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# Multi-Criteria Analysis of Water Resources Planning Options

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## KEY FINDINGS

Multi-Criteria Analysis (MCA) methods based on PROMETHEE can be applied for informed and transparent decision-making in water resources planning.

The analysis of water production and transfer strategies reflects Jordanian and Palestinian stakeholders' desire for water independency through seawater desalination at Gaza and Aqaba. Highly ranked were also combined options of Gaza/Netanya for the West Bank and Haifa/Aqaba for Jordan, which are more cost effective.

For desalination plant concepts at the Mediterranean Sea, alternatives in proximity to the shore are preferred due to lower capital requirements and costs. Offshore concepts perform better on environmental criteria while being less economical.

For Aqaba, desalination concepts with energy supply from photovoltaics and additional molten salt storage perform well overall. Weaknesses are the technical complexity, higher energy demand and impact of brine discharge.

A general preference for centralized wastewater systems has been identified. For decentralized systems, providing more funding opportunities might improve the political acceptance.

## MOTIVATION

Palestine and Jordan, despite great efforts to use local water resources efficiently, suffer from considerable water shortages in all sectors. Over the coming years, this water shortage is expected to worsen so that effective countermeasures are urgently required. Due to the large set of possible technological solutions and the large spatial extent of the resulting water infrastructure solutions, the design and assessment of the water infrastructure system is a complex task. Water resources planning options consist of seawater desalination plants and their respective energy supply systems, water transfer pipelines and electro-mechanical equipment, such as pumping stations. Furthermore, a strategy for the expansion of wastewater systems is to be defined and associated infrastructure solutions are to be assessed.

Due to the broad temporal scope and the inherent complexity of the decision problem, multiple possible consequences must be considered simultaneously in the decision process, taking various criteria into account, such as the cost, environmental sustainability or public and political acceptance of a project. Therefore, the assessment of water resources planning options in SALAM is conducted via selected methods of Multi-Criteria Analysis (MCA) to allow for an informed and transparent decision.

The goal of this work is to structure the decision problem and elicit the preferences and objectives of the decision makers and stakeholders. Likewise, the performance of different water resources planning options on these objectives are determined and aggregated in the assessment to identify preferred options. Special emphasis is put on the consensus-building between the stakeholder groups involved. Strengths and weaknesses of water resources planning options are highlighted and uncertainty in the underlying assumptions is assessed by sensitivity analysis.

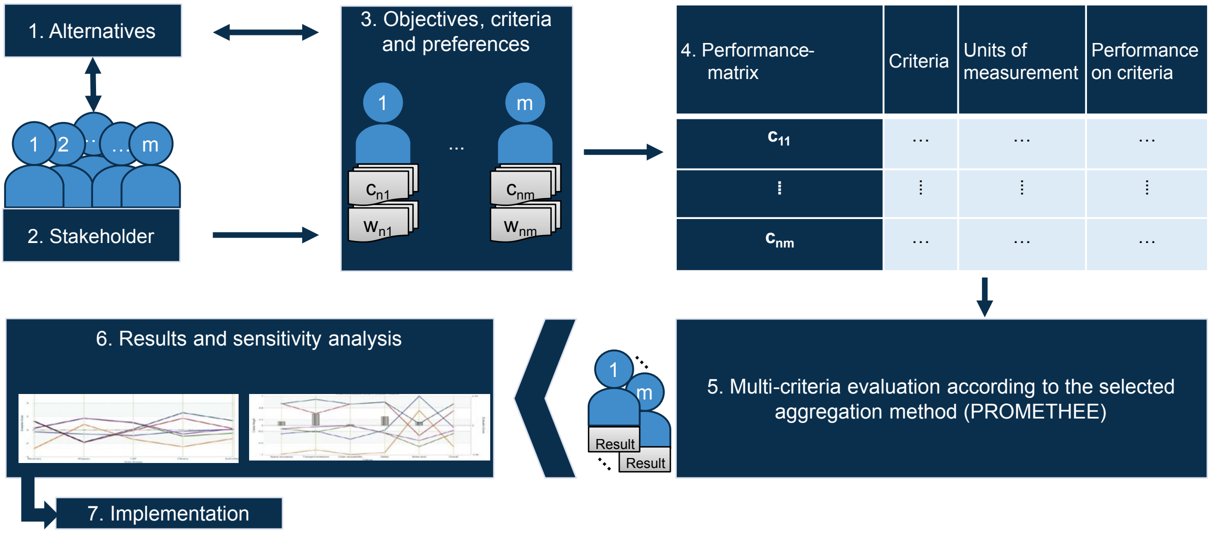


Figure 1: General framework of multi-criteria decision support in SALAM. The framework is adapted and extended from Macharis et al. (2009).

