Energy Transitions in the Gulf: Key Questions on Nuclear Power

Edited by Ali Ahmad

Gulf Research Centre Cambridge
Knowledge for All

1866
AUB
American University of Beirut
الجامعة الأميركية في بيروت

Issam Fares Institute for Public Policy and International Affairs
معهد عصام فارس للسياسات العامة والشؤون الدولية

Energy Transitions in the Gulf: Key Questions on Nuclear Power

Energy Transitions in the Gulf: Key Questions on Nuclear Power

Edited by

Ali Ahmad, PhD

Gulf Research Centre Cambridge

1866 AUB American University of Beirut
الجامعة الأميركية في بيروت

Issam Fares Institute for Public Policy and International Affairs
معهد عصام فارس للسياسات العامة والشؤون الدولية

Gulf Research Center

E-mail: info@grc.net
Website: www.grc.net

Jeddah
Gulf Research Center
19 Rayat Al-Itehad St.
P.O. Box 2134
Jeddah 21451
Kingdom of Saudi Arabia

Geneva
Gulf Research Center
Foundation
WMO Building - 2nd Floor
Avenue de la Paix, 7bis
CH-1211 Geneva
Switzerland

Cambridge
Gulf Research Centre
Cambridge
Centre of Islamic Studies
University of Cambridge
Sidgwick Avenue
Cambridge CB3 9DA, UK

First published 2018
Gulf Research Centre Cambridge

ISBN: 978-1-909864-20-7

About the
Energy And Security Program

The Energy Policy and Security Program at the Issam Fares Institute for Public Policy and International Affairs was launched in 2016 as a Middle East-based, interdisciplinary, platform to examine, inform and impact energy and security policies, regionally and globally. The Program closely monitors the challenges and opportunities of the shift towards alternative energy sources with focus on nuclear power and the Middle East. The Program has been established with a seed grant support from the John D. and Catherine T. MacArthur Foundation.

About the
AUB POLICY INSTITUTE

The AUB Policy Institute (Issam Fares Institute for Public Policy and International Affairs) is an independent, research-based, policy-oriented institute. Inaugurated in 2006, the Institute aims to harness, develop, and initiate policy-relevant research in the Arab region. We are committed to expanding and deepening policy-relevant knowledge production in and about the Arab region; and to creating a space for the interdisciplinary exchange of ideas among researchers, civil society and policy-makers. Main goals ▶ Enhancing and broadening public policy-related debate and knowledge production in the Arab world and beyond ▶ Better understanding the Arab world within shifting international and global contexts ▶ Providing a space to enrich the quality of interaction among scholars, officials and civil society actors in and about the Arab world ▶ Disseminating knowledge that is accessible to policy-makers, media, research communities and the general public

About the
Gulf Research Center

The Gulf Research Center (GRC) is an independent research institute founded in July 2000 by Dr. Abdulaziz Sager, a Saudi businessman, who realized, in a world of rapid political, social and economic change, the importance of pursuing politically neutral and academically sound research about the Gulf region and disseminating the knowledge obtained as widely as possible. The Center is a non-partisan think-tank, education service provider and consultancy specializing in the Gulf region. The GRC seeks to provide a better understanding of the challenges and prospects of the Gulf region.

Contents

Acknowledgments

This volume is based on selected papers submitted for the "Nuclear Energy for the Gulf: Key Questions and Opportunities" workshop organized as part of the 2016 Gulf Research Meeting held in Cambridge, United Kingdom, in August 2016. The workshop was sponsored by the Gulf Research Center (GRC). On behalf of the contributors to this volume, I would like to thank Dr. Abdulaziz Sager, chairman of the GRC, and Dr. Christian Koch, director of the Gulf Research Centre Foundation, for their support in convening the workshop as well as in producing this volume. Also, I would like to thank Elsa Courdier and Sanya Kapasi from the GRC for their help throughout this project. Special thanks go to Dr. Nesreen Ghaddar of the American University of Beirut for her help in running the workshop, and to Dr. Amir Mohagheghi, Dr. Nadira Barkatullah, and Mr. Ruediger Koenig for their valuable feedback and insights during the workshop. The publication of this volume and my work on nuclear power and the Middle East would not have been possible without the support of the John D. and Catherine T. MacArthur Foundation (Grant: G-1511-150437) and their Nuclear Challenges Program. Finally, I would like to thank the authors of the papers included in this book for their valuable contribution to an important and timely topic.

Beirut, Lebanon *Ali Ahmad*

Energy Transitions in the Gulf: Key Questions on Nuclear Power

Ali Ahmad

Introduction

Despite being among the world's top oil producers, Saudi Arabia and the United Arab Emirates (UAE), the Gulf's largest economies, have ambitious plans to invest in nuclear power. The UAE is currently in the process of building four nuclear reactors; the first one is almost complete and is expected to be connected to the grid and generate electricity in 2018. On the other hand, Saudi Arabia has announced its intention to build 16 nuclear reactors by 2032; the date was subsequently revised to 2040. However, unlike the UAE, the Kingdom is yet to announce any contractual agreements with reactor technology vendors. Moreover, it is interesting to note that the Saudi 2030 Vision did not mention nuclear power, though it stated clearly the Kingdom's need for a competitive renewable energy sector, specifically mentioning solar and wind power.

Outside the Gulf, several Middle Eastern countries are also in the process of acquiring, or expanding, their nuclear energy programs. Iran's Bushehr is the only operating commercial nuclear power reactor in the region. The Islamic Republic also has ambitious plans to expand its nuclear program under the Joint Comprehensive Plan of Action that was signed between Iran and the P5+1 (United States, United Kingdom, France, China, Russia and Germany). Other countries such as Turkey, Jordan, and Egypt have committed plans to build nuclear reactors, though none of these plans has yet materialized.

The official rationale for investing in nuclear energy differs from one country to another in the region, but broadly speaking, it seems to emerge from the need to improve energy security through reducing the reliance on oil and natural gas. For producing countries, domestic consumption of oil and gas is perceived as unsustainable, particularly with the high economic and population growth witnessed in the Gulf. Moreover, reliance on oil and gas to generate electricity could entail an opportunity cost when prices are high. As for oil and gas importing countries, price volatility and security of supply provide a major incentive to look for alternative energy sources, including nuclear.

As the interest in nuclear energy in the region grows, the need to better understand the underlying issues becomes a necessity. Specifically, this volume aims to examine the economics of nuclear power for the Gulf and the Middle East. The economic competitiveness of nuclear power depends on its cost relative to traditional energy sources such as oil and natural gas as well as to alternative energy sources such as wind and solar power. Nuclear projects have suffered some major cost and time overruns, even in countries with high nuclear capacity such as France and the US. On the other hand, generation costs of solar electricity have dramatically declined over the last decade and are projected to decline further as relevant technologies mature.

Besides economics, this book also discusses nuclear security and ways to enhance it. The talks over Iran's nuclear program have highlighted the security risk associated with nuclear power. The global expansion of nuclear power is a major challenge to the nuclear non-proliferation regime due to the significant overlap between the technical requirements of a peaceful nuclear power program and that of a nuclear weapons program.

Under the auspices of the Gulf Research Center (GRC), a workshop entitled "Nuclear Energy for the Gulf: Key Questions and Opportunities" was held at the Gulf Research Meeting (GRM) that took place in Cambridge, United Kingdom, in August 2016. The six papers selected for this volume were initially submitted for GRM and were chosen for publication based on their quality and the importance of the issues they highlight. With each chapter covering an important aspect related to the deployment of nuclear power in the GCC and the wider Middle East, this volume attempts to answer six key questions:

1. **What are the determinants of the economic feasibility of nuclear power for the Gulf?**

Omer Akkaya's chapter "Nuclear Energy for the Gulf after the Oil Price Downturn: End of a Fashion?" focuses on the political, economic, and environmental feasibility of nuclear energy in the Gulf, with specific attention paid to how the decrease in oil prices may impact this option. In previous times of elevated oil prices, the costs of nuclear or renewable energy investment were acceptable due to the high opportunity cost of utilizing oil and gas (as using them for electricity generation cut the country's export revenues). The chapter concludes that the most significant determinants in the decision to pursue nuclear energy are oil and electricity prices. Oil price is, however, more significant than electricity price. Akkaya's work suggests that the only method to alter this oil and electricity price dynamic would be to incorporate the variable of a small or medium cogeneration nuclear reactor. Despite oil and electricity price dynamics, governments could implement the nuclear option by either increasing electricity prices for consumers or subsidizing nuclear energy. In addition to this, the chapter also notes that the environment is not a determining criterion for nuclear energy.

2. **Is nuclear power the most cost-effective option for water desalination?**

Rami Bitar and Ali Ahmad examine the coupling between energy production and water desalination in the Gulf and Middle East in their chapter "Economics of Nuclear and Solar Desalination for the Middle East." Their work makes a comparative economic analysis of water desalination plants powered by nuclear and solar energy sources, using a levelized cost methodology. In addition, the chapter aims to assess the specific challenges and incentives of these options using the Desalination Economic Evaluation Program (DEEP), an analysis package developed by the International Atomic Energy Agency (IAEA). In view of governmental economic restraints, relevant policy makers will most probably have to choose one option over the other. Therefore, this chapter provides data and analysis on which policy makers may base their decisions. Bitar and Ahmad's study focuses on the three most used desalination technologies (multi stage flashing [MSF], multi effect distillation [MED] and reverse osmosis [RO]) and assesses which technology, coupled with nuclear and solar energy sources, would yield the most cost-effective option for water-electricity co-generation.

3. Does Saudi Arabia really need nuclear power?

Philippe Chite and Ali Ahmad try to answer this question through presenting an analysis on the "Requirements for High Solar Penetration in Electricity Production in Saudi Arabia." Current energy diversification plans in Saudi Arabia are oriented towards renewable energies, such as solar, wind, geothermal, waste, and nuclear power. This is exemplified by the establishment of the King Abdullah City for Atomic & Renewable Energy and the recently announced "Saudi Arabia 2030" Vision, which proposes extensive reforms in the country's energy sector. In light of these contemporaneous plans, this chapter analyzes the variety of combinations between fossil and non-fossil fuel energy mixes using a duration curve and a residual curve, in addition to examining the general economic feasibility and potential application for solar energy systems coupled with gas turbine technologies. Moreover, the chapter incorporates a calculation of the levelized cost of electricity, helping to determine the optimal level of different energy sources. The results presented can help to determine what policies will be most suitable for the implementation of energy diversification plans in Saudi Arabia.

4. What are the nuclear technologies that are currently available for deployment in the Middle East and how do they compare?

Abdalla Abou Jaoude and Anna Erickson review the nuclear reactor technologies currently available for the Middle East market in their chapter "Nuclear Energy for the Middle East: Technology Choices and Considerations." In order to conduct a review of this subject, the chapter examines the supply side of the nuclear market using a comparative and suitability analysis of reactor designs that are ready to be constructed, i.e., excluding advanced designs that are still in the research and development phase. The comparative analysis is based on three elements: design maturity, level of regional interest, and technological sophistication, including the presence of advanced safety systems. In addition, this chapter highlights the lack of demand for small modular reactors in the region despite their cost and technical advantages to some countries.

