHP method reduces bias in the decision-making process, inconsistencies in expert assessments are easy to fix, builds consensus (important in policy formation), the method is flexible to include both qualitative and quantitative values and easy to control. Complex problems can be considered with conflicting criteria and no cumbersome calculations are needed. The calculations are easy to understand and compare. The AHP method is suitable for modeling situations in which the measures for the decision structure elements are missing since it uses predefined scales for evaluation.

Hsueh et al. (2021) stated that since the method assesses relative weights, the method is suitable for identifying key influential factors in decision-making problems.

Dai et al. (2020) used AHP process to analyze the relationship between influencing factors in coal mining safety risk index -system construction. Calabrese et al. argued that AHP method is flexible with consistency thresholds when compared to other methods that use calculated weights (e.g. MACBETH method requires perfect consistency order of the weights for generating the results). Using the AHP method the threshold can be reduced or increased depending on the deflection of decision-makers.

Islam and Raihan (2019) mentioned that the method was chosen to rank the barriers (criteria) of clean production. Luy et al. (2018) chose the fuzzy AHP approach over other risk assessment methods to manage the complexity of the system.
Zhang et al. (2015) utilized Improved Analytic Hierarchy Process to compare the evaluation results of trained TSFNN (Takagi-Sugeno fuzzy neural network) model.
Chen (2011) mentioned that the data they used originated from various different sources; owners, third-party companies, brokers and managers. The Fuzzy AHP approach offered a way to categorize and analyze the data.

Mosadeghi et al. (2009) compared AHP and FAHP methods to obtain preference weights of suitability criteria. The authors added that these methods have been proven practical in problems that include design of alternatives that aim to optimize the objectives.

Project selection: Tuyet Nhi et al. (2022) revealed that their main reason to incorporate Fuzzy AHP methodology in their work was because very few hybrid MCDM models, especially fuzzy models, have been formed to support evaluating location selection in the renewable energy sector.

Nguyen et al. (2022) stated that AHP method provides flexibility in hybrid approach integration. Noori et al. (2019) noted that AHP has been used in a variety of applications including suitable site selection. AHP produces levels of importance that is a principal information in dam site selection.

Li and Wei (2018) et al. chose to use AHP to calculate criteria weights including evaluation of logistics experts. Agarwa (2016) used AHP explicitly to solve the problem of institution ranking. Ocampo et al. (2019) developed an integrated MCDM approach that enabled simultaneous mapping of both collection and distribution centers. AHP was used in the final stage of the research to rank the potential locations. Ren and Lützen (2015) adopted a fuzzy AHP approach to determine weights and relative importance for unquantifiable criteria. In addition the authors used the traditional AHP to compare and validate their results.
Cho et al. (2015) stated that AHP has been generally used in decision-making research for policy issues. The authors explained that decision makers prefer to use familiar language expressions when assessing the criteria and alternatives. Hsu et al. (2010) declared that FAHP is the most popular MCDM method among lubricant regenerative technology selection. Huang et al. (2008) mentioned that the approach is the most frequently used and powerful method for group decision-making. The criteria used in their research is difficult to quantify and evaluate, so preference assessments were seen as the most suitable to extract the expert judgements.

Project and performance evaluation: Guan et al. (2022) stated that they wanted to secure the robustness and effectiveness in their study and thus adopted the method (AHP-TOPSIS) that has been tested in a large number of previous studies and cases in various fields. Chang et al. (2022) utilized the Fuzzy AHP method to analyze the evaluation dimensions constructed by the DEMANTEL method.

Peng et al. (2021) stated that the motivation of their motive was to find an effective risk assessment method. AHP (together with fuzzy mathematics) was the most suitable to assess the total risk degree of land expropriation and specific aspects that are linked to emergency conditions. Zhou et al. (2009) adopted AHP as a new method to scientifically evaluate community participation in tourism development in protected areas. Mian et al. (2020) appraised that the AHP method helps in achieving reasonable index weighting based on empirical knowledge of experts.

Xu et al. (2020) utilized an intuitionistic fuzzy AHP approach to handle semi-qualitative and semi-quantitative problems and transform them into quantitative calculations. Wahyuni et al. (2020) utilized the AHP method to obtain the importance levels of performance competencies provided by the Fuzzy Delphi process. Altintas et al. (2020) employed AHP for weight determination, but the ranking was performed by using Grey Relational Analysis (GRA).

