energies

MDPI

Article

Transboundary Exchanges of Renewable Energy and Desalinated Water in the Middle East

David Katz * and **Arkadiy Shafran**

Department of Geography and Environmental Studies, University of Haifa, Haifa 39105, Israel; arkady.shafran@gmail.com
* Correspondence: katzd@geo.haifa.ac.il

Received: 30 December 2018; Accepted: 8 April 2019; Published: 17 April 2019

Abstract: The Levant area of the Middle East suffers from both chronic water scarcity and high population growth. It is also a region highly dependent of fossil fuels. In order to address current and expected water demands, several countries in the region, including Israel, Jordan and the Palestinian Authority (PA), are depending increasingly on desalination, which is expected to intensify energy consumption and energy related emissions. Given that the region also benefits from high levels of solar irradiation nearly year-round, much attention has been given to the possibility of developing renewable energy in general and for desalination specifically. This paper presents partial results of a pre-feasibility study assessing the prospects of transfers of desalinated water from Israel and/or the PA, which have access to the Mediterranean Sea, to Jordan, in exchange for renewable solar-produced electricity from Jordan, which, unlike its neighbors, has an abundance of available open space suitable for solar production. The analysis shows that single-axis tracking photovoltaic (PV) systems appear to be the most economically feasible option. Moreover, the study shows that the proposed idea of international cooperation and water-energy exchanges, while facing political obstacles, could provide numerous economic, environmental and geopolitical benefits to all parties involved. As such, an arrangement such as that examined may be a more promising means of promoting both desalination and renewable energy than if each country unilaterally develops desalination and renewable energy in isolation from one another.

Keywords: desalination; renewable energy; solar energy; photovoltaics; concentrating solar power; water-energy nexus; Middle East

1. Introduction and Study Rationale

Large-scale seawater desalination is already developed in Israel and is being planned in Jordan and the Palestinian Authority (PA). Integration of renewable energy into water desalination systems could both reduce environmental impacts of desalination and reduce the region's dependence on imported fossil fuels. While all three abovementioned parties have plans to significantly develop both desalination and renewable energy, thus far, the two fields are being developed separately. This paper examines the feasibility of connecting these goals as a potentially cost-efficient and politically acceptable means of advancing both, while at the same time promoting regional cooperation.

Israel, Jordan and the PA share scarce water resources. While Israel and the PA have access to the Mediterranean, and thus, relatively easy access to desalination, they have relatively little available open spaces necessary for large scale renewable energy facilities. Jordan, on the other hand, has access to the sea only via Aqaba along the Red Sea, relatively far from its population centers in the northwest of the country, but has a large amount of open space that is very suitable for producing renewable energy, particularly solar. All three parties have committed to developing renewable energy, both for meeting environmental objectives, as well as to reduce their dependency on imported fossil fuels; however, to date, they have had very limited achievements in this regard.

Given the comparative advantages of the different parties, there is a potential for water-energy exchanges in which Israel and/or The Palestinian Authority would produce desalinated water for use in Jordan, and in exchange, Jordan would supply renewable energy for the region. A pre-feasibility study of such a project was conducted by the authors on behalf of a regional non-governmental environmental organization, Ecopeace—Middle East, with funding from the Konrad Adenauer Stiftung [1]. This paper primarily presents an updated version of the technical and cost assessments of such a project's renewable energy production potential, along with a discussion of some of the geo-political implications of such an arrangement.

The paper proceeds as follows: Section 2 presents a very brief review of some of the literature on renewable energy for desalination. Section 3 describes the current situation in the study area in terms of water and energy production and consumption, including transboundary energy and water sharing in the region. Section 4 presents the methodology for conducting the assessment, including outlining of assumptions and data sources. Section 5 provides the results of the analysis of renewable energy production. Section 6 evaluates some of the geopolitical implications of such a project, and Section 7 provides conclusions.

2. Literature Review

According to some calculations, desalination will be responsible for 400 million tons of carbon equivalent annually by 2050 [2], prompting many to investigate the potential for renewable energy to fuel expected growth. An extensive literature exists on the use and potential use of renewable energy for desalination facilities. Several reviews of this literature already exist (see, for instance, [3–9]). As such, this study makes no attempt to review this. Rather, we outline some key strands and conclusions of studies that are relevant for this work.

One common theme is the negative political and environmental impacts of fossil fuel dependency, especially for studies focusing on the Middle East [10], which hosts the largest share of the world's desalination capacity. Renewable energy is seen by many as the only option for certain countries to meet their energy needs, while also meeting environmental commitments and providing energy security. Solar desalination applications are viewed as part of a potential solution in arid regions such as the Middle East where fresh water scarcity, solar resource abundance and saline water availability coincide (see, for instance, [11–14]).

Cost estimates for desalination water production powered by renewables show a great variance, depending on technology and scale [15]. Much of the focus has been on reverse osmosis (RO) and photovoltaic (PV) systems, respectively, as arguably the most mature and market-ready of the existing technologies. Several studies have found that renewable powered desalination is cost-effective primarily in remote locations (e.g., [9]). The possibility of driving desalination systems using heat engines powered by concentrating solar thermal production collectors has generally appeared less economically feasible than PV [16–18], but is viewed by some as a promising technology, especially in the medium term [8,19].

Given that desalination systems often operate continuously, while solar systems are limited to daytime production, several studies have looked at the need for storage facilities (heat storage or batteries) or integration with a steam generator, including the possibility of fossil fuel backups and/or hybrid (renewable and fossil fuel) systems [11]. Additionally, coproducing desalinated water and renewable energy at the same location may be inefficient, as optimal locations for desalination and for solar energy production may not coincide [19]. This is especially true given the often high costs of land near coastal areas, as is the case in our study area.

Of course, these challenges are in addition to general challenges to promoting activity in renewable energy sector, including:

- Economic barriers, such as high initial capital costs, unfavorable power pricing rules, subsidies for competing fuels, transaction costs, etc.
- Legal and regulatory barriers, such as lack of legal framework for independent power producers, network interconnection requirements and non-discriminatory transmission access
- Administrative barriers, such as lack of access to credit, perceived technology performance uncertainty and risk, and lack of technical or commercial skills and information [20,21].

While much research has found that costs are an obstacle to renewables deployment, these costs, especially for PV, are decreasing, and in some cases are already at levels in parity with unsubsidized electricity rates in areas of high solar irradiation, such as in the Middle East [13].

3. Water, Energy and Land in the Study Area

3.1. Water

Annual renewable freshwater (surface and groundwater) supplies among Israel, Jordan and the PA collectively are estimated to be roughly 2600 million cubic meters (mcm) [22]. Distributed across a population of nearly 23 million (including refugees and other non-citizens currently residing in Jordan) (see Table 1 below); this means that the region's population has less than 120 cubic meters per capita annually (m^3/c/y). The Falkenmark index of water stress, commonly used metric, specifies that countries with annual supplies of less than 500 m^3/c/y suffer from chronic water scarcity [23]. Thus, the region as a whole, and each of the individual countries, all already face severe chronic water scarcity, a situation which, if not addressed, will only intensify due both to rapid population growth in the region, and predicted decreases in rainfall and increased evaporation due to climate change [24–27].

Existing natural freshwater resources in all three countries are being exploited at beyond renewable rates. Desalination, almost entirely RO, already accounts for the equivalent of 80% of Israel's domestic water supplies and plans exist to expand this capacity significantly [27,28]. At present, desalination production is relatively limited in the PA and Jordan. Plans, as well as funding pledges from the international community, exist to develop large-scale RO desalination in the Gaza Strip, the PA [29]; however, these are currently stalled due to security concerns and an inability to guarantee secure energy supplies.

The three parties have also indicated their support for a joint desalination mega-project, which would produce desalinated water from the Red Sea, primarily for Jordanian consumption, with brine being pumped to the Dead Sea to compensate for declining sea levels resulting from upstream abstractions from its primary water source, the Jordan River system. A World Bank funded feasibility study of this "Red-Dead" project indicated that locating desalination facilities along the Mediterranean would be more cost-efficient than at the Red Sea due both to proximity to population centers in northern Jordan, as well as lower salinity levels of the source water [22]. However, the Red-Dead option is preferred by the governments for political reasons, including, most significantly, a desire by Jordan that the facilities be located in its territory for purposes of water security [30]. The parties are currently advancing a pilot phase of the project, which would involve freshwater exchanges between parties in order to minimize delivery costs, though a full scale version of the project faces numerous objections based both on expected costs and environmental impacts.

3.2. Energy

All three nations are highly dependent on imported fossil fuels for their energy production. Jordan imports 96% of its energy needs, and energy imports account for roughly 20% of the nation's total Gross Domestic Product [31]. Israel imports up to 92% of its total primary energy supply and around 46% of energy products for its electricity supply [32], while the PA obtains over 90% of its energy (electricity and fuels) via Israel. Imports of fossil fuels represent a major drain on foreign currency reserves [33]. Imports from outside the region have also been precarious and subject to disruption due to political events outside of the region, as was demonstrated by the cessation of natural gas supplies to the region from Egypt on multiple occasions following the outbreak of the Arab Spring [34].

In addition to the economic incentive to produce local energy sources, there are clear environmental and public health reasons as well. All three countries have declared policy goals of achieving various specific levels of energy production from renewable sources, and all three have signed and ratified the Paris climate accord of 2016. However, according to various sources, renewable energy accounts for less than 2% of total electricity production in each of the three countries [35,36]. None of the three are currently on track to meet their own self-defined renewable energy goals of up to 10% of energy from renewable sources that they set for themselves for 2020 [37–40]; this is despite having amble potential for renewable energy, especially from solar energy sources.

