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WATER ENERGY NEXUS

A PRE-FEASIBILITY STUDY FOR MID-EAST WATER-RENEWABLE ENERGY EXCHANGES

EcoPeace
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1. INTRODUCTION

The Levant area of the Middle East suffers from scarce supplies of fresh water and lacks developed renewable energy supplies. The region is also facing rapid population growth and climatic change, placing additional pressures on limited natural resources. As such, the region's countries are in need of long-term strategic planning in the water, energy and land-use sectors.

Israel and Palestine have access to the Mediterranean, and thus, relatively easy access to desalination, but have relatively little open spaces necessary for large scale renewable energy facilities; whereas Jordan's access to the sea is far from its population centers, but it has a relatively large amount of unpopulated spaces that are very suitable for producing renewable energy, particularly solar. This report presents a pre-feasibility study of an initiative for water-energy exchanges between Israel, Jordan and Palestine as a means of addressing water and energy needs in an economically efficient and environmentally sound manner. The overarching idea is that Israel and/or Palestine could produce desalinated water and supply this to Jordan, while Jordan could supply Palestine and Israel with renewable energy. As such, all sides stand to gain from mutual dependencies of regionally integrated water and energy sectors.

As a pre-feasibility study, the objective is to present a workable framework for how such an arrangement could be implemented, to evaluate various technological options for achieving such an arrangement, to undertake initial economic analysis of such a project, and to identify political benefits and challenges to project implementation. The following sub-sections in this introduction will present a brief survey of some of the resource scarcity issues facing the region, followed by a description of some of the policies in place to address these issues, and finally a more detailed description of and rationale for the proposed water-energy exchanges.

1.1. Regional Resource Scarcity

Water

Annual renewable freshwater supplies (accessible net recharge) among Jordan, Palestine, and Israel collectively are less than 3000 million cubic meters (mcm).[1] Distributed across a population of over 22 million (including refugees and other non-citizens currently residing in Jordan), this means that the region's population has less than 150 cubic meters per capita annually ($m^3/c/y$). For reference, the commonly used Falkenmark index of water stress, indicates that countries with annual supplies of less than 1000 $m^3/c/y$ suffer from water scarcity and those with less than 500 $m^3/c/y$ suffer from chronic water scarcity.[2,3] Thus, the region as a whole (and each of the countries individually) must deal with severe chronic water scarcity.

Due to rapid population growth in the region coupled with predicted decreases in rainfall and increased evaporation due to climate change, the quantities of water available per capita are expected to drop even lower. All three countries still have growing populations due to high fertility rates, and, in the case of Jordan, a massive influx of refugees in recent years. In addition, precipitation in the region is predicted to decrease due to climate change

1   Allan, J.A., A.I.H. Malkawi, and Y. Tsur. 2014. Red Sea–Dead Sea Water Conveyance Study Program Study of Alternatives Final Draft Report Executive Summary and Main Report.

2   Falkenmark, M. and Lindh, G. (1976). Water for a Starving World. Westview Press: Boulder, CO, USA.

3   Lawrence, P., Meigh, J. and Sullivan, C.. (2002). The Water Poverty Index: an International Comparison. Keele Economics Research Papers 2002/19. Keele University. UK.

by over 20% in several climate scenarios,[4,5,6] and there are already indications that this process is already in effect, reducing average annual renewable water supplies.[7] These developments are adding to the existing pressures currently placed on natural water resources and thus, the countries are actively seeking the development of additional water sources.

Energy

At present all three nations are highly dependent on imported fossil fuels for their energy production. Energy usage in general, and electricity consumption in particular, have been rising at rates faster than the rate of population growth, due to economic growth and changes in lifestyle. This places heavy economic, political, and environmental costs on the countries of the region. Imports of fossil fuels represent a major drain on foreign currency reserves.[8] Palestine relies on Israel for over 90% of its energy (electricity and fuels). Jordan, which imports 96% of its energy, needs, spends the equivalent of roughly 20% of the nation's total Gross Domestic Product (GDP) for its energy imports.[9,10] 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.

Fossil fuel based energy sources also have numerous deleterious environmental impacts, including both local air pollution as well as contributing to global greenhouse gas emissions (GHG). Per capita GHG emissions in Israel are more than double world averages, and local air pollution in Israel alone, stemming in large part from fossil fuel use, was found to be responsible for 2,200 premature deaths annually.[11] Palestine, while contributing much less to GHG emissions, likely suffers from similar local pollution impacts. Jordan's GHG emissions are below world averages, however, the Kingdom has levels of energy intensity and carbon emissions per unit of economic production (as measured by GDP) far above world averages.[12,13,14]

Land

The region is also densely populated, which places continuous pressure on rapidly diminishing open spaces. In a United Nation's ranking of population density based on figures 2015, both Palestine and Israel were among the most densely populated nations.[15] The Gaza Strip is considered one of the most densely populated areas in the world, trailing only behind city states such as Hong Kong, Singapore, and Monaco. The West Bank also ranks among the world's most crowded areas.[16]

4   Alpert, P.; Krichak, S.O.; Shafir, H.; Haim, D.; Osetinsky, I. (2008). Climatic trends to extremes employing regional modeling and statistical interpretation over the E. Mediterranean. Global Planetary Change 63: 163–170.

5   Paz, S.; Kutiel, H. (2003). Rainfall Regime Uncertainty (RRU) in an Eastern Mediterranean region—A methodological approach. Israel Journal of. Earth Science 52, 47–63.

6   The World Bank. (2012). The Little Data Book on Climate Change II. The World Bank: Washington, DC, USA. (Climate Data Surveys for Israel, Jordan, and West Bank & Gaza).

7   Israeli Water Authority. 2012. Long-Term Master Plan for the National Part A - Policy Document Version 4 August 2012.

8   Younan, M.,and E. Popper. (2012). Regional Cooperation in Energy. In: Arnon,A, and S. Bamya (Eds.),The Arab Peace Initiative and Israeli-Palestinian Peace. Aix Group, pp.300–359.

9   El-Katiri, L. (2014). A Roadmap for Renewable Energy in the Middle East and North Africa. Oxford Institute for Energy Studies. OIES Paper MEP 6.

10   World Nuclear Association. (2017). Nuclear Power in Jordan. http://www.world-nuclear.org/information-library/country-profiles/countries-g-n/jordan.aspz

11   Rinat, T. (2017). 2200 people die each year in Israel due to exposure to air pollution. Haaretz 15 March, 2017. (In Hebrew)

12   https://knoema.com/EIAIES2014Aug/international-energy-statistics-february-2015?location=1001200

13   Regional Center for Renewable Energy and Energy Efficiency (RCREEE). (2015a). Arab Future Energy Index (AFEX) 2015 – Energy Efficiency.

14   The World Bank. World Development Indicators website. http://data.worldbank.org/data-catalog/world-development-indicators

15   United Nations. (2017). World Population Prospects: The 2017 Revision. United Nations, Department of Economic and Social Affairs, Population Division.

16   The World Bank. (2017). World Development Indicators website. http://data.worldbank.org/indicator/EN.POP.DNST

Moreover, access to land is also an issue in the West Bank. Land use there is highly restricted due to regulations and policies put in place by the Israeli Civil Administration, inhibiting development there, including development of renewable resources.[17] In Israel, most of the remaining open spaces are in the southern desert, where much of the lands are either reserved for military use or are natural reserves and other protected areas.[18]

Jordan, on the other hand, while the most populated of the three countries, is much less densely populated. Much of Jordan's population is concentrated in the Amman metropolitan area and the Jordan Valley, with much of the eastern and southern portions of the country largely unpopulated with a relatively large amount of open spaces.

Table1 - Population Density

Territory	People per square kilometer	
	2015 estimates	2030 forecast
Gaza Strip	5,046	
West Bank	466	
Palestine (West Bank and Gaza)	775	1,124
Israel	409	481
Jordan	103	134

Sources:[15,17] and official government population growth estimates.

17   World Bank Group. (2017). Securing Energy for Development in West Bank and Gaza. Summary Report. June 13, 2017.

18   For example, in Israel's four largest regional councils all located in desert areas in the country's south, protected areas represent between 50-72% of the total land. http://moazot-green.com

1.2. Efforts at Addressing Scarcity

Water

In terms of addressing water scarcity, for years, policy in the region has been to withdraw unsustainable amounts of water, depleting and contaminating aquifers and desiccating streams and other aquatic ecosystems. Despite the development of alternative water sources, as will be discussed shortly, this policy continues till this day. While all three countries have stressed the importance of efficiency, there is growing recognition that the absolute scarcity they face, coupled with growing populations and climate change, necessitates additional water resources. Desalination has emerged as the primary source of such additional water supplies.

Israel is considered a world leader in developing and applying technologies to address limited water supplies,[19] including development of large-scale reverse osmosis (RO) sea-water desalination. Since the activation of the first large sea-water RO plant in Ashkelon in 2005, desalination has added a quantity equivalent to an additional 40% of Israel's natural renewable freshwater supplies. Desalination currently supplies almost 80% of all domestic consumption. While not solving water scarcity issues, desalination has at least allowed for Israel to maintain safe reliable water supplies for domestic purposes for a growing population. Given that roughly 80% of municipal water is reused in Israel, each cubic meter of desalinated water actually adds 1.8 cubic meters to the national water budget.

Development of desalination is also high on the agenda of the Palestinian Authority and the Kingdom of Jordan.[20] Small sea-water and brackish water desalination plants are currently functioning in the Gaza Strip, but supply a small share of the local con-

19   OECD (2011), *OECD Environmental Performance Reviews: Israel 2011*, OECD Publishing, Paris: p.104.

20   Grover, V. I., Darwish, A. R., & Deutsch, E. (2010). Integrated Water Resources Management in Jordan Economic Research Forum Working Paper. Cairo, Egypt: The Economic Research Forum.

sumption.[21,22] Furthermore, as desalination in Gaza is unregulated and lacking oversight, many unlicensed private suppliers are suspected of pumping water from illegal wells and delivering contaminated water.[23] Upgrading of an existing sea-water desalination plant and construction of a large-scale plant are being planned by the Palestinian Water Authority and, if/when operationalized, will add an additional 25% and eventually an additional 66% to current supplies.[24] This should both alleviate much of the severe local water scarcity there as well as the overpumping of the local groundwater.

The West Bank lacks access to the sea, and thus, to large-scale desalination. At present, it is restricted to the allotted quantities of water as per the Interim Peace Agreement of 1993 between the Palestine Liberation Organization and Israel (the Oslo Accords), and purchases additional water from Israel. The Oslo Agreement was designed as a five-year interim agreement, but has not been replaced with a permanent agreement. Currently, Palestinian options for developing local West Bank water resources are limited, as all development must be approved by the Joint Water Committee (JWC) established by the Oslo Accords. Meetings and approvals of the JWC have often been lacking or infrequent due to non-water related political issues between the parties. The PA is eager to negotiate a reallocation of shared resources which would give it a larger share of natural water sources, including both an increased shared of the Mountain Aquifer (both fresh and brackish water), as well as rights to Jordan River water. Regardless of any reallocation, however, additional water is likely to be needed to satisfy future Palestinian water needs. At this stage, there is no plan for transfer of desalinated water from Gaza to the West Bank, though this measure figures in some of the PA's long term water plans.

The primary element in Jordan's planning for addressing its water scarcity needs is the development of massive desalination in Aqaba, a regional water development program within the framework of a proposed Red-Dead canal. If built, this project, estimated to cost over $10 billion[25], and according to some estimates significantly more, would provide for up to 800-1000 mcm of desalinated water, primarily to Jordan, but also to Palestine and Israel, and a similar amount of brine would be delivered by pipeline through Jordan to the Dead Sea in an effort to stabilize the Sea's level. This project has undergone extensive feasibility studies, supported by the World Bank, and has the official support of all three governments, despite widespread concerns about cost-effectiveness and environmental impacts, such as impact on coral reefs in the Gulf of Aqaba, and the development of algal blooms and gypsum in the Dead Sea.

In 2013, representatives of the three governments signed a Memorandum of Understanding for construction of a desalination plant in Aqaba which would provide between 80-100 mcm of freshwater to southern Jordan and southern Israel. In exchange for desalinated water delivered to Israel from Jordan in the south, Israel would provide Jordan with water from the Sea of Galilee/Jordan River basin in the north, closer to Jordanian population centers and existing water infrastructure. In addition, the Palestinian Authority would be allocated 20-30 mcm to be purchased from

21   UNICEF. (2017). EU and UNICEF inaugurate Gaza's largest seawater desalination plant. Press Release. From 19 January, 2017. https://www.unicef.org/media/media_94423.html.

22   Mogheir, Y., Foul, A.A. Abuhabib, A.A.,and Mohammad, A.W. 2013. "Assessment of Large Scale Brackish Water Desalination Plants in the Gaza Strip." Desalination 314: 96–100.

23   Abou Jala, R.l. 2015. Gaza water desalination plants cause severe health risks. http://www.al-monitor.com/pulse/originals/2015/01/gaza-drinking-desalinated-water-contamination.html

24   Office of the Quartet, Report for the Meeting of the Ad-Hoc Liaison Committee, May 3-4 2017, Brussels.

25   Coyne-Et Bellier, Tractebel Engineering and Kema. 2014. Red Sea - Dead Sea Water Conveyance Study Program
Feasibility Study Draft Final Feasibility Study Report Summary.

Israeli desalination facilities. Such water exchanges set an important precedent for the potential for regional resource exchanges, such as the ones proposed in this study, to promote both regional cooperation and economic efficiency. The water exchange is planned to eventually be integrated into the Red-Dead project. At the time of the writing of this report, the government of Jordan was entertaining bids for small scale pilot of the Red-Dead Canal.

The Oslo Accords and the peace treaty between Israel and Jordan both call for joint development of desalination. To date, this has yet to be operationalized. The water-swap described above as part of the Red-Dead Canal project would be the first instance of joint development. Israel has offered to build desalination plants and sell desalinated water to the Palestinian Authority (PA) and Jordan, but these offers have largely been resisted, primarily for reasons of political and economic independence, and in the case of the PA due to a reluctance to pay for desalinated water, when they believe they deserve a greater share of natural shared waters.[26,27] However, while neither the PA nor Jordan are eager to increase their dependency on Israel for water resources, the pressing nature of water scarcity in both countries is such that both are, in fact, increasing their purchases of water from Israel.

Energy

In terms of energy, the parties have taken different approaches to address energy dependence, encourage energy efficiency and promote renewable energy. Israel has discovered large reserves of offshore natural gas and a transition from the current coal-natural gas fuel mix to an almost solely natural gas fuel mix for electric-

ity consumption is the cornerstone of both Israel's goal of reduced dependence on imports (and evening becoming a net energy exporter) and of reducing its carbon emissions footprint. Israel is also planning on selling natural gas to Jordanian industry and electricity and, according to a recent agreement, to a power plant in Jenin, in the West Bank.

Palestine is almost completely dependent on Israel for its energy supplies, with a small amount supplied by Egypt and a small share of electricity provided to the Jericho region supplied by a link to the Jordanian energy grid. Natural gas reserves were discovered off the shore of the Gaza Strip, but have not been developed due to insistence by Israel that funds go through Israel and insistence by the international community that funds be deposited in an international account to which Hamas would not have access. Both of these restrictions have been rejected by Hamas, which controls Gaza.[28] Palestinian energy policy has concentrated primarily on developing and managing its own electricity distribution network (though supplies still come via Israel) and on increasing energy efficiency, by measures such as operationalization of a revolving fund for financing energy efficiency projects in the public sector, which began in 2014.[29]

Jordan has invested in energy efficiency, with policies to remove energy subsidies and to promote minimum energy efficiency standards for household products.[30] However, as these efforts are unlikely to be sufficient to provide for Jordan's growing energy consumption, Jordan has also looked to develop alternative energy sources, including contacts and international agreements with several countries, including Canada, France,

26   Fischhendler, I., S. Dinar, and D. Katz. (2011) The politics of unilateral environmentalism: cooperation and conflict over water management along the Israeli-Palestinian border. 11(1): 36-61.

27   Aviram, R., D. Katz and D. Shmueli (2014) Desalination as a game-changer in transboundary hydro-politics. *Water Policy* (16)4: 609–624.

28   Ahmad, N.M. (2012). "Israel's war for Gaza's gas." Le Monde Diplomatique 28 November 2012.

29   RCREEE, 2015a.

30   RCREEE, 2015a.

Korea, the United Kingdom and most recently Russia, to develop nuclear energy, including for use in desalination.[31] Various goals for incorporating nuclear energy have been published in several different government energy plans, however, to date, no infrastructure has begun to actualize such goals.

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 2015. However, renewable energy represents a small share of overall energy production in all three countries.[32] 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; this is despite all three having amble potential for renewable energy, especially from solar energy sources. All three also have more ambitious longer range commitments to developing renewable energy, and meeting these objectives will require large-scale investment in solar, wind and/or other renewable technologies, and not just incremental application of existing technologies.

Jordan has committed to developing solar energy for the purpose of covering water pumping needs, much as envisioned in this project. To date, however, the project is at a national, not regional level, and is meant to cover some of the costs of pumping groundwater from Jordan's south, rather than the needs of desalination.[33]

Table 2 – Declared Renewable Energy Policy Goals

Country	Renewable Energy as % of Total Energy Production	
	2020	2030
Israel	10%	17%
Jordan	10%	14%
Palestine	5% of primary energy 10% (of electricity)	None declared

Sources: [34,35,36,37,38]

31   World Nuclear Association, 2017.

32   Specific statistics on the percentage of energy supplied by renewable sources differ according to source, but according to most sources, they at or below 2% for all three countries.

33   Namrouqa, H. 2015. http://www.jordantimes.com/news/local/projected-solar-plant-south-cover-water-sector%E2%80%99s-energy-needs%E2%80%99 and Namrouqa, H. 2017. http://www.jordantimes.com/news/local/five-water-pumping-stations-operate-solar-power-%E2%80%94-water-ministry

34   International Renewable Energy Agency (IRENA). 2014. Pan-Arab Renewable Energy Strategy 2030. IRENA.

35   Israeli Ministry of National Infrastructures. 2017. " Israel's Fuel Economy."

http://energy.gov.il/English/Subjects/Subject/Pages/GxmsMniIsraelsFuelEconomy.aspx

36   Israeli Ministry of Environmental Protection. 2015. "Israel Commits to Reducing GHG Emissions 26% by 2030." Press Release from on 14 January 2017. 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

37   Regional Center for Renewable Energy and Energy Efficiency (RCREEE). (2015b). Arab Future Energy Index (AFEX) 2015 – Renewable Energy.

38   Namrouqa, H. (2015). 'Paris deal to give momentum to Jordan's efforts to address climate change'. Jordan Times, 15 December, 2015. http://www.jordantimes.com/news/local/paris-deal-give-momentum-jordans-efforts-address-climate-change

1.3. Proposed Regional Water-Energy Exchanges – Description & Rationale

Desalination is likely to be a key element in meeting projected water needs for the region. Both Oslo Accords (Annex III, Article 40) and the Peace Treaty between Jordan and Israel (Article 6) call for bilateral and regional cooperation protection of existing water resources and development of future water supplies. As the Israel-Jordan Peace treaty states, "The Parties recognise that their water resources are not sufficient to meet their needs. More water should be supplied for their use through various methods, including projects of regional and international co-operation." The treaty goes on to state that " water issues along their entire boundary must be dealt with in their totality, including the possibility of trans-boundary water transfers... to alleviate water shortage".

Regional initiatives, such as the Memorandum of Understanding signed by representatives of the three countries in 2013 that calls for exchanges of desalinated Red Sea water as well as water from the Sea of Galilee / Jordan River system, show the potential economic and environmental benefits of integrated regional approach to development of water supplies.

Cooperation on energy, including integration of regional electricity grids and joint development of renewable energy supplies, is also a long-standing policy issue that is specifically called for in both the Oslo Accords (Annex VI, Article 5) and the Israeli-Jordanian Peace Agreement (Article 19), and which has been discussed by parties since the signing of these agreements. The benefits would potentially include increased diversification of sources, supply reliability, increased economic efficiency, and reduced environmental impacts.