Haryana et al. (2020) employed Fuzzy AHP for the method's ability to fracture complex and unstructured decision problems into manageable components in a hierarchical structure. Chen and Zhang (2019) utilized AHP method to overcome the problem of simultaneous use of qualitative and quantitative indicators. Gao et al. (2011) stated that using the FAHP it was possible to comprehensively evaluate the reliability of grid-connected wind power farms. Indirect factors like ''economy'' can be considered to affect the reliability of wind power and the FAHP method is able to include these factors in the analysis.

Markaki et al (2010) agreed that the evaluation of the e-government website quality is a hierarchical process by its nature. Kahraman et al. (2008) argued that hierarchical structure is suitable for analyzing complicated evaluation problems.

6.1.3 Why was the Fuzzy Set Theory employed?

Policy planning and assessment: In Hsueh et al. (2021) research employed fuzzy numbers in their complex logic inference algorithm. Hsueh et al. (2021) explained that using conventional mathematical equations to compute mixed computation and data units would have been difficult. Dai et al. (2021) based their coal mining safety risk index evaluation on fuzzy theory which realizes the different dimensions of index system data based on fuzzy logic and reasoning. Shete et al. (2020) employed Pythagorean membership grades to deal with the possibility that the data input for AHP analysis is imprecise and vague; Pythagorean membership offers greater freedom for the decision-makers to express their opinion since the membership and non-membership sum can be greater than one.

Calabrese et al. (2019) explored the selection of relevant sustainability issues and noted that evaluating ethical aspects and social responsibility was better achieved through fuzzy numbers.

Islam and Raidan (2019) stated that FAHP is an excellent tool to deal with the linguistic side of their research, that is, the stakeholders opinions and assessment. Luy et al. stated that vagueness is always present in decision-making. Thus a good decision-making model considers the vagueness of factors. Zhang et al. (2015) the control system in TSFNN model, that was being compared, utilized fuzzy rule rule base.

Chen (2011) unraveled that if uncertainty of human decision-making is not considered, the results might be misleading. Chen (2011) added that FAHP has been used in a number of systemic approaches.

Mosadeghi et al. (2009) described that the approach enables the integration of experts' knowledge and moderate personal judgements as part of the decision-making process.

Project selection: Ngyen et al. (2022) incorporated a spherical fuzzy approach in their model application to tackle the challenges of uncertain nature of human's decision-making process. They noted that fuzzy MCDM models have been frequently developed and applied in the renewable energy industry, but only few research have utilized Spherical fuzzy theory. Noori et al. (2019) were studying suitable dam locations; they found that by incorporating a fuzzy approach, they were able to narrow down the area of suitable land for further analysis, whereas traditional AHP method resulted in an area that was almost 4 times larger. Noori et al. (2019) stated that the fuzzy model is more suitable for clustered areas; a fuzzy approach yielded much more accurate results. Li and Wei (2018) utilized a fuzzy approach to assess the performance of alternatives because of the lack of numeric information. Ocampo et al. described that conditions that limited their decision framework development were fuzzy. In their research, fuzzy measures were also used in integrated DEMANTEL and ANP methods.

Agarwa (2016) stated that humans are more comfortable to use linguistic variables in ill-defined or complex situations. Agarwa (2016) also noted that non-crisp values are flexible and allow the generalization of problems. Ren and Lützen (2015) stated that fuzzy numbers are more suitable than crisp numbers for depicting human preference. Hsu et al. (2010) state that many concepts in real life are fuzzy, thus the definite values should be converted into fuzzy numbers. Huang et al. (2008) mentioned that they integrated previous research findings in their work that had also employed fuzzy criteria methods.

Project and performance evaluation: Guan et al. (2022) integrated fuzzy approach to ensure the validity and reliability of their results. Chang et al. (2022) stated that a fuzzy approach was adopted to overcome the problem of inherent ambiguity of the complex, multifaceted and uncertain field of data science that lacks data science personnel and has to tolerate data format disorders. Peng et al. (2021) expressed that the results may not be consistent using the traditional AHP and that – consequently – affects the reliability of the method. The authors added fuzzy mathematics to overcome the problem of uncertain data and ambiguous decision environment.

