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Water–Energy Nexus: Addressing Stakeholder Preferences in Jordan

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Abstract: The water and energy sectors are fundamentally linked. In Jordan, especially in the face of a changing climate, the water–energy nexus holds a number of challenges but also opportunities. A key point in exploring synergies is the identification of such, as well as the communication between the water and energy sectors. This paper promotes the importance of using a co-creative approach to help resolve opposing views and assessing stakeholder preferences in the context of the water–energy nexus in Jordan. A computer-supported, co-creative approach was used to evaluate stakeholder preferences and opinions on criteria and future scenarios for the energy and water sector in Jordan, identifying common difficulties and possibilities. The criteria describe socio-ecological aspects as well as techno-economic aspects for both systems. Discussing a set of preliminary scenarios describing possible energy and water futures ranked under a set of sector relevant criteria, a consensus between both stakeholder groups is reached. The robustness of results is determined, using a second-order probabilistic approach. The results indicate that there are no fundamental conflicts between the energy and water stakeholder groups. Applying a participatory multi-stakeholder, multi-criteria framework to the energy-water nexus case in Jordan promotes a clear understanding of where different stakeholder groups stand. This understanding and agreement can form the basis of a joint water–energy nexus policy used in the continued negotiation process between and within national and international cooperation, as well as promoting and developing acceptable suggestions to solve complex problems for both sectors.

Keywords: water–energy nexus; Jordan; energy policy; multi-criteria decision analysis; participatory governance and co-creation; compromise-oriented policy solutions

1. Introduction

The water and energy sectors are interconnected and fundamentally linked. Energy generation requires water. Water treatment and transportation consume energy. The newfound understanding of the water–energy nexus can identify challenges and opportunities. One key factor here is a comprehensive dialogue between sectors. A participatory governance approach, as presented here, including multi-criteria decision analysis, aids in exploring synergies and facilitates dialogue in the first place.

Jordan is facing several energy and environmentally related problems as one of the driest countries on earth. With 150 m^3/year, it has one of the lowest levels of water resource availability per capita [1]. Water scarcity will become a more pressing issue in the context of climate change with unpredictable intensity, duration, and frequency of precipitations, rising temperatures, and evaporation rates. Additionally, there are challenges regarding current patterns of water usage in the country as well as the large number of Syrian refugees in Jordan [2]. The sustainability of water supply in Jordan is not only affected by depleting water reserves but also by growing electricity tariffs. Water pumping systems are consuming 15% of the total electricity, making the Water Authority of Jordan (WAJ) the largest electricity consumer [3]. In the last decade, tariffs for electricity were growing steadily whereas tariffs for water remained the same. The division between revenues in the form of water tariffs and expenses in the form of costs for electricity threatens the financial sustainability of WAJ.

Given the number of possible synergies, there is currently limited dialogue between the two sectors, leading to very few cooperations between the water and energy sectors. A water–energy nexus in Jordan could, for example, mean renewable energies providing the electricity needed for water pumping systems. Existing feasibility studies show that such solutions could significantly reduce electricity generation costs [4]. The saved budget can be used for, e.g., investments in improved water pumping systems to avoid water losses. In the energy sector, the utilization of existing water basins as hydro energy storage systems, given suitable geographical features, can facilitate further deployment of renewable energies. However, implementations of participatory governance solutions require trade-offs in both water and energy policies.

This paper discusses how a participatory governance approach can contribute to and increase sustainability in the water sector as well as the energy sector. The results described here are the outcome of stakeholders' interactions at a workshop with relevant parties of the Jordanian water and energy sectors such as the Water Authority of Jordan (WAJ), National Electric Power Co (NEPCO), Energy & Minerals Regulatory Commission (EMRC), Aqaba Water Company (AWC), Ministry of Energy and Mineral Resources (MEMR), Ministry of Water and Irrigation (MWI), and Yarmouk Water Company (YWC) as well as scientific partners such as University of Jordan (UJ) and international participants such as Europa Universität Flensburg (EUF) and International Institute for Applied systems analysis (IIASA) in Amman, Jordan in October 2019. The workshop was supervised by GIZ, EUF, IIASA, and UJ and established in expert-led break-out groups, discussing techno-economic aspects of the energy and water system followed by a multi-criteria decision analysis (MCDA) to evaluate social-ecological aspects, preferences on a number of criteria important for both sectors as well as technical specifications and synergies for systems' solutions.

2. Background

The water–energy nexus is a complex problem that requires upgrading existing infrastructure, changes in legal and institutional frameworks, new technological solutions, and new forms of cooperation between various stakeholders involved in the energy and water sectors. There is no fixed definition for the water–energy nexus. It merely describes the interdependencies between the water and energy sectors. The first generation of nexus research focused on quantitative input-output modelling to empirically demonstrate interdependencies and options for optimizing resource management; currently, the number of scientific works on how nexus approaches are conditioned by property rights regimes, economic growth strategies based on resource extraction, and the ability to externalize environmental costs to other regions and states [5].

It became and is becoming increasingly necessary to respond to the production and consumption trade-offs, which have emerged with the increase of scarcity and competition over the last decades. The nexus highlights the need to study and develop the use and management of both resources in a joint way. Prerequisite to technological solutions, infrastructure developments, or even legal frameworks in the nexus context is a profound understanding of joint challenges and opportunities and the will to cooperate between the relevant stakeholders. This is facilitated through participatory governance methods and multi-criteria decision-making exercises to find a consensus and important criteria for the nexus.