As has been mentioned, Jordan has limited access to the sea, but has relatively plentiful open space with high radiation potential suitable for solar energy. Israel and Palestine, on the other hand, are relatively limited in terms of open spaces, needed for most commercially viable renewable projects, but have access to the Mediterranean. Thus, there is potential for mutual exchanges of water and energy between the parties.

This project looks at the potential for an exchange in which desalinated water from the Mediterranean Sea is provided by Israel and/or Palestine and in exchange Jordan supplies all three parties with renewable energy. In this report we look exclusively at solar energy provision. In future work, this may be expanded to include wind or other renewable sources and perhaps optimal mixes of renewable production from all three countries.

In addition to the provision of additional water supplies water and clean, renewable energy, significant achievements in themselves, such a project could have several other potential benefits. Given the common pool resource and public goods aspects of water and energy, cooperative arrangements are often economically and environmentally beneficial. Unilateral actions in this respect, while often taken for political reasons, can be sub-optimal both in terms of economic costs and benefits, and in terms of environmental protection.[39] A significant literature has demonstrated that shared management of natural resources can serve as a platform for increased collaboration in other spheres. Such spillover effects can be a basis for more cooperative and peaceful relations overall.[40]

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[39]   Fischhendler, et al, 2011.

[40]   Such positive spillover effects are in line with functionalist theory in international relations. For examples of works documenting such potential see: Carius, A. (2006). *Environmental Cooperation as an Instrument of Crisis Prevention and Peacebuilding: Conditions for Success and Constraints.* Adelphi Consult.; Matthew, R. A., Brown, O., & Jensen, D. (2009). *From conflict to peacebuilding: the role of natural resources and the environment* (No. 1). UNEP/Earthprint.; Dabelko, G. (2014) An uncommon peace: Environment, development and the global security agenda. pp. 244-257 in Conca, K., & Dabelko, G. (Eds.). (2014). Green planet blues: Critical perspectives on global environmental politics. Westview Press.

It can be claimed that such a project would create even more international dependencies, a situation which is often politically challenging, especially when concerning basic inputs such as water and energy. However, an advantage to the proposed project is that it involves creating interdependence, rather than creating unidirectional dependence, as is currently the norm, with Israel being an increasingly important source of water and gas for both parties. That is, parties would be interdependent on one another, which reduces the potential for unilateral actions that could harm one party. This is a significant advantage over previous attempts at collaboration, such as Israel's offers to sell desalinated water or natural gas to its neighbors, which were seen as only increasing asymmetric dependency. Also, the project would also allow for a diversification of suppliers, for instance, enabling Palestine to reduce its dependence on Israel for both water and energy supplies.

Finally, the private sector plays a prominent role in much of the recent major infrastructure projects in the fields of desalination and renewable energy. As such, the project, while envisioned as regional cooperation, need not be primarily government led or financed. Allowing for private sector leadership may reduce political obstacles that may face government led projects.

1.4. Report Structure

The aim of this project is to investigate the potential feasibility for developing mutually beneficial exchanges of water and energy between the three countries. As a pre-feasibility study, we develop various possible scenarios for types of water and energy facilities and their requisite distribution infrastructure, and attempt to assess the initial technical, economic and political feasibility of their implementation. The following section presents the methodology of the report including scenario assumptions and data sources. Section 3 presents technical and social assessments of future water needs in the region. Section 4 presents technical and social assessments of energy needs and solar energy generation potential and distribution requirements. Section 5 presents an initial economic assessment of the costs of the water-energy exchanges. Section 6 presents an overview of the geopolitical challenges and opportunities entailed in such a project. Finally, Section 7 presents conclusions and outlines potential directions for further research.

2. METHODOLOGY

As this is a first and preliminary study, it was necessary to limit the number of scenarios for various scales and types of technologies. Also, several guiding assumptions were necessary. The following are the scenarios and primary working assumptions made in order to carry out this pre-feasibility study.

2.1. Scenarios

The study takes two scenarios for the scale of desalination envisioned and two scenarios for the scale of renewable energy used.

2.1.1. Basis Year

Given the scale of projects being investigated, implementation cannot be undertaken immediately. As such, the study will take as a focal point for calculations the year 2030. This choice of year was made as one that could be reasonable for implementation.

2.1.2. Population Estimates

In order to determine future water and energy demands, it is necessary to have estimates of populations. In terms of future population forecasts, the figures used are based on official reports published by the governments themselves, supplemented with United Nations' data. Jordan currently has the highest number of residents, due in large part to the recent influx of refugees and other immigrants from Syria and Iraq. In the case of Jordan, we used population estimates and medium range population growth forecasts from the national Department of Statistics.[41] In the case of Palestine, we use figures from the report *Palestine 2030*, published by the Prime Minister's Office and

the UN.[42] In the case of Israel, we rely on the Israeli Central Bureau of Statistics' (CBS) medium range population projection.[43] As the CBS gives estimates for 2025 and 2035, we extrapolate a 2030 projection based on CBS numbers using a polynomial best-fit regression. These figures are presented in Table 3 and Figure 1.

Table 3. Populations and Population Forecasts

Country	Population Estimates	
	2015	2030
Jordan	9.4	12.0
Israel	8.3	10.6
Palestine	4.7	6.9
Total	**22.4**	**29.5**

Sources: *15, 38, 39,40*
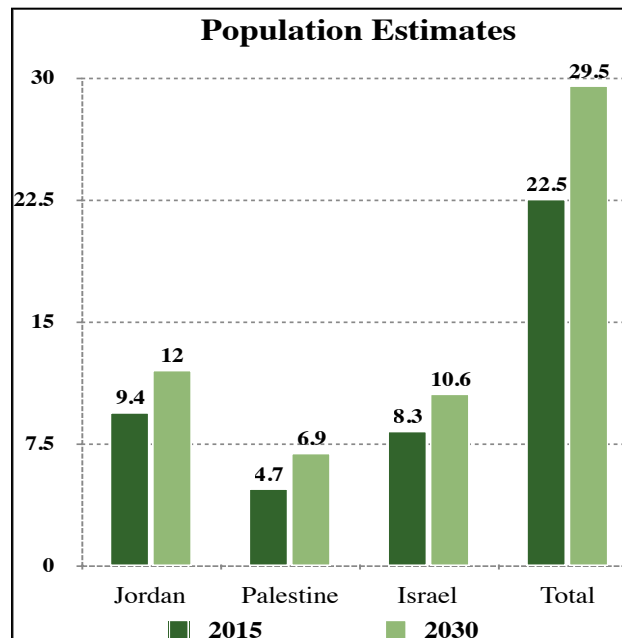
Figure 1. Current Populations and Future Population Forecasts (in millions)

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41   Department of Statistics, 2016, *Population Projections for Kingdom for the Period 2015-2050* (In Arabic). Note: Figures for Jordan are somewhat uncertain, especially regarding the number of non-Jordanian residents. Other estimates, by the same source, as well as by the UN's World Population Prospects (2017), give a range of figures for the 2015 population from 9.1-9.5 million residents.

42   State of Palestine - Prime Minister's Office of Population & UNFPA, 2016. *Palestine 2030.* http://palestine.unfpa.org/publications/palestine-2030-demographic-change-opportunities-development

43   Central Bureau of Statistics. 2013. http://www.cbs.gov.il/www/hodaot2013n/01_13_170t1.pdf

2.1.3. Water Supply Scenarios and Estimates

In terms of the scale of desalination to investigate, the study examines two scenarios.

a) The first scenario calculates the amount needed to keep current per capita domestic consumption at current levels, given the anticipated population growth, while leaving current levels of freshwater consumption by agricultural, industrial and other sectors undiminished.[44] This scenario was decided upon after receiving feedback on minimum needs from various roundtable discussions held in the three countries, and, in the case of Jordan, highly correlates with the Ministry of Water's declared target of providing roughly 120 liters per capita per day (roughly 43.8 m³/c/y).[45] In the case of Israel, per capita domestic consumption levels were capped at 80 cubic meters per person annually (nearly 220 liters per capita per day), in line with its long-term masterplan for the water sector.[46] All additional water for the domestic sector is assumed to come from desalination. The amounts cover gross provision of water supplied for domestic purposes, and includes leakages and other non-revenue water. It is not a measure of actual end of pipe consumption by consumers.

b) The second scenario calculates the amount of water needed to provide each of the estimated populations in the year 2030 with 80 cubic meters of freshwater per capita per year for domestic consumption purposes. That is, it calculates the amount necessary to provide each resident in the region with the amount similar to that designated in Israel's long term masterplan for the water sector. This is substantially higher than current per capita consumption for Palestinians and Jordanians, and is presented for the sake of highlighting the scale necessary to achieve social equity in the water sector.[47] Again, it is assumed that all of this additional water for the domestic sector would come from seawater desalination and that there would be no overdraft of renewable supplies.

Neither scenario precludes significant water savings that could potentially be achieved through conservation campaigns, reduced leakage, pricing reforms, and other demand management measures, which should be encouraged regardless of this project.

In both cases future use needs estimates also do not allow for overdraft of renewable water reserves. Also, in both cases renewable water quantities are assumed to be equivalent to current levels; this despite the predictions of reduced rainfall and increased evaporation and runoff due to climate change, and despite the very real possibility that some water supplies may become unusable due to saltwater intrusion or other contamination.

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44   Actual allocations to other sectors may increase under such a scenario should increased desalination result in increased reuse of treated wastewater or due to various conservation techniques.

45   This target was for the population of Amman, with other cities receiving somewhat less. Source: Hashemite Kingdom of Jordan - Ministry of Water and Irrigation. 2015. National Water Strategy 2016 2025.

46   Zaide, M. Presentation given 1.3.2017 in Tel Aviv.

47   Feedback received from roundtable discussions in Amman and Ramallah, however, indicated that such levels of water supply, are likely not realistic and affordable in the time-frame envisioned for this project.

2.1.4. Energy Supply Scenarios and Estimates

In terms of the amount of renewable energy to produce, two separate scenarios are evaluated:

a) The first scenario is one in which the desalinated water produced in the two scenarios above would be carbon neutral, i.e., the amount of new renewable energy produced would be equal to the amount needed to offset the energy consumption resulting from desalination of the projected quantities of water in each of the scenarios described above, including the transfer of this water to a main national water delivery system. It is not the intent that the energy produced would be directed specifically for the purposes of desalination, but rather, that it represents an equivalent amount to that consumed by the desalination aspect of the project.

b) In the second scenario the amount of renewable energy produced is equal to 20% of total projected electricity production for each country. This amount is significantly more than in the previous scenario. The figure of 20% was chosen as it is a relatively ambitious one, 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.[48] While the 20% figure currently exceeds the declared commitments of any of the parties, as energy consumption grows, as it is projected to do, the 20% figure provided by the project will decrease over the project's life-

time. Thus it would only account for 20% of consumption at the project's inception and presumably a lesser share thereafter. The future energy needs for each country are taken from official government forecasts.

2.2. Technical Assumptions

In both cases the study will look at technologies already commercially available. In the case of desalination, we will take into consideration only reverse osmosis (R/O), given that this is the dominant technology already in place 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] Currently, R/O desalination in Israel consumes between 3.4-3.7 kilowatt hours (kwh) per cubic meter. While a certain amount of improvement in energy efficiency is likely by 2030, it is difficult to project what that might be. As such we use a figure of 3.4 kwh per cubic meter.

For the electricity needs of pumping water, we use 1.26 kwh per cubic meter. This is slightly higher than average energy consumption of water delivery in Israel (Hoffman, 2014).[50] The figure is an estimate of the electricity needed to pump water from the northernmost existing desalination plant, located in 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.[51]

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48   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.

49   German Aerospace Center (DLR) et al., 2007. Concentrating Solar Power for the Mediterranean Region. http://www.dlr.de/tt/Portaldata/41/Resources/dokumente/institut/system/publications/MED-CSP_complete_study-small.pdf

50   Hoffman, D. 2014. Potential for energy savings in the Israeli water sector. Water Engineering, 91: 27-34. (In Hebrew)

51   The calculation was based on the following formula: TC = 4.2(ME+CE), where TC is total consumption in watts per cubic meter, ME is meters in elevation and CE is compensating elevation to cover the effects of friction. CE was calculated as 2.5 meters per kilometer distance. The study used an elevation of 150 meters (Eshkol Reservoir) and a distance of 60 km (the distance from Hadera to the Eshkol Reservoir).

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. For instance, pumping needs for Gaza and the Israeli coast would be almost negligible, while delivery from a desalination plant in Gaza to the West Bank would necessitate roughly double the electricity of the figure used here due primarily to high elevations. For Jordan, this figure only covers the pumping of water to the Jordan Basin, and not the actual delivery of the water to end consumers throughout Jordan.

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. Calculating actual optimization of production and delivery is left to the full feasibility study.

In the case of electricity supply, the study considers only transmission of electricity from Jordan to a single location within Palestine and Israel. It does not look at transmission of electricity within Palestine or Israel.

2.3. Economic Assumptions

Though prices for both water and energy are likely to change by 2030, however, as the extent to which they will is difficult to determine, this study bases calculations on current prices.

For solar electricity, current capital and operating and maintenance costs for large-scale photovoltaic energy production will be used, as cost estimates for emerging technologies such as concentrating solar power are still unreliable, especially in this region, as they have yet to be implemented at a commercial level. Further studies may wish to incorporate cost estimates for these alternative technologies.

2.4. Political Assumptions

The study assumes that there is the requisite political will for such a project. For the purposes of calculations, it also assumes that, by 2030, Palestine will be a fully independent state and will include the population of East Jerusalem within this state. This is in line with the vision of EcoPeace, and is not meant to be a pre-requisite for beneficial water-energy exchanges of the type explored in this pre-feasibility study. The study also assumes that exchanges of water and energy between Gaza, the West Bank, Israel and Jordan are politically acceptable to all parties. This is not the current reality in which political differences have led to restrictions on such transfers. These issues are elaborated upon later in Section 5, which addresses political feasibility.

3.WATER

This section presents a brief overview of the water sectors in each of the three parties and then presents calculations based on minimum supplies necessary to provide for future consumption in each country. Quantities presented herein represent currently managed supplies and in no way are meant to indicate a stance on rights to water or the legitimacy of claims to rights of water, which, in some cases, are contested. The section then presents a cost assessment for provision of such water via desalination.

3.1 Water Supplies and Consumption

Natural water supplies in the region are shared between the three countries as well as with Syria and Lebanon. Primary transboundary water bodies include the Jordan River / Sea of Galilee System (including the Dead Sea), which is shared by all five riparians, as well as the Mountain and Coastal Aquifers, which are shared by Israel and Palestine. The Mountain Aquifer is shared between Israel and the West Bank, while the Coastal Aquifer is shared between Israel and the Gaza Strip, though this latter aquifer is largely managed independently by the two different parties. In addition, Israel and Jordan have other, non-transboundary aquifers.

Both the Oslo Accords and the Israeli-Jordanian Peace Treaty set out terms for joint management of shared waters. As the Oslo Accords were meant to be an interim agreement, the issue of water rights between Israel and Palestine is still outstanding. Issues of water rights between Israel and Jordan are considered largely settled. Both agreements establish bodies for joint coordination and consultation in management of the shared waters. The functioning of these bodies, especially in terms of the Israeli-Palestinian case, is intermittent and often contested.

3.1.1. Jordan

The Kingdom of Jordan is supplied by the Yarmuk River (part of the Jordan River system) as well as by several aquifers, supplying both renewable and non-renewable (fossil) water supplies. Surface water supplies are concentrated in the north, close to population centers, while groundwater is distributed throughout the country, including fossil water in the south. Water supplies along the Yarmuk are highly dependent on policy in Syria, the upstream riparian. Following the 1994 Peace Treaty with Israel, Jordan is also allowed to store winter flows in the Sea of Galilee and receive additional supplies from Israel during the summer. Jordan has also recently agreed to purchase additional water from Israel in the Jordan River basin.

According to the Jordanian Ministry of Water and Irrigation, safe yields of groundwater in the Kingdom are estimated at 275 mcm annually and renewable surface water supplies an additional roughly 260 mcm. In addition, in recent years Jordan has been consuming approximately 140-150 mcm of non-renewable groundwater and 160 mcm of overabstraction (abstraction of water at levels exceeding annual recharge) from renewable aquifers. It also augments its supplies with roughly 125 mcm of reused treated wastewater and a small amount of desalinated water. All in all, renewable fresh water resources are estimated at between 550-600 mcm per year.[52,53]

Figures for quantities of water supplied in Jordan differ significantly from figures for water consumed by end-users as much water is lost to leakage and unlicensed connections. The poor state of much of the water delivery infrastructure has resulted in supplies being intermittent and unreliable in much of the

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52   Hashemite Kingdom of Jordan. Ministry of water and Irrigation. National Water Strategy 2016 2025. Dec. 2015

53   Included in Jordan's water supplies are water supplied by Israel, as per the Israeli-Jordanian peace agreement. This is not listed separately. Rather, this report simply considers these as Jordanian water.

country. Water resource planning and supply is particularly complicated given the large influx of refugees and non-citizens from Syria and Iraq in recent years. This has necessitated development of new supply infrastructure, both temporary and permanent. The primary component of Jordan's strategy for addressing water scarcity is development of desalination. At present the only seriously considered option for this is via the proposed Red-Dead Canal.

3.1.2. Palestine

As mentioned, currently, Palestinian water supplies are regulated by the Oslo Agreement, which was intended to be an interim agreement. As such, the issue of Palestinian water rights is still unsettled, and is not reflected in current consumption. The official position of the Palestinian Water Authority (PWA) is that they be granted a larger share of water from the Mountain Aquifer, especially, the eastern portion, as well as rights to the Jordan River system. Furthermore, the PWA seeks additional access to brackish water from the Mountain Aquifer, which it could desalinate at rates much less expensive than the cost of desalinated sea-water.

According to official PA statistics, annual water supplied in Palestine, as of 2015, was 365 mcm, of which 188 mcm was for the West Bank and 177 mcm was for Gaza. This figure, however, includes unsustainable pumping of the aquifer in the Gaza Strip, estimated at 100-110 mcm annually.[54] It also includes roughly 70 mcm/y purchased from Israel, as well as 4 mcm/y of desalinated water.[55] It does not include unlicensed pumping in the West Bank and Gaza, as reliable data for this is unavailable.

As of 2015, the West Bank consumed roughly 187 mcm, of which 64 mcm was purchased from Israel, while Gaza consumed 177 mcm, of which 6 mcm was purchased from Israel and 4 mcm was from desalination.[55] It should be noted that the water in Gaza is of poor quality due to seawater intrusion in the aquifer as a result of long-term overpumping, and as a result of poor wastewater treatment, as facilities lack basic inputs (electricity, equipment, and funding). As such, it is not used for drinking purposes. Safe yields in Gaza are estimated at 50-60 mcm per year, though some estimates suggest that due to seawater intrusion and other water quality issues, virtually none of Gaza's water may be potable in the near future. A desalination plant for Gaza is planned, with funding from the international community. It is to initially produce 55 mcm/year, with an eventual capacity of 110-130 mcm/year.[20] At present, the issue of securing a reliable electricity supply for the plant is still unresolved.

Water supply in the West Bank is highly restricted due to regulations imposed by the Israeli Civil Administration and other Israeli governing bodies. According to the governance mechanisms established in accordance with the Oslo Accords, new infrastructure projects in the West Bank must gain approval of both Palestinian and Israeli officials. This gives both sides veto power over development in the area, but in practice, however, this puts the Palestinians at disadvantage, as West Bank Palestinians are dependent on the two parties achieving consensus, while Israel has numerous alternative options for water supply outside of the West Bank. Recent agreements (2017) between the Israeli and Palestinian water officials are to give Palestinian regulators somewhat more autonomy in water planning in the West Bank,[56] though it is too early to know how this will affect overall water management there. The PWA is eager to get rights to increased shares of the Mountain Aquifer, including rights to potentially large quantities of brackish water in the eastern portion of the aquifer, which could undergo relatively cheap desalination to become potable. As of now, however, Israel has not agreed to transfer water rights or to increased Palestinian withdrawals.