Zhou et al. (2021) first carried out a traditional AHP procedure to determine the weight of each indicator. The authors then proceeded to evaluate the empirical research using a comprehensive fuzzy analysis method. Zhou et al. (2021) incorporated fuzzy mathematics to define the evaluation value of tourism empowerment based on the set of linguistic evaluation grades.

Mian et al. (2020) elucidated that fuzzy mathematics enables objective evaluation of attributes when multiple affecting factors need to be considered simultaneously. Xu et al. (2020) described that intuitionistic fuzzy analytic hierarchy process (IFAHP) is superior in multi-attribute evaluation processes. The authors added that IFAHP has already been used in selection of start-up companies for the government venture capital (GVC) programs.

Wahyuni et al. 2020) utilized fuzzy Delphi method to confirm the importance of teachers competencies based on expert opinions. The authors stated that the fuzzy approach provides more advantages compared to the traditional Delphi method. Altintas et al. (2020) noted that the vagueness of human judgements in real life can not be compressed into a nine-point numerical scale. Triangular fuzzy numbers enabled the geometric mean to be used in determining the fuzzy weight for criteria. Haryana et al. (2020) integrated fuzzy numbers to represent the scale of importance. The authors noted that different results in related studies have been demonstrated depending whether AHP or FAHP was utilized.

Chen and Zhang (2019) incorporated fuzzy mathematics to quantify factors which are not otherwise easily quantified nor their boundaries are clear. Ligus (2017) incorporated fuzzy set theory to measure the ambiguity and uncertainty in experts' judgements. Gao et al. (2011) explained that Fuzzy Comprehensive Evaluation (FCE) is a suitable design for fuzzy phenomena that occur in real life. Markaki et al. (2010) deployed a fuzzy approach since they saw that the objectivity of judgements is not guaranteed and vagueness of the assessments should not be overlooked.

Zhou and Huang (2009) used fuzzy mathematics to convert linguistic evaluations into quantitative data for further evaluation. Fei et al. (2008) stated that traditional AHP is insufficient and imprecise to quantify the judgements of decision-makers.
Kahraman et al. (2008) integrated fuzzy numbers to take imprecise linguistic expressions into account with a hierarchical structure.

6.1.4 Why were possible hybrid methods integrated with the FAHP?

Policy planning and assessment: Tadić et al. (2023) noted that the AHP method is usually used to assess the criteria weights while evaluation and ranking of the alternatives are performed using different methods. Tadić et al. (2023) used the MARCOS (Measurement of Alternatives and Ranking according to the Compromise Solution) method to evaluate and rank the alternatives to ideal and nonideal solutions.
Hsueh et al. (2021) used Delphi (a structured communication technique)method to assess and validate development incentives.
Dai et al. (2020) used GIS and big data visual technology to display the diverse data related to coal mining safety risk research. Calabrese et al. (2019) , Islam and Raidan (2019), Luy et al. (2018), Chen (2011) and Mosadeghi et al. (2009) used FAHP as a stand-alone method.
Zhang et al. (2015) used Improved Analytic Hierarchy Process (IAHP) in their comparison.

Project selection: Meniz and Özkan (2023) introduced the Interval Type-2 Fuzzy-AHP-VIKOR approach for the first time in the literature. Their purpose was to select ideal COVID-19 vaccination for multiple different countries with unique requirements and preferences; VIKOR approach offers a set of optimal solutions rather than a single solution. The authors reminded that AHP can be used for the final ranking, but the optimality of the second-ranked and the next-ranked might not be clear.

For selecting a location for a geothermal power plant, Tuyet et al. (2022) used FAHP model to determine the weights of each criterion and sub-criterion, but for ranking they employed WASPAS (weighted aggregated sum product assessment).

Nguyen et al. (2022) introduced a spherical fuzzy based model that utilized AHP and VIKOR methods in solar energy location selection; their proposed hybrid method was a contribution to the growing research in the renewable energy industry. Noori et al. used FAHP as a stand-alone method.