5. What are the dynamics of nuclear proliferation in the Middle East?

Ryan Snyder attempts to lay out the challenges associated with managing the dynamics of nuclear proliferation in the Middle East in his chapter "Iran, Uranium, and Future Proliferation Dynamics in the Middle East." The chapter first outlines the history of clandestine nuclear programs in the region and uses this history—and some examples of programs from outside the region—to outline the future challenges associated with detecting them. A brief discussion of US foreign policy in the Middle East over the last several decades is then used to provide context for how the US has analyzed its interests and responsibilities and how more creativity may be necessary to bring stability to the regional chaos. Next, the motivations that states have for acquiring nuclear weapons are placed into the regional context and dynamics are identified that present the risk of further proliferation. The chapter advances an argument for multinational control of Iran's nuclear program that would provide regional states and the P5+1 with more assurance about its peaceful use after current JCPOA restrictions expire. Lastly, the conditions for successfully aligning political factors to advance the idea for multinational control of Iran's program are discussed.

6. What can be done to improve nuclear security and advance the proposal of Weapons of Mass Destruction Free Zone in the Middle East?

Marianne Fisher's chapter "Confidence Today; Weapons of Mass Destruction Free Zone in the Middle East Tomorrow" is concerned with the lack of progress towards establishing a Weapons of Mass Destruction Free Zone (WMDFZ) in the Middle East. Given that this proposal was introduced forty years ago, the chapter examines how best to tackle problems that hinder its realization. Fisher's underlying suggestion, due to current limitations of unilateral or government-to-government initiatives, is that the international community could employ NGOs in order to initiate a multi-track process, in addition to supporting regional confidence-building measures and participation. Within this overall framework, the chapter focuses on the nuclear aspect of such a zone, which, it is argued, is the primary step towards a more encompassing WMDFZ.

1

Economic Determinants of Nuclear Power in the Gulf

Omer Akkaya

Abstract

The Gulf Cooperation Council (GCC) countries have been spending much effort to transform their fossil fuel dependent structure not only economically but also in terms of energy. Electricity generation remains the key field where diversification of energy sources can be realized most effectively. In this context, the use of nuclear energy in the Gulf region has been discussed a lot, and some serious steps have been taken as in the case of the United Arab Emirates. However, the extent to which nuclear energy can replace oil and gas in the Gulf is disputable, especially after the oil price crash. Despite nuclear power plants' (NPP) obvious environmental and technological benefits, the short-term economic advantages of oil and gas use due to their abundance in the region as well as NPPs' high fixed costs make the desired transformation of the energy mix even more difficult in the case of nuclear energy. Discussing these issues in detail, this chapter evaluates current or proposed nuclear programs in the GCC as a function of oil prices. The direct effect of oil price on nuclear programs is caused by the oil price being the key determinant of the opportunity cost of nuclear energy in the Gulf. On the other hand, oil price is the main pillar of capital accumulation in the Gulf and, hence, it is an indirect

determinant in terms of financing investments. The chapter also elaborates other important factors in the growth of nuclear in the region such as the role of the state and state-owned companies, construction and operation models (build-own-operate, build-operate-transfer, and so on) and financing methods of NPPs, natural limits (landscape, demand restrictions etc.) to dissemination of the use of nuclear energy, and the new global wave in the nuclear sector. Taking the relevant variables like levelized cost of electricity by sources or cost of carbon emissions into account, the chapter argues that oil price still remains a key determinant, and a long-run price level below $50 threatens the future of nuclear in the Gulf.

Introduction

The Gulf countries are known for their abundant fossil fuel reserves. They hold most of the world's proven crude oil and natural gas resources. This dominance of oil and natural gas as primary energy sources reflects on the generation of a secondary energy, or energy carrier, which is electricity. Electric power generation in the Gulf relies completely on these two sources. However, since these two sources are fossil fuels, this reliance has serious health and environmental implications. Besides, other economic and political concerns have also pushed policy makers as well as scholars to work on possible options to diversify energy sources used in power generation. As soon as this issue is brought to the agenda, nuclear and renewable (particularly solar and wind) energy are proposed as alternatives.

The oil market has experienced a dramatic drop in prices in the last few years. There is no doubt that this fall in oil prices has hit the economies of the Gulf countries directly. At the same time, there are several critical indirect impacts of this fall too, among which is the diminishing opportunity cost of power generation from fossil fuels. As the global crude oil prices were around $100 per barrel till a few years ago, it was implicitly costly to use oil for electricity as this would dent export revenues. However, this also meant that the high fixed cost of energy investments in different fields such as nuclear or renewable energy was bearable, as the alternative method of utilizing oil and gas for power generation had a high opportunity cost. This high opportunity cost was supported by two factors: high oil prices in global markets and very low electricity prices in domestic markets. Therefore, the drop in oil prices has influenced the analyses on these parameters. Against this backdrop, this chapter focuses on the economic, environmental, and political rationale behind the proposal of nuclear energy as a solution for the previously mentioned issues and assesses how feasible and sustainable this option is through various perspectives, especially considering the change in oil prices in the last few years.

It is clear that though there are many logical motivations for nuclear, its sustainable and widespread use is not so simple given the current circumstances.

Electric Power in the Gulf

Due to the abundance of oil and gas in the region, electric power generation in the Arab Gulf relies almost completely on these two sources as shown in Table 1.1. Although recent renewable energy investments, particularly in solar energy, have added a new aspect, the overall scene has not changed much yet.

Table 1.1: Electricity generation by source in the GCC states (2013, % of total)

GCC Member	Oil	Gas
Bahrain	0.0	100.0
Kuwait	63.2	36.8
Oman	2.6	97.4
Qatar	0.0	100.0
Saudi Arabia	47.2	52.8
United Arab Emirates	1.3	98.7

Source: World Bank, 2016, World Development Indicators, World Data Bank, retrieved on April 30, 2016 from http://databank.worldbank.org/data/home.aspx.

The dependence on oil and natural gas for electricity is easy to understand; however, this situation gives rise to several concerns. As these are fossil fuels, electricity production leaves an impact on the environment as well. Besides, fuels used in power generation take away from export revenues. In addition, the GCC countries face an electricity demand growth of over 6 percent annually.[1]

1. The exact value is calculated as 6.2 percent using the data from GCC Stat for the latest

As part of economic diversification efforts, the Gulf countries have attempted to modify this oil and gas dependent power generation structure. These efforts especially became significant in the early 2000s when oil prices rose, technological advancements were made in the renewable energy sector, and the global nuclear market started to expand again. The GCC placed special focus on nuclear energy, and in 2006 a study was done on the possibility of using nuclear in the region in collaboration with international institutions like the International Atomic Energy Agency (IAEA). Until now, the United Arab Emirates (UAE) has been the fastest with four reactors under construction currently. Saudi Arabia, too, made an ambitious start for nuclear with plans to build several nuclear power plants. It formed a special body to carry out the projects on renewable and atomic energy; however, the timeline set earlier for nuclear energy use has been delayed. The Kingdom keeps broadening the program, and serious negotiations are being undertaken—and agreements are being reached—with different countries and international companies. Kuwait formed a national committee for nuclear energy, too. Nevertheless, following the Fukushima accident in 2011, the country suspended its plans for nuclear use in power generation. Qatar and Oman have evaluated the option of nuclear as well, but no serious step has been taken due to economic, political, and technical reasons.[2]

Subsidized Electricity

Similar to other oil and natural gas exporters, the Gulf countries provide implicit energy subsidies[3] to their residents and industry. These subsidies are so generous that they contribute to the Gulf countries ranking among the most energy intensive ones in the world, despite the fact that they do not have large energy dependent sectors. For instance, as shown in Table 1.2, all the GCC states rank among the most per capita CO_2 intense countries in the world, Qatar being the first and Kuwait the third.

available five years (2010-2014).

2. WNA, "Nuclear Power in the United Arab Emirates," 2016, retrieved on June 16, 2016 from http://www.world-nuclear.org/information-library/country-profiles/countries-t-z/united-arab-emirates.aspx; L. El-Katiri, The GCC and the Nuclear Question, Oxford Energy Comment (The Oxford Institute for Energy Studies, 2012).
3. Implicit energy subsidy refers to much lower energy prices within the country compared to global or export prices of those energy sources.

Table 1.2: Top 15 countries in per capita CO_2 emissions (tons of CO_2 per capita)

Rank in 2013	Country	2011	2012	2013
1	Qatar	32.82	34.55	33.38
2	Curaçao	24.22	30.04	28.91
3	Kuwait	26.07	26.47	24.96
4	Bahrain	19.85	19.73	21.24
5	United Arab Emirates	17.79	18.53	17.93
6	Luxembourg	20.25	19.39	17.93
7	Trinidad and Tobago	16.68	16.49	17.12
8	Australia	17.15	16.91	16.70
9	Brunei Darussalam	17.23	16.91	16.39
10	Saudi Arabia	15.65	16.38	16.39
11	United States	16.73	16.01	16.18
12	Oman	17.96	16.86	15.95
13	Canada	15.27	15.08	15.26
14	Gibraltar	14.89	14.62	15.12
15	Kazakhstan	14.18	13.93	14.38

Source: CO_2 Emissions from Fuel Combustion (2015 Edition), Paris: International Energy Agency, 2015.

Not only oil and gas, electricity is also implicitly subsidized so that electricity prices in the Gulf are among the lowest ones in the world. This system owes to the historical dominance of state-owned power and utility companies that were provided low price oil and gas through mostly state-owned oil and gas companies.[4]

4. L. El-Katiri, *Interlinking the Arab Gulf: Opportunities and Challenges of GCC Electricity Market Cooperation* (Oxford: Oxford Institute for Energy Studies, 2011).

In other words, low electricity prices are maintained through both low fuel costs and low (or sometimes even negative) profit margins of utility companies.

Table 1.3: Residential electricity prices in the GCC countries[5]

GCC Member	USD/MWh
Bahrain	42.5
Kuwait	7.2
Oman	51 .9
Qatar	27.0
Saudi Arabia	40.0
United Arab Emirates	78.8

Source: *Electricity Tariff in the Arab Countries 2012,* Arab Union of Electricity, 2012.

Power generation systems used historically in the Gulf, i.e., oil and gas plants, have low investment costs. Since the fuels are extracted internally or imported from neighboring countries at cheap costs, subsidies in the electricity markets have been bearable. However, the very high fixed investment costs of nuclear power plants (NPP) will make such a subsidy difficult to be sustained. Thus, the structure of the electricity market in the GCC makes the nuclear energy option more difficult as will be discussed later.

Determinants of Nuclear Energy Use

Scholars and experts have laid out the many different and key determinants that will influence the decision of whether or not to use nuclear energy. The discussion also extends to how much nuclear energy is needed once the decision of utilizing it is made. Departing from these points, this study attempts, first, to list the determining factors and then to assess them in a quantitative model.

5. Since electricity prices are sensitive to consumption interval, the figures included here are for the first interval above 6000 kWh for each country.