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54   Palestinian Central Bureau of Statistics. http://www.pcbs.gov.ps/Portals/_Rainbow/Documents/water/water-E-main.htm

55   These figures are set to increase somewhat in 2017.

56   Times of Israel. "Israelis, Palestinians sign deal to jointly improve West Bank water supply" 15 January, 2017.
http://www.timesofisrael.com/israelis-palestinians-sign-deal-to-jointly...

3.1.3. Israel

Estimated renewable resources used in Israel are thought to be between 1200-1500 mcm/ annually. In the past, they were estimated at slightly higher levels, but have been revised in recent years to reflect decreasing annual rainfall. In addition to the Mountain and Coastal Aquifers, Israel has access to several local aquifers as well as the Jordan River system, including the Sea of Galilee, the region's only large lake. In addition to the natural water resources, Israel has invested intensively in the reuse of treated wastewater. Currently roughly 80% of domestic wastewater is treated and reused in agriculture. This source adds an additional 500 mcm to the annual water balance, and this amount increases as the amount of wastewater from the domestic sector grows and the share of treated wastewater grows.

In addition to wastewater reuse, Israel's primary supply management (augmentation) policy has been development of large-scale seawater desalination. Large-scale desalination of Mediterranean seawater began in 2005. Currently there are 5 large desalination plants operating along the coast, all of which use the reverse-osmosis process. Collectively they have a production capacity of roughly 550 mcm per year. This amount is roughly equivalent to 70% of municipal/domestic annual consumption. Currently, desalination plants are located along the central and southern coast and supply water primarily to those regions. Supply of water in the north is primarily from local natural sources, though there are plans to build additional desalination plant along the northern coast to augment supplies there.

3.2. Calculation of Future Municipal Water Supplies

As stated earlier, for the purposes of this study, we calculate the estimated additional water needed for regional supplies in 2030. Because of population growth, municipal supplies for all parties will necessarily need to increase in order to maintain a reasonable standard of supply. As mentioned above, we examine two scenarios. The first maintaining current (2015) per capita consumption for the domestic sector (with Israeli consumption capped at 80 m³/c/y), and the second achieving a level of 80 m³/c/y for all residents of the region. These are gross figures for municipal supply, rather than per capita consumption, as it does not take into account water leakage and other non-revenue water.

Our assumption is that non-municipal (i.e., agricultural and industrial) uses will continue to receive at least their current shares of freshwater. In fact, however, with the increase in municipal supply will come an increase in sewage, which, if treated and reused, would likely lead to increased allocations to agricultural and environmental flows as well.

For each country we first calculate current (2015) per capita consumption for the domestic sector. For the first scenario, we multiply the 2030 population forecast given in Table 3 above by the 2015 domestic per capita consumption rate in order to get an estimate for total future desired municipal supply for the region. For the second scenario, we multiply the population estimates by the 80 m³/c/y figure. This provides the total domestic supplies needed. In order to calculate the additional amount of water needed to meet such supplies we subtract current municipal consumption plus any current overabstraction or supply at beyond safe yields in order to calculate the additional water needed to achieve the target quantities.[57] For Israel, we assume that current supplies are sustainable, though in recent years scarce rainfall has resulted in overpumping, especially in the north of the country not currently supplied by desalination. These figures are presented in Table 4.

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57   For sake of clarity the calculations for future water needs are represented by the following equation:

FN = (FP*PC)-(CS+OD), where FN is future needs, FP is future population, PC is annual per capita consumption (which varies between the two scenarios), CS is current domestic supplies, and OD is declared overdrafts.

Table 4. Current Domestic Water Consumption and Future Water Needs

		2015 Population (millions)	2015 Municipal Supply (mcm)	2015 Per Capita Consumption (m³/y)	Declared Overdrafts from Renewable Sources	2030 Population (millions)	2030 Municipal Supply Needed (mcm)	Additional Water Needed (mcm)
Scenario A Maintain Current Domestic Per Cap Levels	Jordan	9.4	436[58]	46.4	160[59]	12.0	556.6	280.6
	Palestine	4.5[60]	214.9	47.9	107.2[61]	6.9	330.5	222.8
	Israel	8.3	777.8	93.7	0	10.6	848	70.2
	Total	**22.2**	**1,428.7**	**76.3**	**267.2**	**29.5**	**1,735.1**	**573.6**
Scenario B Provide 80 m³/c/y for domestic Use	Jordan						960	684
	Palestine						552	444.3
	Israel						848	70.2
	Total						**1,512**	**1,198.5**

Sources: [62,63,64]

58   The Jordanian figure is based on estimated supplied by officials at the Ministry of Water relating only to residential consumption, as the official figures for municipal water consumption include industrial supplies as well.

59   Represents the amount listed as overdraft according to the National Water Strategy (see footnote 56). Notably, it does not include withdrawals from non-renewable aquifers, which the Ministry includes as "Sustainable Resources"..

60   Represents those supplied by PWA, which does not include much of the East Jerusalem population, which are currently supplied by Israel.

61   Represents the calculated overdraft beyond safe yields from the Coastal Aquifer in Gaza as of 2015.

62   Israel Water Authority, http://water.gov.il/Hebrew/ProfessionalInfoAndData/Allocation-Consumption-and-production/20156/1998-2015.xls

63   Palestinian Central Bureau of Statistics. http://www.pcbs.gov.ps/Portals/_Rainbow/Documents/water/water-E-main.htm , Tables 6 and 8.

64   Hashemite Kingdom of Jordan. Ministry of water and Irrigation. National Water Strategy 2016 2025. Dec. 2015.

Of relevance for this study is the total amount of water needed to fulfil the gap between sustainable water resources and expected demand. In the case of Scenario A (maintaining current levels of water consumption), there is a projected need of 573.6 mcm/y, roughly half of which will be needed in Jordan (Figure 2). Scenario B, in which all residents consume at Israeli levels, would entail double the amount of water produced, at nearly 1200 mcm/y. For reference, currently, the largest reverse osmosis desalination plant in the world is in Israel with a capacity of roughly 150 mcm/y. Thus, there would be a need for the equivalent of 4 similar sized plants for scenario A, and 8 such plants for Scenario B by 2030. While some of this gap could be provided by efficiency improvements and reallocation of water from agriculture to the domestic sector, it is unlikely that such measures could accommodate the scale of water needed. Thus, desalination appears to be an expedient and necessary step.

Given that water rights between Israel and Palestine are still unresolved, pending a permanent final status peace agreement, for the purposes of this study we do not focus on the relative amounts of water needed by Israel and Palestine, as this may change in negotiations. Whether the relative needs are fulfilled by reallocation of existing natural water resources or not, the overall regional gap between current supplies and future needs will be the same. The total additional amount needed for Palestine and Israel collectively, some 293 mcm/y under scenario A and 514.5 mcm/y under Scenario B, will be reduced by 110-130 once the desalination plant planned for Gaza produces at full capacity.
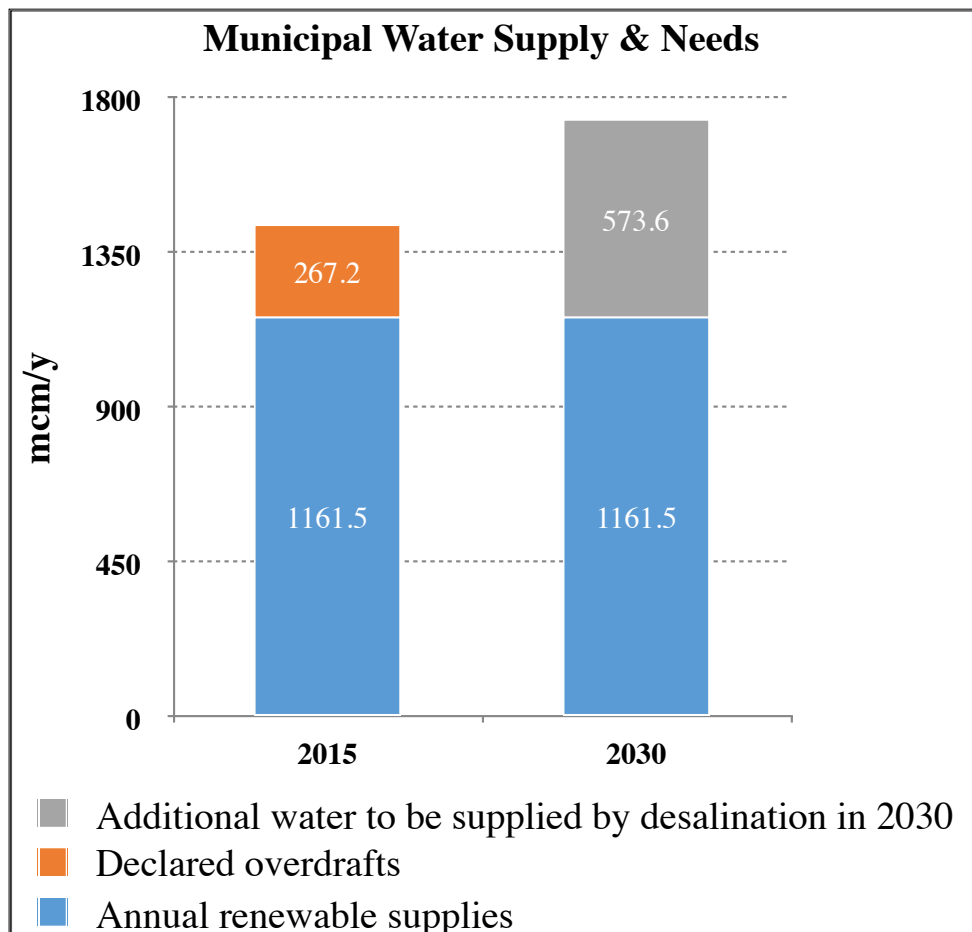

Figure 2. Estimated Municipal Water Supply & Needs (Scenario A)

4. ENERGY

This section provides a brief outline of current energy sources and electricity supply infrastructure in each of the three countries. It then provides an analysis of the technical feasibility of providing electricity sourced from renewable energy to the region as detailed in Section 2.2 above.

4.1. Current Sources & Supply Infrastructure

4.1.1. Jordan

Jordan is not known to have any significant domestic energy sources and is highly dependent on imported energy: 96% of its primary energy demand comes from imported fuels[65] Total generated electrical energy in Jordan amounted 19,011 MWh in 2015, while the imported electrical energy from Egypt amounted to 604 GWh. The total generation capacity of the Jordanian Power System amounted to 4,266 MW in 2015.

In 2015, Jordan's overall electricity generation of 19,011 MWh was generated in combined-cycle units, gas turbines and steam-powered stations. Power generation in Jordan is based on both private company power generation and public-private investment (PPI) partnerships. It is composed of one governmental generation company and four privately owned generation.

Jordan's annual electricity generation and consumption are detailed in Table 5. As can be seen, with average annual growth of consumption at around 5% per year, consumption nearly doubled over the decade 2005-2015.

According to reports by the National Electric Power Company (NEPCO), as of 2015 renewable energy is responsible for 0.9% of electricity generation in Jordan, while according to the Regional Center for Renewable Energy and Energy Efficiency (RCREEE), renewables accounted for 0.5% of generation capacity in that year.[66]

Table 5. Key figures of the electricity sector of Jordan

Year	Capacity, MW	Peak Load, MW	Generation, GWh	Consumption, GWh	Consumption per capita, kWh	Annual Consumption growth (5 Year Avg.)
2005	1,995	1,751	9,654	8,713	1,592	n/a
2010	3,069	2,650	14,683	12,871	2,106	8.1%
2015	4,266	3,300	19,011	16,177	2,320	4.7%

Source: Annual report of the National Electric Power Company (NEPCO), 2015[67]

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65   El-Katiri, L. (2014). A Roadmap for Renewable Energy in the Middle East and North Africa. Oxford Institute for Energy Studies. OIES Paper MEP 6.

66   Figures from other sources document total solar power installed capacity of 150-170 MW and generated energy from solar power at 376.6 GWh in 2016 (NEPCO Bulletin 2016 - http://www.nepco.com.jo/en/nepco_bulletin_en.aspx), which would account for 1.9% from the total electricity generation. This discrepancy is thought to be due to the inclusion of rooftop solar water heaters in the latter estimate. These do not generate electricity, but do reduce consumption.

67   Annual report of the National Electric Power Company (NEPCO), 2015 - http://www.nepco.com.jo/store/docs/web/2015_en.pdf

Electric Power Transmission and Distribution

The current installed electric grid in Jordan has a system capacity of 4,549MW,[68] with a 132kV and 400kV transmission network (Figure 3). The transmission network interconnects with Syria through 230kV and 400kV tie lines and with Egypt through 400kV tie lines. Total installed capacity of the substations 400/132/33kV is 3760 MVA.[69] As mentioned above, a 33kV line also supplies electricity to the West Bank via Jericho. The total length of the 400 kV network is 924 km, 230 kV – 17 km, 132 kV network, with 3511 kilometers (km) of overhead lines and 97 km of underground cables, which sums up to 4,249 km of total length for lines of 132 kV and more.
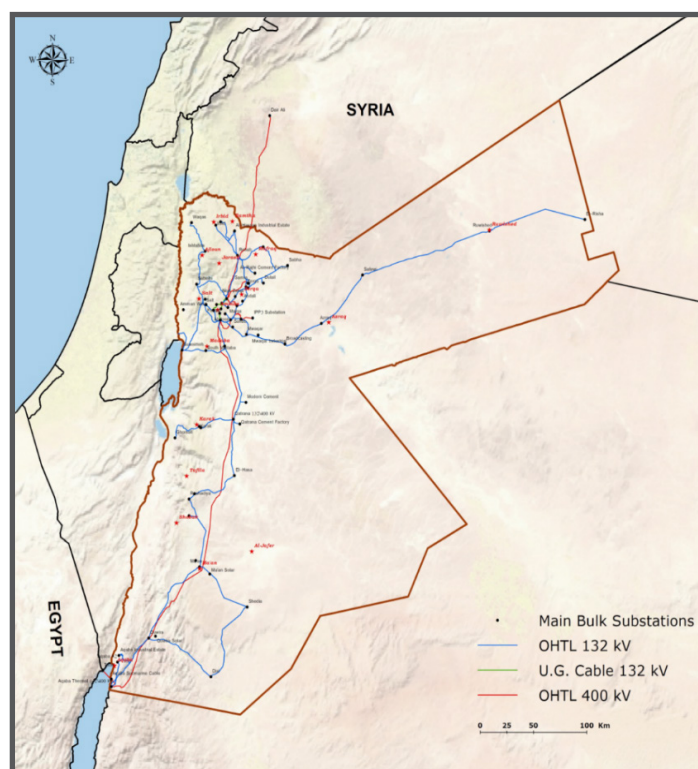
Fig. 3. Jordan National Transmission Grid[70]

4.1.2. Palestine

Palestine lacks conventional energy sources, and imports almost all its energy needs. All petroleum derivatives and natural gas are purchased from Israel, while electrical power in Palestine is imported from Israel (nearly 90% of total consumption), Egypt and Jordan (4-5%), with a small share (just over 6-8%) supplied by the Gaza Power Plant (see Table 6).[71,72] Currently, the Palestine Electric Company has plans to build two power plants in the West Bank, which would give the West Bank its own production capacity. There are also plans to expand capacity of connections to Jordanian and Egyptian grids as well as to connect Gaza directly to Israeli natural gas supplies. Significant natural gas reserves were discovered off the Gazan shore (estimated at 35 BCM) in the late 1990s, but have yet to be developed.

68	Annual report of the National Electric Power Company (NEPCO), 2015 - http://www.nepco.com.jo/store/docs/web/2015_en.pdf
69	Annual report of the National Electric Power Company (NEPCO), 2015 - http://www.nepco.com.jo/store/docs/web/2015_en.pdf
70	NEPCO web site - http://www.nepco.com.jo/en/maps_en.aspx#
71	Regional Center for Renewable Energy and Energy Efficiency (RCREEE). 2013. Palestine – Energy Efficiency Profile.
72	The Gaza Power Plant runs on diesel fuel which results in high costs of power generation.

While nearly all West Bank residents have continuous access to electricity, supplies within Gaza are particularly unreliable given restricted access to fuels and reductions due to a number of economic (primarily lack of payment) and political reasons.

Table 6. Quantity of Electricity Imported and Purchased (MWh) in Palestine (2015)

	Imports				Domestic	
	Israeli Electricity Company	Egypt	Jordan	**Total Imports**	Palestine Electric Company	**Total**
West Bank	4,240,225		41,390	**4,281,615**		**4,281,615**
Gaza Strip	941,282	190,191		**1,131,473**	354,970	**1,486,443**
Total	**5,181,507**	**190,191**	**41,390**	**5,413,088**	**354,970**	**5,768,058**

Source: Palestine Central Bureau of Statistics[73]

Table 7. Palestinian Electricity Consumption Growth Trends

Year	Consumption, GWh	Annual Consumption growth (5 year avg.)
2005	2.90	-
2010	4.57	9.5%
2015	5.77	4.7%

Source: Palestine Central Bureau of Statistics[74] and U.S. Energy Information Administration.

Imports from Israel via the Israeli Electric Corporation (IEC) occur through around 230 connection points on low voltage (LV) and medium voltage (MV) networks. The contracted power from Israel is 890 MW, from Jordan is 20 MW, and from Egypt is 32 MW.[75]

In terms of renewable energy, as of 2015, only 1.4% of overall installed energy capacity was renewable. Solar PV systems accounted for almost all of this capacity (nearly 98%), with a small amount of geothermal capacity as well.[76,77] These figures represent a small share of the estimated renewable energy potential (for solar, wind and biomass).[78,79]

73   Palestine Central Bureau of Statistics. Energy and Energy Balance Tables 2015. http://www.pcbs.gov.ps/Portals/_Rainbow/Documents/tables%202015.xlsx

74   Palestine Central Bureau of Statistics. Energy and Energy Balance Tables 2015. http://www.pcbs.gov.ps/Portals/_Rainbow/Documents/tables%202015.xlsx

75   Palestinian Energy and Natural Resources Authority. 2017. Energy Situation in Palestine.

76   Regional Center for Renewable Energy and Energy Efficiency (RCREEE). (2015a). Arab Future Energy Index (AFEX) 2015 – Renewable Energy. Palestine Country Profile.

77   http://www.rcreee.org/sites/default/files/palestine_fact_sheet_print.pdf

78   Juaidi, Adel, Francisco G. Montoya, Imad H. Ibrik, and Francisco Manzano-Agugliaro. 2016. "An Overview of Renewable Energy Potential in Palestine." *Renewable and Sustainable Energy Reviews 65* (November): 943–60.

79   Abu Hamed, Tareq, Hannah Flamm, and Mohammad Azraq. 2012. "Renewable Energy in the Palestinian Territories: Opportunities and Challenges." *Renewable and Sustainable Energy Reviews* 16 (1): 1082–88.

Electric Power Transmission and Distribution

At the present moment, the PEA does not own any transmission grid, though there are currently agreements in place to transfer control over four substations and some of the delivery infrastructure to the PWA. In addition, Area C which is not under the control of the PA includes the areas in between the cities and villages and any transmission or distribution line that passes through Area C needs licensing and permissions from Israel. The West Bank depends almost entirely on IEC for electricity supply. It is served primarily by three 161/33 kV substations. Electricity is supplied to the center of the West Bank via 33kV and 11kV distribution transmission lines at several connection points with the IEC and to Gaza via 22 kV feeders. The PNA has agreed with Jordan to connect the Palestinian power grid to that of Jordan at Jericho through a 33kV line via King Abdullah Bridge. A request was submitted to upgrade the line to 132 kV, which is compatible with the voltage supplied by the Jordanian electricity company. The Jericho area will be disconnected from the Israeli power grid.

