Chapter 1
Analyzing Swiss Energy Policy Through a Fuzzy BWM-PROMETHEE Approach: A Socio-Political Multi-criteria Decision Analysis

He Huang, David J. Metzger, Eleftherios Siskos, and Peter Burgherr

Abstract In the context of the global transition to sustainable energy solutions, Switzerland is actively pursuing goals of climate neutrality and enhanced energy security. Energy policies play a key role in navigating the country's transition to renewable energy. While these policies have been extensively analyzed in Switzerland, the socio-political dimensions often receive less attention. However, it is these multifaceted socio-political criteria that have a significant impact on the effectiveness of energy policies. This paper explores the Swiss energy policy landscape using a hybrid Multi-Criteria Decision Analysis (MCDA) framework that ingeniously integrates the Fuzzy Best-Worst Method (BWM) with PROMETHEE II to provide a comprehensive policy evaluation tool. The study examines a set of fifteen different energy policy alternatives and assesses their potential to advance Switzerland's transition to renewable energy. By engaging with experts to identify policy preferences, the analysis aims to unravel the socio-political nuances that underpin energy policy preferences. This in-depth assessment sheds light on the complex challenges and opportunities facing Switzerland as it moves toward a sustainable energy paradigm.

Keywords Multi-criteria decision analysis · Policy analysis · Energy · Fuzzy logic

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Introduction

Switzerland is a country with a strong commitment to climate neutrality and energy security [1]. However, it is facing a number of challenges in achieving these goals [2, 3]. To overcome these challenges and put the country on track to meet its goals, improved energy policies are needed to enable rapid expansion of domestic power generation, deep decarbonization through electrification of the energy system, and more efficient use of energy. Progress in Switzerland is also influenced by fundamental changes in the energy markets [4]. These are caused by economic, political and technological developments at home and abroad. Among these, the socio-political aspects represent a critical factor that requires in-depth analysis. The socio-political dimension encompasses the variety of interests, preferences, and values held by different stakeholders, including government agencies, industry actors, environmental advocates, and the general public [1]. It also includes the various institutional, political and societal conditions that have a strong influence on, and are affected by, policy change. Balancing these diverse perspectives, barriers and effects while formulating and implementing energy policy is a complex task, often characterized by competing interests and trade-offs [5]. Understanding how socio-political factors interact with policy decisions is essential for developing effective and socially acceptable strategies for Switzerland's energy transition. Given these challenges and complexities, it is appropriate to apply rigorous methodologies such as Multi-Criteria Decision Analysis (MCDA) to comprehensively assess the performance of Swiss energy transition policies [6]. By systematically evaluating the criteria and indicators that underpin these policies, it can provide insight into the effectiveness and impact of Switzerland's energy transition efforts, while taking into account the complex socio-political landscape that shapes its energy policies.

The application of MCDA in this study requires the involvement of energy experts in the policy evaluation process to ensure the accuracy of the assessments [7]. However, this requirement presents several challenges. While these experts have in-depth knowledge of the energy sector, their familiarity with MCDA methodologies may be limited. As a result, they may need additional time to understand these methods, raising concerns that the results of the MCDA may not accurately capture their preferences. This issue is particularly pertinent in the current study, where some socio-political criteria must be evaluated based on expert perceptions, suggesting the need for more intuitive MCDA approaches.

In our study, we applied an MCDA framework which requires two essential processes: the elicitation of criterion weights and the elicitation of alternative preferences. For weight elicitation, experts are tasked with assessing the importance of each criterion using an MCDA method. For the alternative preference elicitation step, experts assign scores to subjective criteria or configure parameters for objective indicators to ensure accurate scoring or preference generation. It's worth noting that the MCDA methods used for these different steps need not be identical. A hybrid MCDA approach can actually facilitate the evaluation process and increase the reliability of the results [8]. Accordingly, our research depolyed a synergistic combination of the best-worst method (BWM) and outranking MCDA methods, specifically the Preference Ranking Organization Method for Enrichment Evaluation (PROMETHEE). The BWM serves as a simplified yet consistent technique for eliciting expert opinions on criterion weights [9], while PROMETHEE provides a outranking approach for ranking energy policies by effectively comparing their preferences.

The BWM method, a pairwise comparison MCDA method designed to streamline the elicitation process, emerges as a particularly appropriate method for assessing the importance of criteria [10]. In addition, the inherent uncertainty in expert judgments, particularly regarding the weighting of criteria, can be more effectively addressed by applying a fuzzy BWM approach [11]. This method provides an appropriate approach for accounting for the ambiguity commonly associated with expert judgment. To evaluate alternative policies, preferences are elicited from expert perceptions. In this context, the PROMETHEE method are useful [12]. Either these methods facilitate the explicit consideration of detailed preferences and indifferences, allowing for a nuanced understanding of the complex trade-offs involved in energy policy decisions. Therefore, this study adopts a methodological framework that integrates Fuzzy BWM with the PROMETHEE. This combined approach, termed Fuzzy BWM-PROMETHEE, is chosen specifically for its simplicity, effectiveness in dealing with uncertainty, and ability to provide detailed comparisons of alternatives based on established criteria [13]. By leveraging the strengths of both methods, the Fuzzy BWM-PROMETHEE approach provides a holistic assessment of energy policy alternatives which considers uncertainty. This integrated approach leverages the strengths of both methodologies to provide a comprehensive and robust assessment of energy policy alternatives.