Nuclear Proliferation Concerns

Security concerns were the driving force behind the invention and advancement of nuclear energy technologies. Following the discovery and use of atomic bombs during World War II, several industrialized countries of the time invested significantly in the nuclear sector. By the end of 1965, two decades after the use of the first nuclear weapon, five countries had already conducted nuclear weapon tests. Use of nuclear energy for power generation followed this with around a decade of lag. The first commercial nuclear reactor was connected to the grid in 1954 in Obnisk in USSR, and starting from the mid-60s, the nuclear energy sector saw a golden age which lasted through the 1970s. Latecomers to the nuclear armament race tried to obtain the technical knowledge with the help of experimental and commercial power plants together with the enrichment facilities supporting them. Consequently, nuclear proliferation concerns became an important factor in nuclear energy programs. Contemporary international actors and institutions demand very transparent nuclear programs, which make it impossible for a new player in the nuclear market to develop a military-oriented program. As in the case of Iran, actions deemed to have military implications are punished harshly using several international mechanisms.

Energy Dependence and Energy Security

One major factor that determines a country's decision to try the nuclear energy option is its energy dependence (usually measured as the share of energy imported in the overall primary energy demand). Energy dependence is an issue that raises both economic and political concerns. On the economic side, for an energy-dependent state, energy imports constitute a high burden on the foreign trade/current account balance. Besides, the price elasticity of energy supply is high, meaning that energy prices the consumers have to pay are determined at the international level. Practically this implies high end user energy prices; however, it should also be noted that in such a case, the government's subsidizing of domestic energy use goes to the international energy producers as a financial support. Nuclear energy in such a circumstance might not actually provide a cheaper solution in financial terms in the short run due to its high fixed cost. Nevertheless, the long run economic comparison of nuclear versus imported sources reveals some interesting points: the average fixed costs diminish a lot over a period of time and the variable cost of nuclear mostly goes to operation and maintenance, which means domestic employment and economic value, whereas that of imported sources goes to fuel cost, which has very minor domestic value added.

The political implication of energy dependence lies in the fact that it limits the sovereignty of the dependent state, particularly when the dependence is on one or two supplier countries. This was experienced clearly during the oil crisis of 1973, where OPEC took steps that affected oil supply and prices. The energy dependence or energy security issue then moved to the centerstage of politics as seen in the example of US President Gerald Ford's statements in 1973 to reduce oil imports by one million barrels per day by the end of 1975. Policy and scholarly works which analyzed the period sought to establish optimal levels of oil displacement as a function of the expansion rates of nuclear power.[6] In the contemporary global energy markets, on the other hand, if the issue is natural gas supplied through international pipelines, security concerns have become greater. It is because pipelines work continuously and at large scale. These systems' logic depends basically on current supply and current consumption rather than storage. Besides, it is difficult to diversify the supplier quickly.

Securing energy supply, therefore, is not an issue just of "today." In other words, it is as important for states to ensure energy supplies to meet the increasing demand of the future just as it is to have uninterrupted energy supply currently. The electricity demand in the GCC countries has grown at an annual rate of over 6 percent. This means that there is an undeniable need for additional investments in the power sector, even if it is not nuclear energy.

Diversification of Energy Mix

Diversification of energy mix is a concept usually discussed along with energy dependence. Following the oil shock of the 70s, in particular, many countries sought ways to diversify their primary energy supply. Since oil prices rose sharply with the actions taken by OPEC, oil importing economies went through recession. Therefore, diversifying energy supply implied a partial solution for energy dependent states; it became important to have a more balanced primary energy supply basket in terms of primary resources if possible and if that could not be the case, at least diversifying the suppliers of the primary resource. However, more recently, diversification of the energy mix has become a matter relevant not just to energy dependent countries. Even energy exporters have started to search for ways to diversify their energy sources. Energy abundant states have realized that reliance on the sources that they have at almost no economic cost could be a risk for the economy due to several

6. F.L. Toth and H.-H. Rogner, "Oil and Nuclear Power: Past, Present, and Future," *Energy Economics* 28 (2006): 1-25.

reasons. As discussed earlier, such countries provide implicit energy subsidies to their citizens since these sources are perceived as national wealth, and each citizen has the right to use them at the cheapest price. Such significantly subsidized prices lead to wasteful energy use, an undesirable situation, economically and environmentally. Secondly, and connected to the previous issue, domestic use cuts availability for export, and thereby export revenues, assuming satisfactory global demand. Export revenues might also be interpreted from the perspective of politics. In a sense, energy exporters gain political power over their consumer states, though this power diminishes as the exports decrease. Thirdly, and in accordance with the following determinant parameter of nuclear energy, an energy rich country with an undiversified energy mix has a very low price elasticity of domestic energy supply. For instance, in case of a rise in oil prices internationally, an oil exporting country cannot cut the domestic supply and divert it to global markets. The issue of an optimally diversified energy mix thus becomes a determining factor in deciding on a nuclear energy program. This is clear from the case of the UAE, the only country currently constructing NPPs not only in the GCC, but also in the wider Arab world. The energy minister of the UAE underlines the critical role of Barakah NPP in diversifying the nation's energy supply[7] while Emirates Nuclear Energy Company (ENEC) promotes itself as the transformer of the UAE's energy mix.[8]

Oil Prices

Oil prices affect the decision of both oil importers and exporters on whether or not and how much to use nuclear energy. Oil prices are determined through several open market systems globally. On the other hand, natural gas, which actually accounts for a greater part of total electricity production in the world as well as the GCC, has a more closed price mechanism depending more on the geographical locations and bilateral relations of the trading parties especially for the large scale and longer term trade. These factors are included in a price function or basket, where oil prices also play a key role. Therefore, fluctuations in oil prices reflect in gas prices though with some lags. The nature of oil and gas fired systems makes fuel cost the major determinant of the cost of electricity generated because of relatively low fixed costs. In short,

7. ENEC, "UAE Energy Minister Visits Barakah Nuclear Energy Plant," 2016, http://www.enec.gov.ae/media-centre/news/content/uae-energy-minister-visits-barakah-nuclear-energy-plant.
8. ENEC, "Milestones Achieved to Transform UAE Energy Mix," 2015, http://www.enec.gov.ae/media-centre/news/content/milestones-achieved-on-barakah-unit-2-keep-nuclear-program-on-track-to-tran.

higher oil prices imply significantly higher cost of electricity generation of both of these systems. It should be noted that even though higher global prices do not affect the exporters' costs in financial terms, they affect the economic calculations as they constitute an opportunity cost. So higher oil prices make nuclear power generation, which requires enormous initial costs, more favorable. The former Kuwait National Nuclear Energy Committee's (KNNEC) Secretary General Ahmad Bishara said in a statement in September 2010: "Our initial analysis indicates that nuclear is viable as long as oil is above $45 to $50 a barrel"[9] confirming the importance and the awareness of the issue. Academic research on the issue has also emphasized the fact that oil price is a significant factor. For instance, "Unless the price of oil drops substantially below current values, it would be more economically optimal to export the oil than using it for generating electricity."[10] However, the fall in oil prices has now given rise to a new scenario.

Environmental Concerns

In the last few decades, there is growing awareness about climate change and global warming. These problems are closely associated with greenhouse gases (GHG) emissions, of which the major contributor is the energy sector. Fossil fuels—coal, oil, gas—and their derivatives are direct sources of GHG emissions, and many countries have tried to limit these emissions. Several international accords have attempted to tackle this problem, including the Paris Accord. Although joining these international treaties is not obligatory for the GCC countries, they have declared their willingness to contribute to the global goals. Since power generation in the Gulf depends almost completely on these sources, there are many possible improvements to be made in this field, and the option of nuclear energy use should be evaluated from the environmental perspective as well.

---

9. T. Inajima & Y. Okada, "Kuwait Plans to Build Four Nuclear Reactors as It Seeks Alternative to Oil," Bloomberg, 2010, retrieved from http://www.bloomberg.com/news/2010-09-10/kuwait-joins-gulf-push-for-nuclear-power-with-plans-to-build-four-reactors.html.
10. A. Ahmad and M.V. Ramana, "Too Costly to Matter: Economics of Nuclear Power for Saudi Arabia," *Energy* 69 (2014): 682-694.

Public Acceptance

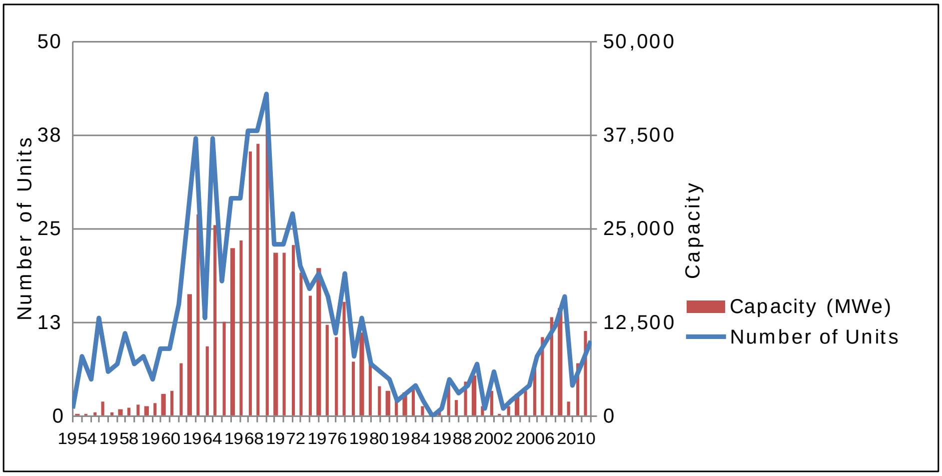
Empirical studies have sought to analyze the causes behind the public's acceptance of nuclear energy. One finding is "that if people are explicitly shown the benefit of nuclear power to mitigate climate change and are asked to choose between nuclear power stations or climate change, they cautiously prefer nuclear power stations and its waste over the consequences of climate change."[11] This finding also underscores that environmental concerns play an important role in the decision to opt for nuclear energy. However, fieldwork also shows that the public supports the adoption of nuclear energy more because it is seen as a source of secure energy supply than for its benefits in terms of environment. It is also clear that the benefit perception overrides the risk perception for the public. In addition, trust is also a determinant and it affects the benefit and risk perceptions. The higher the trust in governments and international organizations, the higher is the public acceptance of nuclear energy.[12]

Overseas Nuclear Investors and the Future of the Global Nuclear Market

Countries with high expertise in nuclear energy, and the global nuclear market being mainly dominated by the companies originated from these countries, have a significant impact on the nuclear programs of latecomers to the nuclear sector. As it is technology-intensive and risk prone, most countries have sought international assistance and investment to enter the nuclear sector. Therefore, a state's own willingness and financial preparedness to initiate a nuclear program alone are not sufficient. Fortunately, contemporary global circumstances are very suitable for the countries evaluating the possibility of launching or broadening a nuclear energy program.

11. V.H. Visschers, C. Keller and M. Siegrist, "Climate Change Benefits and Energy Supply Benefits as Determinants of Acceptance of Nuclear Power Stations: Investigating an Explanatory Model," *Energy Policy* 39 (2011): 3621-3629.
12. Ibid.