Currently electricity is provided to Palestinian end users by six regional electric utilities (5 in the West Bank and 1 in the Gaza Strip) and numerous municipalities and regional councils. Power imports from Israel are not controlled by a Purchase Agreement between PA and Israel; rather, they are regulated by bilateral contracts between IEC and the individual electric utilities, municipalities, or rural councils. This institutional arrangement causes the electric energy sector to be unreliable and unsecure. The establishment of the Palestinian Electricity Transmission Company (PETL), currently underway, aims to establish a single buyer model which will allow power imports from Israel to be controlled by a Purchase Agreement between PA and Israel.

4.1.3. Israel

Long dependent on imported coal and oil, Israel's energy sector is in the processes of transitioning towards increased dependence on natural gas, following the discovery and development of several offshore natural gas reserves in the Eastern Mediterranean. Electricity production from natural gas began in 2004 and as of 2014 overtook coal as the primary fuel source. Israel is currently operating or developing 7 gas fields, the total reserves of which are estimated at approximately 850-880 billion cubic meters (BCM).[80,81] According to the official forecast of the Ministry of National Infrastructure, Energy and Water resources, accelerated growth in the use of natural gas is expected to increase to 12.5 BCM per year by 2020, and to 18 BCM per year by 2030, of which 85% will be used for electricity generation and industry.[82]

In 2015 Israel produced 64,227 GWh (Table 8) of electricity, of which 50,627 GWh (almost 80%) was produced by the Israeli Energy Corporation (IEC), with the rest, 13,603 GWh (20 %), produced by private electricity producers. As of that date, total installed generating capacity in Israel was 16,895 MW.[83] The IEC owns and operates 17 power sites of power stations (all of which are gas or coal based power stations sites, some of them using fuel oil as a secondary fuel) with a total installed generation capacity of approximately 13,617 MW (79% of total capacity). The remainder, 3,278 MW (21%), belongs to the private electricity producers.

80   2C - Best estimate of contingent resources; 2P - Proven and probable reserves.

81   Israeli Gas Opportunities, official paper of the Ministry of National Infrastructure, Energy and Water resources - http://energy.gov.il/English/PublicationsLibraryE/Israeli%20Gas%20Opportunitties.pdf

82   http://www.energy-sea.gov.il/English-Site/Pages/Oil%20And%20Gas%20in%20Israel/Natural-Gas-Supply--Demand-.aspx

83   The Israel Electric Corporation Annual Report - https://www.iec.co.il/EN/IR/Documents/Financial_Reports_December_2015.pdf

Table 8. Key figures of the Israeli electricity sector

Year	Capacity, MW	Generation, GWh	Consumption, GWh	Consumption, Annual Growth (5 year avg)	Export, GWh	Peak Load, MW
2005	10,113	49,833	44,198		1,666	903
2010	12,771	56,102	49,904	2.5%	4,010	10,914
2015	16,895	64,227	52,700	1.1%	5,197	12,905

Source: The Central Bureau of Statistics of Israel[84]

Renewable energy sources represent roughly 2% of total energy production, not including passive sources, such as rooftop solar water heating. The principal source of renewable energy currently in use in Israel is solar (91% of total renewable production), primarily photovoltaic.2

Electric Power Transmission and Distribution

Electricity transmission and transformation activity is conducted by the IEC under a license received from the State of Israel. The IEC is acting as a monopoly in the field of electricity transmission and transformation and has no competitors. It is required to allow private electricity producers to use its transmission system. The transmission grid consists of extra high voltage lines (400 kilovot (kV)) and a high voltage grid (161 kV). Some large industrial users, such as the national water company Mekorot and some desalination facilities are connected directly to the extra high voltage lines. Most of the electricity, however, is converted to the distribution segment of the grid via substations. The distribution system consists of distribution lines of 33 kV, 22 kV and 6.3 to 12.6 kV tension levels (all of these are high voltage lines), low voltage lines and a distribution transformer that interconnects them.

As of 2015, the distribution system consisted of approximately 26 961 km of medium-voltage grid lines; approximately 48 825 distribution transformers with a total output of approximately 24 476 megavolt-amperes and approximately 20 298 km of low-voltage grid lines.

4.2. Jordanian Renewable Energy Generation – Technical Feasibility

As mentioned, this study explores two scenarios of electricity demand: the first, evaluating the energy necessary to compensate for the estimated increased demand for desalinated water, as detailed in Section 3. The second scenario assumes simply that the project would produce the equivalent of 20% of total electricity consumption for each of the three countries from renewable sources. In this section, we analyze technical aspects for renewable power generation in Jordan and its transmission to Palestine and Israel. While both Palestine and Israel have domestic potential for renewable energy, including solar, wind, and others, access to open spaces necessary for large-scale production is very limited in both. This is due both to high population density, and to numerous land use restrictions. The following sub-section presents the calculations for energy needs in the different scenarios, while the section after presents the rationale for choice of renewable energy technology (solar) and presents calculations for the technical feasibility of several different solar technologies.

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84   The Central Bureau of Statistics, Energy section - http://www.cbs.gov.il/reader/?MIval=%2Fcw_usr_view_SHTML&ID=564

4.2.1. Calculating Energy Needs

The first scenario considers additional electricity generation equivalent to the energy needs of the desalination as detailed in Section 3, and as such, it has two sub-scenarios, based on the different water needs estimates.

Scenario 1

Scenario 1.A considers electricity needs necessary to maintain current per capita consumption for the countries in the region. According to the calculations presented in the previous chapter, the additional water needed in 2030 in the region will be 573.6 mcm for scenario 1.A. (maintaining current per capita domestic consumption rates) and 1198.5 mcm and for **scenario 1.B.** (providing all residents in each country with an average of 80m3/y). We assume that energy needs for both desalination and delivery are identical between Israel and Gaza.

We take the average figure for the energy consumption by water desalination plants in Israel of 3.4 kWh/m³. This is likely to be a somewhat high-end estimate, as it is based on existing facilities, and does not account for efficiency improvements over time. To this we added 1.26 kWh/m³ for water pumping, based on our calculations considering possible distances for the water pumping and elevation friction losses. This produced a figure of 4.66 kWh/m³. We also take into consideration average losses in transmission and distribution in the Jordanian grid, which, according to NEPCO, are almost 14%.[85,86]

Scenario 2

In calculating electricity needs for 2030, for the three countries, our estimates for electricity consumption are taken from official governmental documents and reports.[86,87,88] These quantities are presented in Table 9 and Figure 4. All countries are planning for significant increases in consumption. Especially in the case of Israel, the projected growth is at a significantly higher rate than over the previous decade.

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85   Currently losses in the Jordanian system are at 14%. Almost 50% of these losses are due to non-technical losses (thefts and non-metered consumption). There are programs being implemented by the distributors and even requirements by the regulator to reduce such losses. As it is difficult to make a reliable assessment of how successful these efforts will be, we apply a rate of 14% for future electricity losses.

86   NEPCO annual report, 2015. http://www.nepco.com.jo/store/docs/web/2015_en.pdf

87   PENRA (undated). "Energy Situation in Palestine."

88   Israeli Ministry of Energy & Water. http://energy.gov.il/Subjects/Electricity/Pages/GxmsMniAboutElectricity.aspx

Table 9. Estimated Electricity Consumption for 2030 (GWh)

Demand	2015	2030	Implied Annual Growth Rate	20% of 2030
Palestine	5,768	12,850	5.5%	5,570
Israel	52,700	94,500	4.0%	18,900
Jordan	16,177	42,419	6.6%	8,483.8
Total	**74,666**	**149,769**	**4.8%**	**29,953.8**

Electricity Demand (GWh/year)

Jordan
- 16,177
- 42,419

Palestine
- 5,768
- 12,850

Israel
- 52,700
- 94,500

Total
- 74,666
- 149,769

-     80,000   160,000

■ 2015   ■ 2030
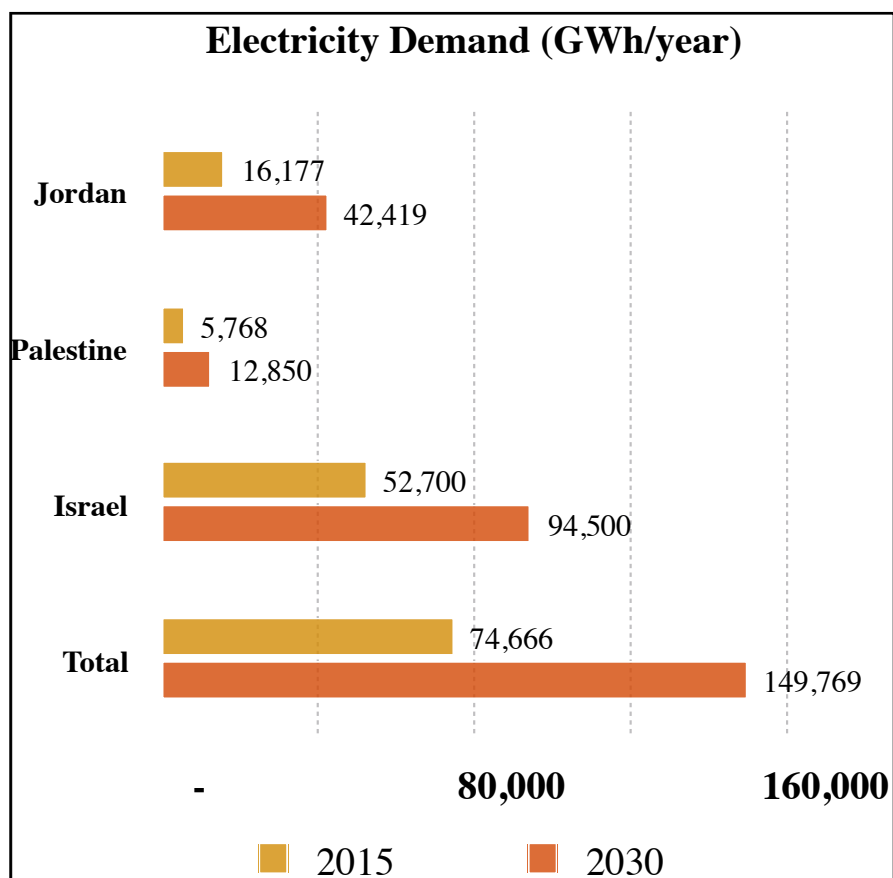
Figure 4. Current and Estimated Electricity Demand

Table 10 summarizes the energy production estimates used in each scenario in this study.

Table 10. Data inputs and outputs for electricity consumption needs from renewables calculation

Parameter	Value
Scenario 1.A – Desalination needs (current consumption rates)	
Additional water supply needs, total for the region (mcm)	573.6
Electricity need per 1 m³ water desalination (kWh/m³)	3.4
Electricity need per 1 m³ water transmission (kWh/m³)	1.26
Electricity transmission and distribution losses (%)	14
Electricity consumption needs in 2030 (GWh annually)	2,672
Electricity consumption needs with transmission and distribution losses in 2030 (GWh annually)	**3,108**
Scenario 1.B – Desalination needs (80 m³/c/y)	
Additional water supply needs, total for the region (mcm)	1,198.50
Electricity need per 1 m³ water desalination (kWh/m³)	3.4
Electricity need per 1 m³ water transmission (kWh/m³)	1.26
Electricity transmission and distribution losses (%)	14
Electricity consumption needs in 2030 (GWh annually)	5,585
Electricity consumption needs with transmission and distribution losses in 2030 (GWh annually)	**6,495**
Scenario 2 – 20% of consumption	
Total electricity demand in 2030 (GWh annually)	149,769
20% of Total electricity consumption needs in 2030 (GWh annually)	29,953.80
Electricity consumption with transmission and distribution losses in 2030 (GWh annually)	**34,830**

4.2.2. Choice of Renewable Energy Technologies

In this study, we initially considered both solar and wind energy. Jordan has potential for wind energy production, having wind speeds of 7-8 meters per second in some regions, which is considered as exceptional.[89] However, preliminary calculations show that placing PV solar power stations on the same spots, taking the same area, can provide more power generation. Furthermore, solar can be cultivated in all parts of the kingdom, while Jordan's wind resource is localized, often on private property or in urban settings.[90] 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.[91] While this does not preclude the use of wind energy in Jordan, for the purposes of this pre-feasibility study, we consider only solar energy technologies. Specifically, we analyze two different types of solar energy production: photovoltaic (PV) and Concentrating Solar Power (CSP).

Solar Power

Jordan has excellent potential for solar 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 solar plants.[92] An installed capacity of 100 GW over this area would allow production of approximately 250,000 GWh annually. Restricting solar generation capacity to 1% of the surface of Jordan would allow for 20 GW of installed capacity, with an electrical production capacity of 50,000 GWh. Roughly triple total electricity consumption in Jordan in 2015.

Radiation levels zoning

Average solar radiation levels in Jordan are 5 – 7 kWh/m² per day with about 300 sunny days in a year (1500-2100 kWh/m² per year). For the purposes of our research we utilize the map of solar irradiation from the National Energy Research Center of Jordan, which is used by the government of Jordan (Figure 5). According to the map there are 10 zones with the different solar irradiation figures, which can be generalized into 5 regions[93]:

- The southern region representing the Ma'an and Aqaba area, has the highest solar isolation in the country and has the lowest values of diffuse irradiance. The annual average daily global irradiance is between 6-7 kWh/m²/day.

- The eastern region representing the semi-desert and the (Badia) remote area has an annual daily irradiance level of between 5.5-6 kWh/m²/day.

- The middle region has an average global irradiance of 4.5 – 5 kWh/m²/day, but with the highest annual daily average of diffused irradiance.

- The northern region has an annual average global irradiance of about 5.5 kWh/m²/day.

- The western region representing the Jordan Valley area, situated below sea level, has an average annual daily global irradiance below 4.5 kWh/m²/day.

89   Azzam, Salah. (undated) Renewable Energy in Jordan. National Center for Research and Development.

90   http://www.greenpeace.org/arabic/Page-Files/481146/Jordan_Report2013.pdf

91   http://www.dlr.de/tt/Portaldata/41/Resources/dokumente/institut/system/publications/MED-CSP_complete_study-small.pdf

92   http://brawa.uest.gr/uploads/Salah_Azzam.pdf

93   http://www.nerc.gov.jo/Pages/viewpage.aspx-?pageID=180
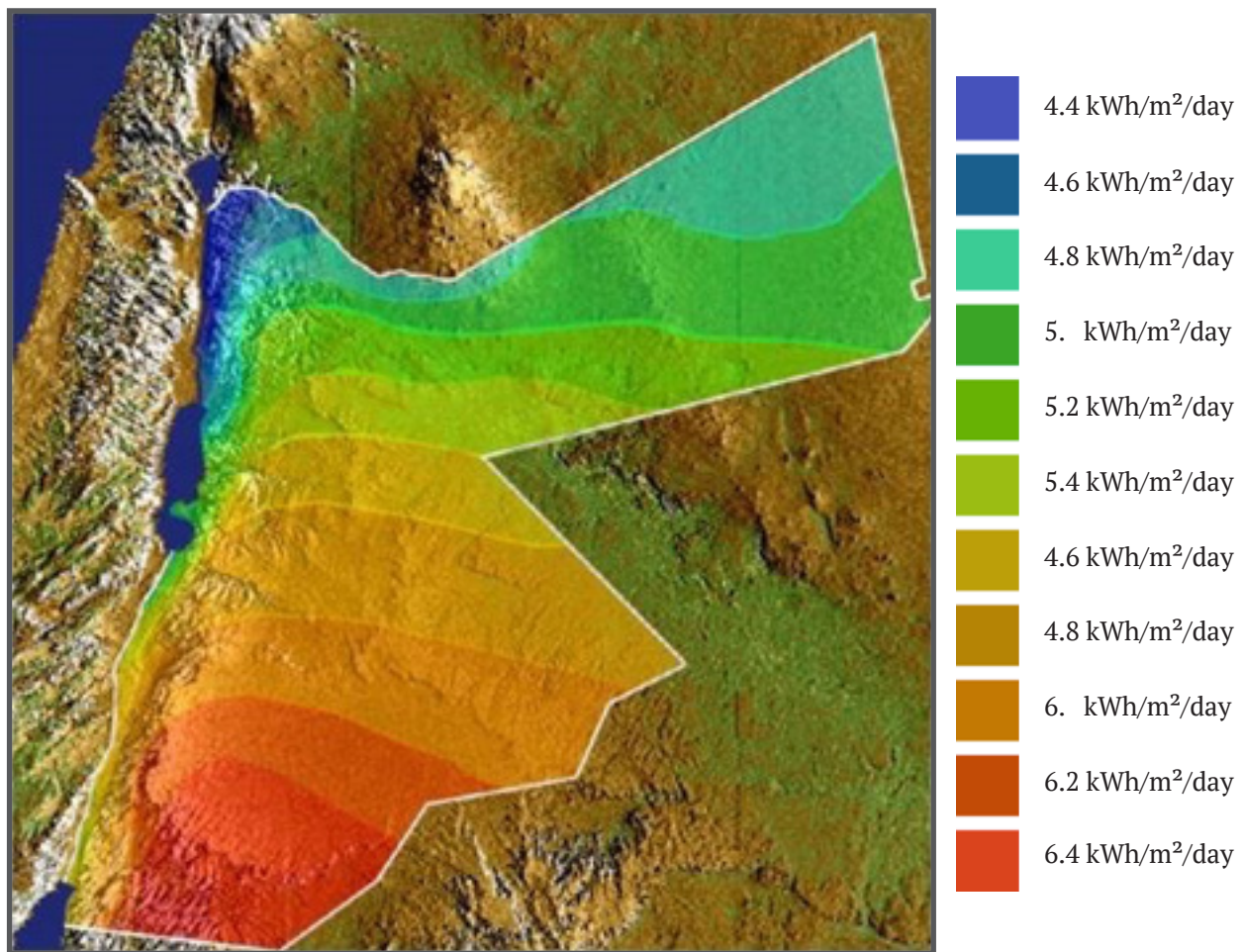
Figure 5. Global horizontal irradiation (GHI) in Jordan.

Source: Ministry of Energy & Mineral Resources of Jordan, National Energy Research Center of Jordan[94]

These figures show that the resources Jordan possesses are enough for solar power station to be placed in any part of the country. The lowest figures for irradiation potential on Jordanian territory are 1600-1800 kWh/m² (Figure 6), which corresponds to the irradiation levels in the regions providing the highest solar generation in China, Japan, Italy, and significantly more than the irradiated regions producing solar energy in Germany, United Kingdom, France, and Spain, 7 out of the world's top 8 countries in terms of installed solar power capacity[95] (Table 11). Southern Jordan has the highest solar irradiation potential, at levels up to 2800 kWh/m², levels much higher than even the highest of the world's top installed facilities.