MCA provides a sound basis for the following strategy implementation. Since conducting an MCA can also facilitate the process of refining the current set of options, directions for future research are given. In more general terms, the results presented should not be viewed in a normative manner, but as an informed starting point to facilitate the decision process. This is achieved by increasing the transparency of the decision process and explicating the strengths and weaknesses of options to ultimately facilitate consensus building and actual implementation of options.

## METHODOLOGY

Within this project, we applied selected MCA methods in close cooperation with project partners, decision-makers and stakeholders, in order to demonstrate the potential of MCA for decision makers in the project region. The framework is summarized in Figure 1. The aim of MCA methods is to support one or more decision-makers in evaluating different options, henceforth called alternatives, regarding multiple often conflicting criteria given in different units of measurement. Furthermore, this allows to manage the inherent complexity of a decision problem in a structured manner (Belton and Stewart 2002). The method has already been applied often in environmental management problems.

In the first step, we employed the strategy generation table method (Howard 1988) to structure the general and broad decision context of water resources planning options into manageable sub-decisions, and to iteratively screen for alternatives in each subset. Table 1 provides an overview on the decision problems and respective alternatives assessed during the SALAM Initiative. For a description of these alternatives we refer to the Policy Briefs of the corresponding partner institutions.

In the next steps, stakeholders' objective systems and preferences were elicited during multiple onsite workshops and online surveys. Elicitation was conducted according to the revised Simos method, also known as the method of cards (Figueira and Roy 2002). Based on the results, the objective systems were organized in a hierarchical manner, with overarching objectives from the technical, economic, environmental, social and political domain at higher hierarchy levels and more operational, measurable criteria at the lowest level of the hierarchy. Preferences map the relative importance a stakeholder allocates to the respective criteria. For each stakeholder group and each decision problem, a dedicated criteria hierarchy and preference modelling has been established.

The alternatives for each subset of the strategy generation table and their performance on the identified criteria has been determined in collaboration with the German and regional partner institutions from the project consortium. The collected information was then synthesized in performance matrices to conclude step four.

The ranking of alternatives in the following step five was conducted according to the Preference Ranking Organization METHod for Enrichment Evaluation (PROMETHEE) (Brans and de Smet 2016). PROMETHEE is an established outranking method, and we chose it for this particular case since comparison of alternatives on criteria with different units of measurement (e.g., kWh/$m^3$ and \$/$m^3$) is explicitly allowed. Furthermore, PROMETHEE allows for comprehensive sensitivity analysis as part of the results evaluation.

## RESULTS

We applied the MCA procedure based on preliminary results elicited with SALAM project partners. It should be noted that MCA is an iterative process, and that the ranking yielded has to be rediscussed with the decision makers. In the following, selected and exemplary results are

| DECISION PROBLEM | DECISION ALTERNATIVES FOR EACH DECISION PROBLEM IN THE SALAM INITIATIVE | | | | |
|---|---|---|---|---|---|
| Desalination plant near Haifa | Land reclamation | 1 km offshore at 12 m water depth | 5 km offshore at 30 m water depth | | |
| Desalination plant near Netanya | Onshore plant | 1 km offshore at 12 m water depth | 2.5 km offshore at 30 m water depth | | |
| Desalination at the Red Sea | New plant at Aqaba Port combined with existing power plant | New plants at Wadi Araba & Aqaba | New plant at Aqaba with PV and molten salt storage | New plants at Dead Sea & Aqaba | |
| Wastewater Management System Expansion | Decentralized Expansion | Centralized Expansion | Mixed expansion (cost-efficient solution) | | |
| Transboundary Water Production and Transfer Strategies | Supply via Netanya and Aqaba (Alternative 1b) | Supply via Gaza and Aqaba (Alternative 2 + 4) | Supply via Haifa and Aqaba (Alternative 3d) | Supply via Gaza, Netanya, Haifa and Aqaba (Alternative 2b + 3e) | Cost-minimal alternative (Alternative Cost Min) |