The structure of this paper is organized as follows to ensure a logical flow and a comprehensive understanding of the research conducted. In section "Methodology", we present the framework along with the methodologies included in this framework, providing a foundation for our analysis. Section "Hybrid MCDA Framework" is dedicated to presenting the policies and criteria that are considered in the evaluation of Swiss energy policy. Section "Swiss Energy Policy Evaluation" discusses the results and their implications.

Methodology

To thoroughly evaluate energy policies and accurately capture expert preferences, we have developed a systematic, expert-based Multi-Criteria Decision Analysis (MCDA) framework [14]. Discussing the choice of MCDA methods is crucial, given the large number of methods available, each with its merits for different aspects and application domains. In addition, the integration of different MCDA methods, i.e., hybrid approaches, offers distinct advantages. A widely accepted and intuitive approach involves eliciting criterion weights on the one hand, and alternative preferences based on the criteria on the other. This approach provides a straightforward process that is easily understood by experts.

For weight elicitation, the pairwise comparison method is a popular choice, exemplified by the Analytic Hierarchy Process (AHP), one of the most well-known MCDA methods [15]. This approach allows experts to assess the relative importance of pairs of criteria without requiring extensive comprehension, followed by a consistency check to ensure reliable weight assignments. However, AHP typically requires considerable time for pairwise comparisons. In response to this criticism, the Best-Worst Method (BWM) has emerged as a streamlined and efficient alternative that retains the robustness of traditional methods with significantly reduced complexity [10]. By focusing on the most and least important criteria, BWM minimizes the cognitive load and time required for experts. This efficiency is crucial in mitigating the potential for inconsistency and judgment fatigue among experts, leading to more reliable elicitation of criterion weights [16]. In addition, BWM's methodological framework requires experts to identify both the most important (best) and least important (worst) criteria at the beginning of the evaluation process. This deliberate structure promotes a balanced and reflective consideration of all criteria, effectively grounding the evaluation between two defined extremes. It reduces the impact of first impressions or random anchors, ensuring that the subsequent elicitation of criteria is less susceptible to such biases compared to other weight elicitation methods [17, 18]. This approach helps achieve a more nuanced and accurate reflection of expert judgment in the decision-making process. The subsequent development of fuzzy BWM extends this methodology to areas of uncertainty, using fuzzy logic to better capture and process the nuances of expert judgment [11].

With respect to alternative preference elicitation, outranking methods account for the non-compensation of criteria [19]. One such method, PROMETHEE, derives preferences for alternatives through pairwise comparisons based on expert-constructed preference functions [12]. Comparing to other outranking method like ELECTRE, PROMETHEE is notable for its ability to express expert preferences based on criterion performance via preference functions, while remaining straightforward. PROMETHEE allows for a variety of generalized criteria and preference functions, enabling analysts to tailor the evaluation process closely to the specific context and nature of the decision problem [20]. This flexibility ensures that the method can be adapted to accurately reflect the preferences of the decision-makers.Unlike another outranking method ELECTRE, which involves more complex procedures like concordance and discordance indices, and the construction of outranking matrices, PROMETHEE utilizes direct preference functions to compare alternatives [21]. While both methods can handle incomparabilities between alternatives, PROMETHEE's approach is often perceived as more straightforward, as it directly incorporates these into the preference modeling and analysis process. ELECTRE's treatment of incomparabilities, though robust, can sometimes lead to more complex interpretation of results [14]. In the PROMEHTE family, PROMETHEE II extends the analysis by providing a complete ranking of all alternatives from best to worst. PROMETHEE II is particularly suited to situations where a definitive ranking of all alternatives is required, making it very useful in comprehensive decision-making processes that require a clear ranking of preferences.

In this study, we have chosen to integrate the Fuzzy BWM and PROMETHEE II methods as our evaluation framework. Such hybrid approaches combining BWM and PROMETHEE have proven successful in various domains, which is also appropriate for our study [22–25]. The subsequent subsections will introduce these methods and outline the workflow of our framework.

Fuzzy BWM

The BWM uses a 1-9 scale for pairwise comparisons, but differs significantly from AHP by focusing solely on reference comparisons. That is, it only requires determining the preference of the best criterion over all others and the preference of all criteria over the worst, using a numerical scale from 1 to 9 [10]. This approach simplifies the process and increases both accuracy and efficiency by eliminating the need for secondary comparisons. However, the qualitative judgments inherent in BWM, such as those based on the 1–9 scale for pairwise comparisons, often embody characteristics of ambiguity and intangibility [26]. Decision-makers (DMs) face difficulty in providing precise numerical values due to uncertain or incomplete information [27]. Consequently, when applied to practical problems, the reference comparisons in BWM can benefit from the incorporation of fuzzy numbers instead of crisp values. Consequently, Guo and Zhao have extended BWM to a fuzzy environment, which allows the elicitation of weights through fuzzy comparative judgments [10]. This adaptation allows for a more nuanced and flexible approach to capturing expert judgments, taking into account the inherent uncertainty in decision-making processes.

Before presenting the steps of the fuzzy BWM, it is essential to introduce some basic definitions related to fuzzy sets and triangular fuzzy numbers (TFN). Readers looking for a detailed explanation of these terms can refer to the literature [11, 28]:

Definition 1.1 Let $\tilde{v}$ a set of fuzzy pairs $(x, \mu_{\tilde{v}}(x))$, where x is an element within a finite universe of discourse X, and $\mu_{\tilde{v}}(x) \in [0, 1]$ represents the membership function of $\tilde{v}$. This function quantifies the degree to which the element x is considered a member of the fuzzy set $\tilde{v}$.