While studying the energy-water nexus in the Middle East and North African region, [6] a highly skewed coupling of water and energy was found, with a relatively weak dependence of energy systems on freshwater, but a strong dependence of water abstraction and production systems on energy.

2.1. The Energy Sector

Currently, about 39% of the primary energy is used for electricity generation, with smaller shares for transport, heating, industrial use, and others. In 2018, renewable energy projects contributed to 10.8% of the generated electricity and 23% of the total installed capacity [7]. In 2018; about 82% of Jordan's electricity was supplied by imported oil, 12% by imported natural gas, while only about 8% were covered by renewable energy resources [8], which is an increase from only 2% (Renewable Energy Sources) RES in 2013 [9]. The aim for 2020 is to generate 20% of electricity by RES, 15% by oil shale, and to reach 30% renewable energy generation by 2022 [9]. Table 1 below lists some key figures from the energy sector in recent years.

Table 1. Key figures from the energy sector in recent years.

	Peak Load (MW)	Available Capacity (MW)	Generated Energy (GWh)	Consumed Energy (GWh)	Loss Percentage (%)
2014	3050	4189	18,269	15,419	14.40
2015	3470	4455	19,012	16,178	14.89
2016	3250	4465	19,661	16,700	13.77
2017	3220	4529	20,824	17,504	13.10
2018	3205	5236	20,692	16,392	13.30

Source: Ministry of Energy and Mineral Resources, 2019; NEPCO, 2018; EDAMA, 2019.

One of the targets of the energy policy in Jordan, which is reflected in two major documents, the updated National Energy Strategy (2015–2025) and National Master Plan of the Energy Sector (2007–2020), is to reduce the nation's dependence on imported energy sources.

The sustainability of the energy sector in Jordan, on the other hand, is influenced by the ongoing energy transition. In 2019, the Ministry of Energy declared to pause further development of renewable energy sources because of insufficient grid capacities and lacking technical abilities to manage demand peaks due to the volatility of electricity generation from renewable energy sources [10]. This solution is unsustainable, in the light of potential electricity demand growth due to growing needs for, e.g., cooling and desalinization, especially considering the abundance of renewable energy sources in the country. Furthermore, one major aim of the Jordan energy security policy is a reduction of energy import dependencies, which could be achieved with a higher share of renewable energy in the system or utilizing domestic fossil energy sources, such as oil shale [11].

2.2. The Water Sector

The water policy in Jordan is mainly driven by concerns about the current and future water supply. Currently, Jordan is among the 18 countries in the world with the highest risk of water scarcity. Competition for the use of the water resource can lead to conflicts between water users in irrigation and agriculture as well as in energy generation and private consumption [12]. Water supply and sanitation in Jordan can be specified by severe water scarcity exacerbated by forced immigration [13].

Jordan shares surface and groundwater resources with neighbouring countries. The surface water is shared through the water flows from the Yarmouk and Jordan Rivers to the Dead Sea. In the 1940s and 1950s, Jordan's river flow was 1.2 billion m^3 annually but in 2016, the flow was limited to 150 MCM (million m^3) because of the excessive use, diversion, and damming of the Jordan River's water by neighbouring countries. The share of the Jordan and Yarmouk river water for Jordan was stipulated in agreements between Jordan and upstream neighbouring countries, however, these quantities are not being realized. The groundwater of Jordan is shared with Saudi Arabia through Disi Aquifer, a signed agreement to share the aquifer between the two countries [4].

Risks to energy and water security are recognized globally as one of the most serious and significant risks. In 2016, the World Economic Forum conducted a ranking of global risks. Three out of the top five risks are concerned with energy (a failure of climate change mitigation and adaptation, or a severe energy price shock) or water (water crises). Given all the interrelationships between water and energy, it is apparent that the subject has to be approached in an integrated way. Still, the delivery chains of water and energy are mostly managed in 'silos,' where the silos not only represent different professions and sectors but also different institutions. It is apparent that the infrastructures of energy and water have to be designed and operated in a more integrated way [14]. Additionally, there are several cases from various countries where requirements for water by energy generation became an issue of serious social conflict [15]. While studying various cases of conflicts above water energy usage, scientific evidence shows that localized challenges for the water–energy nexus are diminished when considered from broader perspectives, while regionally important challenges are not prioritized locally [16].

There is a number of potential international projects to increase the water supply of Jordan such as Red Sea–Dead Sea Project (RSDSP). This is an international project which includes three beneficiary parties: Jordan, Israel, and Palestine. The major aim of this project is to save the Dead Sea from environmental degradation and to provide desalinated water to reduce water shortage in Jordan. However, the implementation of the project is currently delayed because of political tensions between the participating countries.

Jordan has an annual availability of water of less than 150 m^3 per person. Jordan's per capita water availability has decreased from 3,600 m^3/year in 1946 to 150 m^3/year in the present, putting the nation far below the 500 m^3/year level as defined by the WHO [3].

The water policy framework in Jordan is well-developed and includes a number of specified policies such as Water Demand Management Policy or Groundwater Sustainability Policy. Currently, implementation is a key challenge. The policy targets are mainly shaped by the National Water Strategy for the period 2016–2023, including the financial sustainability of the water sector, enhanced services of water and wastewater, supply of water to meet the demand for all uses as well as water resource sustainability and protection [4].