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94   http://www.nerc.gov.jo/Pages/viewpage.aspx?pageID=180

95   http://www.iea-pvps.org/fileadmin/dam/public/report/PICS/IEA-PVPS_-_A_Snapshot_of_Global_PV_-_1992-2015_-_Final_2_02.pdf
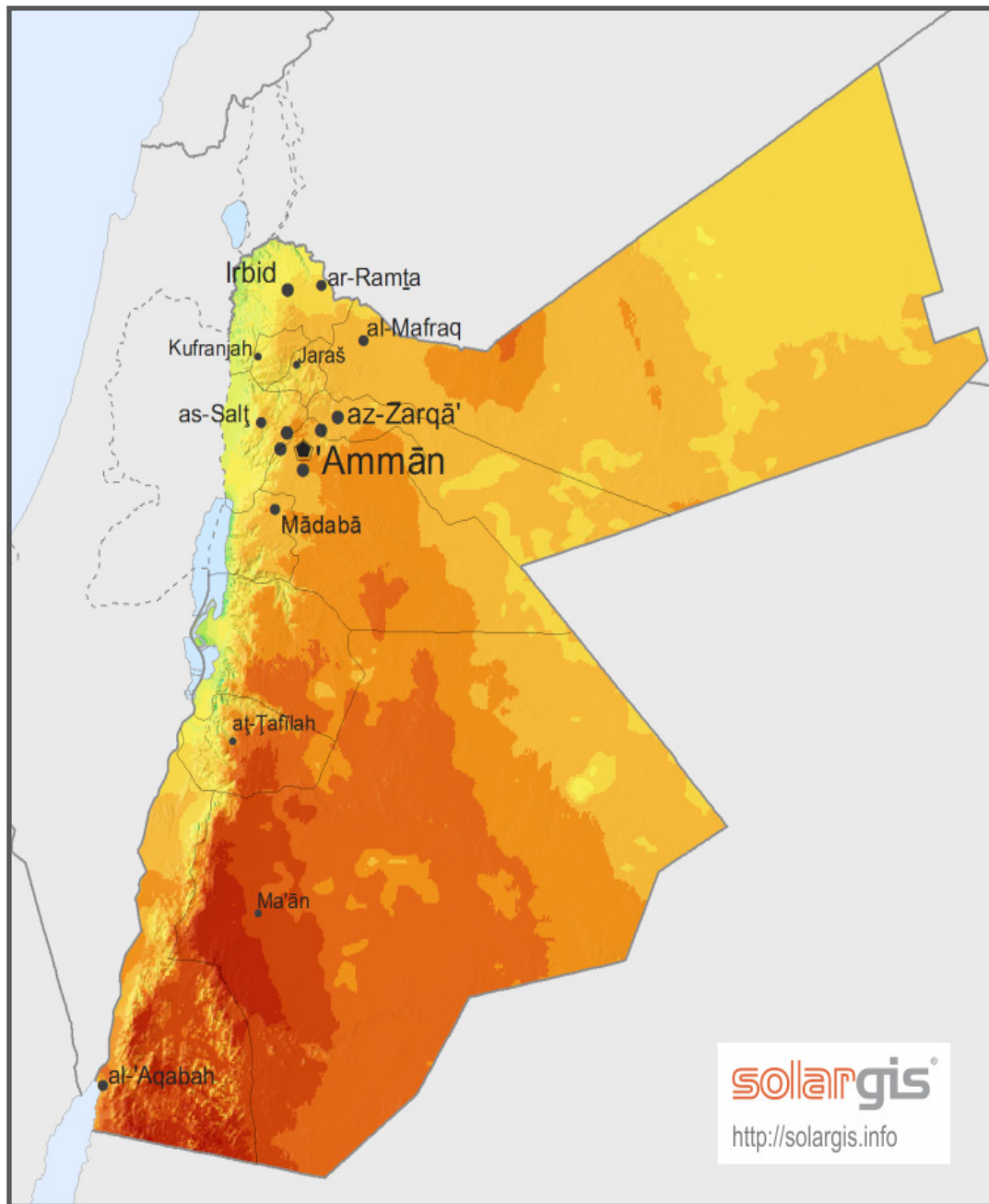
Figure 6. Direct normal radiation in Jordan
Source: SolarGIS

Table 11. The biggest installed capacity of PV countries.

Country	Cumulative installed capacity of photovoltaics in 2015, GW	The biggest photovoltaic power plant in the country			Solar irradiation for the areas with the biggest solar power plants, kWh/m²
		Name	Installed capacity, MW	Generation, GWh	
China	43.5	Longyangxia Dam Solar Park	850	824	1,700-1,900
Germany	39.7	Solarpark Meuro	166	n/a	1,000-1,200
Japan	34.4	Eurus Rokkasho Solar Park (Aomori)	148		1,200-1,300
USA	25.6	Solar Star	579	1,664	2,000-2,200
UK	8.8	Southwick Solar Farm	48	n/a	1,000-1,200
France	6.6	Cestas Solar Farm	300	380	1,200-1,400
Spain	5.4	Olmedilla Photovoltaic Park	60	87,5	1,600-1,800
Australia	5.1	Nyngan Solar Plant	102	233	1,900-2,100
India	5	Kamuthi Solar Power Project	648	n/a	1,800-2,000

Photovoltaic Power (PV)

Photovoltaic power converts sunlight directly into direct current electricity. With an installed capacity, greater than 137 GWs worldwide[96] and annual additions of about 40 GWs in recent years[97], solar PV technology has become an increasingly important energy supply option. Currently two types of panels dominate the PV market: crystalline wafers and thin-film. Crystalline wafers provide high efficiency solar cells but are relatively costly to manufacture. In comparison, thin film cells are typically cheaper due to both the materials used and the simpler manufacturing process. However, thin film cells are less efficient. They do, though, perform better in hot climates and have a better response to partial shading or soiling.[98] For this reason, thin film was chosen as the representative technology in this study.

The most significant factors for traditional power stations deployment are the position relative to the consumers and the energy resources, and the transmission grid availability. In case of the solar power there are additional factors as irradiation, weather and seasonal variations, and flatness of the surface.

According to the NERC data, the southern region represented by Ma'an and Aqaba have the highest solar isolation in Jordan and the lowest values of diffuse irradiance

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96　Utility-Scale Solar Photovoltaic Power Plants. A Project Developer's Guide. - International Finance Corporation, 2015

97　IEA, "Trends 2014 in Photovoltaic Applications"

98　Typically efficiency of PV panels declines at temperatures above 25 degrees Celsius.

(6.2-6.4 kWh/m²/day). The area is connected to the existing 132kV transmission line and is 30 km from 400kV line from Egypt.[99] Also, the suggested area is characterized as flat, which is a beneficial for a large-scale PV power plant installation. As of 2016, the area already has an operational PV power station next to Ma'an town. For this reason, we chose to perform the analysis for PV potential in this region.

From a strategic perspective, distributing production across multiple locations, especially in the case of Scenario 2, for which quantities are considerable, would distribute loads (and risk) across transmission and distribution links, rather than concentrating them on particular lines. In fact, the difference between Maan and other regions in to the north in terms of generation capacity are relatively minor, as are the differences in transmission losses due to differences in distance. Therefore, it is recommended to distribute production. For the purposes of this study, however, we present calculations for the Maan region only.

Application to Project Scenarios 1 and 2 – Thin Film PV

Globally the PV solar power station output is calculated according to the formula:

$$E \ = \ A \times R \times H \times P \times R$$

Where:

E = Energy output (kWh)

A = Total solar panel Area (m²)

R = Solar panel yield (%)

H = Annual average irradiation on tilted panels

PR = Performance ratio, coefficient for losses in generation

The following analysis is undertaken for thin-film technology (Cadmium telluride (CdTe)), with both fixed panels and one-axis tracking,[100] applied to the Maan region. Solar panel yield is estimated according to the First Solar technical datasheet.[101] A performance ratio is estimated as a coefficient for losses of different kinds, such as temperature losses, inverter losses, cables losses, dust, etc. Annual average irradiation on titled panels is estimated according to NASA Atmospheric Science Data Center database.[102] The results are presented in Table 12.

As the effectiveness of current PV systems declines over time, in order to ensure that Scenarios 1.A. and 1.B. are, in fact, carbon neutral for the life of the project (assumed to be 25 years), we added additional production to the estimates for these scenarios. Based on current technologies, we assume a reduction rate of 0.5% of output annually. Thus, for instance, instead of the figure of 3,108 GWh annual production calculated in Table 10 above for Scenario 1.A., we use a production capacity of 3,372 GWh for 2030, meaning that actual production will be greater than the 3,108 GWh demand in the early years of the project and less than actual demand in the later years.

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99   At the present stage, it is difficult to estimate the existing transmission lines loads. We make an assumption, that the future power stations can be connected to the existing power grid, however, as in the case of water, capacities of existing infrastructure is something that will need to be investigated in a full feasibility study.

100   Tracking is a technology in which the panel sits on a movable axis that allows orienting the solar panels relative to the position of the sun throughout the daylight hours such that the energy capture by the panels is maximized.

101   http://www.firstsolar.com/en-EMEA/-/media/ First-Solar/Technical-Documents/Series-4-Datasheets/ Series-4-Module-Datasheet---V3-103116-(1).ashx

102   Database of NASA Atmospheric Science Data Center - https://eosweb.larc.nasa.gov/cgi-bin/sse/sse. cgi?skip@larc.nasa.gov

Table 12. Inputs and Outputs of PV Technologies

Parameter	Scenario		
Input	**1.A**	**1.B**	**2**
Energy generation (GWh)	3,108	6,495	34,830
Energy generation (with annual production degradation of 0.5%) (GWh)	3,372	7,046	34,830
Solar panel yield (%)	17	17	17
Global horizontal irradiation (daily inputs) (total kWh/m²/year)	2,042	2,042	2,042
Performance ratio, coefficient for losses[103]	0.9	0.9	0.9
Output fixed at 29° tilt			
Annual average irradiation on titled panels (kWh/m²/year)	2,171	2,171	2,171
Total installed capacity of the system (MWᴀᴄ)	**1,720**	**3,593**	**17,600**
The area of land required (km²)	10.2	21.2	104.5
Capacity factor (%)	22.4	22.4	22.4
Output one-axis tracking			
Annual average irradiation on tracking panels (kWh/m²/year)	2,714	2,714	2,714
Total installed capacity of the system (MWᴀᴄ)	**1,513**	**3,161**	**15,630**
The area of land required (km²)	9	18.6	92
Capacity factor (%)	25.5	25.5	25.5

As can be seen from the above table, 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 increase 25% over no tracking systems.[104] Second, according to NREL,[105] capacity and generation-weighted land-use requirements for one-axis tracking systems are just 10% higher over fixed-tilt panels.[106]

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103   Estimated according to the theoretical works: http://www.nrel.gov/docs/fy13osti/57991.pdf, http://www.nrel.gov/docs/fy13osti/56487.pdf

104   http://www.dcesolar.com/docs/Single-Axis-Tracking-Systems.pdf

105   http://www.qualenergia.it/sites/default/files/articolo-doc/Studio_NREL_FV_e_consumo_suolo.pdf

106   Estimated for regions with similar weather conditions.

Concentrating Solar Power

Concentrating Solar Power (CSP) systems produce electricity by focusing sunlight to heat a fluid. The fluid then boils water to create steam that spins a conventional turbine and generates electricity or it powers an engine that produces electricity.[107] CSP plants consist of three major subsystems: one that collects solar energy and converts it to thermal energy; a second that converts the thermal energy to electricity; and a third that stores thermal energy collected from the solar field and subsequently dispatches the energy to the power block. The primary advantage of CSP over PV is the potential storage capacity, allowing for electricity production during periods without sunlight. In general, relative to PV systems, CSP technologies are not currently widely deployed worldwide. A total of 4356 MW[108] of capacity was installed in 2016, nearly all of which was in Spain and the USA.

Three primary CSP technologies exist: Parabolic Trough (PT), Central Receiver (CR) or Solar Tower (ST) and Linear Fresnel Reflector (LFR). PT is currently the most proven technology. It uses parabolic troughs to concentrate sunlight onto thin tubes carrying thermal oil, the heat from which is applied to water to produce steam, which then is used to rotate turbines to generate power. In ST systems, mirrors concentrate sunlight onto a boiler atop a tower, which produces steam from water, which, in turn, rotates turbines to generate power. LFR is similar to parabolic trough collectors, but use a series of long flat, or slightly curved, mirrors placed at different angles to concentrate the sunlight on either side of fixed receivers, through which water flows and is converted into steam. This system has advantages of low costs, but it is not commercially proven, and for this reason is not considered in this study, as performance data is unreliable.

Radiation levels zoning

CSP plants require abundant direct solar radiation in order to generate electricity, given that only strong direct sunlight can be concentrated to the temperatures required for electricity generation. This limits CSP to hot, dry regions, making the Middle East and Jordan in particular a perfect place for this technology application. To be economically efficient at present a CSP plant's direct normal irradiance levels (DNI) must be of 2 000 kWh/m²/year or more. As can be seen in the above maps (Figures 5 & 6), Jordan has much territory suitable for CSP production. The solar power capacity zones for CSP can be generalized into 3 regions.

- The northern region – to the north and north-east of Amman, with annual irradiation levels of 2000-2200 kWh/m^2;

- The central region – south of Amman to al Tafilah town, with levels of 2200-2600 kWh/m^2 annually;

- The southern region – south of al Tafilah town (this region includes Ma'an), with levels of 2600-2800 and more kWh/m^2 annually.

The decision factors for choice of CSP deployment are the same as for the PV power. The southern region represented by Ma'an and Aqaba has the largest potential due to the highest solar isolation in Jordan and the lowest values of diffuse irradiance, existing 132kV transmission line and is 30 km from 400kV line from Egypt.

107   Richter, C.; Short, R.; Teske, S. (2009). "Concentrating Solar Power Global Outlook 09: Why Renewable Energy is Hot." ESTELA, Green Peace International, and Solar Paces. Amsterdam, Netherlands

108   http://cspworld.org/cspworldmap?field_country_map_tid=All&field_purpose_tid=All&field_status_tid=244&order=field_power&sort=desc

Application to Project Scenarios 1 and 2 - CSP

The configuration of a CSP plant is a function of what is called 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 solar multiple 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.[109,110]

The solar field is defined by the collector area in square meters, which can be estimated by the simplified equation:[111]

$$CA = \frac{G}{e \times I}$$

Where:

CA = collector area (m²)

G = amount of energy generation (kWh)

e = net annual efficiency, Solar to Electric

Table 13 presents the calculations for the land use requirements for the various solar energy technologies evaluated in this study.

Table 13. Efficiency and Land Use Requirements for Concentrated Solar Energy

Parameter	Scenario		
Input	**1.A**	**1.B**	**2**
Energy generation (GWh)	3,108	6,495	34,830
Annual efficiency (trough)[112] (%)	15	15	15
Annual efficiency (tower) (%)	20	20	20
Annual average insolation (kWh/m²) [113]	2,500	2,500	2,500
Output			
Total installed generator capacity (MWAC)	1,420	2,966	15,905
Trough			
The area of land required SM1 (km²)	8.3	17.4	92.9
The area of land required SM2 (km²)	16.6	34.7	185.8
Tower			
Total installed generator capacity (MWAC)	888	1,854	9.941
The area of land required SM1 (km²)	6.3	13	69.7
The area of land required SM2 (km²)	12.5	26	139.4

109 Franz Trieb, Christoph Schillings, Marlene O'Sullivan, Thomas Pregger, Carsten Hoyer-Klick. Global Potential of Concentrating Solar Power, German Aerospace Center, Institute of Technical Thermodynamics. - http://www.solarthermalworld.org/sites/gstec/files/global%20potential%20csp.pdf

110 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.

111 Assessment of Parabolic Trough and Power Tower Solar Technology Cost and Performance Forecast, Sargent and Lundy LLC, NREL, 2003

112 Database of NASA Atmospheric Science Data Center - https://eosweb.larc.nasa.gov/cgi-bin/sse/sse.cgi

113 https://www.irena.org/DocumentDownloads/Publications/IRENA_RE_Power_Costs_2014_report.pdf

I – annual insolation (kWh/m²)
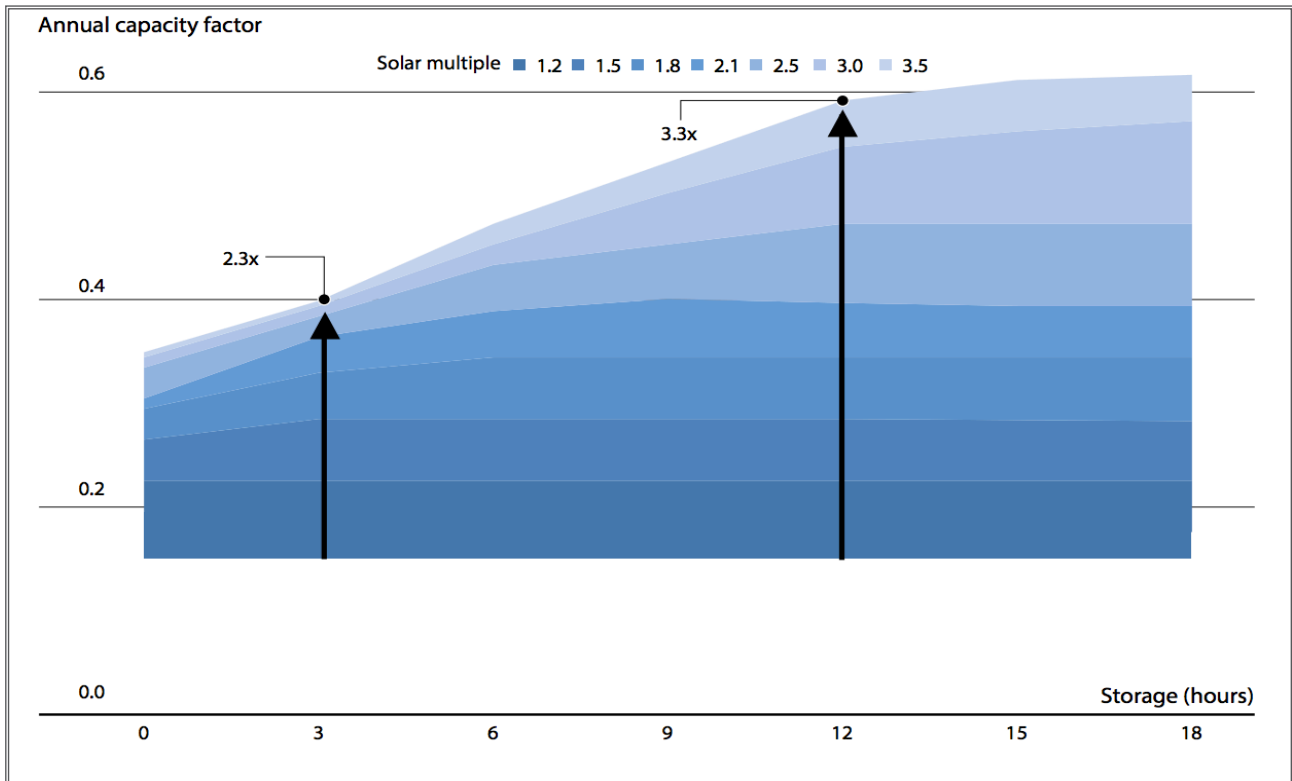
Figure 7. Capacity factor for a 100 MW parabolic trough plant as a function of solar multiple and thermal energy storage (Based on IRENA Renewable Cost Database and Trieb et al., 2009. Source: [114])

As shown in Figure 7 capacity factor grows only with the solar multiple. If the field stays the same size, the storage does not influence the efficiency. The best way to increase the power yield with the capacity factor is to increase the field size. In the model we assumed, that the capacity factor for SM 1 for both technologies is 25% and 40% for SM 2 giving an opportunity for 9-hours of storage.

114   https://www.irena.org/DocumentDownloads/Publications/IRENA_RE_Power_Costs_2014_report.pdf

5. ECONOMIC ASSESSMENT OF WATER-ENERGY EXCHANGES

5.1. Economic Analysis of Water Supplies

In this study we assume that all additional water for domestic purposes will be supplied using reverse-osmosis technology, as this is currently the most energy efficient of the commercially available desalination technologies. Because this is the technology currently in place in Israel, it is also the technology for which we have the most reliable cost figures.

Estimates of capital costs for seawater desalination plants in Israel with a capacity of 100-150 mcm/y are in the range of US $200-450 million.[115] Capital costs for construction of the desalination plant in Gaza, intended to be of similar capacity (111-120 mcm/y) in its final stage, are significantly higher, and are estimated at $660 million.[116] This higher cost in Gaza relative to Israel is likely due to several issues including the lack of functioning port, the poor state of existing infrastructure, and additional security measures needed. Should the political climate change for the better, construction costs in Gaza might decrease substantially.

This translates into a figure of roughly $2-$3 per m³ capacity in Israel, and $5.5 per m³ in Gaza. Taking the low end figure of $2 per m³ capacity, the cost of constructing facilities to supply the necessary 574 mcm from Scenario A, would be nearly $1.2 billion, while a high-end estimate, using the cost figures from Gaza, would place the cost at nearly $3.2 billion. The cost estimates for Scenario B would be approximately double that, or roughly $2.4 billion and $3.6 billion respectively.