3.3. Regional Integration of Water and Energy Supplies

Israel, Jordan and the PA share both surface and groundwater sources, with the PA being entirely dependent on shared sources. In terms of electricity grids, there is near total integration of Israeli and Palestinian grids, while the Jordanian grid is almost completely separate, with the exception of one transmission line supplying electricity from Jordan to the Jericho region of the West Bank.

Both the Israeli-Palestinian interim peace agreement (the Oslo Accords) and the Israeli-Jordanian Peace Agreement call for joint development and management of new water resources, including desalination, and for joint development of renewable energy supplies. To date, however, other than the Red-Dead project, which has yet to be implemented and faces numerous challenges, little cooperation on desalination has taken place, with the exception of Israel selling limited amounts of water to Jordan and the PA, a move which arguably would not have happened without developed desalination capacity in Israel. Efforts to integrate electricity grids, long suggested as a means of increasing system reliability and encouraging regional cooperation, have failed to move forward, primarily due to political reservations [41]. Here too, the parties are developing energy supplies and infrastructure largely unilaterally.

3.4. Open Spaces

Allocating land necessary for large scale renewable energy facilities in the PA and Israel is challenging. The PA, including both the Gaza Strip and the West Bank, is among the most densely populated countries in the world [42]. Furthermore, it faces many restrictions on land use and construction imposed by the Israeli Civil Authority, which governs much of the West Bank. Israel is among the most densely populated of the industrialized nations, and while it has open desert areas in the south of the country that are appropriate for solar energy production, many of these areas are either closed military zones or nature reserves. Jordan, on the other hand, is much less densely populated (see Table 1 and Figure 1) and has ample available open space with high irradiance that is suitable for solar energy production.

Table 1. Population and Population Density Estimates for 2015 and 2030 [42–46]. PA: Palestinian Authority.

Territory	Population Estimates (Millions)		Population Density (Persons per Km^2)	
	2015	**2030 Forecast**	**2015**	**2030 Forecast**
The PA	4.7	6.9	775	1124
Israel	8.3	10.6	409	481
Jordan	9.4	12.0	103	134
Total	22.4	29.5		

Note: The figure for Jordan refers to residents, not only citizens.

Given Israeli and Palestinian access to the Mediterranean, but limited open spaces, and Jordan's relative plethora of open spaces, but lack of desalination opportunities close to population centers, we investigated the technical and economic feasibility of transboundary exchanges of desalinated water and renewable energy.

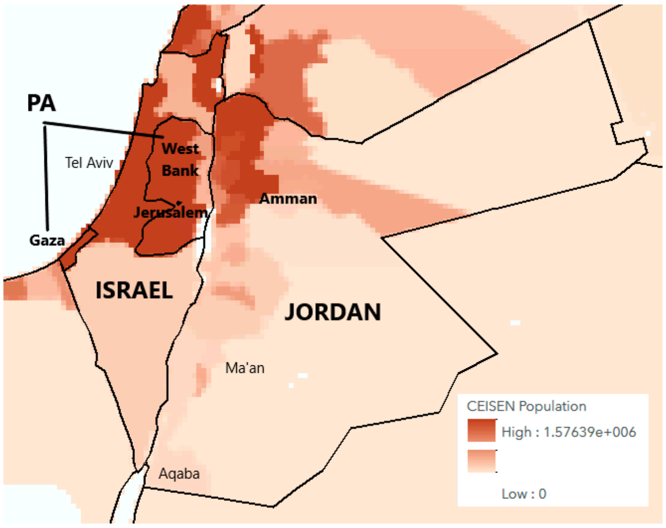


Figure 1. Population Density. (Adapted from [47]. ESRI, 2012.)

4. Methodology

4.1. Determining Desalination Production Scale

In order to evaluate such a proposal, we chose 2030 as a base year and used mid-range population estimates from the individual governmental authorities (shown in Table 1). In terms of evaluating water needs, the amount water was taken as the additional water necessary to keep per capita domestic consumption at current levels in Jordan and the PA (both between 45–50 m^3/c/y), without decreasing allocations to agricultural and industrial sectors. (Water policies are likely to also focus on demand management in all sectors, especially in Jordan, in which substantial subsidies exist for water. Such policies are desirable from an economic efficiency perspective, but their implementation is not assumed in this study). In the case of Israel, per capita domestic levels were assumed to decrease from recent levels of 94 m/c/y to 80 m/c/y, as past policies and campaigns have shown the potential for significant conservation [48]. (An additional scenario in which enough water would be produced to supply 80 m/c/y to all residents of the region, irrespective of nationality, was dropped after Jordanian and Palestinian experts indicated in roundtable discussions that such targets were not realistic and not something that policymakers are likely to consider).

We assumed constant long-term average precipitation rates and natural renewable freshwater supplies, and that all additional water would be sourced from desalination. This may be an underestimate of actual water needs, as climate change is predicted to reduce future supplies. As there is no consensus on the extent of change, however, no attempt was made in this study to incorporate such decreases. We also imposed a constraint that natural use be limited to renewable rates. Thus, desalination would be needed in order to cover both current over withdrawals as well as future increases in demand.

According to our model assumptions the additional water needed in 2030 in the region would be nearly 574 million cubic meters (mcm) annually, of which just over 280 mcm would be for Jordan (see Table 2). (In reality, the parties are currently planning for both decreases in natural freshwater availability as well as increases in demand. As such, actual desalination needs are likely to be even larger).

We assumed that all desalination would be accomplished using reverse osmosis, since this is the dominant technology in use in Israel, and the technology planned for desalination in Gaza and

Aqaba, and given that it is considered the most energy efficient of the currently commercially viable desalination methods [49].

Table 2. Additional Municipal Water Needed by 2030 [50–52]. Technical details and notes explaining the figures provided in Table 2 are available in the full study [1].

	2015 Municipal Supply (mcm)	**2015 Per Capita Consumption (m^3/y)**	**Declared Overdrafts from Renewable Sources (mcm)**	**2030 Population (Millions)**	**2030 Municipal Supply Needed (mcm)**	**Additional Water Needed (mcm)**
Jordan	436	46.4	160	12.0	556.6	280.6
The PA	214.9	47.9	107.2	6.9	330.5	222.8
Israel	777.8	93.7	0	10.6	848	70.2
TOTAL	1428.7	76.3	267.2	29.5	1735.1	573.6

4.2. Determining Energy Production Scales

In this article, we initially examined two different potential scales for renewable energy production, meant to represent lower and upper bounds for a plausible range of production. For each, the quantities of water were fixed as detailed in the previous section.

Scale 1—Lower Bound

In what is likely a lower-end estimate for the scale of energy production in a project of this nature, we calculated the amount of solar energy necessary to offset the estimated increased demand for desalinated water, as well as the transfer of this water to a main national water delivery system in the case of Jordan. That is, the amount necessary for the desalination and transfer of water to Jordan to be carbon neutral. For Israel and the PA, distribution systems were assumed to be proximate to proposed desalination facilities. We used current electricity consumption rates for RO plants in Israel, 3.4 kWh/m^3, for production. For the electricity needs of pumping water, we used 1.26 kWh per cubic meter, a figure slightly higher than average energy consumption of water delivery in Israel [53]. The figure is an estimate of the electricity needed to pump water from a point midway along the Israeli-Gazan coast (roughly equivalent to the location of the desalination plant in the Israeli city of Hadera) to Atar Eshkol, a large water reservoir in Israel, from which water could flow largely by gravity to the Jordan River Basin, and from there to Jordan The figure is meant to be representative and illustrative only. Actual energy consumption from pumping will depend highly on where the water is being produced and where it is consumed. An economically efficient solution would be to use desalinated water closer to the source and deliver natural fresh water to the extent possible to areas removed from the coast. Thus, for instance, to increase the supply of water in the West Bank from the mountain aquifer and the supply to Jordan from the Jordan River system, and increase Israeli's reliance on desalinated waters. This produces a figure of 2700 GWh annually. To this, we added 14% to compensate for transmission and distribution losses, as this is currently the average loss level in the Jordanian electricity grid [54]. This gives a figure of 3100 GWh annually.

Scale 2—Upper Bound

In the second scale examined, the amount of renewable energy produced is equal to 20% of total projected electricity production for each country in 2030. This figure is unrelated to the amount of desalinated water produced. It is a relatively ambitious target, similar to that promoted by several developed countries, yet it is not so high as to dominate the energy market, as issues of intermittency and dispatchability currently limit market share for renewables. (Intermittency refers to the fact that solar energy is not available 24 hours per day, but limited to sunlight hours, while the related concept of dispatchability refers to the fact that producers do not have the capability of regulating the quantity of energy produced to meet demand at any given time). While the 20% figure currently exceeds the declared commitments of any of the countries, as energy consumption grows, the 20% figure provided by the project will decrease over the project's lifetime; that is, it would only account for 20%

of consumption at the project's inception and presumably a lesser share thereafter. This represents our upper bound estimate of realistic renewable energy production for such a project.

The future energy needs for each country were taken from official government forecasts [55–57] and are shown in Figure 2. As can be seen, 20% of total forecasted regional demand in 2030 amounts to roughly 30,000 GWh per year, or nearly 35,000 GWh when accounting for transmission losses.