Jordan's water withdrawal or water demand, which is the annual amount of water withdrawn, amounts to 1.1 billion m^3 per year. "Water consumption" or "water use" is the portion of water use that is not returned to its original water source after being withdrawn. The sources of water in Jordan are 27% surface water, 14% treated wastewater, and 59% groundwater. The available renewable water resources for different purposes are around 853 MCM annually, while the estimated water demand quantity for all sectors is 1412 MCM in 2017, of which 54% is used for the agriculture sector, 52% for the domestic sector, and 3% for the industry sector. In 2016, there were 33 different Wastewater Treatment Plants (WWTPs) discharging approximately 137 MCM per year of effluent. This volume combined with the decreased volumes of freshwater is available for irrigated agriculture [3].

Greywater reuse has been practiced in Jordan for a long time. A report by the Center for Development Research in 1999 estimated that 60% of the households in Amman and 30% in rural Jordan reused water within the household. However, there are some barriers to implement greywater reuse systems in an extensive way in Jordan, which include: (1) hydraulic systems in Jordanian houses which include, in most cases, the pipes of greywater which are not separated from blackwater pipes; (2) characteristics of wastewater in Jordan which are different from other countries because the average salinity of municipal water supply is 580 ppm of TDS and the average domestic water consumption is low; (3) low cost of water as the water sector in Jordan is highly subsidized and the domestic consumers are not paying the actual costs of the water. The low prices of water reduce the effective 'financial savings' to be made by reusing greywater.

Rainwater is being harvested in many Jordanian houses. The Ministry of Public Works and Housing (MPWH), in cooperation with MWI, has included rainwater harvesting in the new water and sanitation plumbing code [17]. This code illustrates where and how rainwater harvesting is feasible and cost-effective. However, for customers paying at the low water tariff, the preliminary feasibility analysis indicated that the harvesting system is not economically feasible when compared to utility water supply [18].

Groundwater contributes to around 59% of the total water supply, which makes around 618.8 MCM per year. The groundwater mainly comes from 12 major groundwater basins. Six of these basins are already over-exploited [2]. There is a high risk that the country's aquifers will be completely depleted by 2030 because of the impacts of climate change and unsustainable water usage. The impacts of global warming, such as an increase in temperature, less frequent precipitation, and an increase in the intensity of extreme weather events, affect water quality and quantity [19]. According to the Global Freshwater Initiative, the precipitation in Jordan will decline by 30% in comparison to the current level, and the occurrence of drought will triple by the year 2100 as a result of climate change. It is projected that by 2025, the water demand in Jordan will exceed the available water resources by more than 26%. According to the Regional Initiative for the Assessment of Climate Change Impacts on Water Resources and Socio-Economic Vulnerability in the Arab Region (RICCAR), the decrease in water availability will be particularly severe after the year 2040 [20].

Around 42% of the drinking water for Amman stems from water sources situated 20 to 76 km away. As these sources are elevated up to about 1,200 m, they consume around 14% of the total electricity generated in Jordan, which amounts to 1,685 GWh.

Currently, the average electricity consumption per cubic meter of billed water is 4.31 kWh/m^3 [4]. Water pumping is the largest energy consumer in the water sector as the water system in Jordan has to rely mainly on resources located at a considerable distance from urban areas.

The reliability of the water supply is influenced by growing energy tariffs. Electricity consumption by the water sector continues to grow due to groundwater depletion that requires pumping water from lower levels, water desalination projects, and overall increased water demand. Currently, the revenues in the water sector are sufficient to cover around 70% of the total operation and maintenance costs, which also include capital costs, depreciation, and recovery. In the year 2017, electricity costs constituted 43% of the total operation and maintenance costs of the water sector and the electricity bill amounted to 161 million Jordanian Dinar (JD). The electricity tariffs continue to grow since in the year 2017, the water sector purchased electricity with a tariff of 0.094 JD per kWh, and in the year 2018, the electricity tariffs jumped to 0.140 JD per kWh, according to the conducted interview with the Former Head of finance and International Cooperation Directorate at Water Authority of Jordan-WAJ [21]. However, the published tariff for water pumping is 0.115 JD per kWh for the period from July 1, 2018 until now, according to the official website of Electricity Distribution Co (EDCO).

Moreover, a significant share of electricity is wasted because of the inefficiencies and physical losses mentioned above. For example, in the year 2017, the estimated non-revenue water was estimated at 48% with corresponding energy losses. Furthermore, administrative inefficiencies account for more than 50% of these losses and the remaining losses are due to physical losses from the networks [3].

2.3. Challenges and Opportunities

The water–energy nexus is mainly regulated by the Energy Efficiency and Renewable Energy Policy for the Jordanian Water Sector which was published in 2015 by the Ministry of Water and Irrigation of Jordan. It has two main targets: the reduction of energy consumption billed water by 15% and an increase of the share of renewable energy sources in the power generation for the water sector by 10% until 2030 in comparison with the year 2018.

There are a number of possible synergies between the water and energy sectors, but each of them has associated benefits, risks, and costs that require trade-offs in decision-making and policies as well as coordinated actions for implementation. These options include international and national cooperation and the implementation of renewable energies in the water sector. For example, renewable energy projects such as solar pumps can be an option to contribute to sustainability in the water sector while reducing the specific power consumption.

Due to the high cost of energy used within the water sector, the Ministry of Water and Irrigation (MWI) aims to improve the performance and sustainability of the water sector through improving the energy efficiency in water facilities in order to decrease the specific power consumption for water supply and introducing renewable energy technologies to protect the environment and to reduce energy price volatilities in the water sector [4].