Li and Wei (2018) employed THOWA (2-tuple hybrid ordered weighted averaging) method to aggregate overall evaluation values to rank the alternative. Ocampo et al. (2019) combined DEMANTEL (Decision making trial and evaluation laboratory), analytic network process (ANP) and AHP to establish a novel approach for simultaneous selection of multiple locations. Ren and Lützen (2015) integrated the VIKOR method to extract the prior sequence among the decision alternatives. Cho et al. (2015) paired BOCR analysis (benefits, opportunities, costs, risks) with FAHP because of its ability to consider negative priorities in decision-making. Hsu et al. (2010) utilized fuzzy Delphi method to form the set of critical factors of the regenerative technology industry. Agarwa (2016) and Huang et al. (2008) employed FAHP as a stand-alone method.

Project and performance evaluation: Chang et al. (2022) adopted fuzzy DEMATEL to overcome the problem of FAHP simplifying the evaluation criteria and weight determination relationship. FAHP method provides only direct relationship between different dimensions of the hierarchy suggesting the dimensions or criteria are conditionally independent. DEMATEL offsets this disadvantage offering indirect relationships to be explored. Mian et al. (2020) integrated FCE with AHP method to evaluate the decision attributes that are affected by various factors simultaneously. Xu et al. (2020) integrated intuitionistic fuzzy set theory (IFS) with the AHP. According to the authors, IFS decreases the subjectivity of the index weight vector determination compared to the FAHP method. Wahyuni et al. (2020) utilized Fuzzy Delphi method to determine teachers' performance competencies. AHP method was then applied to obtain the importance levels of aforementioned competencies. In their research, 6 experts participated in the Fuzzy Delphi process and 6 other experts in AHP. Finally, the competency gaps were demonstrated in the importance-performance matrix (IPA-matrix). Altintas et al. (2020) proposed the Grey Relational Analysis (GRA) method to be used in establishing the overall energy sustainability index (OESI by determining the ranking of the alternatives.

Haryanta et al. (2020) utilized IS/IT Business Value Template to identify the benefits of IT investment in government organizations. Chen and Zhang (2019), Gao et al. (2011), Markaki et al. (2010), Zhou and Huang (2009) and Fei et al (2008) used the FAHP as a stand-alone method. Ligus (2017) used the Delphi method to identify the criteria. Kahraman et al. (2008) applied the SWOT framework (Strengths, Weaknesses, Opportunities, Threats) to scan the internal and external factors that affect the strategic planning process. The identified factors were then used in pairwise comparison utilizing the SWOT setting.

6.1.5 Was the FAHP method and obtained results feasible for researchers' purposes?

Policy planning and assessment: Tadić et al. (2023) argued that the obtained results can provide guidance for planners and those making executive decisions about initiative selection. The authors concluded that the results can be further analyzed and defined.

Hsueh et al. (2021) stated that the transparency of their hybrid Delphi-FAHP method encourages residents to participate in public policies. They also added that the model is able to convert complex government policy challenges into easily-understand quantitative values which enables residents to perform self-evaluation to identify relevant factors that the sustainable development policies should focus on.

Shete et al. (2020) concluded that in their method, only human source input was used and thus the evaluation process needs adjunct attention despite the sensitivity analysis. Calabrese et al. (2019) concluded that the staged structure is highly useful for allocating scarce resources. The company's CEO that was participating in Calabrese et al.'s (2019) research claimed that the effort in comparing the criteria and alternatives was considerable. They later added that the net benefit of implementing the method has turned out to be beneficial.
Islam and Raidan (2019) stated that the practitioners and experts feel more comfortable giving their opinions via linguistic approach. They added that the FAHP method enables managers to be proactive about the clean production barriers and allocate resources correspondingly. Zhang et al. (2015) showed that their TSFNN-IAHP comparison successfully validated the TSFNN model evaluations.

Chen (2011) did not directly assess the feasibility of the chosen method. Chen (2011) did mention that for future research a broader and/or more detailed scale of criteria would be valuable to reconfirm the research findings.

Mosadeghi et al. (2009) concluded that the results of both approaches (AHP and FAHP) are satisfactory. They added that new approaches to evaluate coastal management plans, such as MCDM techniques, are certainly useful as uncontrolled development may lead to degrading natural resources and affect the quality of life for residents.