Definition 1.2 A triangular fuzzy number (TFN) $\tilde{v} = (l, m, u)$ is defined on the set of real number whose membership function follows:

$$\mu_{\tilde{v}}(x) = \begin{cases} \frac{x-l}{m-l}, & \text{if } l \leq x < m; \\ \frac{u-x}{u-m}, & \text{if } m \leq x \leq u; \\ 0, & x < l \text{ or } x > u, \end{cases} \tag{1.1}$$

where l, m, and u denote the lower, modal, and upper values, respectively, that support the fuzzy number $\tilde{v}$. These are all crisp numbers such that $l \leq m \leq u$.

Definition 1.3 Defuzzification method [29]. The graded mean preference integration representation (GMIR) of $\tilde{a}$ - an approach to transform fuzzy weights vector to a crisp value - is defined as follows:

$$\mathrm{GMIR}(\tilde{a}) = \frac{(l + 4 \times m + u)}{6}. \tag{1.2}$$

In fuzzy BWM, suppose we have a set of criteria $C = \{c_1, c_2, \ldots, c_n\}$ in the decision-making problem. The DM – in our case the expert – needs to first identify the best (the most important) criterion c_B and worst (least important) criterion c_W. Then the expert should do fuzzy pairwise comparisons on these n criteria. It is performed based on the linguistic variables (terms), i.e. “Equally important (E)”, “Weakly important (W)”, “Fairly Important (F)”, ’Very important (V)”, and “Absolutely important (A)”. The expert compares the preferences of the best criterion over all the others and all the others over the worst criterion. Then, the fuzzy Best-to-Others vector $\tilde{V}_{BO}$ and fuzzy others-to-Worst vector $\tilde{V}_{OW}$ are derived as follows:

$$\tilde{V}_{BO} = \{\tilde{v}_{B1}, \tilde{v}_{B2}, \ldots, \tilde{v}_{Bn}\}, \tag{1.3}$$

$$\tilde{V}_{OW} = \{\tilde{v}_{1W}, \tilde{v}_{2W}, \ldots, \tilde{v}_{nW}\}, \tag{1.4}$$

where $\tilde{v}_{Bi}$ and $\tilde{v}_{iW}$ represent the fuzzy preferences of the best criterion C_B over criterion i, and of criterion i over the worst criterion C_W, respectively. These linguistic evaluations provided by the expert are transformed into fuzzy ratings, expressed as TFNs, in accordance with the transformation rules outlined in Table 1.1. We define that $\tilde{v}_{BB} = (1, 1, 1)$ and $\tilde{v}_{WW} = (1, 1, 1)$ for consistency in the analysis.

With the information obtained, we can derive the optimal fuzzy criteria weights with the following nonlinearly constrained optimization model:

Table 1.1 TFNs transformation rules of linguistic variables

Linguistic terms	Membership function
Equally importance (E)	(1, 1, 1)
Weakly important (W)	(2/3, 1, 3/2)
Fairly Important (F)	(3/2, 2, 5/2)
Very important (V)	(5/2, 3, 7/2)
Absolutely important (A)	(7/2, 4, 9/2)

$$\begin{aligned}
&\min \tilde{\xi}, \\
&\text{s.t.} \quad \left| \frac{\tilde{w}_B}{\tilde{w}_i} - \tilde{v}_{Bi} \right| \leq \xi, \\
&\qquad \left| \frac{\tilde{w}_i}{\tilde{w}_W} - \tilde{v}_{iW} \right| \leq \xi, \\
&\qquad \sum_{j=i}^{n} \mathrm{GMIR}(\tilde{w}_i) = 1, \\
&\qquad l_i^w \leq m_i^w \leq u_i^w, \\
&\qquad l_j^w \geq 0, \\
&\qquad i = 1, 2, \ldots, n,
\end{aligned} \tag{1.5}$$

where $\tilde{w}_B = (l_B^{\tilde{w}}, m_B^{\tilde{w}}, u_B^{\tilde{w}})$, $\tilde{w}_i = (l_i^{\tilde{w}}, m_i^{\tilde{w}}, u_i^{\tilde{w}})$, $\tilde{w}_W = (l_W^{\tilde{w}}, m_W^{\tilde{w}}, u_W^{\tilde{w}})$, $\tilde{v}_{Bi} = (l_{Bi}, m_{Bi}, u_{Bi})$, $\tilde{v}_{iW} = (l_{iW}, m_{iW}, u_{iW})$, $\tilde{\xi} = (l^{\xi}, m^{\xi}, u^{\xi})$. Considering $l^{\xi} \leq m^{\xi} \leq u^{\xi}$, we assumed that $\tilde{\xi}^* = (k^*, k^*, k^*)$ and $k^* \leq l^{\xi}$. The programming model in Eq. (1.5) can be rewritten as:

$$\begin{aligned}
&\min \tilde{\xi}^*, \\
&\text{s.t.} \quad \left| \frac{(l_B^W, m_B^W, u_B^W)}{(l_i^B, m_i^B, u_i^B)} - (l_{Bj}, m_{Bj}, u_{Bj}) \right| \leq (k^*, k^*, k^*), \\
&\qquad \left| \frac{(l_i^W, m_i^W, u_i^W)}{(l_W^w, m_W^w, u_W^w)} - (l_{iW}, m_{iW}, u_{iW}) \right| \leq (k^*, k^*, k^*), \\
&\qquad \sum_{i=1}^{n} \mathrm{GMIR}(\tilde{w}_i) = 1, \\
&\qquad l_i^w \leq m_i^w \leq u_i^w, \\
&\qquad l_i^w \geq 0, \\
&\qquad i = 1, 2, \ldots, n.
\end{aligned} \tag{1.6}$$