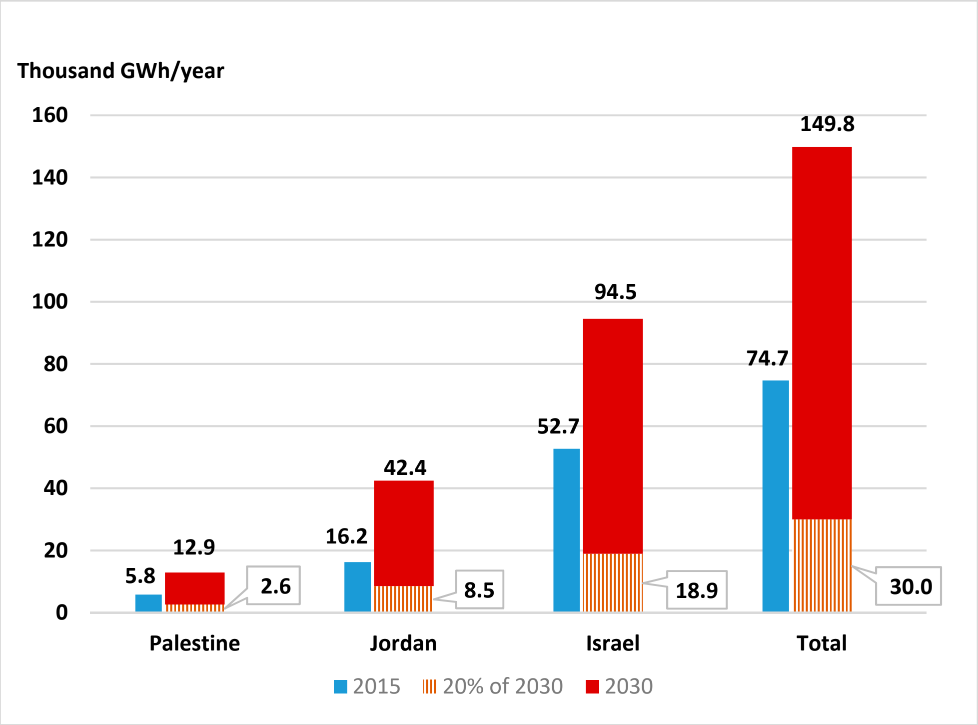


Figure 2. Current and Forecasted Electricity Demand [58–60].

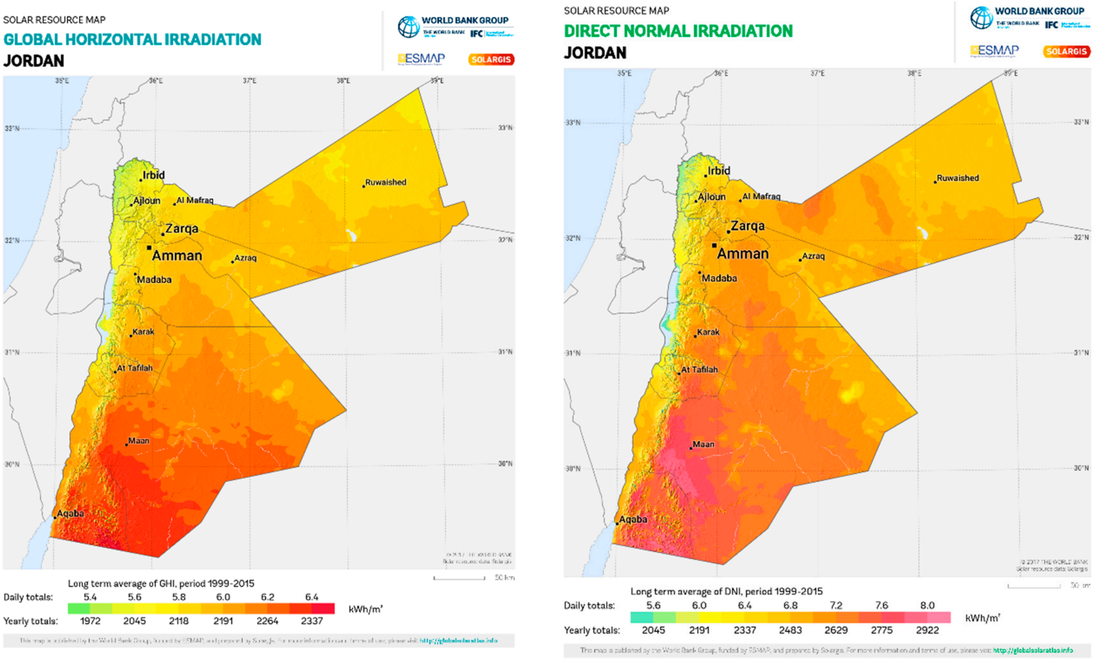
4.3. *Choice of Renewable Technologies*

In terms of renewable energy production, while some evaluations of wind energy in Jordan show that Jordan has exceptional potential for wind energy production, especially in the north [57], a study by the German Aerospace Center (DLR) concluded that Jordan's solar generation potential far outweighs that of wind and is more cost-efficient per unit of land [49]. In addition, solar energy can be generated in all parts of the Kingdom [58]. Moreover, economic analyses have found that the value of solar energy, which is produced during the day, coinciding with peak demand for much of the year in the region, is likely higher than wind energy, which is often produced at night when demand is lower [59]. For these reasons, we considered only solar energy technologies. Specifically, we analyzed two different types of solar energy production: PV and Concentrating Solar Power (CSP).

For PV calculations, we took into consideration First Solar's CdTe PV 17% efficient modules in fixed-tilt and one-axis tracking configurations [60]. The performance ratio estimates a coefficient for losses of different kinds, such as temperature losses, inverter losses, cables losses, dust, etc. Annual average irradiation on titled panels was estimated according to NASA Atmospheric Science Data Center database [61]. It is known that the power output performance of PV systems gradually declines within the module lifetime. For the chosen type of modules this decline is linear and was estimated to reach 14% over 25 years [60]. As our study takes into consideration the whole lifetime of a module, we assumed an average lifetime level of module performance degradation of 8.5%. For CSP calculations we considered Parabolic Trough (PT) and Central Receiver (CR) or Solar Tower (ST), as they are commercially proven.

4.4. Choice of Location of Energy Production

According to the estimations of the National Center of Research and Development of Jordan, 5% of the surface of Jordan is suitable for developing large scale solar plants [62]. Average solar radiation levels in Jordan are 5–7 kWh/m^2 per day with about 300 sunny days in a year, near ideal conditions for solar production. For the purposes of this study, we chose to locate production in a single location, near the southern city of Ma'an, which has the highest solar isolation in the country and has the lowest values of diffuse irradiance, appropriate for both PV and CSP plants (Figure 3) [63]. To be economically efficient, at present, a CSP plant's direct normal irradiance levels should be 2000 kWh/m^2/year or more [64]. Levels in the Ma'an region average 2600–2800 kWh/m^2 annually. In practice, diversification of sources of energy production is likely more practical and reliable than a single location. The choice of a single location was taken for simplification purposes only. Another reason for the choice of a southern location was that for deployment of the large-scale solar power plants in Jordan, only unoccupied governmental land was assumed to be available [65]. According to Jordan's Ministry of Energy and Mineral Resources, the renewable power projects should be established upon Jordanian governmental lands, and most of the free governmental lands are located in the Southern regions, with 10–15% land useable for large PV systems, while in the Northern and Western regions, ljz the governmental lands are smaller with only 5% available for the installation of utility scale solar power plants [65,66].



(**a**) (**b**)

Figure 3. (**a**) Global horizontal irradiation and (**b**) direct normal irradiation in Jordan (Reproduced with permission from [63]. The World Bank, Solar resource data: Solargis, 2017.).

4.5. Modeling Energy Outputs

We modeled the possible PV and CSP generation projects with given technical and economic characteristics, including needed energy generation and capacity, solar panel yield, irradiation levels, performance ratios, losses, the area of land required and capacity factors. In order to verify our calculations, we used multiple types of software for energy system modeling, such as Hybrid Optimization Model for Electric Renewables (HOMER-Pro) [67], and PVsyst [68]. HOMER, developed at the National Renewable Energy Laboratory, is a simulation tool for designing and optimizing electricity systems. PVsyst deals with grid-connected, stand-alone PV systems, and includes extensive databases covering weather conditions and PV systems components.

4.6. Economic Assessment

Though prices for both water and energy are likely to change by 2030, as the extent to which they will is difficult to determine, this study bases calculations on current prices. In calculating the water costs, we took average costs of the least cost existing RO seawater desalination plant in Israel, estimated at roughly US$0.55 per cubic meter ($m^3$) [69], and pumping and infrastructure costs from published literature (e.g., [53]), existing projects and correspondence with the Israeli Water Authority. The choice of least cost for an existing facility was taken given that RO costs have been declining over time. Current estimates for desalination cost in Gaza are higher, given the lack of existing infrastructure and security measures needed [28].

Costs for pumping to Jordan were calculated as also being an additional US$0.18/ m^3, using current electricity prices paid for by the water sector in Israel. The World Bank funded feasibility study of the Red-Dead project provides estimates of costs for supplying water to Amman [22]. In order to compare our estimates with those, we calculated the costs of pumping within Jordan, given current marginal electricity prices in Jordan, a distance of 100 km and a difference in elevation of 1000 m. This produced a figure of US$0.37/$m^3$; thus, producing a total cost of supply to Amman of US$1.10. The per unit costs of supplying desalinated water to Jordan calculated herein were very similar to the low end estimates of supplying water via the Red-Dead canal presented in the World Bank funded feasibility study, which provided a range of US$1.11–1.50 per cubic meter [22].