Table 1: Overview on decision problems in the SALAM Initiative and identified sets of alternatives for each decision problem. The alternatives are detailed in [On- and Offshore Solutions for Large-Scale Seawater Desalination at the Mediterranean Coast, p. 26], [Renewable Energy for Seawater Desalination in the Middle East: Case Study Aqaba, Jordan, p. 30], [Water Production and Transfer Strategies, p. 22], [Regional Wastewater Infrastructure Development Strategies for Jordan and Palestine, p. 40]

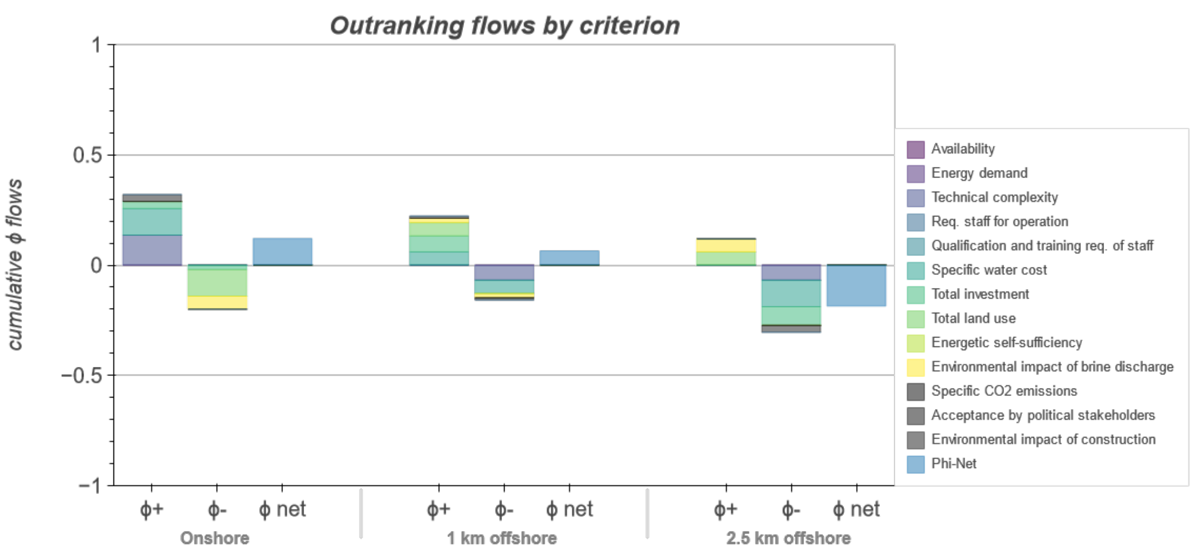


Figure 2: Evaluation of different seawater desalination concepts at the Mediterranean Sea according to PROMETHEE and performance on each of the criteria.

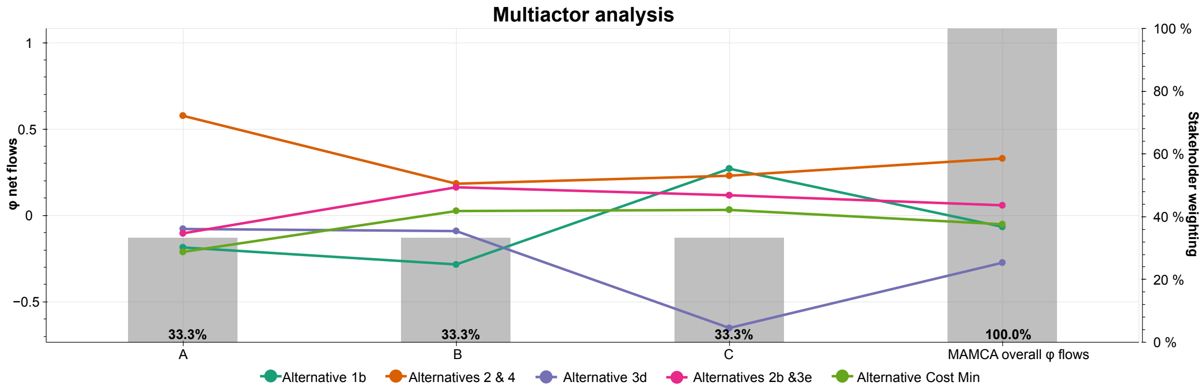


Figure 3: Multi-actor analysis across all stakeholders involved. It shows the net flows per stakeholder according to PROMETHEE and the overall ranking of alternatives.

presented. These results are based on the current state of the elicited data which may not be regarded as fully representative. Nevertheless, this does only affect the implications to be derived from the results, which may change with higher data accuracy, and not the general procedure and its usefulness in such decision contexts.