Another approach is the multiple wastewater recovery, which is nowadays one of the most desirable options. The technology is also mature and feasible. Such an approach can save water. It can also help to reduce production costs and energy demand by eliminating unnecessary treatment and long-range conveyance, as it typically aims at local reuses. There are different wastewater reuse goals such as direct potable use, indirect potable use, non-potable uses, and industrial uses which are connected with various requirements and various technological options [22]. However, the wastewater treatment facilities are among the major energy consumers at the municipal level worldwide and make a significant fraction of the municipal energy bill. On the other hand, wastewater and its by-products contain energy in different forms: chemical, thermal, and potential. Here, new technologies could help to optimize water usage. For instance, recovery of the energy content of process residuals could allow significant additional energy recovery and increased greenhouse emissions abatement [23].

Pumped hydropower plants (PHS) can be another, most beneficial synergy to contribute to the sustainability of the energy sector. PHS plants offer the opportunity to store large quantities of energy, and the flexible management of water pumping can greatly contribute to shaping energy demand profiles by shifting loads from peak consumption hours to peak production hours. Water can be used to store energy in the dams along the Jordan Valley and in Aqaba. The King Talal, Wadi al Arab, and Mujib Dams could provide 500 MW power and store 3,000 MWh/day [2]. The implementation of these projects faces two major challenges; primarily, high investment costs and secondly, a necessary change in the energy tariff scheme to ensure financial sustainability.

Technological solutions for the joint challenges of the water and energy sectors are not the focus of this paper; however, in expert sessions during an on-site workshop in Amman, Jordan, in October 2019, a number of possible options were discussed. The solution with the highest potential according to local stakeholders is the deployment of water pumping systems powered by photovoltaic (PV) as well as pumped hydroelectricity storage systems. Among the other options discussed were in-pipe hydro solutions, floating PV to reduce evaporation rates of water as well as reducing the current 60% of water losses (non-revenue water), constraint zero feed-in for renewable energy to facilitate hybrid systems and desalination plants to meet the increasing water demand. Desalination, however, was not voted to be of the main interest.

2.4. Projects

There are two large-scale international cooperation projects, which are currently under consideration. The Red Sea–Dead Sea Water Conveyance project (RSDS) and the Interconnected Gulf Grid project.

The RSDS project is envisaged to become one of the main sources to meet the increased water demand in Jordan. The major aim of this project is to save the Dead Sea from environmental degradation and to provide desalinated water to reduce water shortages in Jordan. The project includes the construction of a desalination plant in the north of Aqaba city, with a capacity of 80−100 m^3/year of desalinated water, conveying the brine to the Dead Sea in order to reduce the decline of its water level. The project faces two major challenges, one being the international cooperation, especially with

Israel and Palestine, which is not resolved yet, delaying the process since 2013 due to political tension between the parties. The second challenge is the high investment costs of around 11 billion US dollars.

The Interconnected Gulf Grid is another project. In addition to the existing electrical interconnection line with Egypt and Palestine, the National Electric Company (NEPCO) signed a memorandum of understanding with Gulf Cooperation Council Interconnection Authority (GCCIA) during 2016 to conduct technical and economic feasibility studies for electric interconnection with Gulf [9]. In 2019, Jordan, Egypt, and the GCCIA agreed to form a joint technical committee and draft a memorandum of understanding to frame the basics for implementing a power connection project between the Arab Gulf countries' power grid and Europe's power grid through Jordan and Egypt [10]. The Jordanian Energy Minister stated that this project will have positive impacts such as improving the electric system's stability, economies, and enhancing energy exchange.

3. Methodology

The difficulties within the water–energy nexus are connected with existing conflicts between various stakeholders. Therefore, water–energy governance needs the development of cooperation schemes and compromised solutions on contested issues, design, and implementation processes. This can lead to conflicts in decision-making processes, in which some parties are trying to exclude others, resulting in winners and losers. Decision-making processes can also lead to inefficiencies when benefits from synergies in water and energy policy schemes and efforts are ignored and lost. When well applied, a participatory governance methodology can integrate views, visions, and opinions of different stakeholder groups. Such a methodology tends to be more sustainable, less prone to conflict, and better balanced, even though it might be more time-consuming for stakeholders to engage.

The framework of the participatory approach in this paper is a decision analytical approach in a multi-stakeholder and multi-criteria environment, supported by elaborated decision analytical tools and processes. The framework includes various scientific tools and methodologies such as methods for elicitation of stakeholder preferences, a decision engine for strategy evaluation, mechanisms for risk analyses, a set of processes for negotiation, and a set of decision rule mechanisms and processes for combining these items. Such a framework has been shown to be useful for decision-making processes such as agenda settings and overall processes, goals, strategies, policies, sub-strategies, part-policies, understanding of consequences and effects, qualifications and sometimes quantifications of the components, negotiation protocols as well as decision rules and processes [24–28].

3.1. Data

The framework included three steps to collect data for the analysis. The first step was an extensive literature review including scientific analyses, strategies, and reports to identify relevant questions for interviews with key stakeholders of the water and energy sectors.

The second step consisted of in-depth qualitative interviews (between one to two hours), which were conducted in the period between August and October of 2019. The majority of interviews were conducted in person while some interviews were conducted via Skype. Altogether, seven experts from the German International Cooperation (GIZ), the Water Authority of Jordan, the Ministry of Water and Irrigation as well as Dorsch International Consultants were interviewed, identifying key challenges and criteria for Jordan's energy and water nexus.