In terms of the energy production portion, we examined total installed costs, fixed and variable operating and maintenance costs (O&M), and land use costs. We also calculated the levelized cost of electricity (LCOE), a commonly used measure to compare different generation facilities and technologies. While not without its critics, especially when evaluating intermittent energy production (see, for example, [59]), LCOE is a commonly used measure to compare different generation facilities and technologies.

Current capital and operating and maintenance costs for large-scale photovoltaic energy production were used, as cost estimates for emerging technologies such as CSP are still unreliable, especially in this region, as they have yet to be implemented at a commercial level. We calculated LCOE using the Cost of Renewable Energy Spreadsheet Tool (CREST), developed by the US National Renewable Energy Laboratory (NREL) [70]. Due to the lack of accumulated experience with utility scale PV power plants and CSP plants construction in Jordan, in this analysis we used average costs of some of the parameters from around the world.

In addition to production costs, we considered costs of transmission as well, including construction of new transmission capacity. As the purpose of this analysis was to compare an energy exchange between Jordan and the PA and/or Israel, we looked at the transmission from the production source in Jordan to the connection to the national grids in the PA and Israel. The assumption being that the internal transmission and distribution would be similar if the countries were to produce the electricity themselves, and therefore, their costs should not be attributed to the project.

High- and low-end capital expenditures (CAPEX) for PV and CSP were taken from the International Renewable Energy Agency (IRENA) [64,71,72]. O&M costs calculations were based on IRENA estimates and current experience in Jordan based on expert consultation. These figures are summarized in Figure 4 below. Land use needs were taken from NREL data [73] and costs were based on expert consultations regarding actual experience with recent solar power plant construction in Jordan [74]. A land lease for solar development was estimated at 120 Jordanian Dinar per dunam per year (the equivalent of US$168,000/$km^2$/y, using an exchange rate of 1JD = US$1.4). This is less than half the average land lease costs for Israeli solar projects as set by the Israel Land Authority [75], assuming amortization at a 5% annual rate. The land use costs in this study were based on existing projects in Jordan of a much smaller scale than the ones evaluated herein, and thus, the per dunam rate would likely be less for larger scale projects. For this reason, it is likely an overestimate. However, as land use represents a relatively small share of overall costs, this discrepancy is unlikely to substantially affect overall project analysis.

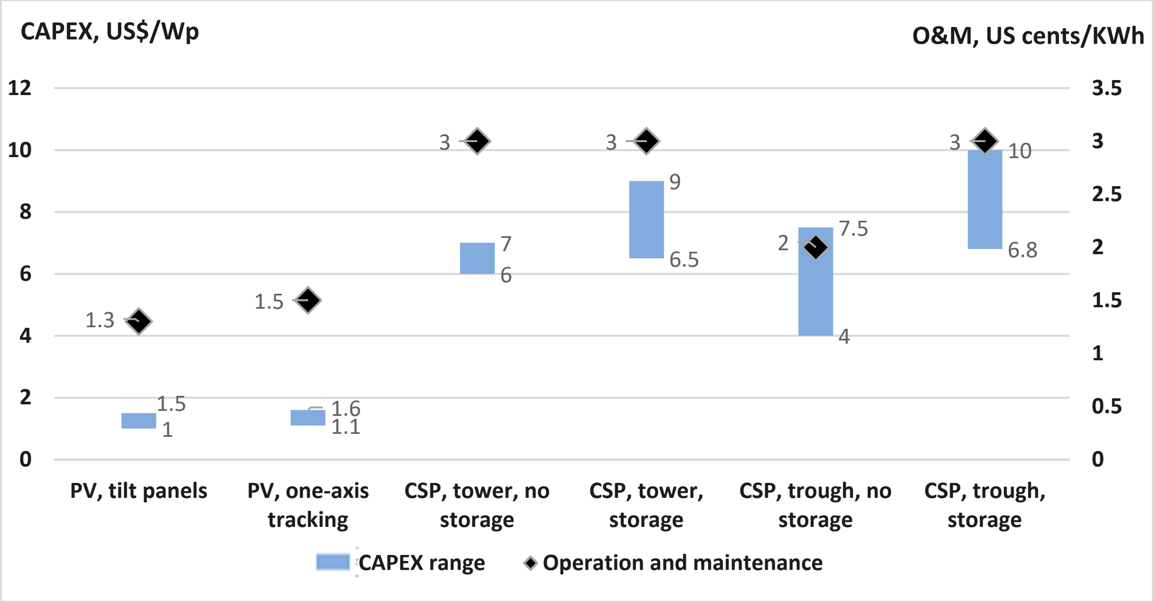


Figure 4. Parameters used for economic analysis: CAPEX and O&M Expenditures [76–78].

The economic calculations were based on the assumptions of a 25 year project life, 100% equity financing, a 5% discount rate and no inflation rate. For purposes of sensitivity analysis, similar calculations were made by varying all three parameters in various permutations. These are not shown herein, but did not change the rankings of technology options in terms of economic preferability.

5. Results

5.1. Technical Analysis

The results for the amount of energy infrastructure and land needed for the upper and lower bound scales are presented in the following tables. Table 3 presents the results for PV systems, while Table 4 presents the results for the CSP systems analyzed.

Table 3. Efficiency and Land Use Requirements for photovoltaic technology (CdTe).

	Project Scale	
Parameter	**Lower Bound**	**Upper Bound**
Input		
Energy generation (GWh)	3100	34,800
Solar panel yield (%)	17	17
Global horizontal irradiation (daily inputs) (total kWh/m^2/year)	2000	2000
Performance ratio, coefficient for losses (Estimated according to the theoretical works [73,78–80].)	0.9	0.9
Output fixed at 29^0 tilt		
Annual average irradiation on titled panels (kWh/m^2/year)	2200	2200
Total installed capacity of the system (MW$_{AC}$)	1600	17,600
The area of land required (km^2)	9.4	104.5
Capacity factor (%)	22.4	22.4
Output one-axis tracking		
Annual average irradiation on tracking panels (kWh/m^2/year)	2700	2700
Total installed capacity of the system (MW$_{AC}$)	1400	15,600
The area of land required (km^2)	8.3	92
Capacity factor (%)	25.5	25.5

Table 4. Efficiency and Land Use Requirements for Concentrating Solar Power (CSP) technology.

	Project Scale	
Parameter	**Lower Bound**	**Upper Bound**
Input		
Energy generation (GWh)	3100	34,800
Annual efficiency (trough) (%)	15	15
Annual efficiency (tower) (%)	20	20
Annual average insolation (kWh/m^2)	2500	2500
Output		
Total installed generator capacity (MW$_{AC}$)	1400	15,900
Trough		
The area of land required SM1 (km^2)	8.3	93
The area of land required SM2 (km^2)	16.6	185.8
Tower		
Total installed generator capacity (MW$_{AC}$)	900	9900
The area of land required SM1 (km^2)	6.3	70
The area of land required SM2 (km^2)	12.5	139.4

As can be seen from Table 3, installing trackers would increase the total output. It would raise the capacity factor to 25%. Moreover, modern technologies with solar panels efficiency of 17%, allow higher energy output while decreasing the area of land required. In the given climate conditions, the area of land for a one-axis tracking system required for covering the needed capacities is 15% less, than the fixed tilt. This is possible due to two factors. First, the energy production at 30-degree latitude increases 25% over no tracking systems [70]. Second, according to NREL, capacity and generation-weighted land-use requirements for one-axis tracking systems are just 10% higher over fixed-tilt panels [73] (Estimated for regions with similar weather conditions.).

The configuration of a CSP plant is a function of a Solar Multiple (SM). A steam cycle power station with SM1 has one solar field just large enough to provide turbine capacity under nominal irradiation conditions. A CSP plant with a SM2 would have a solar field twice as large and a thermal energy storage system large enough to store the energy produced by the second solar field during the day. Thus, one solar field directly drives the turbine, while the other solar field fills the storage for night time operation [78]. Storage capacity and collector field size can be increased to SM3 and SM4. Increasing solar fields further does not make sense, as during high irradiation periods they would increasingly produce unused surplus energy.

In terms of land use, CSP towers actually demand less land for the same amount of generation capacity, however, as will be shown in the following section, land use costs amount to only a small share of the overall costs of the project, regardless of scenario or technology. Moreover, the high-end estimate of 93 square kilometers amounts to just 0.1% of Jordan's territory, and only slightly more of its open spaces.

5.2. Economic Analysis

5.2.1. Renewable Energy Production Costs

Table 5 displays calculations of investment costs for the different scenarios, including both high and low-end costs. Given the current level of PV and CSP technologies development the lowest cost option in terms of capital expenditures is a PV system with one-axis tracking system. This technology needs around 5% less capital investment than the next cheapest option and requires less area for covering same electricity needs. CSP options are significantly more expensive, but offer the possibility of energy storage, and thus, reduce the problem of supply intermittency.

Table 5. Economic analysis—Investment Costs.