It is likely that these per unit figures will be lower for larger capacity facilities, as there are likely economies of scale. However, as the current plants in Israel are the largest capacity reverse-osmosis plants in the world, we lack data on how these costs are likely to change. In addition, it is likely that much of the needed capacity could come from expanding the capacity of existing desalination plants, rather than constructing new facilities. This would likely reduce capital costs significantly. Additionally, given that one large-scale desalination plant is already being planned for Gaza, provision of additional water from there is likely to be less costly than for the initial facility.

Most large-scale seawater desalination plants in Israel were built by the private sector under Build Operate Transfer (BOT) contracts. As such, they bore the capital and operating expenses (primarily energy costs), which were reflected in the cost of water according to long-term contracts (typically for a period of 25 years). Costs for desalinated water from BOT contracts in Israel range from 2.0-2.9 shekels per cubic meter of water supplied. This price in US dollars has fluctuated with exchange rates. As of the writing of this study, the cost in US dollars ranged from $0.55 to $0.80 per cubic meter. Taking the low-end estimate, assuming cost savings due to economies of scale and technological improvement over time, regional annual costs would be in the range of $316 million for Scenario A and $660 million for Scenario B.

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115   Spiritos, E. and Lipchin, C. 2013. Desalination in Israel. In Becker, N. (ed.) Water Policy in Israel. Springer Press. pp.101-123.

116   Palestinian Water Authority. 2017. Gaza Central Desalination & Associated Works Program - Executive Donor Information Handbook.
Office of the Quartet, Report for the Meeting of the Ad-Hoc Liaison Committee, May 3-4 2017, Brussels.

The above calculation assumes that all additional water supplied is priced at the marginal cost of desalinated water, as it assumes that current renewable sources are fully exploited and that additional water will come from desalination. In practice, current water transfers from Israel to Jordan are of water from the Sea of Galilee and therefore are at a cost lower than that of desalination. Given that any international transfers will be compensated for by increased desalination, however, the marginal cost is representative of the actual cost of provision.

To these costs one needs to add the cost of delivery. For Gaza and Israel's coastal region, this amount would be minimal, as consumption is local. In the case of the West Bank and the rest of Israel, the cost of delivery would be dependent on the location of the desalination plants supplying the water. As explained in Section 2.2 above, for this study a figure of 1.26 kwh per cubic meter was used as a representative average figure. Assuming a cost of US$0.082 per kwh (current prices paid by the water sector in Israel), pumping costs would add an additional US$0.103 per cubic meter or US$59 million annually for Scenario A and US$124 million for Scenario B.

The pumping figure was based on delivering the water to the Jordan River system. For Jordan, there is the additional cost of delivery from the Jordan River system. A study on the delivery of 50 mcm/y of water from Israel to Jordan indicated additional pumping and operation costs of between $0.077 and $0.115 per cubic meter for delivery from the Sea of Galilee region to the King Abdullah Canal, Jordan's primary national water carrier system.[117] In the case of flows of the scale envisioned in this report, actual costs are likely to be lower, as there are economies of scale in the delivery. For this reason, this

study assumes the lower-bound estimate, which, when applied to the share of water designated for Jordan, would entail an additional $22 million annually for Scenario A and $53 million for Scenario B. This does not include the costs of pumping from the King Abdullah Canal to the eventual end users throughout the Kingdom.

Summarizing the costs, water provision within Israel and Palestine would cost roughly US$0.65 per cubic meter, while it would cost US$0.73 per cubic meter to deliver it to Jordan. The above calculations assume that capacity in the delivery system within Israel/Palestine are sufficient to deliver the specified amounts. Should additional piping or other infrastructure be needed, this would increase the cost somewhat, but likely not at a scale that would dramatically affect overall prices. Furthermore, we assume that the infrastructure to deliver this amount of water in these countries would occur regardless of whether or not water-energy exchanges such as those investigated here tale place.

It is difficult to calculate the cost of delivering the water throughout Jordan, however, assuming the same pumping coefficients as in Israel, pumping from the King Abdullah Canal to Amman, for instance, with an elevation difference of 1000m and a distance of approximately 100km would entail an extra 5.25 kwh per cubic meter. The cost of electricity in Jordan is variable and subsidized making direct calculations complicated. According to a "Master Strategy for the Energy Sector in Jordan for the Period 2007 – 2020," prepared by the electric utility NEPCO the projected marginal cost of electricity in 2030 is projected to be US$0.071.[118] Using this cost would entail a price of US$0.37/m³ for delivery.

117   Shaham, G. 2015. Options for Supply of Additional Water to the Kingdom of Jordan. The Kinneret Drainage and Rivers Authority – Sea of Galilee Administration.

118   Coyne-Et Bellier, Tractebel Engineering and Kema. 2014. Red Sea - Dead Sea Water Conveyance Study Program
Feasibility Study Draft Final Feasibility Study Report Summary.

Adding this to the cost of delivery up to the King Abdullah Canal gives a cost of US$1.10/ m³ (Figure 8). This is very similar to the lowest-end costs estimate for the Red-Dead canal examined within the context of the World Bank sponsored feasibility study,[119,120] as well as to the costs of bringing water from the Disi Aquifer in southern Jordan (a major source of current water supply),[121] and is significantly lower than the high end estimates of such sources. In contrast to water from Aqaba or Disi as a source, the actual distance water would need to be pumped in this project would be less, and so would associated costs, as much of Jordan's population is located in the North, closer to the King Abdullah Canal.

Cost of Desalinated Water ($/m3)
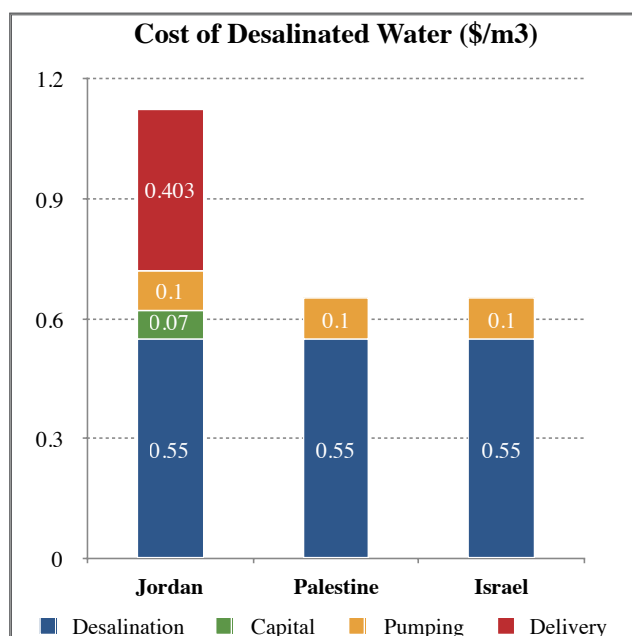
Figure 8. Estimated Costs of Desalinated Water per Country

Water subsidies in Jordan are extensive. Between 2005-2011 they were estimated to be 0.4% of Kingdom's total GDP.[122] This is a serious drain on government coffers, and phasing out of these subsidies is a significant part of the Jordanian Ministry of Water and Irrigation's strategic plans.[123] Therefore, attaining water in a cost efficient manner is an important economic and national priority.

Summarizing the costs of the water project, annual costs would be US$500 million for Scenario A, of which over 60% are for water supply to Jordan. In the case of Scenario B, annual costs are US$1088, of which nearly 70% is for water supply to Jordan (See Table 14). Taking a 25 year framework with no discount rate[124] applied this works out to be US$9.9 billion and US$20.9 billion respectively. Applying a 5% discount rate would produce a net present value (NPV) of project costs of US$5.9 and US$12.4 billion respectively, while applying a discount rate of 10% would reduce the respective NPVs further to US$4.0 billion and US$8.3 billion (Table 15). Taking a 25 year framework with no discount rate[125] applied this works out to be US$12.5 billion and US$27.2 billion respectively. Applying a 5% discount rate would produce a net present value (NPV) of project costs of US$7.4 and US$16.1 billion respectively, while applying a discount rate of 10% would reduce the respective NPVs further to US$5.0 billion and US$10.9 billion (Table 15).

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119   Ibid 2014 and Allan, J.A., A.I.H. Malkawi, and Y. Tsur. 2014. Red Sea–Dead Sea Water Conveyance Study Program Study of Alternatives *Final Draft Report Executive Summary* and Main Report.

120   One need be careful regarding comparisons of costs from this project with those of the Red-Dead Canal, as they are not designed to achieve the same purposes and therefore include different types of infrastructure and calculations were undertaken with somewhat different assumptions. Thus, the comparison is for illustrative purposes only.

121   USAID. 2012. Review of Water Policies in Jordan and Recommendations for Strategic Priorities.

122   Ibid, 2012.

123   Jordan Ministry of Water and Irrigation. 2016. Water Sector Capital Investment Plan – 2016-2025.

124   Various discount rates are used in order to compare costs over time and in order to present figures from different time periods in terms of net present value. The choice of an "appropriate" discount rate is largely a function of actual cost of capital at the time of construction. Therefore, the choice of 0%, 5%, and 10% are for illustrative purposes only.

125   Various discount rates are used in order to compare costs over time and in order to present figures from different time periods in terms of net present value. The choice of an "appropriate" discount rate is largely a function of actual cost of capital at the time of construction. Therefore, the choice of 0%, 5%, and 10% are for illustrative purposes only.

Table 14. Annual Costs of Desalination and Pumping

Scenario		Additional Water Needed	Desalination Costs	Pumping Cost	Additional Pumping Cost for Jordan to KAC	Pumping within Jordan	Total
		(mcm)	(US$ million)				
A	Israel	70.2	38.6	7.2			**45.8**
	Palestine	222.8	122.5	22.9			**145.5**
	Jordan	280.6	154.3	28.9	21.6	103.8	**308.7**
	Total	**573.6**	**315.5**	**59.1**	**21.6**	**103.8**	**500.0**
B	Israel	70.2	38.6	7.2			**45.8**
	Palestine	444.3	244.4	45.8			**290.1**
	Jordan	684	376.2	70.5	52.7	253.1	**752.4**
	Total	**1,198.5**	**659.2**	**123.4**	**52.7**	**253.1**	**1,088.4**

Table 15. Net Present Value of Water Project Costs (in billions of US$) (25 year time period)

	Applied Discount Rate		
	0%	**5%**	**10%**
Scenario A	12,500	7,399	4,992
Scenario B	27,209	16,106	10,867

Critically, this analysis assumes that no additional infrastructure is necessary for delivery and that the additional amounts of water could be delivered within the current and planned national delivery systems. Future analysis will need to clarify estimated capacity limits and the potential need for infrastructure improvements and expansion necessary to accommodate the scale of flows envisioned in this study.

It is important to note that in the case of Palestine and Israel, the calculated costs are likely to be identical to the costs of water delivery regardless of whether they are undertaken within the framework of a regional water-energy exchange or not. In the case of Jordan, the costs would have to be compared to alternative means of accessing such water. Currently the only existing plan for doing so is the Red-Dead Canal. While detailed cost estimates have been made for the Canal, it would be inappropriate to compare these costs directly with those in this analysis, as the scales, goals and projected outcomes of the projects are not identical. Analysis of alternatives to the Red-Dead Canal, however, like this study, found that supply of water from a Northern route, i.e,. via Israel would be cheaper than the Red-Dead route eventually chosen.[126] Furthermore, the cost of delivery from the King Abdullah Canal to the end users would be substantially less than from the Dead Sea, given the difference in elevation, the proximity to end users, and the existing infrastructure already in place.

126   Allan, J.A., A.I.H. Malkawi, and Y. Tsur. 2014. Red Sea–Dead Sea Water Conveyance Study Program Study of Alternatives *Final Draft Report Executive Summary* and Main Report.

5.2. Initial Economic Analysis of Renewable Energy Supplies

5.2.1. Electricity Production

Analysis of the economic feasibility of the energy production portion of the project can be undertaken in a number of different ways, each bringing its own insights. Typical costs examined include equipment costs (e.g. PV modules, solar reflectors), financing costs, total installed cost, fixed and variable operating and maintenance costs (O&M), fuel costs and the levelized cost of energy (LCOE). Due to the lack of accumulated experience with utility scale PV power plants and CSP plants construction in Jordan, this analysis uses average costs of some of the parameters from around the world.

High and low-end costs for photovoltaics are based on the assumptions for capital costs from theoretical works and expert consultations – USS1/W for a low-end and US$1.5/W for the high-end scenario for stationary tilt panels. For moveable one-axis technology, the costs are 10 cents higher, or US$1.1/W and US$1.6/W respectively. High and low-end costs for CSP are based on the assumptions of capital costs for power plants construction taken from the International Renewable Energy Agency (IRENA).[127] The land use costs were based on expert consultations regarding experience of solar power plants construction in Jordan. For Jordan this amounted to 120 Jordanian Dinar per dunam per year (US$168,000/km²/y).[128] This figure is likely an overestimate as it is based on projects of a much smaller scale than the ones evaluated herein, and thus the per dunam rate would likely be less for larger scale projects. Operation and maintenance costs calculations were based on current experience in Jordan, expert opinions, and IRENA estimates.[129]

The calculations shown below are for 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 using values 50% debt financing, no discount rate, and a 3% inflation rate. These are not shown herein, but did not change the rankings of technology options in terms of economic preference.

Tables 16-18 display calculations of investments for the projects for the different scenarios, for 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.

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127   https://www.irena.org/DocumentDownloads/Publications/RE_Technologies_Cost_Analysis-CSP.pdf, https://www.irena.org/DocumentDownloads/Publications/IRENA_RE_Power_Costs_2014_report.pdf

128   Using an exchange rate of 1JD = US$1.4

129   https://www.irena.org/DocumentDownloads/Publications/RE_Technologies_Cost_Analysis-CSP.pdf, https://www.irena.org/DocumentDownloads/Publications/IRENA_RE_Power_Costs_2014_report.pdf

Table 16. Parameters for economic analysis. Scenario 1A

	PV, tilt panels	PV, one-axis tracking	CSP, tower, no storage	CSP, tower, storage	CSP, trough, no storage	CSP, trough, storage
Installed generator capacity, MW	1,720	1,513	1,420	888	1,420	888
CAPEX, low estimate, million US$	1,720	1,665	8,515	5,766	5,677	6,032
CAPEX, high estimate, million US$	2,579	2,421	9,934	7,983	10,644	8,870
CAPEX, low estimate, US$/Wp	1	1.1	6	6.5	4	6.8
CAPEX, high estimate, US$/Wp	1.5	1.6	7	9	7.5	10
Land use cost (annual), million US$	1.7	1.5	1.1	2.1	1.4	2.8
Land use cost (rent for all period), million US$(undiscounted)	42.5	37.4	26.5	52.5	34.9	69.7
Land use cost (rent for all period), million US$ (5% discount rate)			15.7	31.1	20.6	41.3
Operation and maintenance, c/kWh	1.3	1.5	3	3	2	3

Table 17. Parameters for economic analysis. Scenario 1B

	PV, tilt panels	PV, one-axis tracking	CSP, tower, no storage	CSP, tower, storage	CSP, trough, no storage	CSP, trough, storage
Installed generator capacity, MW	3,593	3,161	2,966	1,854	2,966	1,854
CAPEX, low estimate, estimate, million US$	3,593	3,478	17,792	12,047	11,862	12,603
CAPEX, high estimate, estimate, million US$	5,389	5,059	20,758	16,680	22,240	18,534
CAPEX, low estimate, US$/Wp	1	1.1	6	6.5	4	6.8
CAPEX, high estimate, US$/Wp	1.5	1.6	7	9	7.5	10
Land use cost (annual), estimate, million US$	3.6	3.1	2.2	4.4	2.9	5.8
Land use cost (rent for all period), estimate, million US$ (undiscounted)	88.8	78.1	54.6	109.2	73.1	145.7
Land use cost (rent for all period), estimate, million US$ (5% discount rate)			32.3	64.6	43.3	86.3
Operation and maintenance, c/kWh	1.3	1.5	3	3	2	3

Table 18. Parameters for economic analysis. Scenario 2

	PV, tilt panels	PV, one-axis tracking	CSP, tower, no storage	CSP, tower, storage	CSP, trough, no storage	CSP, trough, storage
Installed generator capacity, MW	19,270	16,957	15,905	9,941	15,905	9,941
CAPEX, low estimate, estimate, million US$	19,269	18,653	95,425	64,610	63,616	67,592
CAPEX, high estimate,estimate, million US$	28,904	27,131	111,329	89,461	119,281	99,401
CAPEX, low estimate, US$/Wp	1	1.1	6	6.5	4	6.8
CAPEX, high estimate, US$/Wp	1.5	1.6	7	9	7.5	10
Land use cost (annual),estimate, million US$	19	16.1	11.1	23.4	15.6	31.2
Land use cost (rent for all period), estimate, million US$(undiscounted)	476.1	418.9	292.7	585.5	390.2	780.4
Land use cost (rent for all period),estimate, million US$ (5% discount rate)			173.3	346.6	231	461.9
Operation and maintenance, c/kWh	1.3	1.5	3	3	2	3

One important finding from the analysis is that land 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 Palestine 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 Palestine and Israel and the regulatory and bureaucratic obstacles to obtaining approval for construction of such facilities there.

Capital investments, however, is not the only, nor the most representative measure of project costs or preferability. Levelized cost of electricity measures the per unit costs of electricity production over the lifetime of a project. As such, it allows for comparison of projects of different technologies, scale, duration, capital costs, etc. The approach used in the analysis presented here is based on a discounted cash flow analysis.[130]

The formula used for calculating the LCOE of renewable energy technologies is:

$$LCOE = \frac{\sum_{t=1}^{n} \frac{I_t + M_t + F_t}{(1+r)^t}}{\sum_{t=1}^{n} \frac{E_t}{(1+r)^t}}$$

Where:

$LCOE$ = the average lifetime levelized cost of electricity generation;

I_t = investment expenditures in the year t;

M_t = operations and maintenance expenditures in the year t;

F_t = fuel expenditures in the year t;

E_t = electricity generation in the year t;

r = discount rate; and

n = life of the system.

The results of the analysis for LCOE are presented in Figure 9. Again, a PV system with a one-axis tracker produced the lowest cost option, at 5.25 US cents per kWh using the low-end assumptions and 6.85 US cents using the high-end estimates. These values are comparable to current state of the art renewable energy projects and are competitive with fossil fuel produced electricity.

The values listed in Figure 9 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.

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130   Calculations were made using the LCOE Calculator of the National Renewable Energy Laboratory of the U.S. Department of Energy https://www.nrel.gov/analysis/tech_lcoe.html, and its Cost of Renewable Energy Spreadsheet Tool (CREST) https://financere.nrel.gov/finance/content/crest-cost-energy-models.
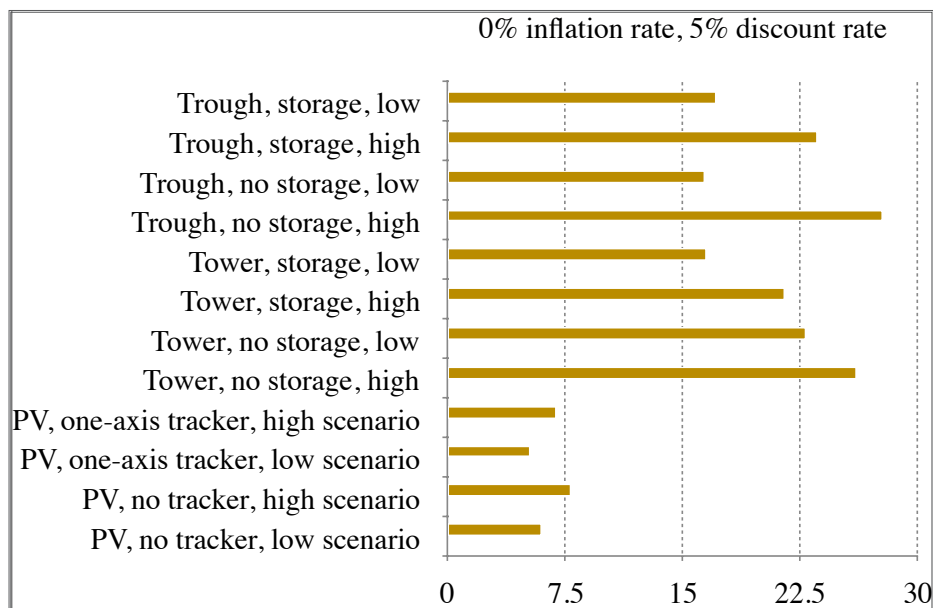
Figure 9. Levelized cost of electricity for different kinds of electricity generation

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 is 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. The water requirements for the scale of project evaluated in this study, however, are such magnitude that this option was not investigated in depth. Compressed air energy storage (CAES) 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 a full feasibility study.