The PROMETHEE outranking flows express the strengths and weaknesses of each alternative. Positive outranking flows ($\Phi_+$) indicate how much an alternative dominates other alternatives across the different criteria, and negative outranking flows ($\Phi_-$) indicate how much it is dominated by other alternatives. Aggregating positive and negative outranking flows yields the net flow ($\Phi_{net}$), which is also used to rank alternatives.

To showcase, for an assessment of three different desalination plant concepts at the Mediterranean Sea, alternatives in proximity to the shore are ranked highest, indicated by higher net flows as visualized in Figure 2. Furthermore, PROMETHEE allows the breakdown of outranking flow contributions on a criterion level. This provides insight into the performance of the alternatives on each criterion and is displayed by the colored bar sections in Figure 2, while $\Phi_+$ contributions denote preference and $\Phi_-$ contributions indicate weakness of an alternative regarding the respective criterion. The main reasons for preference of near and onshore concepts in this case are the lower capital requirements and water costs. Offshore plants at high water depths perform better on the environmental criteria but are also associated with higher investments and costs.

For Transboundary Water Production and Transfer, five alternatives have been evaluated. In SALAM, three different stakeholder groups were considered. At first, evaluation was conducted for each stakeholder on an individual level, before results were aggregated across stakeholders for consensus evaluation. In Figure 3, the results of this MCA aggregation over all stakeholders are displayed as well as the individual evaluations. Each stakeholder group was granted an equal weight. Alternatives 2 & 4 (Gaza to supply West Bank/Aqaba to supply Jordan) and 2b & 3e (Gaza and Netanya to supply West Bank/ Haifa and Aqaba to supply Jordan) are preferred overall, while the Cost Min alternative (Netanya and Ashdod to supply West Bank/ Haifa and Aqaba to supply Jordan) performs consistent across all stakeholder groups.

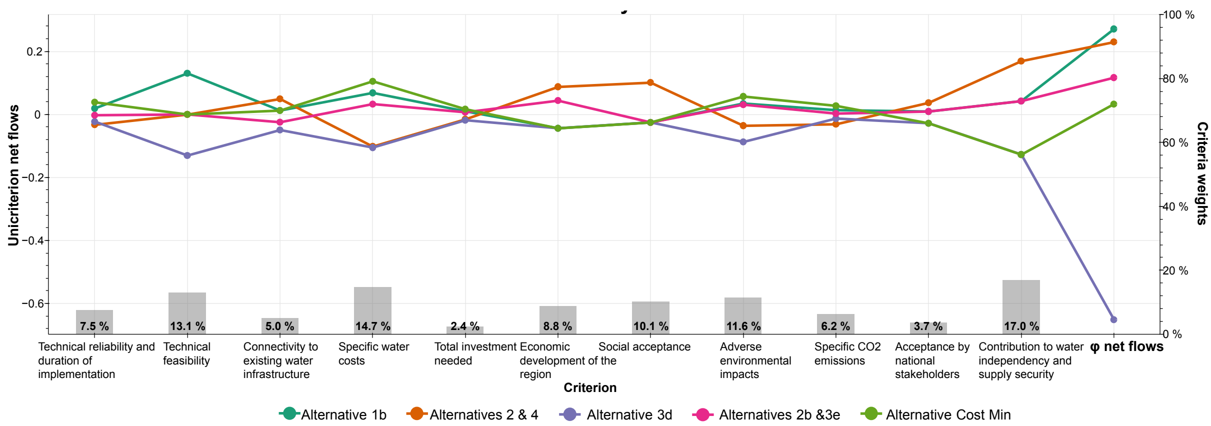


Figure 4: Intrastakeholder analysis for stakeholder C. The net flow contributions per criterion (unicriterion net flows) highlight the specific strengths and weaknesses of alternatives. Furthermore, elicited criteria weights are displayed.