Figure 1.1: Number and capacity of annual construction starts of nuclear reactors



Source: Nuclear Power Reactors in the World, Reference Data Series No. 2, Vienna: IAEA, 2016.

Figure 1.1 shows annual new nuclear reactor construction starting from 1954 (when the first on-grid reactor was connected to the grid in the Soviet Union) up to date. It is seen that from the second half of 1960s to the late 1980s, the nuclear energy sector experienced its golden age. In the 80s, primarily with the start of the widespread use of natural gas and also influenced by the Chernobyl disaster of 1986, the expansion of the sector slowed down. Natural gas, then, was a cheap fuel newly penetrating the energy markets with relatively very low fixed cost requirements for its conversion to electricity. Chernobyl, on the other hand, led to the common people questioning nuclear energy and higher sensitivity in the international community regarding the transparency and safety of NPPs. The influence of such an economic, public, and technical environment persisted till the 2000s. Rise in natural gas prices, energy security concerns due to the difficulties of transporting and storing, ever increasing electricity demand, rising price of electricity, improvements in nuclear reactor technologies, and environment concerns—particularly those related to global warming and GHG emissions—brought the nuclear option back on the agenda as an important alternative energy source. The expansion this time was slightly different in terms of its distribution worldwide: Much of the new demand was from emerging economies and countries such as China, India, and Russia. Though this second wave was hit by the unfortunate Fukushima accident in 2011, as also seen from the graph, the following two years still witnessed expansion of the market. This second wave was strongly supported by the old nuclear companies entering new markets as well as the more freshly built capacity of companies of newcomers. Rosatom of Russia, AREVA of France, Westinghouse of the US, MHI of Japan, KEPCO and Doosan of South Korea, CFHI, NPIC and DEC of China, and NPCIL of India can be listed as pioneers in this group. While many of them carried out operations within their country of origin, they have been willing to extend cooperation and investments overseas. The companies aim to fulfill this either through an Engineering-Procurement-Construction (EPC) model, where the contractor is responsible for delivering the agreed plant fully commissioned to the owner (either a state-owned company or a private one in the case of market-driven countries), or with a Build-Own-Operate (BOO) model, which requires the contractor to carry the whole or most of the investment burden in return for complete or partial ownership and right to operate the plant. The issue of investing overseas is taken so seriously that, for instance, Rosatom established Rosatom Overseas in 2011 to market Russian nuclear technology globally with a goal of opening 20 branches worldwide.[13] Besides operating on their own, AREVA and MHI formed a new company, ATMEA, with the aim of pooling their expertise and widening their operations worldwide. The company now provides the ATMEA1 reactor, which is a mid-size, generation III+ pressurized water reactor.[14] KEPCO, to give another example, won the race for the UAE's Barakah NPP project of four units with the consortium it leads, where Doosan is also an important party.[15]

A Simple Model to Assess the Rationale of Nuclear Energy for the Gulf

The factors that could influence the decision of a state on the use of nuclear energy were discussed in the previous section. Most of these factors are valid in the case of the GCC countries. This section aims to estimate their relative impacts and to find the most influential one(s) along with making an overall prediction on whether there is a brighter future for nuclear energy in the Gulf. The model used here is a very simple one though the decision to initiate a nuclear energy program involves a much more complicated process. Besides, it is also true that these kinds of 'strategic' decisions are sometimes made not on rationalist parameters alone but also considering immeasurable national interests. Therefore this chapter,

13. Rosatom, "ROSATOM Kurumunun Nükleer Enerji Alanındaki Entegre Teklifi," Rosatom Overseas, Moskova 2013.
14. ATMEA, The ATMEA1 Reactor (Courbevoie: ATMEA, 2013).
15. ENEC, "Prime Contractor," 2014, retrieved on May 26, 2016, from http://www.enec.gov.ae/our-nuclear-energy-program/prime-contractor/.

rather than making a firm forecast, proposes a modest explanation of the rationality or irrationality of launching or broadening a nuclear program under the given circumstances for the GCC countries.

Assuming that investments of countries are based on rational expectations, there are several tools that help this decision-making process. As feasibility studies focus solely on cost-revenue aspects of projects, they are preferred by private companies. Cost-benefit analysis (CBA), social return on investment (SROI) analysis, fiscal impact analysis (FIA), and economic impact analysis (EIA) can be listed as the more convenient methods for policy makers. While SROI focuses on investments with greater social focus, CBA and FIA could be options for making a decision on a project from the economic angle. Both CBA and FIA evaluate the financial revenues and costs, while FIA also seeks those incurring on third parties. EIA, however, considers financial revenues and costs of a project itself and those incurring on third parties as well as non-financial direct and indirect impacts. As these non-financial parameters are usually quantified in terms of monetary values, EIA might resemble the other methods. Nevertheless, the scope in EIA differs significantly. So in terms of its scope, this study adopts an approach closer to EIA.

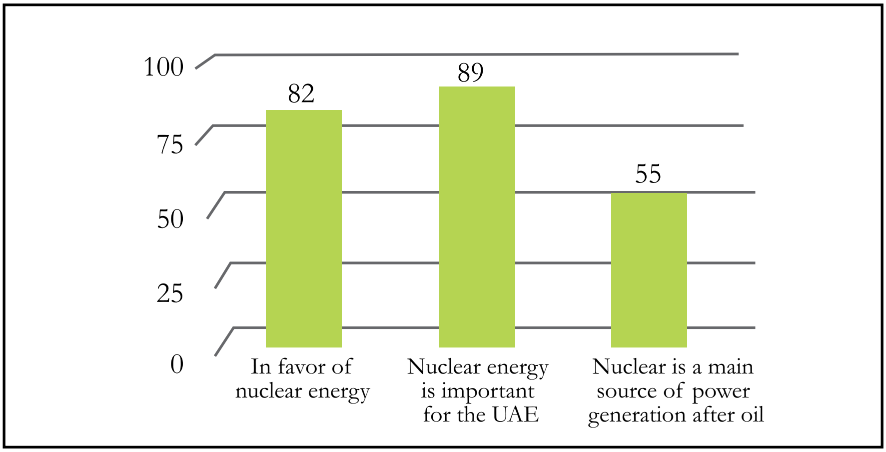
Revisiting the previously discussed determinants of the use of nuclear energy, some criteria could be marked as necessary conditions but are invariant to the scale of a nuclear program. For example, elements such as public acceptance and presence of foreign nuclear contractors are required to implement a nuclear program, but they are not needed nor could be measured in an economic impact analysis (EIA). If these elements are not satisfied, it is unlikely that there will be a nuclear program, and therefore, it is not logical to go further in EIA. But once they are satisfied, their impacts do not differ quantitatively. So the model will focus on other variables.

As mentioned before, there is a growing nuclear market internationally and several large companies with expertise are seeking new nuclear projects. At the same time, public acceptance is a more controversial issue. There is very limited survey data on this available for the different Gulf States. As the UAE is the one to have actively initiated a nuclear energy program, field studies were conducted there. The results of a survey conducted in December 2012 illustrate that there is high public support for nuclear energy use. Eighty nine percent of the citizens surveyed believe in the importance of nuclear energy while 82 percent are in favor of its use. Besides, 55 percent perceived nuclear energy as a main source for power generation after oil.[16] For the other GCC countries, public acceptance of nuclear

16. WNA, "Nuclear Power in the United Arab Emirates," 2016, retrieved on June 16, 2016 from

energy programs is not a given. For example, "It is notable that in the Gulf states nuclear programs are certain where political power is most strongly vested in ruling monarchy elites (the UAE and Saudi Arabia) and have been abandoned in response to public opinion by governments in countries with strong legislatures (Kuwait and Bahrain)."[17] Since this is an issue requiring independent fieldwork, it is set aside and other influential factors are focused on for the rest of the chapter.

Figure 1.2: Public opinion in the UAE on nuclear energy (%, 2012)



Source: WNA, "Nuclear Power in the United Arab Emirates," retrieved on June 16, 2016 from http://www.world-nuclear.org/information-library/country-profiles/countries-t-z/united-arab-emirates.aspx.

The variables considered in the model, along with their overall impact, are demonstrated as a function of the utilized nuclear power capacity. In other words, since the gains and costs are dependent on how much nuclear energy is to be used, or how many reactors are considered, it is better to have them as functions. The total economic impact of nuclear energy, which includes indirect or third party effects, is denoted by f(NE). f(PG) stands for net monetary gain of power generation from nuclear energy with discounted lifetime revenues and costs. All the fixed and variable costs of nuclear power plants as well as their sales revenues are components of this function. f(OGE) represents potential export revenues of oil and gas to be saved thanks to the use of nuclear energy in power generation. f(EnB)

http://www.world-nuclear.org/information-library/country-profiles/countries-t-z/united-arab-emirates.aspx.

17. Adnan Shihab-Eldin, "Nuclear Power in the Middle East Following Fukashima," International Seminar on Planetary Emergencies, Erice, Italy, 2012.

corresponds to environmental benefits provided by the use of nuclear energy. Since nuclear investments are highly capital intensive, and the GCC countries consider using domestic capital as in the case of UAE's Barakah, there could be a significant amount of opportunity cost of capital invested in nuclear. This is shown as f(OCI) in the equation, with net costs shown in negative figures. Finally, e stands for the error term, which represents all the omitted variables of the model as well as irrationality aspect of decision making. All the impacts are quantified and expressed in terms of monetary values. The total political benefit that could be provided by the factors discussed previously in the energy dependence and diversification of energy mix sections are ignored as it is really difficult to quantify and its relative impact could be assumed to be relatively low.

$$f(NE) = f(PG) + f(OGE) + f(EnB) + f(OCI) + e$$

Where:

$f(NE)$ = Total economic impact of nuclear energy use

$f(PG)$ = Net monetary gain of power generation from nuclear

$f(OGE)$ = Additional oil and gas export revenues provided by nuclear in power generation

$f(EnB)$ = Environmental benefits achieved by nuclear energy use

$f(OCI)$ = Opportunity cost of capital investment

e = Error term

If this model is assumed to be a simple representation of decision making on whether to construct a nuclear power plant, it is required that the derivative of the model in terms of nuclear power employed should be positive. In other words, when some certain amount of nuclear energy is used, the equation should yield a positive value at that amount so that investing that much in nuclear could be accepted as a rational choice.