By solving the programming model in Eq. (1.6), $\tilde{\xi}^*$ can be calculated and a fuzzy weight vector can be obtained, denoted as $\tilde{W} = \{\tilde{w}_1, \tilde{w}_2, \ldots, \tilde{w}_n\}$. Then, the consistency of the result should be checked. The consistency index (CI) with regard to different linguistic terms are listed in Table 1.2, which helps to calculate the consistency ratio (CR):

$$\mathrm{CR} = \frac{\xi}{CI} \tag{1.7}$$

Following the consistency check, the crisp value weights are derived by applying GMIR in Eq. (1.2) to the fuzzy weight vector $\tilde{W}$.

Table 1.2 Consistency index (CI) for fuzzy BWM

Linguistic terms	E	W	F	V	A
$\tilde{a}_{BW}$	(1, 1, 1)	(2/3, 1, 3/2)	(3/2, 2, 5/2)	(5/2, 3, 7/2)	(7/2, 4, 9/2)
CI	3.00	3.80	5.29	6.69	8.04

PROMETHEE II

PROMETHEE I and PROMETHEE II are two widely used methods within the PROMETHEE family [12]. While PROMETHEE I provides partial ranking, PROMETHEE II provides a complete ranking of alternatives from most preferred to least preferred. This complete ranking is appropriate in scenarios where decision-makers require a definitive prioritization of options, allowing clear choices to be made and facilitating the definition of policy or strategic directions.

The PROMETHEE II is calculated based on pairwise comparison under preference structure. Suppose there are m alternatives $\{a_1, a_2, \ldots, a_m\}$, the deviations between every two alternatives a_i, a_j on performances on criterion $c_{i'}, c_{i'} \in C$, denoted as $g_{i'}(a_i)$, $g_{i'}(a_j)$ are elicited based on a preference function:

$$P_i'(a_i, a_j) = \begin{cases} F_{i'}[d_{i'}(g_{i'}(a_i), g_{i'}(a_j))] & \text{for criterion to be maximized} \\ F_{i'}[-d_{i'}(g_{i'}(a_i), g_{i'}(a_j))] & \text{for criterion to be minimized} \end{cases}, \forall a_i, a_j \in A, \tag{1.8}$$

where $d_{i'}$ is the differences between alternatives on criterion c_i', denoted as:

$$d_{i'} = g_{i'}(a_i) - g_{i'}(a_j). \tag{1.9}$$

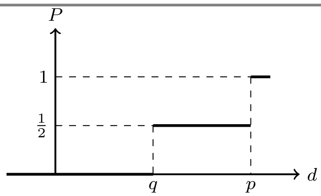
The preference ranges from 0 to 1, where a value of 1 signifies maximum preference and a value of 0 denotes a state of indifference between alternatives. It is important to note the following asymmetry in preference intensities:

$$P_i'(a_i, a_j) > 0 \implies P_i'(a_j, a_i) = 0, \tag{1.10}$$

which implies that if alternative a_i is preferred over a_j, then a_j cannot be preferred over a_i simultaneously. Regarding P, various preference functions corresponding to different generalized criteria have been proposed in the literature [21]. In this context, we present the Type 4 preference function utilized in our analysis, as illustrated in Table 1.3, where q is a threshold for indifference, p is a threshold of strict preference ($P_i'(a_i, a_j) = 1$).

Each alternative a_i is evaluated against the remaining $n - 1$ alternatives within the set A. In the context of PROMETHEE II, two distinct forms of outranking flows are calculated:

Table 1.3 Preference function used in the study

Generalized criterion	Criterion	Definition	Parameters to fix
Type 4: Level criterion		$P(d) = \begin{cases} 0 & d \leq q \\ \frac{1}{2} & q < d \leq p \\ 1 & d > p \end{cases}$	p, q

$$\begin{aligned} \phi^{+}(a_i) &= \frac{1}{n-1} \sum_{a_j \in A} \sum_{i'=1}^{n} P_{i'}(a_i, a_j) \times w_{i'} \quad \text{(Positive outranking flow)} \\ \phi^{-}(a_i) &= \frac{1}{n-1} \sum_{a_j \in A} \sum_{i'=1}^{n} P_{i'}(a_j, a_i) \times w_{i'} \quad \text{(Negative outranking flow)} \end{aligned} \tag{1.11}$$

where $w_{i'}$ is the criterion weight on criterion $c_{i'}$. In our study, $w_{i'}$ is elicited by fuzzy BWM. The positive outranking flow quantifies the extent to which an alternative a_i is preferred over all others in the set. It reflects the outranking character of the alternative. The larger the value of $\phi^{+}(a_i)$, the more preferable the alternative is considered. Conversely, the negative outranking flow measures the degree to which an alternative a_i is outranked by the others. It indicates the outranked character of the alternative. The smaller the value of $\phi^{-}(a_i)$, the better the alternative is considered.

Then, the net outranking flow is calculated:

$$\phi(a_i) = \phi^{+}(a_i) - \phi^{-}(a_i), \tag{1.12}$$

the higher the ϕ the better the alternative. All the alternatives are comparable. When $\phi(a_i) > 0, a_i$ is more outranking other alternatives on all criteria, and when $\phi(a_i) < 0$ it is more outranked.