	PV		CSP			
	Tilt Panels	**One-Axis Tracking**	**Tower, No Storage**	**Tower, w/Storage**	**Trough, No Storage**	**Trough, w/Storage**
Scenario 1						
Installed generator capacity, MW	1585	1395	1420	888	1420	888
CAPEX, low estimate, million US$	1585	1534	8515	5765	5677	6032
CAPEX, high estimate, million US$	2377	2231	9935	7983	10,644	8870
Land use cost (annual), million US$	1.6	1.4	1.1	2.1	1.4	2.8
Land use cost (rent for all period), million US$ (undiscounted)	39.5	34.9	26.5	52.5	34.9	69.7
Land use cost (rent for all period), million US$ (5% discount rate)	23.4	20.6	15.7	31.1	20.6	41.3
Scenario 2						
Installed generator capacity, MW	17,760	15,629	15,905	9941	15,905	9941
CAPEX, low estimate, million US$	17,760	17,191	95,425	64,610	63,616	67,592
CAPEX, high estimate, million US$	26,640	25,006	111,329	89,461	119,281	99,401
Land use cost (annual), million US$	17.6	15.5	11.7	23.4	15.6	31.2
Land use cost (rent for all period), million US$ (undiscounted)	438.9	386.4	292.7	585.5	390.1	780.4
Land use cost (rent for all period), US$ million (5% discount rate)	259.8	228.7	173.3	346.6	231.0	461.9

One important finding from the analysis is that land leasing costs represent a relatively minor share of total project costs, regardless of technology choice. In no cases are they more than 2.5% of total capital expenditures, and in most cases substantially less. This seems to imply that lower land use costs in Jordan, relative to the PA and Israel, are unlikely to be a factor in locating the facilities. More important are the lack of available open spaces for such facilities in the PA and Israel and the regulatory and bureaucratic obstacles to obtaining approval for construction of such facilities there.

Capital investment, however, is not the only, nor the most representative measure of project costs or preferability. Figure 5 presents the calculations for the LCOE per technology, the per unit costs of electricity production over the lifetime of a project. These figures were based on a discounted cash flow analysis using tools available through the National Renewable Energy Laboratory of the U.S. Department of Energy [76,77]. (The values listed in Figure 5 are for a 5% discount rate and a 0% inflation rate. Using a 0% or 10% discount rate changes the values for all technologies by an average of 35%, but does not change their relative ranking in terms of LCOE. Similarly, introduction of an annual inflation rate of 3% raises the LCOE by 4–10% depending on the technology, but again, does not affect the relative ranking.)

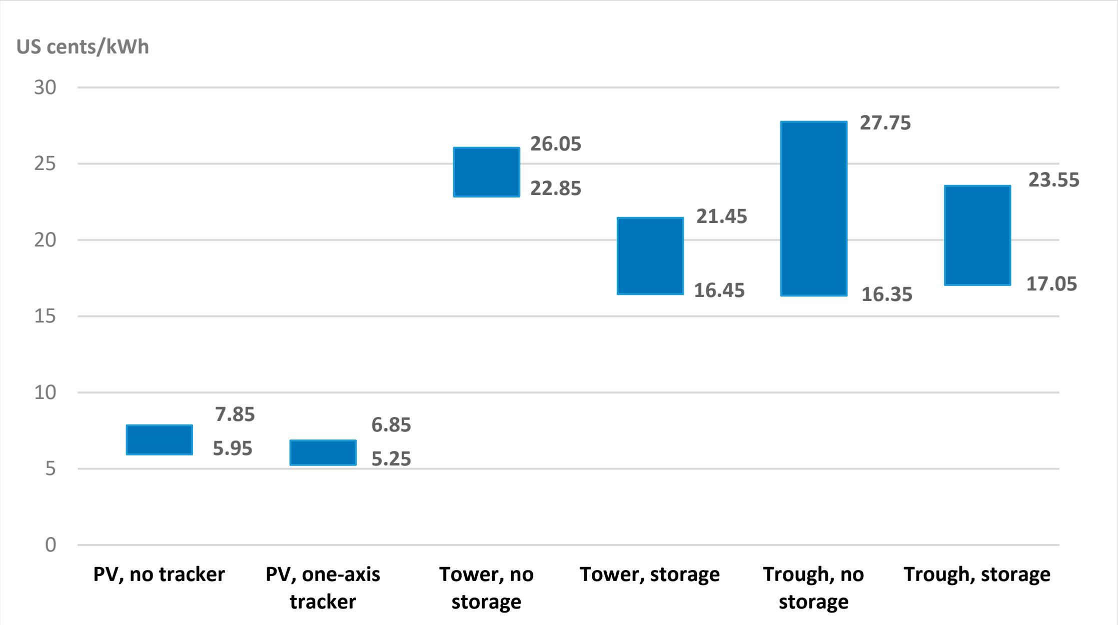


Figure 5. Levelized cost of electricity for different kinds of electricity generation. PV: photovoltaic.

A PV system with a one-axis tracker produced the lowest cost option, at 5.25 US cents per kWh. These values are comparable to current state of the art renewable energy projects and are less per kWh than fossil fuel produced electricity in the region. A winning tender for a medium-scale PV project in Jordan in 2015, for instance, offered production at 6.13 US cents per kWh [81], and according to the Jordanian Minister of Energy and Mineral Resources, as of 2018 generation was possible at just 4 US cents per kWh [82]. Several bids for solar projects in the region offered production at or below 3 US cents per kWh [83]. Thus, the estimate of this study is within the range of current solar projects and may, in fact, be a conservative estimate of actual costs.

The price calculated herein, was, in fact, similar to a recent winning bid for solar energy in Israel, which offered to produce at 5.53 US cents per kWh [84]. If the estimate of 4 US cents for Jordanian production is accurate, this would imply that production in Jordan is significantly (nearly 30%) cheaper than comparative projects in Israel. However, the primary advantage of the supply of energy from Jordan is the limitation of available open spaces needed for production of large-scale solar in both Israel and the PA.

A primary disadvantage of PV systems is their lack of storage capacity. CSP technologies have the advantage of storage capacity, but do not appear to be cost competitive at present. Currently, there are a number of technologies to integrate storage capacity into PV systems. For instance, pumped hydro storage, wherein electricity is used to pump water to a specified elevation during the day and the water is released at night to provide hydro-electric power, is one such means. However, the water requirements for the scale of project evaluated in this study are of such a magnitude that this option was not investigated in depth. Compressed air energy storage systems store energy by compressing air, and require large, low-cost natural buffers (e.g., caverns) to store compressed air, which is then used in gas-fired turbines to generate electricity on demand. As this technology is still being developed, it was not analyzed in this study, but may be considered in the future.

To date, the most proven storage technologies are batteries, such as lithium ion based ones. At present, however, these are limited in terms of hours of production, and thus, do not substantially mitigate the problem of intermittency. Furthermore, the batteries' efficiency and functionality decline in hot weather conditions, such as those in Jordan. Based on IRENA figures, the LCOE from the batteries is still not commercially competitive and so results for this technology are not presented herein, though the same sources estimates that costs may decline significantly by 2030 [85]. In conclusion, while CSP with storage is more cost-efficient than a similar system without storage capacity, it is still not yet competitive with PV.

5.2.2. Balancing Water and Electricity Costs

Given the cost estimates, in addition to the lower and upper bound scales examined, we were also able to calculate the amount of renewable energy that Jordan would have to supply in order to break even financially in terms of the costs of importing water. This provides an intermediate scale for renewable energy production. Given annual water needs for Jordan of just over 280 mcm, and taking the cost of US\$1.10/m^3, as detailed in Section 4.6 above, the project cost of delivering water from the Mediterranean to Amman would be US\$309/year. In reality, this is likely a high estimate, as not all of the water would need to go to Amman, and, depending on the supply route and delivery point to Jordan, much of the water may be consumed at locations closer and less costly than Amman.

Figure 6 shows the amount of electricity needed for Jordan to supply in order to balance the costs of the import of 280 mcm of water annually, using a range of electricity costs of between 4–10 US cents per kWh. At a supply of 4 cents/kWh, for instance, Jordan would have to supply 7725 GWh annually, while at a cost of 5.25 cents/kWh, our lowest cost estimate, it would need to supply 5886 GWh. An additional 14% percent would be necessary in estimating energy production as opposed to supply, in order to account for transmission losses. This is shown in Figure 5 as the dashed line.

Of course, the actual cost of electricity supplied would need to take into consideration not only production costs, but also transmission costs. Currently, lack of grid capacity is a serious limitation on development of renewable energy in Jordan [86], and clearly, transmission infrastructure would need to be significantly expanded. Obtaining reliable costs regarding necessary transmission infrastructure was difficult to assess, given the large scale of infrastructure needed. Additionally, it is difficult to translate infrastructure costs from existing projects into a per kWh cost, as the share of transmission and distribution costs in overall electricity prices are highly dependent on a number of factors, including location, fuel type, production facilities and existing capital and infrastructure. An analysis of US electrical utilities, for instance, showed that transmission costs averaged between 6–9% of production costs between 2011–2015, while transmission, distribution and maintenance collectively averaged 22–28% of production costs [87]. Applying such ratios to the LCOE calculated above, however, would risk being extremely inaccurate as such figures are highly location-specific. We therefore leave estimation of actual costs for building and operating the necessary transmission and distribution infrastructure to a full feasibility study. We do note that the transmission costs are generally a fraction of the production costs. For this reason, we present in Figure 6 a range of reasonable prices.