The third step included a workshop, which was conducted on the 21st and 22nd of October 2019 in Amman, Jordan. The workshop was joined by 37 representatives of the water and energy sector. The water sector was represented by the Water Authority Jordan (WAJ), Dorsch Engineering Consulting, Aqaba Water Company (AWC), the Ministry of Water and Irrigation (MWI), Jordan Valley Authority (JVA), Jordan Water Company Miyahuna, Jordan Water Management Initiative (WMI) and Yarmouk Water Company (YWC). The energy sector was represented by the National Electric Power Company (NEPCO), the Energy and Minerals Regulatory Commission (EMRC), and the Ministry of Energy and Mineral Resources (MEMR). In a plenary session, the background of the energy–water nexus in Jordan was introduced as well as the MCDA methodology and modelling approach. In three groups, one represented by energy sector stakeholders and two from the water sector, the MCDA methodology was applied. The participants were then subsequently split into three break-out groups, regardless of sector, for a moderated discussion about joint synergies and challenges of the energy–water nexus.

3.2. Process

The interactions with stakeholders in this context were in a co-creative format. The concept of co-creation has existed in many contexts over the years as a process for active involvement of end-users in various stages of planning and production [29]. As argued, for instance in [30,31], the underlying understanding is that co-creation (or co-production) will improve the efficiency of processes, yield faster response times, make them more secure by reducing human errors and increase inclusion, democracy, and participation, as the process ideally provides the same opportunities to different actors. There is also a growing body of evidence that trust is a key issue in the successful deployment of any kind of infrastructure and that participatory governance and co-production methods increase the level of trust [32,33].

Another component is a decision analytical tool for evaluating the multi-stakeholder decision problem, allowing to make preference assessments. One of the problems with standard methods is that numerically precise information is seldom available and most decision-makers experience difficulties with entering realistic information [24,25]. There have been many suggestions for handling the requirements for decision-makers to provide precise information, such as approaches based on capacities, sets of probability measures, upper and lower probabilities, interval probabilities and utilities, evidence and possibility theories, as well as fuzzy measures [34–37].

The computational complexity can, however, be problematic. This is extensively discussed in, for example, [38,39]. We suggest here an implemented method for integrated multi-attribute evaluation under risk, subject to incomplete or imperfect information. The software originates from our earlier work on evaluating decision situations using imprecise utilities, probabilities, and weights, as well as qualitative estimates between these components derived from convex sets of weight, utility, and probability measures. Therefore, for the evaluation of the stakeholders' preferences [40–43], the software DecideIT was used.

The software manages imprecise utilities, probabilities, and weights, as well as qualitative estimates between these components derived from convex sets of such measures [39]. Furthermore, higher-order distributions for better discrimination between the possible outcomes are introduced to managing belief mass over the output intervals, giving a measure of how plausible it is that an alternative outranked the remaining ones, and thus provide a robustness measure.

Danielson and Ekenberg compare a number of state-of-the-art methods and, utilizing a simulation approach, discuss the underlying assumptions and robustness properties while demonstrating how the ranking evaluation procedure provides a better result than hitherto popular methods, e.g., from the SMART family as well as AHP [44,45].

The method also includes the P-SWING method, suggested in [46]. P-SWING consists of an amended swing-type technique while allowing for intermediate comparisons as well, allowing for analyses of solution robustness. The multi-criteria decision problem is evaluated as a multi-linear problem calculating weighted averages over the polytopes spanned up by the ordering constraints, or, more precisely, equations of the format $E(A_j) = \sum w_i v_{ij}$, where w_i is the weight variable of criterion i and v_{ij} is the value variable of strategy j under criterion i. The value $E(A_j)$ is computed by solving successive optimization problems by the software, see [47] for mathematical details [48].

The ranking of criteria and scenarios could be represented as a matrix of choice, where trade-offs between scenarios can be identified as well as the most popular and accepted scenarios.

The application of the decision framework includes the following stages:

- Development of relevant criteria, which were determined based on available literature examining the water and energy sectors in Jordan, their targets, challenges, and existing strategies to achieve policy targets.
- Presentation of an overview of the socio-economic and environmental background on energy and water issues in Jordan, introducing previously set criteria.
- Discussion with stakeholders in interviews and during the workshop in a plenary manner to collect feedback on the selection of criteria, to find out whether criteria should be added or removed.
- Ranking of criteria according to their importance to the stakeholders and relative importance in relation to other criteria.
- Ranking of previously developed preliminary scenarios describing possible energy and water futures with regard to their importance to stakeholders and relative importance in relation to other scenarios.
- Quantification of criteria based on the ranking of criteria and of scenarios.
- Identification of trade-offs between sector ratings of criteria and favourable scenarios for each stakeholder group.

3.3. Criteria

The interviews and a review of background literature identified 25 criteria of relevance for the energy and water sectors in Jordan. Furthermore, the criteria were clustered and cumulated based on their similarities into 12 overarching criteria, which were discussed during the stakeholder workshop. These criteria were classified into four major groups: economic, environmental, technical, and institutional/regulatory. The definitions of the criteria were discussed and further developed together with the stakeholders during the workshop.

The group of economic criteria includes annual system costs per kWh. This criterion, in turn, includes three sub-criteria, namely investment, operation and maintenance costs as well as tariffs. The investment criterion includes all costs connected with planning, preparation, and construction of energy or water-related infrastructure. It also includes all other related investment costs. The operation and maintenance criterion summarizes all costs connected with the operation and maintenance of water and energy infrastructure. The tariffs criterion includes tariffs for water and energy paid by private and industrial/institutional consumers. Annual system costs per kWh should be the basis for tariffs.