Since reaching consensus is crucial for the transboundary alternatives considered in SALAM, the evaluation across all stakeholders is of particular importance. Noticeably, Alternative 1b is preferred by stakeholder C, while ranking low for stakeholders A and B in the above mentioned case. Therefore, an intrastakeholder analysis has been conducted. This additional analysis layer of the applied MCA framework may help in revealing each stakeholders' crucial trade-offs and indicates compromise options. Figure 4 depicts the intrastakeholder analysis for stakeholder C and shows that the strong performance on the technical and economic criteria leads to an overall preference, while the higher water costs for stakeholder C in Alternative 2 & 4 are responsible for the comparatively weaker preference of this alternative.

Moreover, three generic expansion alternatives for Wastewater Management in Jordan were examined. According to the preliminary results of the MCA, Jordanian stakeholders prefer a centralized expansion of the wastewater management system. Even if a decentralized expansion performs better on environmental criteria and requires fewer trunk lines, stakeholders associated it with a lower political acceptance and voiced difficulties to acquire funding.

## CONCLUSIONS

The goal of our work was to provide a framework for decision support in water resources planning by structuring the decision problem, eliciting stakeholders' preferences and objectives and identifying potentially preferred alternatives. The framework should enable decision-makers to consider diverging objectives of different stakeholder groups and provide aid for consensus building. For this purpose, selected Multi-Criteria Analysis (MCA) methods based on PROMETHEE have been adopted to suit the context of SALAM and applied using preliminary project data to showcase the frameworks' contribution for informed and transparent decision-making. The MCA process developed in this work should help decision-makers and water planners to take informed decisions regarding water infrastructure planning.

Results highlighted how the framework can be used to reveal the alternatives' strengths and weaknesses across multiple stakeholders. This may facilitate the process of reaching consensus between all stakeholders and foster a decision's acceptance, like the evaluation of Transboundary Water Production and Transfer strategies demonstrated. The evaluation of different desalination plant sites and concepts at the Mediterranean and Red Sea revealed potential preference for novel concepts, incorporation of offshore solutions and renewable energy technologies and energy storage.

Nevertheless, some remarks have to be made. From a methodological point of view, preference elicitation procedures like the method of Simos are easy to apply and can lessen stakeholders' cognitive stress associated with translating preferences to numerical criteria weights. However, these interactive procedures can also lead to ambiguous preference mappings and an instable ranking of alternatives because of their design. For the decision problems addressed above, rank robustness analysis show that the evaluation is highly sensitive to slight changes in criteria weights and performance values. Since we applied the MCA procedure based on preliminary data from the current project phase, additional feedback by stakeholders is required to confirm or refine the preference model presented in this work before drawing further implications.

Besides, a more detailed design and techno-economic assessment of Wastewater System expansion variants is now required to advance decision-making in this context after the preliminary assessment in this project phase. In this sense, conducting the MCA allows to refine selected Water Resources Planning Options based on the elicited objectives and preferences of the stakeholders.

### PROMETHEE CLOUD

The MCA evaluations have been carried out using the PROMETHEE-Cloud, a software tool developed by the University of Duisburg-Essen. PROMETHEE-Cloud is a web-based implementation of the PROMETHEE set of methods with comprehensive evaluation and sensitivity analysis features along with intuitive visual representations of the results. The tool is structured according to the general procedure of an MCA, starting with the creation of a performance matrix. Furthermore, it provides the opportunity to export the results and visualizations created, and contains elements of interactive guidance which makes it user-friendly. Using the tool allows decision makers to simultaneously take different objectives into account and get an overview of the strengths and weaknesses of the different alternatives under consideration. All visualizations provided by the PROMETHEE-Cloud can be exported in common graphics formats.

The PROMETHEE-Cloud can be accessed via the SALAM IES or directly on https://promethee.pom.uni-due.de/.

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**References**

Belton, V., & Stewart, T. (2002). Multiple criteria decision analysis: an integrated approach. Springer Science & Business Media.

Brans, J. P., & De Smet, Y. (2016). PROMETHEE methods. In Multiple criteria decision analysis (pp. 187-219). Springer, New York, NY.

Figueira, J., & Roy, B. (2002). Determining the weights of criteria in the ELECTRE type methods with a revised Simos' procedure. European journal of operational research, 139(2), 317-326.

Howard, R. A. (1988). Decision analysis: Practice and promise. Management science, 34(6), 679-695.

Macharis, C., De Witte, A., & Ampe, J. (2009). The multi-actor, multi-criteria analysis methodology (MAMCA) for the evaluation of transport projects: Theory and practice. Journal of Advanced transportation, 43(2), 183-202.