Projects selection: Nguyen et al. (2022) compared Spherical fuzzy AHP-VIKOR, Spherical fuzzy-AHP-WASPAS and Fuzzy-AHP-WASPAS results and observed significant differences in their results. Authors suggested decision-makers to utilize the conjunction of the research results.

Noori et al. (2019) concluded that hierarchical comparison of contributing factors is necessary in dam site selection. Li and Wei (2018) concluded that based on the sensitivity analysis, their method has high robustness. They added that their AHP-THOWA approach is effective and practical to use in municipal planning departments under the limited quantitative information.

Ocampo et al. (2019) stated that in their research, the limitation of FAHP was the number of alternatives. Agarwa (2016) concluded that adoption of fuzzy numbers allowed the users to attain better estimation flexibility considering the importance of attributes and alternatives. Ren and Lützen's (2015) conclusion was that the suggested method was validated by comparing the results with traditional AHP and VIKOR methods. The authors also saw that the results were consistent with other published emission reduction research.
Cho et al. (2015) were the only ones who reported that expert's survey responses were excluded from the analysis because their consistency ratios surpassed 0.15. Cho et al. (2015) excluded two expert assessments out of 19. Huang et al. (2008) research included an interview of experts considering the feasibility of the FAHP approach for selection of government-sponsored projects. The authors concluded that the FAHP approach helps to resolve the disparity of expert judgements. Limitations of the method were that it can not identify the relationship between criteria. Criteria is interpreted merely as independent.

Project and performance evaluation: Guan et al.'s (2022) analysis indicated that their Fuzzy AHP-TOPSIS method had good stability and robustness, although the authors noted that in their future studies they would hope to obtain more general results through larger numbers of statistical investigations and analyses. Chang et al. (2022) stated that the scale they provided through DEMANTEL-FAHP method was merely oriented towards the current status of open data service industry. For future studies, the authors suggested expanding the research through other tools such as analytic network process and best-worst methods for further aggregation of expert opinions from different backgrounds.

Peng et al. (2021) concluded that the FAHP method was effective in evaluating the risk degree of land expropriation and enriches the managerial means of conflict resolution. The evaluation indexes were successfully established based on experts' opinions and suggested methods. Zhou et al. (2021) finished by stating that the method supplemented the research system of community empowerment and provided significant support for practical guidance. Zhou et al. (2021) reviewed their own process and stated that the selection of evaluation factors need to be improved in the future studies due to the subjectivity of the selection process. The authors would also expand the sample size in the future studies to enhance the representativeness.

Mian et al.'s (2020) conclusion was that empirical results indicated the feasibility of the proposed evaluation index system and authors' method design. Mian et al. (2020) were able to establish a design that was both practical and flexible for popularization. Xu et al. (2020) stated that the proposed IFAHP method effectively avoids the problem of data subjectivity hampering research results. Evaluation results were described to be more authentic and accurate when the hesitation margin (the pillar of IFS) was considered during weight determination.

Wahyuni et al.'s (2020) three-fold research approach (Fuzzy Delphi, AHP, IPA-matrix) expanded the research literature by determining the gaps in teachers' competencies. Previous studies have mainly considered establishing standards for teachers' performance without including quantitative approach analysis. Altintas et al. (2020) proposed a benchmark index for policy makers assessing energy sustainability performances. The authors mentioned that it was difficult to define who would be a qualified expert in the selected research area (35 OECD countries), reaching a sufficient number of experts and receiving their responses on time for the research.

Altintas et al. (2020) observed that scalability of the FAHP-GRA method was an issue since a high number of comparisons easily becomes unmanageable. The authors concluded that a method that integrates both objective and subjective weighting increases the reliability of procedures and alleviates the problem of scalability. Haryanta et al. (2020) concluded that their proposed model can overcome the challenge of organizational differences in used criteria and their interpretation. The authors suggested that alternative criteria weighting methods should be compared with results of the FAHP method in the future studies.

Ligus (2017) revealed that the same results considering the rating of low-emission technologies were attained by using FAHP and direct weighting by experts. This fact confirmed the coherence and applicability of the research results, but questioned the necessity of the proposed FAHP approach.