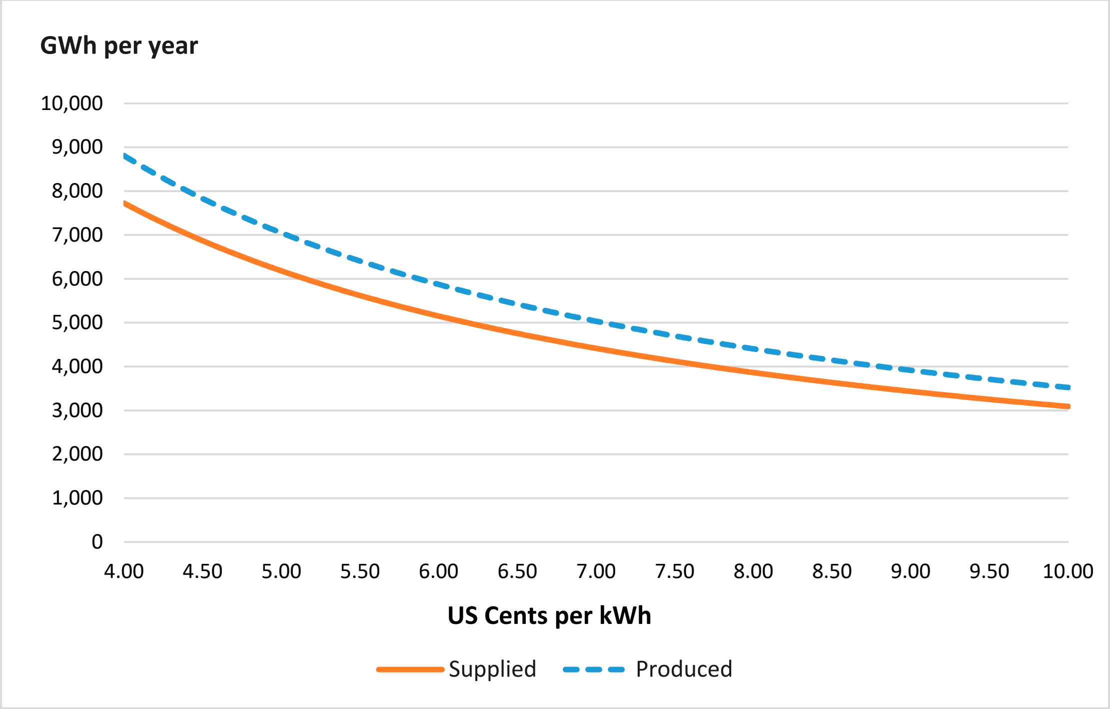


Figure 6. Annual energy supplies needed to balance Jordanian water import costs.

5.2.3. Renewable versus Fossil Fuels

In order to compare the cost of Jordanian produced solar with fossil fuel production, we utilized data for a recently constructed combined cycle gas fired power plant in Israel (the Tzafit Gas Power Plant which began operation in July 2015) [88]. LCOE of a natural gas power plant in the region was calculated at 7.35 US cents per kWh, which is more expensive than the cheapest options found in this study. This is without taking into consideration the environmental externalities from fossil fuel production, which, according to the Israeli Ministry of Environmental Protection, averaged roughly 2.8 US cents per kWh of electricity, though this figure is expected to decrease as the region phases out coal and relies increasingly on natural gas [89].

These factors seem to favor solar over gas production. However, electricity produced at gas-powered stations can produce at all hours and production can be scaled to fluctuating consumption patterns. In addition, such stations can be built in geographic proximity to consumers, which would reduce the costs for new transmission and distribution capacities, together with technical and economical transmission and distribution losses. Moreover, solar facilities also entail economic externalities [90], though the value of these was not calculated in this study.

Even given these limitations, production of wide-scale solar energy production in Jordan for regional consumption appears economically rational on the condition that there is guaranteed consumption and no need for storage, and/or if undertaken as part of government commitments to achieve designated policy goals stipulating a minimum level of renewable energy provision, or a maximum level of carbon emissions.

6. Geopolitical Considerations and Implications

Given that the renewable energy and desalination options in the scenarios considered in this study are not co-located and that the energy produced is not necessarily dedicated to desalination, one may question why the two have been presented together in terms of exchanges. They indeed are largely two separate analyses. The reason for doing so lies in geopolitical considerations. The fact that producing desalinated water for Jordan would be cheaper from the Mediterranean than from the Red Sea is already documented [22]. However, Jordan's desire to develop a Red-Dead desalination option rather than a less costly Med-Dead one is evidence that Jordan is willing to pay a premium for domestically sourced water. Similarly, countries are naturally leery of increasing dependence on foreign energy supplies, especially in conflict regions such as the Middle East, where relations between neighbors are tense. The experience of Israel and Jordan having natural gas supplies from Egypt disrupted during the Arab Spring emphasizes the risks involved in outsourcing supplies. For these reasons, the parties evaluated in this study have, in the past, often pursued unilateral strategies regarding resource development and environmental policy, rather than regional ones [91].

Such concerns would argue against the type of project evaluated here. However, there are several factors that mitigate or offset some of these genuine and important concerns. A considerable literature exists on policy-packages and linkages [92,93] that explains how combining issues, even seemingly unrelated issues, can provide win-win options in situations in which each element would be unacceptable to at least one party if seen in isolation. In this case, Jordan's reluctance to increase unilateral dependence on Israel or the PA for water supplies would be partially offset by becoming an energy supplier. That is, the concept of water-energy exchanges replaces unilateral dependencies with mutual interdependencies, in which each side has some leverage as it is a supplier of either water or energy, a prospect much more politically acceptable.

Moreover, such a project satisfies several other policy goals of the various parties. Israel is eager to promote regional cooperation with amicable Arab countries, and is actively pursuing economic ties with such nations. Palestinians are eager both to decrease their dependency on Israel as well as promote integration of infrastructures and economic relations with the rest of the Arab world, from which it is largely isolated, despite cultural ties. Jordan, currently a big importer of energy, would, at least in the second scenario, position itself as a regional energy supplier and would gain much needed foreign currency.

In addition to issues of water and energy independence, general political objections to Arab-Israeli cooperation represent a potential challenge to such a project, including by other Arab nations who are currently connected to Jordan's electricity grid. That said, commitments to cooperation on large joint infrastructure initiatives such as the Red-Dead project show that such objections are not insurmountable. In addition, in roundtable talks in all three countries, a few strategies were discussed that could mitigate such objections. Firstly, the project could be led either by the international community or could be private sector led, rather than being government to government. Secondly, the project could also be bilateral Palestinian-Jordanian or Israeli-Jordanian, in the event that one of those two parties is not interested in participating. In the event of a Palestinian-Jordanian project, this would only need Israeli approval for building of a pipeline traversing a small portion of its territory. Finally, third party guarantees for resources or, alternatively, compensation could be offers. Such guarantees for energy supplies were crucial, for instance, in getting the parties to agree to the Egyptian-Israeli peace agreement of 1979 [94].

7. Conclusions

The countries of the study region are increasingly turning towards desalination to provide fresh water to their growing populations. Likewise, the countries have committed to production of renewable energy, which necessitates relatively large tracts of lands given current technologies and the scale of demand anticipated. This work set out to examine whether, given the relative distribution of access to the sea for desalination and available open spaces necessary for large-scale renewables, water-energy exchanges offer a potential for promoting sustainable development to meet growing resource demands.

Our initial findings show that such a project appears to be both technically and economically feasible. The cost of water for Jordan and renewable energy using PV systems for Israel and the PA would be lower than if pursued unilaterally. Based on Jordan's current preference for developing more costly desalination from the Red Sea, it seems that countries are willing to pay a premium for resource independence, and thus, the economic incentive alone is unlikely to overcome the political preference for resource independence. However, as this article shows, there are several factors that may offset this preference. In the case of energy, the limiting factor for Israel and the PA is available land, and thus the possibility of outsourcing supply, rather than cost savings, would likely be their primary incentive for such an arrangement. In the case of Jordan, an additional incentive would be the possibility of becoming a regional energy supplier. Mutual interdependencies may be more politically acceptable than unilateral dependencies, even if the latter are cost effective.

As with any initial study much of the value herein is in identifying knowledge gaps and needs for future exploration. While such a project would face numerous technical and political challenges, and would be dependent on a fair amount of good will and trust of the parties themselves, the significant potential economic and geopolitical benefits to be reaped by each of the parties make further study of such an option worthwhile.

Author Contributions: D.K. was responsible for project conceptualization, administration and funding acquisition. A.S. was responsible for technical analysis and modeling of energy systems. D.K. and A.S. were jointly responsible for formal analysis and writing.