Hybrid MCDA Framework

We present the hybrid MCDA framework for policy evaluation that integrates the fuzzy best-worst method (BWM) and PROMETHEE II. This framework is detailed in Fig. 1.1 and is divided into three main components. The first part involves problem structuring. Key elements here are the identification of alternatives and criteria. Alternatives, in our context the policies, are systematically outlined through an exhaustive literature review. Similarly, the criteria for evaluating the policies are

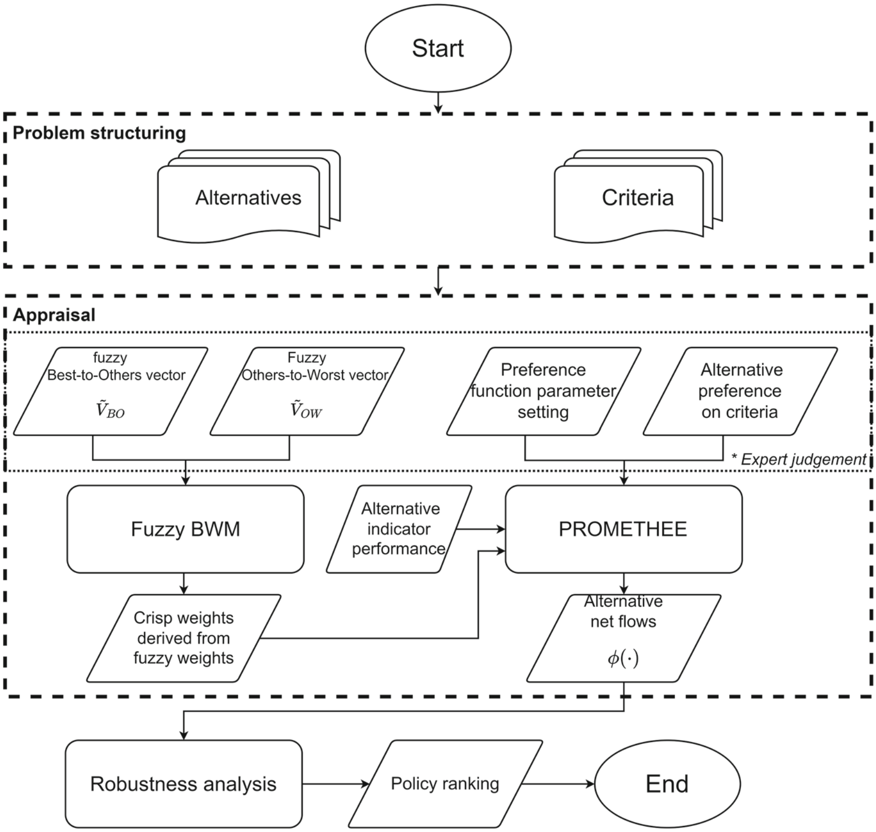


Fig. 1.1 Hybrid MCDA flow chart

determined through a comprehensive review of the relevant literature and, where necessary, consultation with subject matter experts.

The second part is about appraisal, which is divided into two parts. First, experts are consulted to determine the weights of the criteria using the fuzzy BWM process. This requires identifying the most and least important criteria, denoted as C_B and C_W, respectively. Experts use linguistic terms to make pairwise comparisons between criteria to form the fuzzy BO and OW vectors. The fuzzy BWM then yields crisp weights from these fuzzy ratings, which are then used as input weights in the PROMETHEE II analysis. The second step is to elicit preferences based on the PROMETHEE II method. Experts set parameters for the preference functions of each criterion and evaluate the performance of alternatives according to qualitative criteria. For criteria with quantifiable indicators, data are fed into the PROMETHEE II framework. PROMETHEE II identifies preferences among alternatives and calculates net flows. Given the focus of our study on socio-political dimensions, the qualitative nature of most of the criteria requires substantial reliance on expert judgment, underscoring the need for experts well versed in the research domain.

The final component is a robustness analysis, which is conducted to verify the reliability of the policy rankings with respect to the criteria weights. This phase ensures the credibility of the final rankings.

Swiss Energy Policy Evaluation

Policy Selection

In this study, we selected 15 signature policies for evaluation, as shown in Table 1.4. Eight solar and wind policies were selected from a comprehensive list of policies for their relevance to the ongoing energy crisis. These policies are notable because they are the most recent additions and have not previously been analyzed. In addition, seven critical geothermal policies were included due to their significant but challenging role as envisioned in the 2050 Energy Strategy [30]. The subset of policies related to the energy crisis is particularly interesting: they have been the subject of parliamentary debate, are regularly featured in the news, and therefore have considerable visibility. Surveys conducted during periods of intense public debate provide valuable insights [31].

Criteria Selection

In this study, we selected seven criteria on which to evaluate the policies. To do this, we conducted a literature review. An important starting point was the STEEPED wheel proposed in the *Guidelines for Foresight-Based Policy Analysis* of the European Parliament Think Tank [41]. STEEPED is an acronym for the seven areas the think tank proposed to consider: societal, technological, economic, environmental, political, ethical and demographic. Other important sources were the policy criteria identified by Nikas et al. through interviews with members of the Greek administration [42] and the analysis of the implementation barriers to the Swiss energy strategy by van Vliet et al. [43]. The risks in criteria c_1, c_2 and c_5 are so-called implementation risks. If they materialize, they hinder the implementation of the policy or render it ineffective. In contrast, the risks and benefits in c_3 and c_4 materialize as a consequence of implementing the policy and are therefore called consequential risks (or co-benefits). An important consequential risk in the socio-political dimension are the distributive effects of policies, especially in the context of climate and energy policy, because of enormous wealth and carbon inequalities which continue to grow [44]. We therefore included c_3, the risk of causing economic inequality in our analysis. Finally, c_6 and c_7 address the policy effect and cost (Table 1.5).