Gao et al. (2011) interpreted the different levels of AHP hierarchy as layers of evaluation index. The results were compatible to meet market requirements as well as to guide the policy makers and power companies considering the reliability of wind farms. Markaki et al (2010) stated that their results provide valuable reference for e-government implementations.

Fei et al. (2008) concluded that the FAHP method is flexible to use both quantitative and qualitative criteria when the process is subject to inadequate information and knowledge. The authors added that the FAHP method is easily extended to include approaches involving subjectivity of human judgements. Kahraman et al. (2008) compared the results of SWOT-AHP and SWOT-FAHP analyses. The two methods generated different rankings of the alternatives although the priority weights were nearly the same in both approaches. This was the result of different types of information being gathered from the expert groups.

6.2 Compiled table of literature review

Compiled table of systematic literature review displays the application categories along with answers to each review question. The table of literature review is assembled based on authors' perceptions that were derived during the review process. Section 5.

concludes the results of the literature review by identifying the key elements that affect the implementation of the FAHP method in practice.

	Policy planning and assessment	**Project selection**	**Project and performance evaluation**
What are the characteristics of the implementation environment?	– Lack of planning/ previous research, – Inappropriate approaches (e.g. used tools) – Weak implementation of policies – Diverge perceptions of measuring decision implication aspects – Lack of relevant laws and regulations – Lack of transparency – Stakeholder pressure – Lack of cooperation – Desire to gain knowledge – Desire for scientific management, – Financial challenges or possible gains – Need for strategic reassessments – High-stake decision-making	– Complex evaluation schemas and multiple dimensions affect decision-making (e.g. interconnected restrictions) – Change in environment; demand for new strategies because of climate change, geopolitical events, pollution and congestion – Competition – Selection process needs to achieve compliance with regulations, environmental performances and social concerns.	– Novelty of the research area – Development processes are given conditions (e.g. sustainability standards) – Need for new/ defined accurate metrics and indexes – Previous approaches are outdated – Complex causes of conflicts lead into significant casualties – Need for enhancing utilization of resources – Expanding existing evaluation framework into new dimensions – Multiple simultaneous policy goals – Change in people's expectations; performance needs to meet the new expectation levels – Change of administrative regime
Why was the AHP method employed?	– Systematic approach; easy-to-follow and control – Allows qualitative and quantitative values – Possible to use mixed data from various sources – Simple solutions for practical problems – Produces rankings	– Provides importance levels and produces rankings – Flexibility – Allows hybrid methods to be integrated – Widely used in case studies and applications – Effectiveness of the method – Handles (unquantifiable)	– Widely used and tested in previous studies – Suitable method to evaluate novel approaches – Effective and comprehensive – Scientific approach to vague concepts – Attains reasonable

	– Bias reduction; builds consensus – Allows conflicting criteria – Suitable for modeling situations when information is incomplete (predefined scales for evaluation) – Identifies key influential factors and analyzes their direct relationship, – Flexible consistency thresholds – Calculations are easy to understand and compare – To compare results between oher methods simultaneously	criteria that is challenging to evaluate – Most frequently used MCDM method – Paralleled with results from different methods for validation purposes – Humans prefer to use familiar language expressions when assessing criteria and alternatives	index weighting utilizing empirical knowledge – Handles semi-qualitative and semi-quantitative problems – Possibility to operate using information that was collected or produced using different method – Ability to fracture complex and unstructured decision problems – Qualitative and quantitative indicators can be used simultaneously through the process – Decision process is hierarchical by its nature
Why was the Fuzzy Set Theory employed?	– Conventional crisp numbers were not suitable to handle mixed data units – Used in previous research literature/ application studies – Existing system utilized fuzzy logic and reasoning – Allows imprecision and vagueness – Integrates experts tacit knowledge – Realizes different dimensions of reasoning – Handles opinion expression in intangible dimensions like ethical and social responsibility – ''Vagueness is always present in decision-making'' thus it needs to be considered and if not, results might be misleading	– Novelty of the research – Previous literature utilizing FST – Handling uncertain nature of human decision-making – Results are more detailed/ sophisticated (cf. coastline paradox) – Mends lack of information – Conditions that limit decision-making are fuzzy – Fuzzy values are flexible and allow generalization of problems. – Fuzzy numbers are more suitable than crisp numbers to depict human preferences; concept in real life are fuzzy	– Enhances the validity and reliability – Supplements the lack of consistent information or expertise – FAHP is more intuitive but also scientific approach to calculate criteria weights than traditional AHP – Fuzzy weights are being compared with empirical results for validation purposes – Objective evaluation when multiple factors need to be considered simultaneously – Provides more advantages (integration, accuracy etc.) than many other approaches (e.g probability theory) – Objectivity of the judgements is not guaranteed