Funding: This research was funded by Ecopeace Middle East and the Konrad Adenauer Stiftung.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Katz, D.; Shafran, A. (Eds.) A Pre-feasibility study for mid-East water-renewable energy exchanges. In *Water Energy Nexus*; EcoPeace Middle East/Konrad-Adenauer-Stiftung: Amman, Jordan, 2017; Available online: http://ecopeaceme.org/wp-content/uploads/2018/03/WEN_Full_Study_Final_Web.pdf (accessed on 26 March 2018).
2. Shahzad, M.W.; Burhan, M.; Li, A.; Kim, C.N. Energy-water-environment nexus underpinning future desalination sustainability. *Eng. Adv.* **2017**, *413*, 52–64. [CrossRef]
3. Mittelman, G.; Ornit, M.; Abraham, D. Large-scale solar thermal desalination plants: A review. *Heat Transf. Eng.* **2007**, *28*, 924–930. [CrossRef]
4. Ghermandi, A.; Rami, M. Solar-driven desalination with reverse osmosis: The state of the art. *Desalin. Water Treat.* **2009**, *7*, 285–296. [CrossRef]
5. Li, C.; Yogi, G.; Elias, S. Solar assisted sea water desalination: A review. *Renew. Sustain. Energy Rev.* **2013**, *19*, 136–163. [CrossRef]
6. Sharon, H.; Reddy, K.S. A review of solar energy driven desalination technologies. *Renew. Sustain. Energy Rev.* **2015**, *41*, 1080–1118. [CrossRef]
7. Pugsley, A.; Zacharopoulos, J.; Mondol, D.; Smyth, M. Global applicability of solar desalination. *Renew. Energy* **2016**, *88*, 200–219. [CrossRef]
8. Darwish, M.A.; Abdulrahim, H.K.; Hassan, A.S.; Mabrouk, A.A. PV and CSP solar technologies & desalination: Economic analysis. *Desalin. Water Treat.* **2016**, *57*, 16679–16702.
9. Alkaisi, A.; Mossad, R.; Barforoush, A.S. A Review of the water desalination systems integrated with renewable energy. In Proceedings of the 1st International Conference on Energy and Power, ICEP2016, RMIT University, Melbourne, Australia, 14–16 December 2016; pp. 268–274. [CrossRef]
10. Griffiths, S. A review and assessment of energy policy in the Middle East and North Africa region. *Energy Policy* **2017**, *102*, 249–269. [CrossRef]
11. Abu-Jabal, M.; Karniyab, I.; Namsakib, Y. Proving test for a solar-powered desalination system in Gaza-Palestine. *Desalination* **2001**, *137*, 1–4. [CrossRef]
12. Sagie, D.; Feinerman, E.; Aharonl, E. Potential of solar desalination in Israel and in its close vicinity. *Desalination* **2001**, *139*, 21–33. [CrossRef]
13. Vardimon, R. Assessment of the potential for distributed photovoltaic electricity production in Israel. *Renew. Energy* **2011**, *3*, 591–594. [CrossRef]
14. Fthenakis, V.; Morin, O.A.; Atia, A.; Bkayrat, R.; Sinha, P. New prospects for PV powered water desalination plants: Case studies in Saudi Arabia. *Prog. Photovolt. Res. App.* **2016**, *24*, 543–550. [CrossRef]
15. Ali-Karaghouli, A.; Kazmerski, L.L. Energy consumption and water production cost of conventional and renewable-energy–powered desalination processes. *Renew. Sustain. Energy Rev.* **2013**, *24*, 343–356. [CrossRef]

16. Delgado-Torres, A.; Garcia-Rodriguez, L. Preliminary assessment of solar organic rankine cycles for driving a desalination system. *Desalination* **2007**, *216*, 252–275. [CrossRef]
17. Penate, B.; Garcia-Rodriguez, L. Seawater reverse osmosis desalination driven by a solar organic rankine cycle: Design and technology assessment for medium capacity range. *Desalination* **2012**, *284*, 86–91. [CrossRef]
18. Wellmann, J.; Meyer-Kahlen, B.; Morosuk, T. Exergoeconomic evaluation of a CSP plant in combination with a desalination unit. *Renew. Energy* **2018**, *128*, 586–602. [CrossRef]
19. Olwig, R.; Hirsch, T.; Sattler, C.; Glade, H.; Schmeken, L.; Will, S.; Ghermandi, A.; Messalem, R. Techno-economic analysis of combined concentrating solar power and desalination plant configurations in Israel and Jordan. *Desalin. Water Treat.* **2012**, *41*, 9–25. [CrossRef]
20. Elkarmi, F.; Abu Shikhah, N. *Power System Planning Technologies and Applications: Concepts, Solutions and Management*; IGI Global Publishing: Hershey, PA, USA, 2012.
21. Abu-Shikhah, N.; Hiasat, M.A.A.; Al-Rabadi, W.J. A photovoltaic proposed generation promotion policy—The case of Jordan. *Energy Policy* **2012**, *49*, 154–163. [CrossRef]
22. Allan, J.A.; Malkawi, A.I.H.; Tsur, Y. Red Sea–Dead Sea Water Conveyance Study Program Study of Alternatives. In *Preliminary Draft Report*; Executive Summary and Main Report; The World Bank Group: Washington, DC, USA, 2014; Available online: http://siteresources.worldbank.org/EXTREDSEADEADSEA/Resources/5174616-1416839444345/SoA-FINAL_March_2014.pdf (accessed on 22 April 2017).
23. Falkenmark, M.; Lindh, G. *Water for a Starving World*; Westview Press: Boulder, CO, USA, 1976.
24. Alpert, P.; Krichak, S.O.; Shafir, H.; Haim, D.; Osetinsky, I. Climatic trends to extremes employing regional modeling and statistical interpretation over the E. Mediterranean. *Glob. Planet. Chang.* **2008**, *63*, 163–170. [CrossRef]
25. Paz, S.; Kutiel, H. Rainfall regime uncertainty (RRU) in an Eastern Mediterranean region—A methodological approach. *Israel J. Earth Sci.* **2003**, *52*, 47–63. [CrossRef]
26. The World Bank. Climate Change Knowledge Portal. 2018. Available online: https://climateknowledgeportal.worldbank.org/region/middle-east/climate-data-historical (accessed on 2 August 2018).
27. Israeli Water Authority. Allocation, Consumption and Production Data. 2018. Available online: http://www.water.gov.il/Hebrew/ProfessionalInfoAndData/Allocation-Consumption-and-production/Pages/default.aspx (accessed on 20 April 2018). (In Hebrew)
28. Office of the Quartet. Report on the Activities of the Office, January 2016–June 2017. 2017. Available online: http://www.quartetoffice.org/files/Annual%20report%202017.pdf (accessed on 26 September 2017).
29. Israeli Water Authority. *Long-Term Master Plan for the National Part A—Policy Document Version*; Israeli Water Authority: Tel Aviv, Israel, 2012.
30. Cohen, O. Jordan Won't Budge on Red Sea-Dead Sea Project—and Israel Will Pay the Price. *Haaretz*, 29 January 2019.
31. El-Katiri, L. *A Roadmap for Renewable Energy in the Middle East and North Africa*; Oxford Institute for Energy Studies: Oxford, UK, 2014.
32. Energy Balance of Israel (detailed by products). 2016. Available online: http://www.cbs.gov.il/reader/?MIval=%2Fcw_usr_view_SHTML&ID=564 (accessed on 8 September 2017).
33. Younan, M.; Popper, E. Regional Cooperation in Energy. In *The Arab Peace Initiative and Israeli-Palestinian Peace*; Arnon, A., Bamya, S., Eds.; Aix Group, Aix-Marseille University: Palestine, Israel, 2012; pp. 300–359.
34. BBC. New Attack on Egypt Gas Pipeline to Israel and Jordan. Available online: https://www.bbc.com/news/world-middle-east-15670301 (accessed on 10 November 2011).
35. World Bank. Renewable Electricity Share of Total Electricity Output (%). From Database: Sustainable Energy for All. 2018. Available online: https://databank.worldbank.org/data/source/sustainable-energy-for-all# (accessed on 30 December 2018).
36. RCREEE—Regional Center for Renewable Energy and Energy Efficiency. Arab Future Energy Index (AFEX)—Renewable Energy. Palestine Country Profile. 2015. Available online: http://www.rcreee.org/sites/default/files/palestine_fact_sheet_print.pdf (accessed on 16 August 2017).
37. International Renewable Energy Agency (IRENA). Pan-Arab Renewable Energy Strategy 2030. 2014. Available online: https://www.irena.org/DocumentDownloads/Publications/IRENA_Pan-Arab_Strategy_June (accessed on 2 April 2017).

38. Regional Center for Renewable Energy and Energy Efficiency (RCREEE). Arab Future Energy Index (AFEX) 2015—Renewable Energy. 2015. Available online: http://www.rcreee.org/content/AFEXRE2015 (accessed on 16 August 2017).
39. Israeli Ministry of National Infrastructures. Israel's Fuel Economy. 2017. Available online: http://energy.gov.il/English/Subjects/Subject/Pages/GxmsMniIsraelsFuelEconomy.aspx (accessed on 17 August 2018).
40. Israeli Ministry of Environmental Protection. Israel Commits to Reducing GHG Emissions 26% by 2030. 2015. Available online: http://www.sviva.gov.il/English/ResourcesandServices/NewsAndEvents/NewsAndMessageDover/Pages/2015/Oct-10/Israel-Commits-to-Reducing-GHG-Emissions-26-percent-by-2030.aspx#GovXParagraphTitle1 (accessed on 14 January 2017).
41. Fischhendler, I.; Herman, L.; Anderman, J. The geopolitics of cross-border electricity grids: The Israeli-Arab case. *Energy Policy* **2016**, *98*, 533–543. [CrossRef]
42. United Nations. *World Population Prospects: The 2017 Revision*; United Nations, Department of Economic and Social Affairs, Population Division: New York, NY, USA, 2017.
43. Department of Statistics. Population Projections for Kingdom for the Period 2015–2050. 2016. Available online: http://www.cbs.gov.il/www/hodaot2013n/01_13_170t1.pdf (accessed on 22 April 2017). (In Arabic)
44. State of Palestine—Prime Minister's Office of Population & UNFPA. Palestine 2030. 2016. Available online: http://palestine.unfpa.org/publications/palestine-2030-demographic-change-opportunities-development (accessed on 20 April 2017).
45. Central Bureau of Statistics. Statistical Abstract of Israel. 2013. Available online: https://www.cbs.gov.il/en/publications/Pages/2013/Statistical-Abstract-of-Israel-2013-No64.aspx (accessed on 2 August 2017).
46. United Nations. Demographic Yearbook. 2015. Available online: https://unstats.un.org/unsd/demographic/products/dyb/dybsets/2015.pdf (accessed on 2 August 2017).
47. ESRI. World Population Density. 2012. Available online: https://www.arcgis.com/home/item.html?id=1cdb43e39401461397f05c600c7e22a8 (accessed on 2 August 2017).
48. Katz, D. Undermining demand management with supply management: Moral hazard in Israeli water policies. *Water* **2016**, *8*, 159. [CrossRef]
49. German Aerospace Center (DLR) Institute of Technical Thermodynamics, Section Systems Analysis and Technology Assessment. Concentrating Solar Power for the Mediterranean Region—Final Report. Study commissioned by Federal Ministry for the Environment, Nature Conservation and Nuclear Safety Germany. 2005. Available online: https://www.dlr.de/tt/Portaldata/41/Resources/dokumente/institut/system/publications/MED-CSP_complete_study-small.pdf (accessed on 5 May 2017).
50. Hashemite Kingdom of Jordan. *National Water Strategy 2016–2025*; Ministry of water and Irrigation: Dodoma, Tanzania, 2015.
51. Palestinian Central Bureau of Statistics. 2016. Available online: http://www.pcbs.gov.ps/Portals/_Rainbow/Documents/water/water-E-main.htm (accessed on 2 August 2017).
52. Israel Water Authority. 2016. Available online: http://water.gov.il/Hebrew/ProfessionalInfoAndData/Allocation-Consumption-and-production/20156/1998-2015.xls (accessed on 16 August 2017).
53. Hoffman, D. Potential for energy savings in the Israeli water sector. *Water Eng.* **2014**, *91*, 27–34. (In Hebrew)
54. NEPCO. Available online: http://www.nepco.com.jo/store/docs/web/2015_en.pdf (accessed on 16 August 2017).
55. Palestinian Energy and Natural Resources Authority. Available online: http://www.pcbs.gov.ps/Portals/_Rainbow/Documents/Energy-2015-06-e.htm (accessed on 17 August 2017).
56. Israeli Ministry of Energy & Water. Available online: http://energy.gov.il/Subjects/Electricity/Pages/GxmsMniAboutElectricity.aspx (accessed on 16 August 2017).
57. Mohsen, M.S.; Akash, B.A. Potentials of wind energy development for water pumping in Jordan. *Renew. Energy* **1998**, *14*, 441–446. [CrossRef]
58. Greenpeace. Jordan's Renewable Energy Future. 2013. Available online: http://www.greenpeace.org/arabic/PageFiles/481146/Jordan_Report2013.pdf (accessed on 26 December 2017).
59. Joskow, P.L. Comparing the costs of intermittent and dispatchable electricity generating technologies. *Am. Econ. Rev.* **2011**, *101*, 238–241. [CrossRef]
60. First Solar Series 4 PV Module Datasheet. Available online: http://www.firstsolar.com/-/media/First-Solar/Technical-Documents/Series-4-Datasheets/Series-4V3-Module-Datasheet.ashx (accessed on 26 March 2017).