The most proven storage technologies at present 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. Finally, as can be seen from the calculations provided in Table 19 below, the LCOE from the batteries is still not commercially viable.

Table 19. Performance of Storage Technologies

Storage type	Discharge time	Lifetime (year)	Ovearall storage cost (USD/MWh)	Capital cost (USD/kW)
VRB8[131]	2-8 h	10	250-300	3,000-4,000
Li-ion battery	15 m – 4 h	8-12	250-500	2,500-3,000
Lead battery	10 s – 4 h	4-8	n/a	1,500-2,000
NaS battery	4 h	15	50-150	100-2,000

Source: IRENA (2012)[132]

In conclusion, PV systems produce at a lower cost than CSP ones. CSP with storage is more cost-efficient than a similar system without storage capacity, but it is still not competitive with PV, which seems to be a more economically reasonable choice. The importance of solar becoming a dispatchable power source (i.e., providing energy at the quantity and timing desired) should not be underestimated. An advantage of CSP over PV is more balanced distribution of capacity throughout the day, which leads to a certain decrease of power transmission grid growth.

5.2.2. Electricity Transmission

In addition to production costs, it is necessary to consider costs of transmission as well, including construction of new transmission capacity. As the purpose of this analysis is to compare an energy exchange between Jordan and Palestine and Israel, we look at the transmission from the production source in Jordan to the connection to the national grids in Palestine 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.

Obtaining reliable costs regarding necessary transmission infrastructure was exceedingly hard to obtain. Our assumptions regarding power lines and substation costs were based on recent construction of such systems in the region and conversations with experts. We estimate a cost of 250,000 JD (US$354,000) per km of extra high-voltage alternating current (EHVAC) overhead lines (OHL) and about US$10,000,000 for 132/33 substation and US$28,000,000 for 400/132/33 substation. Losses were taken into consideration in the model calculating electricity needs (14%). We assumed transmission capability for EHVAC to be 500-700 MW per circuit. As experts pointed out that the currently existing transmission grid is totally loaded, having little or no additional capacity to meet the project needs, our assumption was, that only new capacities will be needed to transmit the electricity produced in the power plants.

We assume that crossborder electricity transmission in the region will not face considerable difficulties as both Israel and Jordan have the electricity frequency of 50 Hz and power lines of extra high voltage of 400 kV. The connection of Palestine to Jordan would necessitate either an extra high voltage connection line or, less optimally, a substation to convert to lower voltage. In reality, grid integration issues remain an important obstacle and a detailed assessment of grid integration should be undertaken in a full feasibility study.

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131   Vanadium redox flow cells or batteries (VRB) are electro-chemical energy storage systems based on the vanadium ability to exist at four different oxidation levels. Rather complex systems having relatively low energy density by volume.

132   Electricity storage. Technology brief. IRENA. 2012. - https://www.irena.org/DocumentDownloads/Publications/IRENA-ETSAP%20Tech%20Brief%20E18%20Electricity-Storage.pdf

Table 20 presents rough calculations for the additional transmission network necessary for Scenarios 1A and 1B, while Table 21 represents calculations for Scenario 2. Transmission network cost estimates for Scenario 2 were based on the assumption that the electricity produced in Jordan covering the needs of Palestine and Israel will be transmitted straight to the Jordan-Palestine and Jordan-Israel borders respectively by OHL without its integration into the Jordanian transmission grid. It should be noted that the estimates for Scenario 2 are very approximate, as the scale is larger than the entire existing electricity market. A more in depth evaluation of needs and costs should also be undertaken in a full feasibility study.

Table 20. Transmission Network Cost Estimates for Scenario 1

Scenario	1A	1B
Distance for the extra high voltage power lines (generated in Jordan), km	221 – in Jordan before the border with Palestine;	
	44 – in Jordan, before the border with Israel	
Number of substations	1	2
Number of double circuit OHL needed	1	2
Transmission construction cost, double circuit OHL (Jordan), US$/km	354,000	354,000
Capital cost estimation for electricity from Jordan to Jordan-Palestine border, million US$	106.3	212.5
Capital cost estimation for electricity from Jordan to Jordan-Israel border, million US$	43.6	87.2

Table 21. Transmission Network Cost Estimates for Scenario 2

	Transmission line to Israel	Transmission line to Palestine
Distance for the extra high voltage power lines (generated in Jordan), km	44	221
Transmitted power, MW	10,000 (6,500 for CSP with storage)	900 (1400 for CSP with storage)
Number of substations	7 (5 for CSP with storage)	1
Number of double circuit OHL needed	7 (5 for CSP with storage)	1
Capital cost estimation for electricity transmission, million US$	305.1 (218 for CSP with storage)	106.3

Several points are important to stress in terms of transmission costs. The first is that, while these cost are very rough estimates, from the above calculations, it seems that the costs of transmission infrastructure will be a relatively small share of relative project costs.

Secondly, the calculations were made assuming all production was undertaken in southern Jordan near Maan. In fact, as mentioned earlier, production would not change dramatically if distributed throughout Jordan. This would have the advantage of lessening loads on any given transmission line and would distribute risk. For this reason, the above calculations likely do not reflect what would be actual infrastructure costs.

Thirdly, because of the above reasons, it is difficult to infer from these costs a per kWh cost for the project, which would be useful both in determining overall energy costs and the value of water energy exchanges. For this reason, no attempt was made in this study to do so. Analysis of US electrical utilities 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.[133] While it is tempting to apply such ratios to the LCOE calculated above, to do so would risk being extremely inaccurate, as costs are highly dependent on location, fuel type, production facilities and existing capital and infrastructure. We therefore leave estimation of actual costs for building and operating the necessary transmission and distribution infrastructure to the full feasibility study.

5.2.3. Renewable vs. Fossil Fuels

Using similar assumptions to those made for calculating solar, the LCOE of a natural gas power plant in the region produced a figure of 7.35 US cents per kWh. That is, it was equal to the high end estimate for a one-axis PV solar facility and substantially more than the low end estimate for PV solar. This seems to indicate that solar energy would make economic sense, regardless of the environmental benefits. This finding that PV compares favorably with fossil fuels is corroborated by actual market trends in the region. Recent tenders for renewable energy in Israel, for instance, produced a price of 0.199 shekels (5.5 US cents) per kWh,, while the most efficient natural gas production was estimated at 0.21-0.23 shekels (5.8-6.4 US cents) per kWh.[134] Actual production costs based on a coal natural fuel mix are even higher, at roughly 0.27 shekels (7.4 US cents) per kwh. Though we do not have actual production cost figures for the current solar facility in Maan, it is believed to be in the same range as the figures calculated herein.

133   Based on figures provided in US EIA. 2017. Revenue and expense statistics for major U.S. investor-owned electric utilities. https://www.eia.gov/electricity/annual/html/epa_08_03.html

134   Globes. 2017. "Revolution: Solar energy is the cheapest alternative in Israel" 20 March, 2017 (In Hebrew).. http://www.globes.co.il/news/article.aspx?-did=1001181744

Direct cost comparisons between solar and conventional power systems, such as natural gas, using parameters such as LCOE are problematic, however, given that electricity produced at gas-powered stations can produce at all hours and production can be scaled to fluctuating consumption patterns, while solar is produced intermittently and not necessarily in concert with fluctuations in demand.[135] 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.

The problems of such cost comparisons are mitigated somewhat given that the share of renewable energy in overall demand is limited and that production is likely to be highest during hours of peak demand, e.g., during summer when air conditioning units are employed. Also, any economic analysis should take into consideration not only direct costs, but also the cost of environmental externalities, which are significant in the case of fossil fuel production. According to the Israeli Ministry of Environmental Protection, as of 2016, average externalities per kwh of electricity production from fossil fuels were 0.1 shekel, or roughly 2.8 US cents.[136] While this is likely to decrease somewhat as the power production shifts more towards natural gas, adding such costs to the direct costs of gas-generated electricity would improve solar energy's relative competitiveness even further. Furthermore, costs for solar energy production are on a rapidly declining downward trend, meaning that their relative cost effectiveness is likely to improve by the time the project would be implemented.

5.3. Water-Energy Exchanges

As mentioned, without detailed data on the costs of transmission and distribution infrastructure, both for water and for energy, it is difficult to estimate the actual costs of the water-energy exchanges that this study is examining. What can be done, however, is to compare production costs. For the purposes of comparison, we assume that regardless of whether the envisioned exchanges occur, the parties would consume the quantities of water and electricity as detailed in Sections 3 and 4. Therefore, this analysis evaluates only the cost of the exchange; that is, it looks at the costs to Jordan of importation of desalinated water from Israel and/or Palestine less the revenue it would receive from selling electricity to Israel and Palestine.

Because the issue of water rights between Palestine and Israel is still contested, and because no declaration was made on where the proposed desalination would occur, for this section we treat Palestine and Israel as a single water exporter for Scenarios 1.A. and 1.B. In the case of Scenario 2, each party is assumed to import 20% of its anticipated electricity consumption (plus losses). For this analysis, the water and electricity are sold at cost. Water costs are those taken from Table 14 above, while electricity prices are based on the LCOE for the low and high end estimates of one-axis PV systems multiplied by relative shares of electricity consumption in each of the scenarios. The results for Scenario 1.A. and for Scenario 2 are presented in Table 22.

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135   See, for example, Joskow, P.L. 2011. "Comparing the Costs of Intermittent and Dispatchable Electricity Generating Technologies." *The American Economic Review* 101(3): 238–41. Or Edenhofer, et al. 2013. "On the Economics of Renewable Energy Sources." *Energy Economics* 40: S12–23.

136   Based on figures provided in: http://www.sviva.gov.il/subjectsEnv/SvivaAir/Pages/AirExternalCost.aspx

Table 22. Annual Net Revenue for Jordan

Scenario		Quantity	Revenue (million US$/y)	Revenue (million US$/y)
			(at US$0.0525/kWh)	(at US$0.0685/kWh)
1A	Jordanian Water Imports & Pumping within Jordan	280.6 (mcm)	-$309	-$309
	Jordanian Electricity Exports	1587.6 (MWh)	83	$109
	Net Revenue for Jordan		**-$225**	**-$200**
	Jordanian Electricity Exports*			
2	To Palestine	3,000 (MWh)	$158	$206
	To Israel	22,000 (MWh)	$1,155	$1,507
	Total	**25,000 (MWh)**	**$1,313**	**$1,713**
	Net Revenue for Jordan		**$1,004**	**$1,404**

* Values round to nearest 100 MWh

While the figures above are merely illustrative, as they indicate that the net costs to Jordan of water importation are reduced significantly (by roughly half for Scenario 1A and by 30-40% for Scenario 1B. Because of the large scale of electricity production in Scenario 2, Jordan would become a major exporter of energy. Revenues from exports are estimated at between US$ 1.3-1.7 annually. To put this in perspective, this would be 3-4% of Jordan's 2016 Gross Domestic Product (GDP) of US$ 38.6 billion,[137] and would be 11-15% of industry's share of GDP.

137   The World Bank. 2017. https://data.worldbank.org/indicator/NY.GDP.MKTP.CD?locations=JO

5.4. Project Finance

Several options exist for project finance. Should the governments themselves choose to finance it, each side brings with it relative advantages. Israel, as a member of the OECD, has a relatively high credit rating which can attract lower cost financial terms on the open market. Jordan and Palestine, as developing countries, are eligible for financial assistance on favorable terms from institutions such as the World Bank. Other development banks, such as the European Investment Bank or Islamic Development Bank may also be possible sources of funding for the Jordanian and Palestinian portions of the project. In addition, given that the project is promoting renewable energy, various carbon finance instruments may be available, both through development banks and various private carbon markets. These could include low finance loans or grants for carbon offset credits.

As mentioned, there are several reasons to involve the private sector in such a project. All major desalination projects in Israel have been private sector led and/or public-private partnerships, based on BOT project finance models. This has the advantage of deferring upfront costs and much of the risk away from the government and on to the private sector. It also galvanizes private sector knowledge and experience.

Regardless of the source of funding, certain information is critical to investment decisions, most importantly a detailed assessment of project risks. While a detailed assessment of such is beyond the scope of this study, it is clear that a project of the nature and scale envisioned entails several types of risk. First and foremost, given the region in question, there is political risk, e.g., that the partner countries cease or impede project development, cooperation and/or trade of resources, either intentionally or because of regulatory delays and obstacles. Given the volatile history of the region, there is also risk that large infrastructure projects of this nature become the intentional

targets of attacks or are damaged during the course of violent exchanges between parties or citizens of the various parties. Sabotage of Egyptian gas lines supplying Israel and Jordan provides clear and stark precedent for such risk.

There are also technical risks, e.g., that technologies do not work as anticipated. And finally, there are real issues of economic risk, including construction cost overruns, purchase commitments and ability to pay. These are especially relevant considering that the electricity sector in all three countries is in deep arrears and many of both the water and electric utilities suffer from difficulties with cost recovery from their consumers. While water and power purchase agreements would be mandatory, there would still be questions of how to deal with an ability by one or more party to live up to the terms of such agreements.

Given these risks careful attention will have to be paid to drawing up clear, detailed and binding contractual relations between the partners, specifying the obligations and rights to each party involved, and perhaps developing some type of institutional framework for resolving conflicts and/or instances of abrogation of commitments.

6. ENVIRONMENTAL IMPLICATIONS

The envisioned project would have clear benefits for the environment relative to business as usual and even relative to the case of each country pursuing its own unilateral desalination and renewable energy strategy. As mentioned, currently overall per capita annual water supplies for the entire region are at well below 150 m³ for all purposes, considered chronically scarce by international standards. Given anticipated population growth, this figure is likely to drop to 100 m³ by 2030. Overdrafts resulting in depletion and contamination of aquifers, already serious problems in places such as Gaza and Jordan, and will only intensify if additional water supplies are not found. Furthermore, allocation of water to nature and ecosystems will be more difficult unless additional water is found. While policies such as increased conservation, reduce losses, and reclaimed sewage are to be encouraged, desalination is likely to be the only solution to the scale of water needed.

Desalination, however, is an energy-intensive process, and thus, wide-scale desalination, a primary climate adaptation strategy for the region, could end up being an important source of greenhouse gases (GHGs), making it harder for the countries to meet their emission reduction commitments under the Paris Agreement. Supplying water via desalination within the context of the water-energy exchanges described herein, would allow for significant reduction in the environmental impacts of water supply, reducing not only greenhouse gases, but also local air pollutants as well.

Table 23 shows the potential air pollution emissions for scenarios 1A and 2 were they to be supplied by natural gas, as it is assumed to be the primary fuel source for electricity consumption by 2030. It should be noted, too, that natural gas is by far the cleanest of the fossil fuels currently used for production, and thus, is itself probably a lower end estimate of real emissions savings from such a project.

Table 23. Avoided Air Pollution Emissions

Type of Emission	Emissions (grams/KWh)[138]	Scenario	
		1.A.	2.
		Total Pollution (tons/year)	
Sulfur Dioxide (SO_2)	0.02	62	697
Nitrous Oxides (NO_x)	0.3	932	10,449
Particular Matter (PM10)	0.01	31	348
Carbon Dioxide (CO_2)	436	1,355,088	15,185,880

As can be seen, from the above table, making the water provision carbon neutral would reduce over a million tons of CO_2 annually, as well as hundreds of tons of NOx and tens of tons of SO_2 and particulate matter. For Jordan, which represents nearly half of Scenario 1.A. water consumption, the actual savings would be even higher than its proportional share, given that its only other viable option for desalinated water is the Red Sea, which is further and would entail more pumping. Increasing the amount of renewable energy to 20% of total regional consumption (Scenario 2) would multiply the emissions savings by a factor of over 11, given the larger scale of production.

In addition to the environmental impacts of water and energy production, the project would likely have a positive net impact on wildlife habitat and ecosystems, especially if compared to each country pursuing a unilateral strategy of renewable energy production. For Palestine and Israel, the project would allow them to produce renewable energy without adding to pressures on their already limited and highly fragmented open spaces, which provide habitat for numerous endangered species of flora and fauna. While it would add to the pressures on Jordanian lands, these lands are much more plentiful and with much less competition for development, such that the impacts are comparatively minor. Even producing 20% of the region's total projected energy demand would necessitate only 100 square kilometers, or roughly 0.1% of Jordanian territory.

In the case of water production, it is Jordan's environment that would benefit. To the extent that desalination from the project would displace desalination in Aqaba, it would benefit the Red Sea aquatic ecosystem, which, as a narrow closed gulf, with coral reefs, is a much more sensitive than the open Eastern Mediterranean. Jordan's open spaces would also benefit by not having to construct the pipeline to transfer water from Aqaba to population centers in Amman and elsewhere.

138   Source: Coheh, G. and M. Korner. 2016. Israeli Oil & Gas Sector Economic and Geopolitical Aspects: Distinguish between the Impossible, thePotential and the Doable. Samuel Neaman Institute. Haifa, Israel.

7. POLITICAL FEASIBILITY & GEOPOLITICAL CONSIDERATIONS

The proposed project would generate a number of geopolitical advantages to each of the parties involved. As with any project involving regional cooperation, potential benefits of cooperation and integration include economic efficiency and improvement of overall political relations. The project would face some political obstacles before implementation would be possible. In this section we review the specific geo-strategic pros and cons for each of the parties. As will be shown, some issues are common to all parties, such as issues of regional cooperation, the potential that the international community will assist in financing such a project, and concerns over autonomy, while others are particular to each country.

7.1. Jordan

Advantages

The project would provide two primary advantages to Jordan. It would provide the Kingdom with a reliable supply of fresh water close to population centers and existing water infrastructure. Lack of reliable, high quality fresh water is currently both a constraint to economic development and a source of political strife.[139] Purchase of desalinated water via the Mediterranean would also almost certainly be cheaper than the cost of supplying from the Red Sea, Jordan's only option for desalinated water at present.

The second primary benefit to country would be that Jordan, long dependent on energy imports, would become a major exporter of energy to the region. By becoming a regional supplier of electricity Jordan reduce its need for energy imports which currently are a major drain on foreign currency reserves. Under the carbon neutral scenario, electricity exports would provide Jordan with enough revenue to defray much of the cost of obtaining needed water supplies. In the scenario in which it provides 20% of the region's overall electricity, revenues from such exports would be a major contribution to government coffers and to national GDP.

In addition, as opposed to simply being a purchaser of water and gas from Israel and/or Palestine, in which Jordan increases its dependence on outside sources, the project would give Jordan leverage as an electricity supplier.

To the extent that the international community would support the project, this would also defray the costs of developing its water and energy infrastructure and reaching its own objectives of reducing carbon emissions.

Jordan would also boost its regional influence, both as a supporter of the Palestinian economy and as a moderate country that can cooperate with all parties.