The group of institutional and regulatory criteria includes two criteria: transboundary political feasibility and internal institutional feasibility. The transboundary political feasibility criterion includes all issues connected to transboundary cooperation over resource availability such as water management issues or the functioning of interconnected critical infrastructures. This criterion also includes political dialogue with neighbouring countries. The internal institutional feasibility criterion includes all efforts necessary for dialogue and cooperation in a horizontal perspective between various ministries or on the coordination of donor efforts or in a vertical perspective between local, regional, and national levels of governance. It also includes the need to change, adapt, and streamline existing legal and institutional frameworks for water–energy issues, as well as the necessary capacity-building efforts.

The group of technical criteria includes two criteria: security of energy supply and security of water supply. The security of energy supply criterion includes all issues connected with the safety of the social functioning of critical energy supply infrastructures as well as reliable energy generation, transmission, and distribution, including covering supply and demand gaps, intermittency risks and protecting energy critical infrastructure from various natural and man-made hazards. The security of the water supply criterion includes the same issues as listed above, concerning the water sector and infrastructure.

The group of environmental criteria also includes two criteria: local environmental impacts and global environmental impacts. The local environmental impacts criterion includes pressure on local land, air, water, soil, and other kinds of environmental resources resulting from extraction, generation, transmission, and distribution of energy and water services. The global environmental impact criterion relates to the same issues, which have an impact from a global perspective.

3.4. Scenarios

During the workshop, participants weighted not only the criteria they found to be most relevant and important for Jordan's energy and water sectors but also ranked previously developed preliminary scenarios. Based on literature reviews, driven by two main dimensions—water and energy—possible futures were envisioned. The two dimensions can be described by future developments, be it of political, economic, or technological nature. The scenario is a creation of a new future situation, independent of former developments. Here, backcasting rather than forecasting was used, defining a desired future and how to achieve it. The different futures open up the scenario funnel from positive extreme scenarios, alternative futures, trend scenarios, and negative extreme scenarios on the future horizon to 2040. In this case, for a baseline scenario, this may entail expected trends and developments as stated in NEPCO's and WAJ's annual reports.

The energy dimension can have three main expected futures:

- ***Baseline Energy (BE)*** is following expected trends and developments as stated in the NEPCO annual reports, e.g., the demand is expected to increase by an average of 3% annually from 3057 MW. This might include large scale PV and wind installations, as well as small scale nuclear. A higher priority is given to oil shale development, with a 470 MW expected to be operational in 2020, with a focus on energy independence as well as achieving a higher share of power generated from renewable energies, expected to cover 30% of the demand by 2022 [9]. Difficulties: security of energy supply; grid stability; power cut-offs and possible after-effects.
- ***Low Imports (LI),*** originally called ***No Imports(NI)***, was adjusted during the workshop following stakeholder's feedback. The low import assumption is based on findings of the MENA-Select project, aiming at energy independence, with up to 78 GW of installed capacity needed, including substantial wind (15 GW) and solar (25 GW) installations, as well as geothermal plants (3.5 GW). Large-scale CSP projects (20 GW) are needed as well as biomass (0.5 GW). Key in this scenario are extensive storage capacities, as envisioned in the MENA-Select project with 18 GW and 40 GWh respectively. Difficulties: sourcing of biomass; grid stability increasingly difficult with a large share of volatile energy sources introduced; large scale RE developments needed (high costs). It retains the acronym **NI** in the figures and tables below.
- ***Interconnected Gulf System (IGS)***is based on the NEPCO annual report of 2018. Electrical interconnections are possible with Egypt (550 MW), Palestine (26 MW), Iraq and Saudi Arabia to use the strengths of an interconnected electricity system. The currently (as of NEPCO, 2018) active interconnectors are with Egypt and Palestine, the others are stalled due to current prevailing conditions in the region. Difficulties: political tensions; a need for transboundary international cooperation.

The water dimension can be described by:

- ***Baseline Water (BW)***. In the baseline future, which is driven by securing water supply, deeper and additional wells, as well as dams to cover the increasing water demand are considered. A high priority is given to desalination and reduction in water losses. This scenario follows expected trends and planning processes already in the works in the water sector while analysing the expected changes in energy inputs. Difficulties: environmental impacts (disposal of brine from desalination); energy security including the effect of power cut-offs on water supply.
- ***Smart Operation (SO)***. Uses synergies of the water and energy sectors, e.g., using excess energy of electricity system for water pumping (smart operation of pumps), solar-powered water pumping or energy storage through the medium of water-pumped hydroelectricity storage. Difficulties: sector dialogue; internal institutional cooperation.

The combination of both dimensions resulted in six different combined scenarios, five of which were considered during the ranking processes (Table 2).

Table 2. Energy and water dimensions of different scenarios.

		Energy Dimension		
		Baseline Energy (BE)	**Low Imports (NI)**	**Interconnected Gulf System (IGS)**
Water dimension	Baseline Water (BW)	BW_BE	BW_NI [1]	BW_IGS
	Smart Operation (SO)	SO_BE	SO_NI	SO_IGS

[1] BW_NI was not considered in the rankings due to infeasibility.

In a subsequent analysis, the presented scenarios need to be filled with context and definitive figures. The MENA-Select project already offered various energy-driven scenarios developed by local stakeholders. In discussions with water and energy stakeholders, the possible futures needed to be further elaborated, and technological solutions were included [46].