Table 1.4 Overview of energy policies

Code	Shortname	Technology	Description and references
a_1	Alpine Solar	Solar PV	Subsidize the construction of alpine photovoltaic installations until the end of 2025, aimed at boosting domestic winter energy production and advancing the country's energy transition [32]
a_2	PV Min. Price	Solar PV	A minimum electricity purchase price for small photovoltaic (PV) installations under 150 kWp to bolster investment security for smaller, costlier systems [33]
a_3	Mandatory PV	Solar PV	Mandate the installation of solar panels on the roofs and facades of new buildings exceeding 300 square meters of chargeable area, reflecting the country's commitment to sustainable energy practices [33]
a_4	Wind-Express	Wind	Emphasize streamlined development of additional electricity from storage hydroelectric power plants and wind energy, prioritizing national interest projects and simplifying legal processes for construction approvals [34]
a_5	Accel. Decree	Wind and Solar PV	Aim to expedite the planning and construction processes for large renewable energy power plants, through a proposed amendment to the Energy Act, to accelerate the expansion of production capacity [35]
a_6	Sliding Premium	Wind and Solar PV	Support renewable energy projects that contribute significantly to winter electricity production with a sliding market premium to ensure energy security and promote climate-neutral and reliable energy sources [33]
a_7	Green Bank	Geothermal, Wind and Solar PV	Facilitate renewable energy advancements by offering low-interest loans and fostering a supportive financial environment for particularly small-scale geothermal projects and other emerging technologies [36]
a_8	Geo Invest	Geothermal Energy	Provide up to a 60% investment contribution or guarantee for the exploration and development of geothermal resources, as well as for the construction of geothermal plants that produce both electricity and heat [37]
a_9	Geo Licensing	Geothermal Energy	Aim to streamline and harmonize the permitting process for medium and deep geothermal energy projects, reducing the complexity and duration of licensing to mitigate project risks related to time and capital expenditure.
a_{10}	Geo Participation	Geothermal Energy	Mandate local community involvement, through voting and economic shares, in all phases of subsidized geothermal projects to bolster support, reduce opposition, and enhance public acceptance [38]

(continued)

Table 1.4 (continued)

Code	Shortname	Technology	Description and references
a_{11}	AGS Pilots	Geothermal Energy	Expand funding for advanced and enhanced geothermal systems pilot plants, providing up to 100% coverage of non-amortisable investment costs to support the economic viability of geothermal energy in Switzerland
a_{12}	Drilling Research	Geothermal Energy	Advocate for funding research to refine drilling processes and technologies, aiming to reduce both the costs and environmental risks associated with drilling, thereby enhancing public support for these initiatives [39]
a_{13}	Wind in Forests	Wind	Ease the building permit process for wind power projects in forests, which allows for permits even outside of designated building zones. [33]
a_{14}	Elec. Communities	Wind and Solar PV	Enable the formation of local renewable energy communities, where nearby users, producers, and storage operators collaborate to trade electricity internally and enjoy up to 60% lower grid surcharges [33]
a_{15}	Heating Incentives	Geothermal Energy	Encourage both municipalities and households to adopt geothermal district heating as part of a comprehensive federal heating strategy, offering incentives to support the transition [40]

Expert Elicitation

After identifying policies for evaluation and defining criteria, we invited an expert known for his extensive background to elicit preferences. This expert, currently based at the Paul Scherrer Institute (PSI) in Switzerland, has over 15 years of experience in a wide range of energy modeling research projects. His expertise covers a wide range, including energy supply (e.g., oil and gas projects), conversion processes (e.g., power grids), and demand scenarios (e.g., buildings and transportation). In addition, he is well versed in conducting integrated sustainability assessments. His expertise is further underscored by his participation in numerous energy policy workshops with key Swiss stakeholders.

For the initial phase of the process, the expert was tasked with eliciting the weights of criteria using the fuzzy BWM. He identified c_7 “subsidy cost efficiency of the technology” as the most important criterion (best criterion), while c_1 “risk: bureaucratic burden” was considered the least important criterion (worst criterion). The expert then made pairwise comparisons of all the other criteria, using linguistic terms for evaluation. These comparisons are documented in Table 1.6.

Through the application of the fuzzy BWM, we obtained the fuzzy weight vector $\tilde{W}$. Subsequently, the crisp criteria weights are computed utilizing the GMIR. Detailed results from the fuzzy BWM are presented in Table 1.7, with all values

Table 1.5 Overview of the criteria

Code	Criterion	Description
c_1	Risk: Bureaucratic burden	Risk that the policy will not materialize or will be ineffective due to the complexity of the bureaucratic processes required to implement or enforce the policy
c_2	Risk: Favorability of market conditions	Risk of a lack of investment or policy abandonment caused by a regulatory framework which is too demanding compared to market maturity, or caused by the shock of an economic crisis
c_3	Risk: Increasing economic inequality	Risk that the policy will have a greater negative impact on the quality of life of people in the bottom third of income and wealth than those in the top third
c_4	Co-Benefit: Swiss energy technology industry	Magnitude of the positive effect on the national energy technology industry and on increasing its competitiveness
c_5	Risk: Public referendum rejection	Risk that the policy will be rejected in a referendum.
c_6	Policy Effect	Estimated policy effect in terms of additional GWh/y installed or CO2 reduced, in the absence of implementation risks
c_7	Subsidy cost efficiency of the technology	Subsidy per kWh of the technology that is incentivized by the policy, as an approximation of the consequential costs divided by the effect of the policy

Table 1.6 Linguistic BO and OW pairwise comparison vectors

BO	c_1	c_2	c_3	c_4	c_5	c_6	c_7
Best criterion: c_7	A	V	V	F	W	E	E
OW	c_1	c_2	c_3	c_4	c_5	c_6	c_7
Worst criterion: c_1	E	V	V	W	F	A	A

rounded to three decimal places. Notably, the Consistency Ratio (CR) of the model is 0.100, indicating that it satisfies the threshold for consistency.