An important point to be underlined here is that use of nuclear energy is not a continuous function. Most of the commercial nuclear reactors currently in use are large scale and once the decision of investing in nuclear is given, at least one reactor has to be built. According to IAEA data,[18] majority of the 67 reactors under construction as of December 31, 2015 have net power ranging between 900

18. IAEA, "Nuclear Power Reactors in the World," Reference Data Series No. 2 (Vienna: IAEA, 2016).

and 1600 MWe. For instance, the UAE's Barakah NPP consists of four APR-1400 reactors, each one of which has a net design power of 1345 MWe. However, there are several medium and small scale reactors as well.[19] So the weighted average of all these reactors[20] is calculated as 986 MWe. Using the average load factor of nuclear reactors operational worldwide, which is 73.4 percent,[21] it can be assumed that minimum employment of nuclear is 6.34 million MWh in terms of energy and 986 MWe in terms of power. Assuming the economies of scale effect in nuclear energy as zero, these values are used as the correspondents of one unit change in nuclear use.

f(NE)/d(NE) is the decision criteria, where f(NE)/d(NE) > 0 corresponds to initiate the nuclear program option.

f(PG)/d(NE) denotes the net monetary gain, or overall feasibility, of one nuclear reactor at the given power and capacity factor.

f(OGE)/d(NE) is the value of oil and gas savings at export prices for one nuclear reactor at the given power and capacity factor.

f(EnB)/d(NE) is the monetary value of environmental gains achieved thanks to one nuclear reactor at the given power and capacity factor.

f(OCI)/d(NE) is the opportunity cost of investing in one nuclear reactor.

e/d(NE) = 0, assuming an independent error term. This is practically true if there is no omitted variable sensitive to the capacity of nuclear energy used considering that the irrationality aspect is already independent of change in the amount of nuclear energy used.

Some estimated values for parameters are used from the literature. For the sake of simplicity in calculations, environmental gains can be narrowed to the limitation in greenhouse gas (GHG) emissions. So the environmental contribution of nuclear is quantified through market values associated to reduction in GHG emissions, which is accepted as $30 per ton of CO_2 by IEA for OECD members.[22] For the coefficients of decrease in GHG per kWh of electricity, the data from IEA and

19. IAEA classifies reactors with electrical power up to 300 MWe as small reactors, those with a power between 300 MWe and 700 MWe as medium scale reactors and the rest as large scale reactors (IAEA 2011).
20. The figures disregard CAREM Prototype reactor of Argentina, which has a power of 25 MWe.
21. IAEA, "Nuclear Power Reactors in the World."
22. IEA&NEA, *Projected Costs of Generating Electricity* (2015 Edition) (France: OECD International Energy Agency & OECD Nuclear Energy Agency, 2015).

GCC Stat are used. Table 1.3 shows these values. The average of the GCC is 0.82 ton of CO_2 per MWh of electricity generated, which is much above the world average of around 0.5. For all estimations, lifetime impacts are considered and the lifetime of a nuclear power plant is accepted to be 60 years as was done by IEA. Finally, instead of monetary gain and opportunity cost components of the equation, levelized cost of electricity (LCOE) approach is adopted to enable the calculations. LCOE is a concept to compare different sources of power generation in terms of unit costs taking into account lifetime costs (and even decommissioning costs for nuclear, for instance) with some certain annual discount rate. Latest LCOE figures of IEA uses three different discount rates: 3%, 7%, 10%, among which 7% is adopted here.

Table 1.4: CO_2 emissions by power plants per electricity generated (2013)

GCC Member	ton CO_2/MWh
Bahrain	1.33
Kuwait	0.73
Oman	0.58
Qatar	0.50
Saudi Arabia	1.02
United Arab Emirates	0.58
Weighted Average	0.82

Source: Calculated using data from IEA (2015) and GCC-STAT (2016).

Going on from the last point, net monetary gains and capital opportunity cost of an additional reactor could be shown as:

$$f(PG)/d(NE) + f(OCI)/d(NE) = TDEG*EP - TEG*LCOE$$

where TDEG and TEG denotes total (lifetime) electricity generation, first being the discounted value at the given discount rate.[23] LCOE stands for levelized cost of electricity and EP is electricity price. There are different LCOE estimates in the literature among which the most up-to-date and perhaps widely accepted one is calculated in IEA and Nuclear Energy Agency's (NEA) common study titled "Projected Costs of Generating Electricity 2015." The values from this study are provided in Table 1.1. However, LCOE values are country specific and IEA and NEA do not provide data for the GCC countries. On the other hand, Ahmad & Ramana (2014) calculated LCOE estimates for Saudi Arabia. So, in this chapter, both the average value of the countries analyzed in the IEA and NEA study and Ahmad and Ramana's estimate for Saudi Arabia are used.

Table 1.5: Levelized Cost of Electricity (LCOE) per MWh from nuclear plants built between 2015 and 2020

Country	At 3% discount rate	At 7% discount rate	At 10% discount rate
Belgium	51.5	84.2	116.8
Finland	46.1	77.6	109.1
France	50.0	82.6	115.2
Hungary	53.9	89.9	125.0
Japan	62.6	87.6	112.5
South Korea	28.6	40.4	51.4
Slovakia	53.9	84.0	116.5
UK	64.4	100.8	135.7

23. Discounting the electricity generated each year is preferred rather than discounting the price in accordance with IEA. Though it does not affect the result, discounting the price requires the assumption of constant lifetime electricity price. Besides it is more convenient for the analysis made in this study as the impact of low (subsidized) electricity prices will be discussed.

Table: 1.5 continued

USA	54.3	77.7	101.8
China	59.4	89.3	118.8
Average	**52.5**	**81.4**	**110.3**
Saudi Arabia*		**100**	

Source: IEA&NEA 2015.

*Calculated based on the parameters in Ahmad & Ramana (2014).

Using 6.34 million MWh annual electricity generation value and r = 7% discount rate:

$TDEG = 95.2*106$ MWh and $TEG = 380.4*106$ MWh. Then:

$f(PG)/d(NE) + f(OCI)/d(NE) = EP * 95.2*106 – LCOE * 380.4*106$ or

$= EP * 95.2*106 – 30.97*109$ based on IEA&NEA (2015) LCOE value (US $81.4/MWh)

$= EP * 95.2*106 – 38.04*109$ based on Ahmad&Ramana (2014) LCOE value *(US $100/MWh)*

Using 0.82 tons of CO_2 per MWh (shown as EF: emission factor in the formula below) as unit emission value for the GCC countries and $30 value per ton of CO_2 emission reduced (shown as CP: carbon price in the formula below), the environmental benefit of the nuclear use expressed in terms of emission reduction:

$f(EnB)/d(NE) = CP * 77.7*106 = 2.33*109$ USD

It should be underlined that $30 per ton of CO_2 emission reduced is quite a significant value. There could be a real term meaning of this in the markets where carbon emissions are priced. However, apart from that, this value is based on the perception of the country. IEA, for instance, takes this value while estimating the cost of electricity in OECD countries. Nevertheless, for the non-OECD countries IEA ignores carbon pricing, i.e., it assumes CP = 0. Therefore, in the final model the effect of different levels of CP will be given special attention.

In order to forecast f(OGE)/d(NE), baseline values of fuel consumption in power generation are used. These values are presented in Table 1.4. So it is assumed that each GWh of electricity generated from nuclear will preserve 0.268 tons of oil equivalent (toe) of oil and gas (shown as SF: saving factor in the following formula). Since natural gas prices are tied to oil prices and fuel consumption figures used here both for oil and gas are in toe, it will be assumed that all the fuel saved for additional export was oil.

Table 1.6: Fuel consumption in power generation in GCC countries (2013)

GCC Member	Fuel Consumption in Power Generation (toe) Heavy Fuel Oil	Light Fuel Oil	Natural Gas	Fuel Consumption (toe) per GWh of Electricity
Bahrain		3	5,753	390.0
Kuwait	8,700	1,248	6,091	263.0
Oman		2,477	4,878	286.6
Qatar			10,143	292.6
Saudi Arabia	20,009	11,792	21,338	261.3
United Arab Emirates	282	380	27,338	254.6
Total	**28,991**	**15,900**	**75,541**	**268.0**

Source: Calculated using data from AUE (2014) and GCC-STAT (2016)

Since global oil prices are expressed in terms of barrels, toe of oil should be converted to barrels of oil. The conversion rate, 7.14, and per barrel oil price, OP, are expressed in the following equation.

$$f(OGE)/d(NE) = TDEG * SF * 7.14 * OP$$

$$\text{So } f(OGE)/d(NE) = OP * 182.3*106.$$

Gathering all the components together, the decision making equation could be rearranged as:

$$f(NE)/d(NE) = EP * 95.2*106 - LCOE * 380.4*106 + 2.33*109 + OP * 182.3*106$$

*f(NE)/d(NE) = EP * 95.2*106 + OP * 182.3*106 – 28.64*109*
(for LCOE US $81.4/MWh)

or

*f(NE)/d(NE) = EP * 95.2*106 + OP * 182.3*106 - 35.71*109*
(for LCOE US $100/MWh)

As mentioned earlier, for a rational decision on launching a nuclear program, the right hand side of this equation(s) should be positive. However, it is seen that the negative value is much higher than the coefficients of electricity price and oil price.

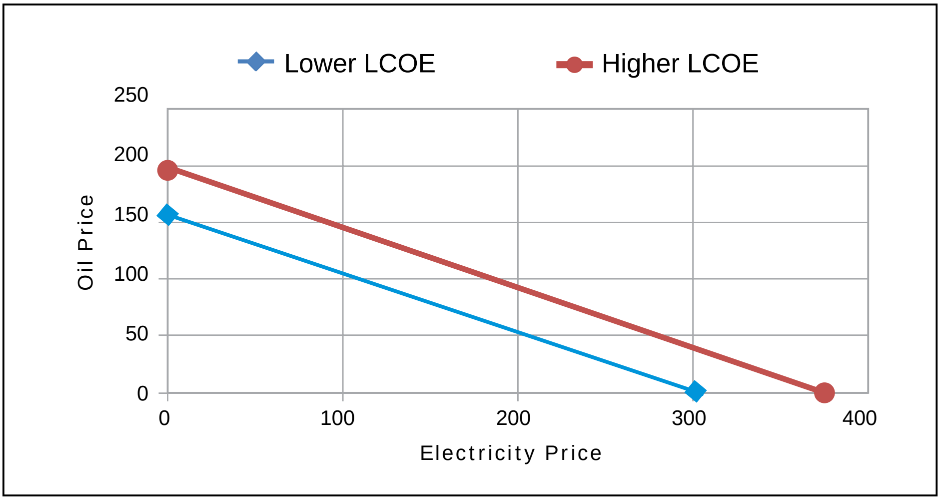
Findings of the Model and Discussion

The final stage in the model yields several important findings for the GCC countries that can help in reaching a decision on launching a nuclear program. The first is that oil price is much (almost two times) more influential on a decision in favor of nuclear energy than electricity price. Thus, although electricity is the main product of a nuclear power plant, its own price level is less influential than the opportunity cost. This conclusion supports the initial arguments of this work on the determinants of nuclear energy use.

Secondly, the environmentally positive impact of nuclear energy disappears in the integrated cost component of nuclear energy. The total LCOE, including the opportunity cost of capital investment, is calculated as more than 13 times the value of environmental benefits even for the lower LCOE alternative. Moreover, this is in a circumstance where emissions due to power generation were already high and the value associated to reduction in CO_2 emissions was significant. However, as the environmental benefit for an additional nuclear reactor is estimated as 2.33*109 USD, it is worth emphasizing nuclear energy for the Gulf from an environmental perspective, though it is not the determining criterion.