			– Traditional AHP is insufficient and imprecise to quantify the judgements
Why were possible hybrid methods employed?	– For producing alternative rankings; ideal to anti-ideal (MARCOS), similarity to ideal solution (TOPSIS), exploring the interdependencies between criteria and sub-criteria (DEMATEL), – Validating the results – For handling data diversity	– Alternative ranking approaches – To obtain set of optimal solutions – Aggregating overall evaluation values (– Novelty of the approach – Enables simultaneous selection of multiple locations – To consider negative priorities in addition to positive priorities	– Exploring the indirect relationships between elements existing in different hierarchical dimensions – Evaluating factors that are affected by various factors simultaneously – Decreasing the subjectivity of weight determination – Comparing results with FAHP results – Identifying criteria/ affecting factors
Was the FAHP method and obtained results feasible for researchers' purposes?	The results of the method… – Provide guidelines – Can be further analyzed and defined – Enhance transparency among stakeholders – Reduce complexity; converts policy problems into easily understandable quantitative factors – Used only human source input, thus evaluation process needs adjunct attention – Are useful since the results are displayed in staged structure – Were considerable according to stakeholders – Enhanced managers ability to be proactive – Validated research results that were obtained using other methods – Did not completely satisfy researcher since the scale of criteria	The results of the method… – Offered robust approach when applied together with sensitivity analysis – Practical and effective to use – Two hybrid approaches produced significantly different results; authors suggested to use the conjunction of compared research results – Suggested it is challenging to identify suitable hybrid approaches – Were affected by limited number of alternatives – Suggested that adoption of FST offered better flexibility for estimation – Excluded expert assessments since CR surpassed the fixed threshold – Help to resolve the disparity of expert judgements – Considers criteria to be inherently independent	The results of the method… – Obtained good overall stability and robustness, although larger number of statistical analyses/ sampling size could refine the results –Produced valuable references – Attained same results as direct weighting by experts – Was merely an orientation towards current status of examined phenomenon; employing hybrid methods could benefit future research – Enriches managerial means in conflict resolution and supplemented existing research – Provided significant support and guidance for practitioners – Could be improved if

	remained too narrow/ vague – Contributed as being useful addition to research literature of given field		the selection of evaluation factors was refined – Together with empirical results, prove to be feasible – Avoid the problem of data subjectivity to hamper the decision process – Overcomes the challenge of organizational differences in criteria and their interpretation –Produced different ranking order than traditional AHP

7. Conclusion

The Fuzzy Analytic Hierarchy method can be utilized in various MCDM settings when the information at hand is uncertain, vague or incomplete. The method constructs an easily comprehended hierarchical structure of the decision problem and allows decision-makers to gradually process multifaceted issues.

Implementation purposes of the FAHP method – in government bound activities– can be divided into three main categories; *Policy planning and assessment, Project selection and Project* and *Performance evaluation.*

The categorization of the review literature can be approached in a time bound manner; studies focusing on *Policy planning and assessment* were in general designed to support decision-making prior to policy or program implementation. This means that research in this category had less predetermined limits and boundaries (e.g clearly established criteria or objectives) compared to the research in two other categories. The reason for the decision environment uncertainty was often the extensive changes and rapid developments in the area of research. New approaches were required for assessing updated relationships between decision elements. This suggests that practitioners who choose to employ the approach in vaguely established settings, will not automatically attain results that are directly applicable.

Studies under the category of *Project selection* aimed at producing solid results that are directly applicable to practice. Research objectives and criteria in the category of *Project selection* were clearly established to produce a definitive ranking of the alternatives. In this category, restrictions (e.g laws and regulations), that affected the selection process, had to be clearly set due to obtaining reliable results.