Next, the expert did the evaluation of alterantives with PROMETHEE II. As the socio-political criteria are measured based on expert judgement, estimation based on literature or internal discussion, all scores are given in a 5-point scale. And the expert agreed that the preference is evaluated based on type 4 preference function. When the difference of policies on criteria is equal to 1, it produce 0.5 preference; when the difference is larger than 1, it produce maximum preference, i.e. 1. The detailed preferences, parameters in PROMETHEE is illustrated as Table 1.8.

Table 1.7 BWM result

		c_1	c_2	c_3	c_4	c_5	c_6	c_7
	l	0.052	0.100	0.100	0.084	0.125	0.180	0.246
Fuzzy weights	m	0.054	0.118	0.118	0.095	0.147	0.201	0.259
	u	0.058	0.143	0.143	0.115	0.170	0.248	0.273
Crisp weights		0.054	0.119	0.119	0.096	0.147	0.205	0.259

Table 1.8 PROMETHEE data

Criterion name	c_1	c_2	c_3	c_4	c_5	c_6	c_7
Orientation	min	min	min	max	min	max	max
Preference function	Type 4	Type 4	Type 4	Type 4	Type 4	Type 4	Type 4
p	1	1	1	1	1	1	1
q	0	0	0	0	0	0	0
a_1	2	3	3	4	3	5	3
a_2	2	2	3	3	1	2	5
a_3	3	3	4	3	2	2	5
a_4	3	3	1	2	3	1	4
a_5	4	3	3	2	2	3	4
a_6	2	2	3	3	1	4	4
a_7	2	2	1	4	2	3	4
a_8	2	2	2	4	3	2	4
a_9	4	3	1	2	3	2	4
a_{10}	4	3	2	2	1	2	4
a_{11}	2	4	1	4	3	1	1
a_{12}	1	4	1	4	1	1	1
a_{13}	4	3	1	2	2	3	4
a_{14}	2	2	3	3	2	2	5
a_{15}	3	3	3	3	1	3	4
Criterion weight	0.054	0.119	0.119	0.096	0.147	0.205	0.259

Table 1.9 PROMETHEE II result

Alternative Name	a_1	a_2	a_3	a_4	a_5	a_6	a_7	a_8
Net flow	0.020	0.196	−0.014	−0.198	−0.072	0.266	0.274	0.033
Alternative Name	a_9	a_{10}	a_{11}	a_{12}	a_{13}	a_{14}	a_{15}	
Net flow	−0.130	−0.032	−0.389	−0.210	0.052	0.117	0.086	

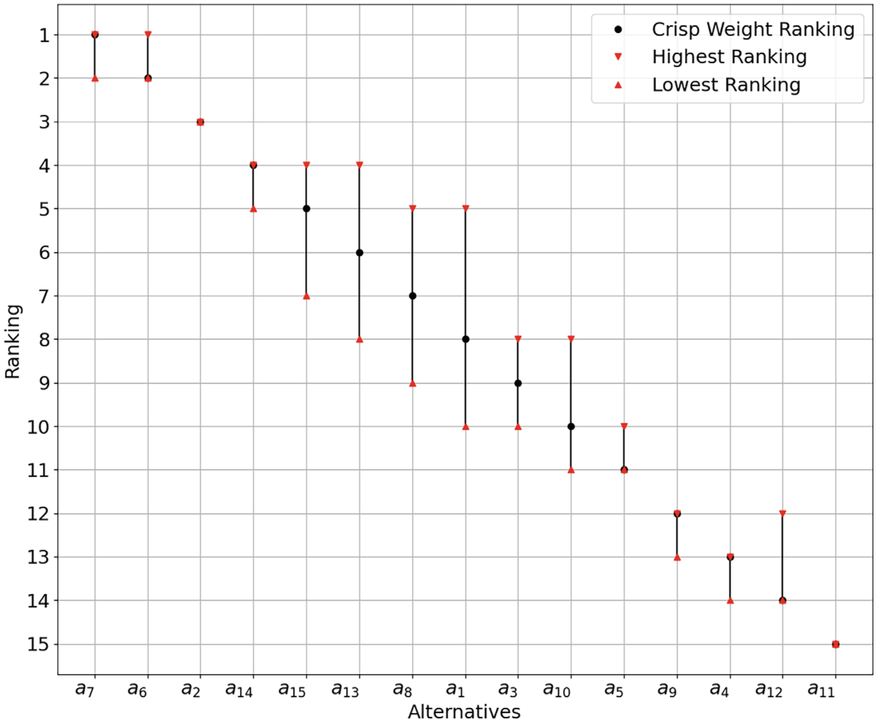


Fig. 1.2 Boundary rankings of alternatives

Result and Discussion

After obtaining all necessary data, PROMETHEE II is applied to calculate the preference values of alternatives (see Table 1.9), where the crisp weights derived from fuzzy BWM is used. As we applied fuzzy BWM, where the weights are elicited based on linguistic terms, it is necessary to test the robustness of the policy ranking. We take the lower and upper bound of weights from the fuzzy BWM into account, validate the maximum and minimum ranking of all alternatives, based on a series of optimization models. Figure 1.2 illustrates the range rankings of the alternatives.