Comparing the negative value with the coefficients of electricity price and oil price, an obvious gap is observed. In other words, high EP and OP figures are needed for the rationality of the nuclear investment. Electricity price in the Gulf is quite stable but quite low as well. As discussed earlier, electricity price varies between $7 and $80 per MWh in the Gulf with an unweighted average of $41.2, which is much below the world average. This is $200 in the US or $300 in Germany, for instance. This electricity price in the Gulf is so low that even a per barrel oil price of $110 yields f(NE)/d(NE) value of $-4.7 billion for the lower LCOE alternative and $-11.7 billion for the higher LCOE alternative. So at this point there arises the question of whether the electricity produced from nuclear will be subsidized by the governments as they do for electricity from oil and gas. If that is not the case, even high oil prices of a few years ago will not be satisfactory. An electricity price of $40 per MWh without any subsidy requires an oil price of around $136.2 per barrel to satisfy the f(NE)/d(NE)>0 condition considering the lower LCOE alternative. Putting it another way, an oil price of around $50 per barrel requires the electricity price to be around $205 per MWh or subsidizing the difference between this level and actual prices. These values become dearer when the higher LCOE alternative is taken into account. Figure 1.3 summarizes this relationship for the two LCOE alternatives.

Figure 1.3: Oil and electricity price combinations satisfying *f(NE)/d(NE)>0* condition



The UAE started building its first nuclear reactor in 2012, when oil prices were above $100. It is worth underlining that the UAE has the highest electricity prices as shown previously with $78.8 per MWh for residential consumers at the consumption interval above 6,000 kWh. Considering this figure in the lower LCOE scenario, the UAE would need a per barrel oil price of around $116, which was more or less the case then. However, considering the electricity prices for Saudi Arabia or Kuwait, oil prices should be $136 or $153, respectively. When the higher LCOE estimate for Saudi Arabia, is adopted, this value jumps to $175. In short thanks to higher electricity prices, it was more feasible for the UAE to initiate the nuclear energy program. Besides, the differences in governments' willingness to subsidize nuclear energy or to increase the electricity price might be an important factor in the variation in the move towards nuclear programs.

Finally, it can be underlined that keeping other factors constant, there is an alternative way to change the dynamic between oil and electricity prices and decision making on nuclear. This is the addition of a new variable into the model in mathematical terms, which could be possible through the development of small or medium scale cogeneration nuclear reactors in real terms. Reactors that can be employed in desalination as a cogeneration plant differ from those exclusively used in electricity generation and then desalination in terms of efficiency. The current model used in this study already reflects the latter as the electricity generated in a nuclear power plant could be used in desalination similar to elsewhere and the model does not ignore this. However, once these are brought together, a significant efficiency gain is achieved, meaning that in the same equation there will be the additional benefit of water production with more or less similar costs.[24] Several studies with pure financial analyses, disregarding the environmental contribution for instance, show the feasibility of cogenerating or even pure thermal nuclear power plants for the Gulf for desalination purposes.[25]

To summarize, nuclear energy could be a good option for the Gulf for several reasons, but it will not be a free lunch. Oil prices and low (or subsidized) electricity prices constitute the key determinants of wider dissemination of nuclear energy in the region. Despite the fact that oil prices greatly influence the decision to opt for nuclear energy, the governments could enable the nuclear option by increasing electricity prices, though this is not a common practice in monarchies. Or the governments could subsidize nuclear energy as they do oil and gas. However, this would imply double subsidizing nuclear energy since the nuclear projects are to be financed by the governments themselves, such as in the case of Barakah of the UAE.

24. For instance, Saudi Arabia has signed a cooperation agreement with South Korea to get its recently developed SMART reactor, which can serve as a cogeneration plant (*Saudi Gazette* 2015).

25. Some examples are Jung et al. 2014, Aljohani 2004, and Al-Mutaz 2001.

2

Economics of Nuclear and Solar Desalination for the Middle East

Rami W. Bitar and Ali Ahmad

Abstract

Increasing water supply by utilizing desalination technologies is an intrinsic part of the energy-water nexus in the Middle East. In response to the need to move away from fossil fuel, countries across the region have been proposing ambitious plans to invest in nuclear and solar power to deal with the increasing demand for electricity and water. This chapter presents a comparative economic analysis of nuclear and solar desalination for the Middle East based on the levelized cost method using parameters and assumptions that are specific to the region. The chapter also aims to examine the challenges and incentives for nuclear and solar desalination in the region. The analysis is conducted using the Desalination Economic Evaluation Program, a computational tool provided and developed by the International Atomic Energy Agency. Of all the desalination technologies and power options studied, we found that the most economically feasible combination is solar PV panels coupled with reverse osmosis technology. However, requirements for high production capacity, lower levels of salinity, and the existence of off-peak heat source could justify the coupling between nuclear power and thermal desalination technologies.

Motivation and Background

The Middle East is witnessing a remarkable increase in water consumption due to economic and population growth.[1,2] Freshwater resources are scarce in the region while the demand for desalinated water has been rising, particularly in the Gulf Cooperation Council (GCC) countries. According to the World Resource Institute, the Middle East will be facing extremely high water stress levels by 2040; by that time, all the GCC countries are expected to rank among the top ten water stressed countries in the world.[3] Clearly, this indicates that they are likely to be more vulnerable to water scarcity than they are today.

The reason behind studying nuclear vis-à-vis solar desalination is that countries across the Middle East are proposing ambitious plans to enhance their energy security and shift away from fossil fuel by adding large capacities of nuclear and renewable energy sources in the coming decades.[4,5,6,7] However, different countries in the Middle East have different economic profiles and some, such as Jordan or Egypt, might not be able to sustain large investments in energy infrastructure projects and thus might have to choose one technology over another. Even resource rich countries, like the GCC states, are susceptible to strained budgets due to declining oil and gas revenues. These countries might also find themselves in a position that requires prioritizing their energy investments rather than embarking on an "all-in" diversification plan.

---

1. J. Allan, "Hydro-peace in the Middle East: Why No Water Wars? A Case Study of the Jordan River Basin," SAIS.
2. M. Dolatyar & T. Gray (eds.), *Water Politics in the Middle East: A Context for Conflict or Cooperation?* 1999.
3. A. Maddocks, R. Young, & P. Reig, "Ranking the World's Most Water-Stressed Countries in 2040," 2015, retrieved from http://www.wri.org/blog/2015/08/ranking-world%E2%80%99s-most-water-stressed-countries-2040.
4. Ali Ahmad & Ryan Snyder, "Iran and Multinational Enrichment in the Middle East," *Bulletin of the Atomic Scientists* 72, no. 1 (2016): 52-57.
5. A. Ahmad & M.V. Ramana, "Too Costly to Matter: Economics of Nuclear Power for Saudi Arabia," *Energy* (2014), http://dx.doi.org/10.1016/j.energy.2014.03.064.
6. S.U.-D. Khan, et al., "Development and Techno-Economic Analysis of Small Modular Nuclear Reactor and Desalination System across Middle East and North Africa Region," *Desalination* (2016), http://dx.doi.org/10.1016/j.desal.2016.05.008.
7. N. Ghaffourn, T. Missimer, & G. Amy, "Technical Review and Evaluation of the Economics of Water Desalination: Current and Future Challenges for Better Water Supply Sustainability," *Desalination* 309 (2012): 197-207.

Desalinating water is an energy intensive process. However, plants that are based on the co-generation model, which allows for the production of both electricity and desalinated water, offer a favorable opportunity for meeting rising electricity and water demands. This coupling potential between generating energy and potable water makes desalination all the more vital and relevant in the Middle East. Within the co-generation model, energy is utilized efficiently; water is desalinated and stored during off-peak hours while electricity is generated at full capacity during peak hours.

This chapter aims to conduct a comparative economic analysis of water desalination plants powered by nuclear and solar energy sources. It also aims to highlight the economic challenges and incentives associated with these two energy sources in the Middle East. The analysis presented in this chapter is based on a levelized cost methodology that takes into account regional parameters and assumptions.

Nuclear and Solar Power Plans in the Middle East

The Middle East holds most of the world's oil reserves. According to current estimates, more than 80 percent of the world's proven reserves are located in OPEC countries. Middle Eastern countries hold around 66 percent of the OPEC total oil reserves.[8] This high reliance on oil and gas limits the diversity of power sources in the region and thus negatively impacts energy security.

In addition to reducing the reliance on oil prices (for exporting and importing countries), costs of renewable technologies are falling fast and this is a trend that is likely to continue in the future. The cost of PV panels has dropped over 80 percent since 2008, making solar power all the more competitive with traditional energy sources.[9]

The hot and arid climate of the Middle East proves to be very promising for solar power, and many countries are showing interest in this developing technology. In April of 2008, the United Arab Emirates (UAE) began actively rooting for the development of solar power generation. Abu Dhabi has launched projects using both PV and CSP technologies and aims for solar power to account for 7 percent

8. OPEC, "OPEC Share of World Crude Oil Reserves, 2015," retrieved from http://www.opec.org/opec_web/en/data_graphs/330.htm.
9. M. Bapna, "4 Reasons Why Low Oil Prices Mean it's Time to Shift to Renewable Energy," 2015, retrieved from http://www.wri.org/blog/2015/09/4-reasons-why-low-oil-prices-mean-its-time-shift-renewable-energy.

of its output by the year 2020. Dubai, on the other hand, is currently focusing on PV systems and aims for solar to reach 5 percent of its total output by 2030. Facilities in the UAE currently account for more than half of the solar capacity in the GCC and the Levant.[10] The Mohammed bin Rashid Al Maktoum Solar Park is a project that will witness an additional 800 MW upon the completion of phase 3. This is a substantially large addition to the existing 13 MW (phase 1) and the under-development 200 MW (phase 2). What was astonishing about this project were the low bidding prices of the participating companies. Dubai Electricity and Water Authority (DEWA) has reported that the lowest bid among them was the never-before-seen price of 2.99¢/kWh making the project the cheapest-ever in the world.[11]

Globally, the share of nuclear electricity has dropped from the peak of 17.6 percent in 1996 to 10.8 percent in 2015.[12] Nevertheless, Russia, China, and India are pushing for to expand their nuclear plans. Several countries in the Middle East are also pursuing nuclear programs to be part of their future energy mix to help cover the high energy demand.[13]

Currently in the Middle East, Iran is the only country that has an operating reactor (the Bushehr-1 reactor). Saudi Arabia, the GCC's largest economy, is planning to build sixteen nuclear reactors by 2040. These reactors will generate 17 GWe, which is enough to meet 15 percent of the country's electricity demand.