4. Results

The results of four rounds of ranking as well as the ranking in the group of energy sector stakeholders showed the prevalence of economic and security rationales, namely, ranking the criterion of average annual system costs per kWh the highest. The availability of resources was ranked as the second most important criterion. The ranking was followed by security of energy and water supply and by internal institutional feasibility and transboundary political feasibility. All environmental criteria such as local and global environmental impacts were ranked at the very bottom. The local environmental impacts were ranked higher than global impacts. The same outcome considering environmental criteria having the lowest ranking was observed during all rounds of ranking with slight differences; as in some rounds, local environmental impacts were ranked higher and during other rounds, the global environmental impacts were ranked higher (see Figure 1 below).

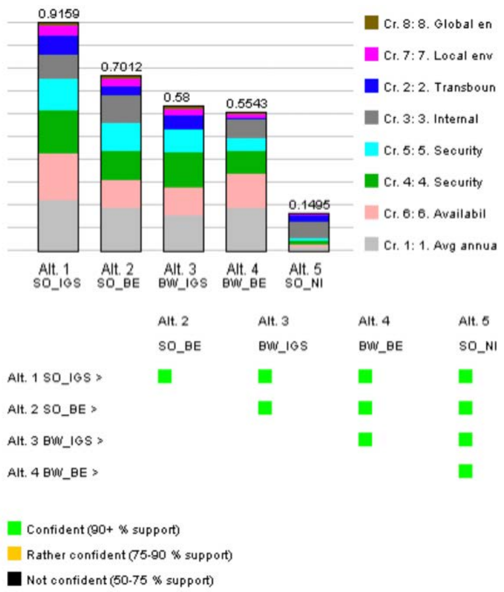

Figure 1. Results of MCDA (multi-criteria decision analysis) ranking for the group of energy sector stakeholders.

The average annual system cost per kWh was not only ranked the highest but significantly higher than other criteria. Figure 1 shows that this criterion has a weight of over 20% in all scenarios.

For the energy stakeholder group, the most preferred scenario is SO_IGS followed by SO_BE. These scenarios were followed by BW_BE and BW_IGS. Interestingly, the SO_NI scenario, which foresees a high share of domestically generated renewable energy sources, was considered the least preferable option, which is contradictory to the aim of utilizing domestic fuel sources such as oil shale and gaining energy independence.

The results of the ranking among the two groups of water energy stakeholders, as well as the results for the energy stakeholder group, are already described above and were more heterogeneous not only between the two groups but also within one group. For both groups, availability of service and security of water supply were the two most important criteria (Figures 2 and 3). Jointly, these two criteria weigh almost 50% for some of the scenarios (e.g., BW_BE). Environmental criteria such as local and global environmental impacts were ranked at the bottom. However, one group ranked global environmental impacts higher and another group ranked local above global impacts.

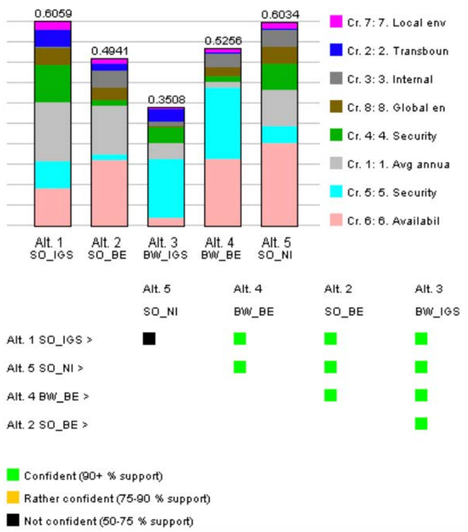

Figure 2. Results of MCDA ranking among the first group of water sector stakeholders.

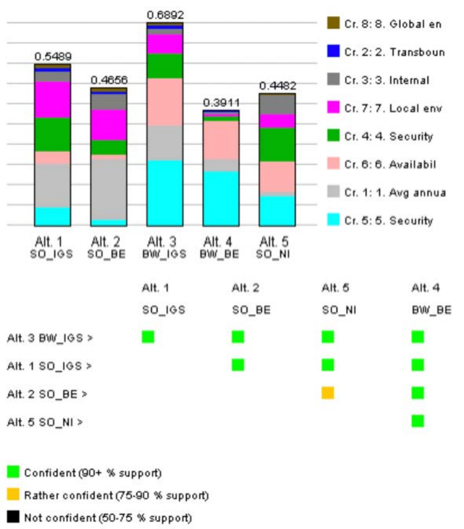

Figure 3. Results of MCDA ranking among the second group of water sector stakeholders.

For the first group of water stakeholders, the ranking was dominated by economic and security criteria such as availability of service, security of water supply, average annual system cost per kWh and security of energy supply. Annual average energy system costs per kWh ranked slightly higher than energy security.

Consideration of lower average annual energy system costs, involving an interconnected gulf grid and electricity trade in the region, made SO_IGS the most preferable scenario in both groups, of energy and water stakeholders. The weights of economic and security criteria in this scenario make up almost 80% of the entire preferences. The same is observed for SO_NI, where economic and security criteria are dominating. However, in this scenario, the role of the availability of services is weighted much higher than the role of the average annual system cost.

The results on energy security also demonstrated a clear preference for domestically available resources as they are perceived to offer more security in terms of supply and vulnerability to political tensions and import risks. The availability of services also got a significant weight in the BW_BE scenario, where the economic and security criteria are dominating.