Based on the ranking chart and the detailed descriptions of the energy policy alternatives, we can draw several insights. The consistently high ranking of the *Green*

Bank initiative (a_7), with its focus on financial incentives for renewable projects, highlights a shared conviction regarding the importance of fiscal strategies in fostering renewable energy adoption. The limited variation in its ranking points to a perceived reliability and broad-based endorsement of the policy.

Similarly, the *Sliding Premium* (a_6) and *PV Min. Price* (a_2) policies demonstrate strong and stable rankings, confirming their perceived efficacy and beneficial role within the socio-political landscape. These subsidy-oriented measures are deemed to be highly advantageous, reflecting their alignment with public policy objectives and the expectations of stakeholders.

On the other hand, geothermal policies such as *Geo Invest* (a_8), *Drilling Research* (a_{12}), *Geo Licensing* (a_9), and *Geo Participation* (a_{10}) are positioned lower in the ranking hierarchy, potentially signaling specific challenges or hurdles within this sector. Even though policies like *Heating Incentives* (a_{15}) and *Geo Participation* (a_{10}) exhibit a slight improvement in ranking, the substantial variability attached to them underscores ongoing concerns regarding their viability and acceptance.

Additionally, policies such as *Alpine Solar* (a_1) and *Wind in Forests* (a_{13}) manifest a wide range of rankings, which reflects the ongoing deliberations or uncertainties associated with their implementation. This disparity in rankings necessitates a careful consideration of the potential benefits against the backdrop of economic and environmental considerations. Such an evaluation is crucial to navigating the complexities inherent in striking a balance between economic viability and the overarching goals of sustainability.

In summary, the results suggest a strong case for policies that support the financial viability of renewable energy projects, particularly solar PV and wind. However, they also point to the need for greater clarity and support for geothermal initiatives, which currently have less preference and confidence.

Conclusion

In the quest for sustainable development and climate neutrality, nations worldwide are confronted with the challenge of transitioning to renewable energy sources while ensuring energy security and economic viability. Switzerland, with its strong commitment to environmental stewardship and energy independence, despite its ambitious goals, the country faces significant hurdles in aligning its energy policies with the dual imperatives of climate neutrality and energy security. Within this context, the socio-political dimension of energy policy emerges as a critical factor.

In this study, we delve into the details of Switzerland's energy policy framework through a comprehensive analysis using a hybrid MCDA approach that integrates the fuzzy BWM with the PROMETHEE II technique. This methodological hybrid allows for a nuanced assessment of different energy policy alternatives, shedding light on their potential impacts and the complex socio-political considerations that shape policy decisions. By examining a selection of fifteen energy policy alternatives, ranging from solar PV and wind power initiatives to geothermal energy investments, this research provides critical insights into the effectiveness and societal acceptability of these strategies. The expert found the hybrid MCDA framework to be straightforward and particularly appreciated the use of linguistic terms in the fuzzy BWM, which were easy to understand and thus facilitated the weight elicitation process.

Our findings underscore the vital role of economic incentives in fostering renewable energy adoption, as evidenced by the strong preference of subsidy-related policies such as the *Green Bank*, *Sliding Premium*, and *PV Min. Price*. Conversely, the analysis reveals the challenges facing geothermal energy policies, highlighting the need for targeted support and regulatory refinement to unlock the potential of this sector. The variability in the rankings of certain policies underscores the inherent uncertainties in evaluating socio-political criteria within the fuzzy context of MCDA. Due to the high variability of the ranking, especially the polices in the middle of the rank, it maybe valuable to apply sorting technique to categorize the policies.

Several possible extension of the work can be done in the future. It is valuable to explore the other forms of fuzzy logic in BWM methods to compare its ability to better represent the preferences of DMs. Several other Fuzzy BWM are proposed but haven't been applied in the energy sector. For example, Amiri et al. prposed another forms of Fuzzy BWM based on triangular fuzzy numbers (TFN) [45], Zeng et al. proposed a trapezoidal fuzzy BWM [46]. The validation of these methods can enhance the robustness and applicability of fuzzy BWM in dealing with fuzzy numbers. Future studies will also aim to involve a more diverse panel of experts or stakeholders to represent a wide array of viewpoints involved in the energy transition. For example, it can be applied in the multi-actor multi-criteria analysis (MAMCA) framework [47, 48], to capture the complexity of socio-political dynamics more effectively and identify possible consensus [49]. Furthermore, acknowledging that some policies may complement each other, it is possible to frame the problem as a portfolio selection issue in subsequent studies. We could possible to apply portfolio selection method for example PROMETHEE V to examine potential synergies between policy alternatives, thereby offering insights into optimal policy mixes that can collectively achieve Switzerland's energy security and climate neutrality goals more efficiently [50].

In conclusion, this paper contributes to the ongoing discourse on energy transitions by providing a methodologically robust framework for evaluating energy policies in the Swiss context. The insights derived from this analysis not only inform policy development and implementation in Switzerland, but also provide valuable framework for navigating the energy transitions. Going forward, the integration of technical, economic, and socio-political analyses will be essential to evaluate effective, equitable, and sustainable energy policies that resonate with a wide range of stakeholders and advance the global agenda for climate neutrality and sustainable development.

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