Challenges

Jordan may be leery of increasing its dependence on foreign sources for its water supplies, as is evident, inter alia, in its support for the Red-Dead canal, which would give it control over its own water supplies, albeit at a high economic cost. Given the

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139   The obligation to supply water to recent refugees, for instance, has become a source of tension among local Jordanian citizens, some of whom view water allocation as a zero-sum game and are resentful of reduced supplies, which they view as water going to refugees at the expense of local communities. Sources: Farishta, A. 2014. The Impact of Syrian Refugees on Jordan's Water Resources and Water Management Planning, Master's Thesis. Columbia University Academic Commons, http://dx.doi.org/10.7916/D80K26P3. Al-Jazeera.com. 2015. Syrian refugee crisis strains Jordan's water supply. 27 August, 2015.

http://www.aljazeera.com/news/2015/08/syrian-refugee-crisis-strains-jordan-water-supply-150827011123701.html

water scarcity issues in Jordan, however, the country has clearly indicated that provision of water is of higher priority than the fear of dependence on supplies from outside sources, as is evident from recent agreements to purchase water from Israel. While this proposed water-energy project would create interdependency rather than unilateral dependency, the level of interdependency is not necessarily symmetric. Arguably, dependence on foreign water supplies entails a bigger risk than dependence on foreign electricity. Jordan could also face critique both internally and from other Arab nations at cooperation with Israel, including a possible repeat of objections to integration in the existing regional electric grid.

Jordan has signed various agreements with international partners to develop nuclear power. Should these be actualized, the country may deprioritize renewable energies, as large-scale nuclear would allow it to meet its carbon emission reduction commitments (though not its commitments to renewable energy) without development of renewables. To date, little progress is evident in operationalizing such plans, and should they progress they are likely to face opposition based on safety and security concerns.

Because, as noted, solar energy, especially PV systems, have problems with storage, Jordan would need firm commitments regarding the purchase of specific quantities of electricity by Palestine and Israel.

7.2. Palestine

Advantages
For Palestine, the primary benefits of the project would be advancing water and energy security, while at the same time diversifying its sources of both resources and reducing its dependence on Israel, both of which are part of the Palestinian Authority's long term strategic objectives.

Production of desalination in Gaza would both reduce Palestine's dependence on Israel and would reduce payments to Israel, which deducts the full cost of water production and delivery from water delivered to the West Bank and Gaza from tax funds collected and transferred to the PA. The project may even advance Palestinian goals of achieving greater rights to natural water sources. While currently water allocation between Palestine and Israel are viewed by many as a zero-sum game, Israel may be more willing to compromise on water issues within the framework of a major regional water agreement such as this. Allowing Palestinians to withdraw more water from areas closer to population centers (i.e., increasing allocations to the West Bank from the Mountain Aquifer) would also be consistent with goals of economic and environmental efficiency.

Though the proposed project would not necessarily promote greater energy independence for Palestine, it would diversify its sources of energy, one of the stated goals of PENRA. It would also do so with minimal demands on land, which, as mentioned, is at a premium in the densely populated West Bank and Gaza Strip. This would avoid the regulatory and bureaucratic obstacles and delays that would be involved in developing land for energy production, which are likely to be significant, especially to the extent that the projects would be built in Area C, which represents the majority of open spaces in Palestine. Payments for electricity would also be to Jordan and would not be subject to Israeli control, as is currently the case.

An additional important benefit would be advancing integration of Palestine with the rest of the Arab world. Though it is integrated in many cultural and political forums, physical integration via shared or connected infrastructure is at present, extremely limited.

Finally, should the project receive the blessings of all parties, the international community would be likely to help support Palestine in developing the necessary infrastructure. This would substantially reduce economic burdens currently on Palestine.

Challenges

The most basic political challenge is simply that the project envisioned would entail both cooperation between Israel and the PA, and between regimes in the West Bank and in the Gaza Strip. The project is likely not feasible from a Palestinian perspective given the current restrictions by the Israeli government on the West Bank and Gaza. Therefore, some political accommodation would be necessary to move such a project forward.

Furthermore, the project would have to overcome the calls to reject cooperation with Israel as long as a permanent political settlement is yet to be enacted. However, given that even under the current political climate, there are increased purchases of water and energy from Israel, there may be little objection to a project that would actually reduce dependence on Israel.

Currently Israel has placed tight restrictions on materials, fuels, energy and currency going into Gaza, for fear of the resources supporting the Hamas regime and possibly being used against Israel. Natural gas offshore of Gaza, for instance, have yet to be developed for this reason, as have, various projects in the water sector. This, despite, various arrangements to address these concerns discussed with the international community. In order for the proposed project to succeed, some type of security arrangement acceptable to all parties would be necessary.

In the past Palestinians were hesitant to develop desalination, as many believed that they deserved a bigger share of the natural fresh water shared with Israel and Jordan. They feared that development of desalination would be seen, in effect, as an abandonment of their claims to fresh water. This is one reason desalination was not developed earlier. The reversal in position by water officials who now support development of large-scale desalination in Gaza, was, in large part, due to the sense that negotiations were not progressing and they could not afford to wait to negotiate a new allocation of natural fresh water.[140] Thus, nothing in this proposal should be seen as in any way impacting the legitimacy of Palestinian claims for reallocation of naturally occurring fresh water.

Finally, while the project would reduce Palestinian dependency on Israel for energy supplies, it would not necessarily increase Palestinian energy independence. Palestinian leaders may prefer to concentrate on developing its own sources in order to promote locally based energy production capacity. In this regard, the project is not intended to be put in place of local capacity development, but, rather, to supplement it.

7.3. Israel

Advantages

Israel's primary benefits from such a project include advancing regional cooperation and reducing sources of regional instability. Secondary, but still important benefits, promoting its international leadership in desalination, diversifying its energy sources, and meeting its renewable energy goals with minimal pressures on its open spaces and with potential financial assistance from the international community.

Israel has long been eager to promote regional cooperation, especially by means of enhanced economic development activities. It sees such a strategy both as a means of ensuring political stability as a means of gaining wider acceptance in the region. This is evident in its support for projects such as the Red-Dead Canal.[141]

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140   Fischhendler, I. and D. Katz (2013) The impact of uncertainties on cooperation over transboundary water: the case of Israeli-Palestinian negotiations. Geoforum 50: 200-210.

141   Cooperation with Jordan on a high profile international project was a large part of the rationale for Israel supporting a Red-Dead route, primarily, if not wholly located within Jordan, despite potentially less expensive options for a similar canal originating in the Mediterranean Sea and flowing wholly within Israel. Sources: Allan, J.A., A.I.H. Malkawi, and Y. Tsur. 2014. Red Sea–Dead Sea Water Conveyance Study Program Study of Alternatives Final Report Executive Summary and Main Report. And Aviram, R., D. Katz and D. Shmueli (2014) Desalination as a game-changer in transboundary hydro-politics. Water Policy (16)4: 609–624.

Lack of supplies of water and electricity can lead to political unrest, with destabilizing effects that are in none of the parties' interests.[142] Therefore, advancing water and energy security among its neighbors reducing security threats to Israel and the associated costs of addressing them.

Israel has often been described as an "energy island", and integration into a regional grid would provide it with additional supplies and serve as both a useful diversification of sources and a possible safety net, especially in terms of addressing peak demands.

In terms of meeting its commitments to reduce greenhouse gases and meet renewable energy goals, the project would allow Israel to do so without using up valuable open spaces and without going through the cumbersome and costly land use planning and regulatory processes that are often a source of long delays for infrastructure projects in Israel.

Finally, Israel has long declared a willingness to take advantage of its expertise in desalination and sell water to both Jordan and the PA. Even selling water at cost would help defray the substantial upfront costs of developing the desalination plants and would showcase Israeli technology in a rapidly growing field.

Challenges

Any project that requires regional cooperation or dependence on other countries, especially in the region, is regarded with hesitation in Israeli political circles. Israel has often preferred unilateral actions to cooperation in order to preserve autonomy, including in the field of water and environment.[143] Israel has long been dependent on energy imports. Prior to relatively recent discoveries of offshore oil and gas reserves in the Mediterranean, Israel was importing nearly all of its energy supplies. As recently as 2003, 96% of energy was supplied by imported fuels.[144] The repeated disruptions of natural gas from Egypt following the "Arab Spring" uprising highlighted the risks of dependency on foreign supplies, especially from suppliers with significant populations that are antagonistic towards Israel. As such, Israeli policymakers have continually stressed the importance of reducing dependence on outside supplies.[145]

Israel has also committed to purchasing agreements with off-shore gas developers and so any arrangement within the framework of the proposed project would have to be coordinated with such agreements.

Previous attempts to integrate Israel with the Jordanian electric grid have failed for a variety of geo-political reasons.[146,147] One such reason has been that Jordan is already connected to a regional Pan-Arab grid, and other Arab countries connected to the grid would have to approve of the connection. In the past, other countries objected to such initiatives. For this reason, Egypt and Jordan's electric grids are connected via marine cables through the Red Sea, rather than an overland connection via Israel. The Israeli officials, as well as the Israeli Electric Company, attempted to promote other land connections, but were refused. The existing connection between Jordan and Jericho, which, in effect represents an integration also with Israel, as Israel is connected to Jericho, was approved as it was limited in scale and meant primarily for

142   For this reason, for instance, Israel has increased water supplies in recent years to Jordan in order to assist the Kingdom in supplying water to recently arrived refugees from Syria and Iraq. Israel is also on record as supporting economic development in Palestine, as a means of reducing discontent there, though it has been criticized by some for emphasizing economic development as a substitute for political compromise.

143   Fischhendler, I., S. Dinar, and D. Katz. (2011) The politics of unilateral environmentalism: cooperation and conflict over water management along the Israeli-Palestinian border. *Global Environmental Politics* 11(1):36-61.

144   The World Bank. (2017c). World Development Indicators website. http://data.worldbank.org/indicator/EG.IMP.CONS.ZS?locations=IL

145   Shaffer, Brenda. 2011. "Israel—New Natural Gas Producer in the Mediterranean." *Energy Policy* 39(9): 5379–87.

146   Younan and Popper, 2012

147   Fischhendler, Itay, Lior Herman, and Jaya Anderman. 2016. "The Geopolitics of Cross-Border Electricity Grids: The Israeli-Arab Case." *Energy Policy* 98 (November): 533–43.

Palestinian use.[148] It remains to be seen if developments since the Arab Spring, and it light of the perceived common threat of Iran, if such objections would still be posed. Recent regional cooperation on scientific projects, such as the participation of Israelis in the Synchrotron-Light for Experimental Science and Applications in the Middle East (SESAME) project located in Jordan would seem to indicate that there is potential for regional cooperation, despite political opposition.

In terms of development of desalination in and supply of energy to the Gaza Strip, while in principle Israel has stated its support, it has raised numerous concerns regarding ensuring that materials and energy are used for peaceful purposes. Restrictions and stipulations by Israel on this matter have been a source of delay in developing desalination in Gaza so far. Israel has also attempted to restrict the flow of funds that could potentially support Hamas in Gaza. Thus, an arrangement would have to be found that would allow for financing the export of desalinated water and import of electricity to and from Gaza that would be acceptable to Israel.

7.4 General

Each of the parties has interests not to increase transboundary interdependencies and rather, to develop local capacity. Furthermore, in the case of both Jordan and Palestine there may be objections to any project that involves cooperation with Israel. In this respect, such positions stand in stark contrast to the actual developments occurring on the ground. Both Palestine and Jordan have recently signed agreements to purchase additional water and energy from Israel. Furthermore, the water-energy project analyzed herein is not meant to serve as an alternative to local capacity development, but rather a supplement to it, and, perhaps an economically efficient and politically expedient one. As stated above, it will promote interdependencies, rather that unilateral dependencies that put countries at greater exposure.

148   Tsur, M. Former Deputy Head of Israel Electric Corporation. Personal communication. 2 April, 2017.

Also, objections to "normalization" are often more directed at intergovernmental relations than at private sector ones. As stated, this project involves regional cooperation, and any large-scale infrastructure projects will necessitate government approval and facilitation. However, it need not be primarily government led or financed. Private sector leadership, and participation by the international community both in funding and by private sector developer, may reduce political obstacles that may face government led projects and increase public acceptability. The project clearly is one that entails and promotes regional cooperation, and can be presented as such to the international donor community. It is also a commercial enterprise that can be justified on market rationales alone.

The international community is likely to assist in planning and funding a regional cooperation project, whereas it would be much less likely to fund unilateral national projects. Furthermore, the terms of assistance are likely to be better for regional cooperation projects rather than unilateral ones (e.g., grants as opposed to loans). The international community might be willing to help fund the aspects of the project that specifically relate to international cooperation, such as transmission grids and connections.

Finally, the integration of water sectors and of electricity sectors in a mutually dependent and mutually beneficial manner may have positive spillover effects in terms of promoting cooperation, information exchange, and other joint initiatives in other fields. The European Union had its start as a regional agreement on two resources – coal and steel – and ended up with the grand economic and political cooperation that has become the EU, covering numerous fields and interests. A regional cooperation project on water and electricity would be a tremendous achievement in its own right; it may, though, lead to even greater outcomes.

8. CONCLUSIONS

This study evaluates the technical, economic, and political potential for integrating water and energy supplies across the three countries of Israel, Jordan and Palestine. The region suffers from a scarcity of both water and energy, and pressures on both are increasing due to population growth, economic development, and climate change. The countries of the region will need to provide fresh water to their populations, whether through unilaterally developed infrastructure, or through joint projects such as the one investigated herein. 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.

Israel and Palestine have high population density, and thus, high demands on scarce opens spaces. This presents a challenge for developing renewable energy domestically. Both, however, have access to the Mediterranean Sea, and thus a source of water for desalination. Jordan, on the other hand, has a lower population density, and an abundance of open space appropriate for generation of solar energy, but is limited in its access to seawater, with its only access point at Aqaba on the Red Sea, far from its population centers.

The motivation for integration of water and energy in all three countries was undertaken for a number of reasons. In addition to the distribution of water and open spaces, as mentioned, since the water sector is a large consumer of energy, and one of the largest consumers of electricity, in the region, there is an obvious rationale to investigate this "water-energy" nexus, especially as meeting additional water needs will almost certainly entail desalination, an energy intensive process.

An additional motivation was to ensure that there is mutual interdependence, however, there is nothing that mandates that water need be exchanged for energy, or vice versa. Hopefully, this study provides initial information and analysis that could be useful to decision-makers even, if, for technical, economic or political reasons, parties would like to advance cooperation on either only on water or only on energy. Likewise, if, for political or other reasons, integration and exchanges involving all three parties is untenable, bilateral exchanges would also be possible and could also make use of the framework set out in this study.

The study outlines numerous benefits of water-energy exchanges for all parties involved. In addition to providing for basic resource needs that would promote a decent standard of living and potential for economic growth and prosperity, the project could reduce regional costs of resource provision and strengthen regional ties. The primary advantages for Palestine are decreased reliance on Israel as a source of water and energy, increased diversification of energy supplies, and the ability to achieve renewable energy goals without adding pressure on scarce open spaces, access to which currently faces numerous restrictions. The latter two benefits would also be shared by Israel, which also would value regional integration in a large scale project in its own right. Jordan would benefit from sale of electricity to its neighbors, and by replacing current dependent relations with Israel with mutual interdependence.

The project would also face numerous political challenges as well. As such, it would be dependent on a fair amount of good will and trust of the parties themselves.

As a pre-feasibility study, this work set out to present a possible framework for regional water-energy exchanges and evaluate the technical needs of such an exchange, as well as attempt to evaluate overarching economic parameters, as well as highlight the idea's geo-political pros and cons. A qualitative assessment of the major pros and cons of the project for each party is presented in schematic form in Table 25 below.

As with any initial study much of the value herein is in identifying knowledge gaps and needs for future study. This initial draft presented working assumptions regarding the scale of the anticipated desalination and electricity and regarding technologies for achieving the objectives laid out. A full feasibility may wish to alter some of these assumptions and/or add additional scenarios. For instance, the choice of 20% of total energy from renewable sources was a somewhat arbitrary one, and the parties may seek to choose their own individual targets.

Regarding technical issues, this study considered a relatively narrow range of technologies, primarily ones that are current commercial available. A full feasibility study could evaluate a broader range or technological approaches, especially as technologies evolve as do their relative costs. Given that what is envisioned is a long-term project, parties will wish to avoid committing to technologies that may no longer be commercially optimal in the near future.

Furthermore, this study did not find reliable information regarding the capabilities of existing and planned infrastructure to accommodate the scale of water and electricity envisioned. A full feasibility study will have to work closely with the relevant government ministries and national utilities to better understand the capacity to integrate and the challenges of integrating such resources.

Regarding geographic assumptions, this study was relatively ambiguous regarding the relative location of desalination facilities, and used a single point source (the Maan region) for calculations of solar potential, this despite acknowledging the benefits of distributed production. A future study should evaluate specific locations, perhaps based on optimization based on proximity to existing or planned infrastructure and/or to end consumers. Also, this study limits itself to Jordan, Palestine, and Israel for reasons of political pragmatism. In the past, various sources have put forth proposals to develop desalination capacity for Gaza within Egypt, based on the lack of open spaces in Gaza and the relative wealth of such areas in Sinai.[149] A full feasibility study may wish to expand the scope of areas evaluated.

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149   See, for example, Bashitialshaaer, R. and Persson, K.M. 2011. A joint power and desalination plant for Sinai and the Gaza Strip. *Water Science and Technology: Water Supply* 11(5): 586-595.

Table 25. Distribution of Project Benefits

Economic

	Reduced Cost of Water Delivery	Reduced Cost of Achieving Renewable Energy	Reduced Regulatory Hurdles for Reducing Emissions	Income from Selling Electricity	Income from Selling Water	International Financial Support
Jordan	++	−	−	++	−	++
Palestine	0	0	++	−	+	++
Israel	0	0	++	−	++	+

Environmental

	Reduced GHG Emissions	Reduced Local Air Pollution	Reduced Pressure on Open Spaces	Reduced Pressure on Freshwater Aquatic Ecosystems	Reduced Pressure on Marine Ecosystems
Jordan	++	++	−	0	++
Palestine	++	++	++	+	−
Israel	++	++	++	+	−

Geo-Political

	Achieving Water Security	Achieving Energy Security	Diversification of Energy Sources	Reduced Dependence on Israel	Promoting Regional Stability	Integration with Arab world	Improved International Standing	Improved Chance of Achieving Reallocation of Water Rights
Jordan	++	++	0	−	++	+	+	0
Palestine	++	++	++	++	++	++	+	++
Israel	0	+	++	0	++	++	++	0

++	**Major benefits**
+	**Benefits**
0	**Neutral/no impact**
−	**Minor disadvantage**
− −	**Major disadvantage**

The biggest unknowns remain in the economic analysis, especially regarding infrastructure and transmission and delivery costs. Furthermore, the economic analysis conducted in this study was done under a limited set of assumptions regarding key parameters such as future price trends, discount rates, inflation rates, equity shares and cost of capital, land use costs, and other issues, including the anticipated time frame of the project. This was done in order to present rough estimates of costs to allow for evaluation of scale and compare between technologies under similar conditions. A full study will need to tailor these assumptions to likely market conditions. As such, it would benefit from doing so in consultation both with private sector actors currently active in the desalination and renewable energy market, as well as with potential funders. It may also benefit from using a broader range of assumptions for purposes of greater sensitivity analysis. A full study should also do a comparative cost assessment of alternative options available to the parties to achieve their various water and renewable energy objectives. As the security risks for such a large scale project are significant, the study may also wish to incorporate estimates of the costs of securing the infrastructure as well as related insurance costs.

Given the scale of such a project a full environmental impact assessment should be undertaken as part of a full feasibility study, including life cycle analyses of all options considered.

Finally, a full feasibility study will have to assess the regulatory issues inherent in implementing such a project, as may wish to examine the legal and contractual issues that would be needed to ensure project execution.

Clearly this study leaves many important questions regarding the viability of a regional framework for water-energy exchanges unanswered. This prefeasibility study, however, shows that the project is technically feasible and would have potentially tremendous environmental and political benefits. Given the scale of these potential benefits to the parties involved, investigation of these outstanding questions deserves to be investigated in depth.

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