Interestingly, in the water stakeholder group, a strong polarization of opinions could be observed between contrasting scenarios. One scenario involved high energy imports and the other relies on domestically available energy resources with low imports. This means that the discussion about energy options involving imports from other countries over domestically available resources is a contested issue. The discussion was mainly driven by the availability of services, the readiness to accept political risk, and further, to accept higher average annual energy system costs in order to obtain a more secure energy supply solution. Domestically available energy sources are perceived as being more secure as their supply does not involve energy imports and political risks. However, in the context of Jordan, the domestically available energy source is oil shale, which has high instalment costs and being a fossil fuel, also high external effects and social costs of energy, adding to an environmentally harmful extraction.

The results for the abovementioned group showed that SO_IGS was the most preferable scenario followed by SO_NI with conflicting opinions between the scenarios regarding the energy dimension. The two following scenarios involve baseline energy futures such as BW_BE and SO_BE. BW_IGS is considered as the least preferable scenario of all.

For the second water group, the security of water supply was perceived as the most important criterion followed by average annual energy system cost per kWh and availability of services. Local environmental impacts were ranked much higher by this group than by any other group. This criterion plays a significant role in the SO_IGS scenario as well as the SO_BE scenario. Security of water supply plays an important role in both scenarios, which involve the baseline water dimension as well as in the SO_NI scenario.

The results for the second water group showed that both scenarios involving IGS on the energy dimension are the most preferable scenarios, with BW_IGS the most preferable scenario and SO_IGS the second most preferable. These scenarios are followed by scenarios involving smart operation in the water dimension, viz. SO_BE and SO_NI. BW_BE was considered to be the least preferable scenario.

The results for all three stakeholder groups show an overarching preference for the Interconnected Gulf System in the energy dimension. Additionally, SO (Smart Operation) is being ranked as the most preferable and second most preferable for all three groups concerning the water dimension (see Table 3 below).

Table 3. MCDA results for all groups of stakeholders.

Ranking	1st	2nd	3rd	4th	5th
Energy group	SO_IGS	SO_BE	BW_IGS	BW_BE	SO_NI
Water group 1	SO_IGS	SO_NI	BW_BE	SO_BE	BW_IGS
Water group 2	BW_IGS	SO_IGS	SO_BE	SO_NI	BW_BE

There are two conflicting opinions apparent. Within water group 1 between IGS and NI on the energy side (see the black square in Figure 2 indicating no clear ranking outcome between SO_IGS and SO_NI), as well as between the two water groups regarding SO or BW as to the most preferable for the water dimension. There seems to be no strong conflict between the energy and water groups regarding the energy dimension since all three groups prefer IGS. However, the conflict between water group 1 and the energy group should be further investigated since the NI energy dimension is considered to be the second most favourable option by water group 1, whereas it was considered the least favourable option by the energy stakeholder group.

5. Summary and Concluding Remarks

The presented results regarding water–energy nexus governance in Jordan can increase the sustainability of the water and energy sectors. Using a computer-supported co-creative approach for evaluating stakeholder preferences on criteria and possible future scenarios of the sectors, joint challenges, opportunities, and preferences were identified. The MCDA approach allowed to value and rank socio-economic aspects as well as techno-economic criteria for both systems and joint scenarios.

The here presented detailed analysis of preliminary scenarios describing possible energy and water futures ranked under a set of water and energy sectors' relevant criteria, indicated that there is no fundamental conflict in opinions between the energy and water sectors. Each scenario's performance was also evaluated with respect to the robustness of the results, where the entire ranges of possible alternative values and criteria weights are considered. Using second-order probabilistic considerations, it was furthermore analysed how plausible it is that a scenario outranks the remaining ones. The analysis of multi-stakeholder multi-criteria situations of this kind requires elaborated calculations, which is why a decision methodology and a software tool for large-scale decisions were used to support the evaluation. The results also indicate that the ranking results are quite stable.

The main problems in the water sector are water scarcity, the high electricity consumption for water pumping, and the low water tariff, as current tariffs do not allow water utilities to recover all their costs. The energy sector suffers from different problems such as excess in generation capacity at a high cost compared to the electricity produced through renewable energy projects, its commitment to long-term agreements to purchase fuel and oil shale projects as a result of predictions, and expectations of increased demand for electric power.

The most preferred scenario by different groups is SO_IGS. This indicates that the two sectors find connecting with other countries to be the most preferable solution to mitigate the problems of both sectors. Through this option, Jordan will play a regional role by connecting to other countries to export the excessive electricity which may enable the energy sector to generate profits and stop the losses. The smart operation scenario will enable the use of innovative energy technologies, such as load shifting, energy storage, water pumping without electricity grid connection, and energy recovery through small hydropower plants.

The water and energy sectors are fundamentally linked. In Jordan, especially in the face of a changing climate, a water–energy nexus holds a number of challenges but also opportunities. A key point in exploring synergies is the identification of such, as well as the communication between the water and energy sectors. The nexus is a complex problem, which requires new forms of cooperation between various stakeholders involved in the energy and water sectors to avoid lasting conflicts and inefficiencies. Employing a participatory multi-stakeholder, multi-criteria framework to the energy–water nexus case in Jordan promotes a clear understanding of where different stakeholder groups stand; especially in the context of the energy–water nexus, where common challenges and synergies need to be identified. The previously poor communicative situation between the energy and water sectors was improved through the presented approach facilitating dialogue and discussion. Furthermore, the sectors were able to develop joint solutions for common problems. This understanding and agreement can form the basis of a joint water–energy nexus policy used in the continued negotiation process between and within national and international cooperation, as well as promoting and developing acceptable suggestions to solve complex problems for both sectors.

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