The UAE is currently constructing four nuclear plants each with a capacity of 1400 MWe.[14,15] The UAE's Barakah nuclear power plant is planned to generate a total of 5.6 GWe, with the first unit to start generating electricity in 2017 and the final unit in 2020.[16]

---

10. Solar GCC Alliance, "The Solar Energy Investment and Development Conference," 2015, retrieved from http://www.solargcc.com/emirates-solar/.
11. S. Mahapatra, "Dubai Gets Record-Low Bid of 2.99¢/kWh for 800 MW Solar PV Project," 2016, retrieved from http://cleantechnica.com/2016/05/02/lowest-solar-price-dubai-800-mw-solar-project/.
12. *The Economist,* "Nuclear Power in the Middle East," 2015, retrieved from http://www.economist.com/news/middle-east-and-africa/21679090-egypt-and-others-alternatives-nuclear-power-hold-more-promise-why-more.
13. World Nuclear Association, "Emerging Nuclear Energy Countries," 2016, retrieved from http://www.world-nuclear.org/information-library/country-profiles/others/emerging-nuclear-energy-countries.aspx.
14. Ahmad & Snyder, "Iran and Multinational Enrichment in the Middle East."
15. World Nuclear Association, "Emerging Nuclear Energy Countries."
16. C. Nakhle, "Nuclear Energy's Future in the Middle East and North Africa," 2016, retrieved

Capacity of Desalinated Water in the Middle East

Far from being a new concept, desalination plants have been utilized in the Middle East for some time; 70 percent of the world's desalination plants are in this region, namely in Saudi Arabia, the UAE, Kuwait, and Bahrain.[17] Current desalination plants in the Middle East are able to produce potable water using both seawater and brackish water. However, historically, distillation technologies such as Multi Stage Flash distillation (MSF) and Multi Effect Distillation (MED) have dominated the seawater distillation market, mainly due to the fact that co-generation of potable water and power is possible.[18]

Saudi Arabia, which produces 20 percent of the world's desalinated water, has some of the largest desalination facilities in the world including the Ras Al Khair desalination plant which is a hybrid system running on MSF and Reverse Osmosis (RO) technologies capable of producing above 700,000 m^3/day.[19] The Shoaiba complex is another desalination plant in Saudi Arabia that utilizes MSF technology to produce 410,000 m^3/day of potable water.[20]

Israel's Sorek plant is the largest seawater RO plant producing 624,000 m^3/day of potable water, while Algeria's Magtaa RO plant produces 500,000 m^3/day.[21,22]

Table 2.1 lists all the major desalination plants in the Middle East with their respective technologies and production capacities.

---

from http://carnegieendowment.org/2016/01/28/nuclear-energy-s-future-in-middle-east-and-north-africa-pub-62562.

17. A. Barton, "Water in Crisis-Middle East," (n.d.), retrieved from https://thewaterproject.org/water-crisis/water-in-crisis-middle-east.
18. Bank Netherlands Water Partnership, "Seawater and Brackish Water Desalination in the Middle East, North Africa and Central Asia," no. 33515 (2005).
19. F. Wali, "The Future of Desalination Research in the Middle East," 2014, retrieved from http://www.natureasia.com/en/nmiddleeast/article/10.1038/nmiddleeast.2014.273.
20. Water Technology, "Shoaiba, Saudi Arabia," 2014, retrieved from http://www.water-technology.net/projects/shoaiba-desalination.
21. IDE Technologies, "World's Largest SWRO Desalination Plant Now Fully Operational," 2013, retrieved from http://www.ide-tech.com/blog/new/worlds-largest-swro-desalination-plant-now-fully-operational.
22. D. Talbot, "Megascale Desalination: The World's Largest and Cheapest Reverse-Osmosis Desalination Plant Is up and Running in Israel," 2015, retrieved from https://www.technologyreview.com/s/534996/megascale-desalination/.

Table 2.1: Desalination Plants in the Middle East[23]

Country [23, 24]	Name of Desalination Plant	Desalination Technology	Plant Capacity
Algeria	Magtaa	SWRO	500,000 m^3/day
Israel	Sorek [25]	SWRO	624,000 m^3/day
Jordan, Gulf of Aqaba [26, 27, 28]	Under construction	Under construction	220,000 m^3/day
Saudi Arabia	Ras Al Khair [29] Shoaiba complex [30, 31]	MSF and RO (hybrid) MSF	728,000 m^3/day 410,000 m^3/day
UAE, Jebel Ali [32]	M Station	MSF	630,000 m^3/day
Cyprus	Larnaca[33] Vasilikos[34, 35, 36]	SWRO SWRO	64,000 m^3/day 60,000 m^3/day

23. T. Freyberg, "Dubai Opens UAE's Largest Desalination Plant," 2013, retrieved from http://www.waterworld.com/articles/2013/04/dubai-opens-uaes-largest-desalination-plant.html.
24. Elsevier, "Hyflux Officially Opens Largest Desalination Plant in Algeria," 12 (2014).
25. Talbot, "Megascale Desalination."
26. S. Al-Khalidi, "Jordan, Israel Agree on $900 Million Red Sea-Dead Sea Project," 2015, retrieved from http://www.reuters.com/article/us-mideast-economy-water-idUSKBN0LU23Z20150226.
27. The Hashemite Kingdom of Jordan Ministry of Water and Irrigation, "Red Sea Dead Sea Project," (n.d.), retrieved from http://www.jva.gov.jo/sites/en-us/RSDS/SiteAssets/rsds%20phase1.aspx?PageView=Shared.
28. A. Justice, "Jordan and Israel Agree on $900m Red Sea-Dead Sea Pipeline," 2015, retrieved from http://www.ibtimes.co.uk/jordan-israel-agree-900m-red-sea-dead-sea-pipeline-1489773.
29. Water Technology 2015.
30. Water Technology, "Shoaiba, Saudi Arabia."
31. Power Technology, "Shoaiba Oil-fired Power Plant, Saudi Arabia," (n.d.), retrieved from http://www.power-technology.com/projects/shoaiba.
32. Freyberg, "Dubai Opens UAE's Largest Desalination Plant."
33. Water Technology 2015.
34. *Cyprus Mail,* "Droughts a Thing of the Past with Sixth Desalination Plant," 2014, retrieved from http://cyprus-mail.com/2014/06/30/droughts-a-thing-of-the-past-with-sixth-desalination-plant/.
35. A. Manoli, "Desalination in Cyprus," Unpublished manuscript, 2010.
36. IDE Technologies. "IDE Celebrates Launch of Vasilikos Desalination Plant in Cyprus." (n.d.) Retrieved from http://www.ide-tech.com/blog/events_site/ide-celebrates-launch-vasilikos-desalination-plant-cyprus/.
37. Greenlee, L.F. et al. "Reverse Osmosis Desalination: Water Sources, Technology, and Today's Challenges," *Water Research* 43, no. 9 (2009): 2317-2348.

The future of desalination plants in the Middle East is not likely to follow the global trend. While 70 percent of the world's thermal desalination plants have switched to RO, only 50 percent of desalinated water is treated this way in the Middle East. This is because the semipermeable membranes used in RO processes have not yet been fully customized for the exceptionally high salinity of the Red Sea and Gulf seawater. At high water salinity levels such as 55,000 mg/L TDS, the pressure required for membrane desalination would be greater than the maximum pressure that the semi semipermeable membrane can withstand, and thermal desalination must be used.

Nevertheless, the region is showing increased interest in desalination plants. A new project is proposed at the Gulf of Aqaba to desalinate seawater from the Red Sea and construct a pipeline linking it with the Dead Sea. It is a joint initiative among Israel, Jordan, and the Palestinian Authority, and the main objective is to provide freshwater and promote regional cooperation. The plant is projected to produce 220,000–274,000 m^3/day of potable water.[38]

Method

The analysis presented in this chapter utilizes the Desalination Economic Evaluation Program (DEEP), a spreadsheet tool developed and maintained by the International Atomic Energy Agency (IAEA). This tool is able to study the performance and cost estimates of different desalination technologies and power sources.[39] Some of the desalination technology options supported by the software include MSF, MED, RO and other hybrid systems, while the energy source options include oil, natural gas, coal, renewables, and nuclear power. However, since the program does not include solar power as an option, we have made changes to the code that would allow its assessment. This was done by adjusting parameters such as power output, capacity factor, reference efficiency, construction cost and duration, decommissioning and O&M costs, fuel costs and the lifetime of the plant.

DEEP allows for editing of hundreds of parameters related to desalination and power technologies, plant operations, economics and finance. The main parameters that have been studied are listed in Table 2.2.

Nominal power, thermal power, and reference efficiency for nuclear and solar PV energy sources were obtained from Ahmad and Ramana's study "Too Costly to

38. Al-Khalidi, "Jordan, Israel Agree on $900 Million Red Sea-Dead Sea Project."

39. IAEA, "DEEP 5 User Manual," International Atomic Energy Agency, 2013.

Matter: Economics of Nuclear Power for Saudi Arabia".[40] The nominal power value assigned to the CSP parabolic trough is referenced from the new Noor CSP plant in Morocco which will generate 522 MWe in 2018, while the value assigned for the CSP tower refers to the largest existing plant in Ivanpah, California, which can produce a gross total of 392 MWe and a net of 377 MWe.[41,42,43]

According to the *World Nuclear Industry Status Report* of 2015, the average construction duration of a nuclear power plant is 7.6 years.[44] Rounding up to eight years, this would be equivalent to 96 months. For solar PV and CSP technologies it is much less, with an average construction time of only two years.[45]

On the other hand, a nuclear power plant has a longer expected lifetime as it can operate for an average of 60 years whereas solar powered technologies can only manage 25 years.[46]

As for operation availability (also known as capacity factor), nuclear power scores higher (90 percent) than solar PV (20 percent) and CSP technologies (53 percent).[47]

The high capacity factor of CSP technologies is due to the fact that they include a thermal energy storage system which can be used at times when sunshine is not available or when energy demand is high. This is also part of the reason behind their high construction costs cited in the IRENA energy report.

The remaining values including construction cost, fuel cost, and O&M costs for nuclear and solar PV plants were also retrieved from Ahmad & Ramana's study.

40. Ahmad & Ramana, "Too Costly to Matter: Economics of Nuclear Power for Saudi Arabia."
41. L. Mearian, "World's Largest Solar Plant Goes Live, Will Provide Power for 1.1M People," 2016, retrieved from http://www.computerworld.com/article/3031659/sustainable-it/worlds-largest-solar-plant-goes-live-will-provide-power-for-11m-people.html.
42. J. Rigney, "World's Largest Solar Thermal Project at Ivanpah Achieves Commercial Operation," 2014, retrieved from http://www.brightsourceenergy.com/ivanpah-achieves-commercial-operation#.V108jfl95aR.
43. National Renewable Energy Laboratory, "Ivanpah Solar Electric Generating System," 2014, retrieved from http://www.nrel.gov/csp/solarpaces/project_detail.cfm/projectID=62.
44. M. Schneider & A. Froggatt, *The World Nuclear Industry Status Report* 2015, Paris, London, 2015; Viola Sidem, "Multiple Effect Distillation," (n.d.) Retrieved from http://www.sidem-desalination.com/Process/MED.
45. International Renewable Energy Agency, "Water Desalination Using Renewable Energy," Technology Brief, 2012.
46. Ahmad & Ramana, "Too Costly to Matter: Economics of Nuclear Power for Saudi Arabia."
47. International Renewable Energy Agency, "Water Desalination Using Renewable Energy."