61. NASA Atmospheric Science Data Center. Available online: https://eosweb.larc.nasa.gov/cgi-bin/sse/sse.cgi?skip@larc.nasa.gov (accessed on 26 March 2017).
62. Azzam, S. *Renewable Energy in Jordan—Desalination of Brackish Water by Solar Energy*; National Center for Research and Development: Amman, Jordan, 2013.
63. World Bank and Solargis. Solar resource maps of Jordan. 2017. Available online: https://solargis.com/maps-and-gis-data/download/jordan/ (accessed on 26 March 2017).
64. IRENA. Renewable Energy Cost Analysis: Solar Photovoltaics. 2014. Available online: https://www.irena.org/DocumentDownloads/Publications/IRENA_RE_Power_Costs_2014_report.pdf (accessed on 22 April 2017).
65. Al-omary, M.; Kaltschmitt, M.; Becker, C. Electricity system in Jordan: Status & prospects. *Renew. Sustain. Energy Rev.* **2018**, *81*, 2398–2409.
66. Jordanian Ministry of Energy and Mineral Resources (MEMR) Annual Report. Available online: http://www.memr.gov.jo/echobusv3.0/SystemAssets/505997da-c229-4f65-8139-9ae8e45b0c78.pdf (accessed on 26 September 2017).
67. HOMER-Pro. 2017. Available online: https://www.homerenergy.com/products/index.html (accessed on 5 May 2017).
68. PVsyst 2017. Available online: http://www.pvsyst.com/en/ (accessed on 5 May 2017).
69. Hoffman, D. *Seawater Desalination and Applications*; Israel Water Authority: Tel Aviv, Israel, 2014.
70. NREL. Crest—Cost of Energy Models. 2017. Available online: https://financere.nrel.gov/finance/content/crest-cost-energy-models (accessed on 26 March 2017).
71. IRENA. Renewable Energy Cost Analysis: Concentrating Solar Power. 2014. Available online: https://www.irena.org/DocumentDownloads/Publications/RE_Technologies_Cost_Analysis-CSP.pdf (accessed on 26 March 2017).
72. IRENA. *Renewable Power Generation Costs in 2017*; International Renewable Energy Agency: Abu Dhabi, UAE, 2018.
73. Ong, S.; Clinton, C.; Denholm, P.; Margolis, R.; Heath, G. *Land-Use Requirements for Solar Power Plants in the United States*; National Renewable Energy Laboratory (NREL): Golden, CO, USA, 2013. Available online: http://www.qualenergia.it/sites/default/files/articolo-doc/Studio_NREL_FV_e_consumo_suolo.pdf (accessed on 20 April 2017).
74. Bundokji, M.; Field Officer, Ecopeace Middle East, Amman Jordan. Personal Communication, 2017.
75. Lichtman, M. Land for solar farms to cost NIS 60-100,000 per acre. *Globes*, 17 January 2017. Available online: https://en.globes.co.il/en/article-solar-farmland-to-cost-nis-60-100000-per-acre-1001172472 (accessed on 16 August 2017).
76. National Renewable Energy Laboratory of the U.S. Department of Energy. LCOE Calculator. 2017. Available online: https://www.nrel.gov/analysis/tech_lcoe.html (accessed on 26 March 2017).
77. National Renewable Energy Laboratory of the U.S. Department of Energy. Cost of Renewable Energy Spreadsheet Tool (CREST). 2017. Available online: https://financere.nrel.gov/finance/content/crest-cost-energy-models (accessed on 26 March 2017).
78. Trieb, F.; Schillings, C.; O'Sullivan, M.; Pregger, T.; Hoyer-Klick, C. Global Potential of Concentrating Solar Power. German Aerospace Center, Institute of Technical Thermodynamics, 2009. Available online: https://www.solarthermalworld.org/sites/gstec/files/global%20potential%20csp.pdf (accessed on 22 April 2017).
79. National Renewable Energy Laboratory (NREL). Life Cycle Greenhouse Gas Emissions from Solar Photovoltaics. 2013. Available online: http://www.nrel.gov/docs/fy13osti/56487.pdf (accessed on 26 March 2017).
80. DCE. Solar Energy Production in Motion the Advantages of Single-Axis Solar Tracking Systems. Available online: http://www.dcesolar.com/docs/Single-Axis-Tracking-Systems.pdf (accessed on 5 May 2017).
81. Khashman, A. Uncertainty and challenges in Jordan's Round 3 RE auction. *PV Magazine*, 7 September 2018.
82. Zawati, H. Renewable energy on rise in resource-poor Jordan. Available online: https://news.yahoo.com/renewable-energy-rise-poor-jordan-014335322.html (accessed on 28 September 2018).
83. Bellini, E. UPDATE: ACWA offered lowest bid in Egypt's 200 MW tender. *PV Magazine*, 8 August 2018.
84. Gorodeisky, S. Trying to close the gap: New Tender for solar electricity production. *Globes*, 2018. Available online: https://www.globes.co.il/news/article.aspx?did=1001261432(accessed on 20 November 2018). (In Hebrew)

85. IRENA. Electricity Storage. Technology Brief. Electricity storage and renewables: Costs and Markets to 2030. 2017. Available online: https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2017/Oct/IRENA_Electricity_Storage_Costs_2017.pdf (accessed on 30 December 2018).
86. Jordan Times. Grid's technical challenges' prompt freeze in green energy projects. *Jordan Times*, 29 January 2019.
87. US EIA. Revenue and expense statistics for major U.S. investor-owned electric utilities. 2017. Available online: https://www.eia.gov/electricity/annual/html/epa_08_03.html (accessed on 26 September 2017).
88. Power Technology. Tzafit Gas Fired Power Plant. Available online: https://www.power-technology.com/projects/tzafit-gas-fired-power-plant/ (accessed on 4 July 2017).
89. Ministry of Environmental Protection (Israel). Environmental Externality Costs from Air Pollution. Available online: http://www.sviva.gov.il/subjectsEnv/SvivaAir/Pages/AirExternalCost.aspx (accessed on 14 May 2017). (In Hebrew)
90. Varun, I.K.B.; Prakash, R. LCA of renewable energy for electricity generation systems—A Review. *Renew. Sustain. Energy Rev.* **2009**, *13*, 1067–1673. [CrossRef]
91. Fischhendler, I.; Dinar, S.; Katz, D. Spatial and temporal politics of unilateral environmentalism: Cooperation and conflict over water management along the Israeli-Palestinian border. *Global Environ. Politics* **2011**, *11*, 36–61. [CrossRef]
92. Fischhendler, I.; Zilberman, D. Packaging policies to reform the water sector: The case of the central valley project improvement act. *Water Resource Res.* **2005**, *41*. [CrossRef]
93. Katz, D.; Fischhendler, I. Spatial and temporal dynamics of linkage strategies in Arab–Israeli water negotiations. *Polit. Geogr.* **2011**, *30*, 13–24. [CrossRef]
94. Rubinovitz, Z.; Rettig, E. Crude peace: The role of oil trade in the Israeli-Egyptian peace negotiations. *Int. Stud. Q.* **2018**, *62*, 371–382. [CrossRef]