Studies under the category of *Project and performance evaluation* were evaluating operative activities after their implication. The studies were able to utilize empirically supported information in evaluative model and index construction. This enabled researchers to augment critical gaps in used evaluation metrics more effectively than studies in two other categories. The FAHP method offered an alternative approach to address inaccuracies and problems of subjectivity that may occur in traditional evaluation practices.

The FAHP method is flexible to integrate other MCDM and optimization methods since practitioners may choose to utilize the process only partially. E.g after pairwise comparison, the criteria weights can be derived using alternative approaches or the ranking order may be produced following a different formula than traditionally suggested.

Recent contributions in the FAHP literature appear to harness the use of hybrid methods for attaining robust research results. Earlier studies used FAHP as a stand-alone method more often. This was the case in research in all the three application categories. This observation implies that the practitioners should be familiar with various other MCDM and optimization techniques as well, in order to choose the most suitable approach.

The trend of optimizing assessment, selection and evaluation processes via hybridization of multiple methods implies that sometimes the FAHP falls short in producing satisfactory results as a stand-alone method. Writer suggests that stand-alone utilization of FAHP is the most suitable in *Policy planning and assessment* purposes; when the objective is to assess unexplored, changed or vague decision-making settings. Decision makers in environments that are not fully benchmarked and include immeasurable and/or unquantifiable elements, could greatly benefit from the FAHP approach.

The biggest challenge of both, the AHP and the FAHP approaches, is that the criteria is considered to be independent. This is a significant factor to take into consideration when a practitioner is evaluating feasible approaches to handle decision problems that require the recognition of interconnected decision attributes. According to Complexity Theory, the fundamental principle that hampers the predictability of complex systems is precisely the interplay of elements. Also, the practitioners should be aware of not to inflate the amount of considered elements in their decision problem since large number of criteria comparisons is exhausting for experts and large sampling size of experts is challenging to facilitate in practice.

The method, along with the traditional AHP, is used in the literature to compare and validate results that were produced by using different methodological approaches. This is a valuable application itself, since in addition to empirical and theory, the calibration of research results can take place in the dimension of human judgment. In one case, the authors suggested the conjunction of the results that were produced by using two distinctive hybrid approaches.

The approach can be used to mitigate risks of misinterpretation between stakeholders. Since the weighting process allows linguistic pairwise comparison, the process is not bound to e.g special vocabulary and can be used flexibly among different participants. This was seen as useful especially in *Policy planning and assessment* studies. The decision of employing fuzzy numbers in the studies of all three categories was to handle the uncertainty of human judgements. Often the FAHP was applied as a continuum of previous research or practices that already employed Fuzzy Set Theory. The necessity of employing fuzzy numbers in the decision-making process should be considered carefully. Sometimes direct weighting of the criteria leads to similar results than the FAHP method and thus employing lengthy FAHP procedures turns out to be useless.

Uncertainty in decision-making should not be considered as a positive remark if the purpose is to attain set goals. Thus the writer suggests that practitioners should prioritize the alleviation of uncertainty among decision-makers and experts (e.g. provide training, information) rather than interpreting a fuzzy approach as panacea to handle uncertainty. Deploying fuzzy numbers can be well justified, for example when the objectivity of judgements is not guaranteed in the first place. Fuzzy approach also considers different dimensions of reasoning, which can expand the volume of active

In almost all of the cases, the importance weights were determined by a group of experts as the founder of the method originally intended. Few examples in the literature employed the FAHP method to aggregate people's opinions in selection cases. Decisions to use other than expert assessments in criteria weighting might cause problems with consistency.

The FAHP approach can offer considerable decision support for managers and decision makers who are planning and assessing policy implementations. Since the method is able to convert complicated issues into easily understandable and quantitative measures, the transparency of the overall decision-making process could be enhanced among the stakeholders. Decision makers are able to include abstract variants, e.g. ethical values, since the method allows generalization of decision problems.

For the future research, reviews that examine the use of hybrid methods in government practices would contribute to their utilization. The FAHP method can be a cumbersome process for decision-makers who are not familiar with the theoretical aspects of MCDM methods in general. On the other hand, researchers who conduct FAHP studies, should remember the empirical validation of their approach; governments would gain valuable insight from practitioners who evaluate their FAHP implementation processes even after the active phase.

8. References

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