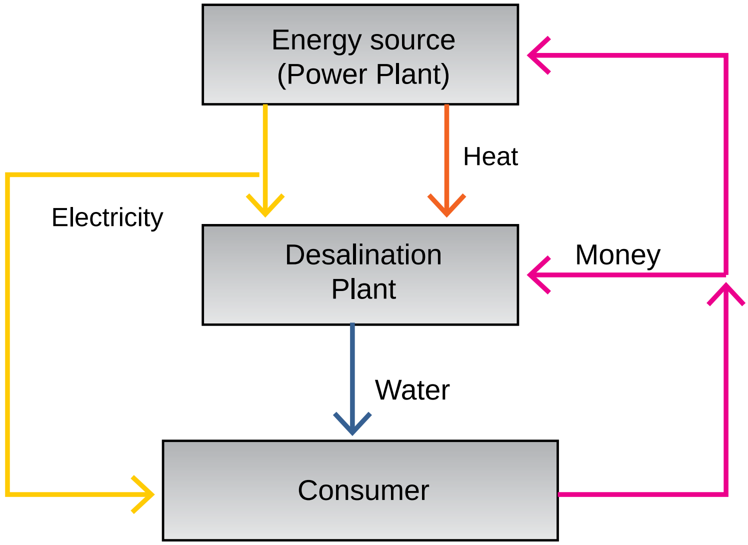
Table 2.2: Reference case parameters

Parameter	Units	Nuclear	Solar PV	CSP Parab Trough	CSP Tower
Thermal power	MWt	3030			
Nominal power	MWe	1000	150	500	400
Discount rate (WACC)	%	variable	variable	Variable	Variable
Construction duration	months	96	24	24	24
Lifetime of energy plant	years	60	25	25	25
Op availability (i.e., Capacity factor)	%	90	20	53	53
Reference efficiency	%	33			
Specific construction cost	or (t)	5,530	2,324	6,300	5,700
Specific fuel cost*	$/MWh(e)	10.12	0.00	0.00	0.00
Primary fuel price	$/ MWh	3.34	0.00	0.00	0.00
Specific O&M cost		15.00	8.64	18.1	16.37

DEEP can be used to calculate the levelized cost of electricity ($/kWh) and the cost of the desalinated water ($/m^3) as a function of quantity, specific site parameters, type of energy source, and the desalination technology used. Each case study was studied separately and its parameters changed accordingly. The different scenarios were then compared side-by-side. The water cost is sub divided into overnight capital costs, other capital expenses, electricity costs, heat costs, and O&M costs.

Every desalination process requires energy to run. Heat energy can be extracted from steam cycles in oil- and gas-fired plants or in nuclear systems. Electrical energy can be taken from the electrical grid or generated by PV panels. DEEP is designed to calculate these energy inputs, the water production costs, and electricity costs. Figure 2.1 shows a simple schematic of how a desalination plant fits in the grid.

Figure 2.1: Desalination plant and the grid[48]



Although DEEP is a powerful tool used to assess the economics of a desalination power plant, it has its limitations. It is limited to the types of power or heating plants, desalination technologies, and the coupling options described previously. The coupling combinations are modeled to meet the World Health Organization drinking water standards while the program's code focuses mainly on plants with a capacity over 100,000 m^3/day. However, DEEP does not have a built-in analysis package for solar desalination. Nevertheless, by adjusting certain parameters as previously described, the source code can be modified in order to generate case studies with PV panels and CSP technologies.

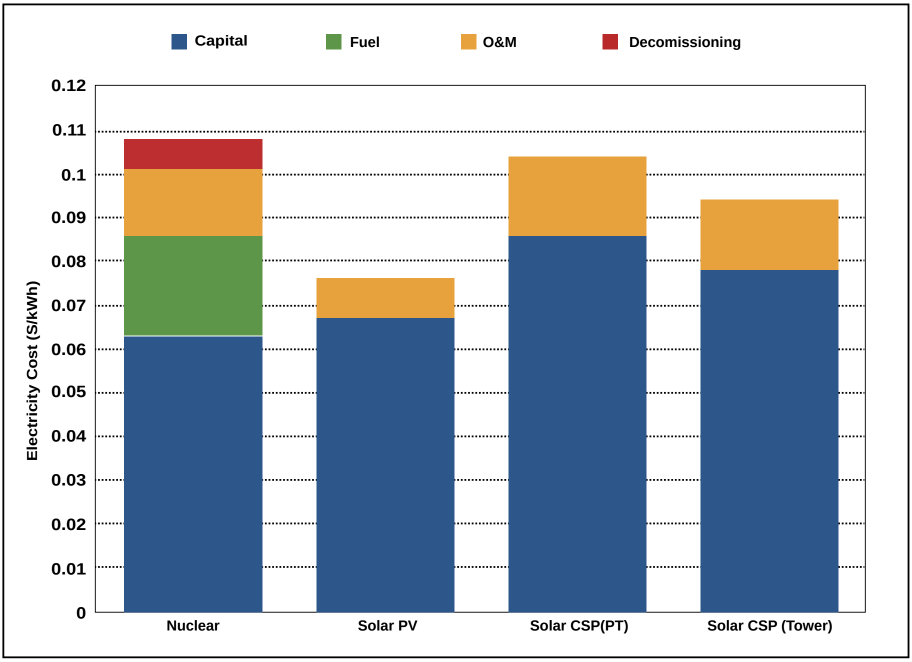
Results

The comparative economics of nuclear and solar desalination plants depends on a wide variety of parameters. It is necessary to analyze the resulting electricity and water desalination costs in relation to these parameters. Looking at Figure 2.2, we can compare the levelized cost of electricity for nuclear, solar PV, solar CSP (parabolic trough), and solar CSP (tower). Evidently, nuclear power is the costliest energy source ($0.108/kWh) based on the assumptions listed in Table 2.2. When it comes to nuclear power plants, the most important contributor to their total

48. IAEA, "DEEP 5 User Manual."

levelized cost is the capital cost. Similarly, both solar PV and CSP technologies have high capital costs yet the difference is their capital cost projections, particularly for solar PV, which shows great potential for cost reduction.[49] On the other hand, we find that solar PV has the advantage of relatively lower capital costs compared to CSP technologies. This explains the resulting electricity costs where solar PV leads at $0.076/kWh followed by the CSP tower at $0.094/kWh and the CSP parabolic trough at $0.104/kWh.

Figure 2.2: LCOE of different energy sources



Unlike nuclear power, solar technologies are characterized by zero fuel costs and low O&M costs. Furthermore, compared to nuclear technology, solar power is underdeveloped and immature. This gives it a promising outlook as the projected capital costs of PV panels in 2030 are roughly half of current values but O&M costs are about the same.[50] This means that the LCOE of solar PV is also expected to decrease, making the technology much more cost competitive. For nuclear desalination, three values of capital costs are studied. The first is the current capital

49. Ahmad & Ramana, "Too Costly to Matter: Economics of Nuclear Power for Saudi Arabia."

50. C. Budischak, D. Sewell, H. Thomson, L. Mach, D. Veron, & W. Kempton, "Cost-minimized Combinations of Wind Power, Solar Power and Electrochemical Storage, Powering the Grid up to 99.9% of the Time," 225 (2012): 60-74.

cost estimated by the US Energy Information Administration (EIA) of $5,530 / kWe. The second is the EIA's -25 percent ($4,000/kWe), roughly reflecting capital costs of nuclear power in Asian markets.[51] The third is the EIA's +25% ($7,000/ kWe), an increase attributed to potential costs and time overruns. The impact of these different values for nuclear capital costs on the desalinated water cost is demonstrated in Table 2.3 for an interest rate of 5 percent and in Table 2.4 for an interest rate of 10 percent.

Table 2.3: Water cost for nuclear desalination with i=5%

Capital Costs	$4,000/kWe	$5,530/kWe	$7,000/kWe
MSF	$1.736/m^3	$1.999/m^3	$2.251/m^3
MED	$1.098/m^3	$1.221/m^3	$1.340/m^3
RO	$0.853/m^3	$0.911/m^3	$0.968/m^3

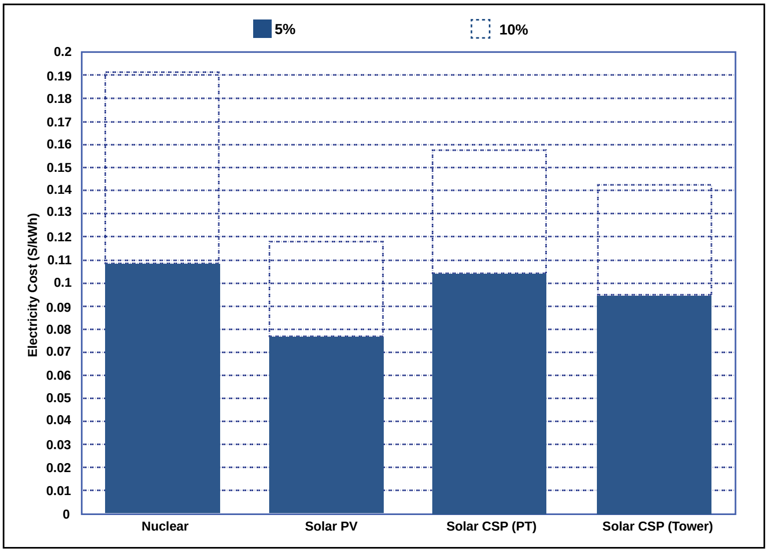
Table 2.4: Water cost for nuclear desalination with i= 10%

Capital Costs	$4,000/kWe	$5,530/kWe	$7,000/kWe
MSF	$2.775/m^3	$3.366/m^3	$3.935/m^3
MED	$1.719/m^3	$1.997/m^3	$2.264/m^3
RO	$1.198/m^3	$1.331/m^3	$1.458/m^3

Another factor that influences the LCOE is the discount rate. The effect of increasing the discount rate from 5 to 10 percent is shown in Figure 2.3. Countries in the Middle East are expected to have discount rates within this range. Resource rich countries such as the GCC states are likely to benefit from low discount rates while other, less capable countries with deteriorating economies, such as Egypt or Jordan, may have to deal with high discount rates closer to the 10 percent mark, if not higher. This is mainly because such countries have poor credit ratings leading lenders and investors to request higher returns on investments. Moreover, the discount rate is dependent on the financial standing of the project developer and other risk factors.

51. US Energy Information Administration, " "Updated Capital Cost Estimates for Utility Scale Electricity Generating Plants," *Independent Statistics & Analysis,* Washington: EIA, 2013.

Figure 2.3: LCOE of different energy sources with 5% and 10% discount rate



The capacity factor or operational availability of a power plant is the ratio of its actual output over a period of time to its potential output if it were possible for it to operate at full nameplate capacity continuously over the same period of time. Capacity factor is an important economic parameter that significantly affects the levelized costs of electricity and water.

When it comes to operational availability, nuclear power offers a big advantage over solar technologies. A nuclear power plant has a capacity factor of 90 percent, while that of solar power is around 20 percent.[52] However, given the fact that solar power is still a growing technology we expect the capacity factor of solar power to witness an increase in the future, especially when coupled with cheap and effective energy storage systems. On the other hand, nuclear power is a fully mature technology. Therefore, in this section, we will keep the capacity factor of the nuclear power plant fixed at 90 percent, and we will study three different cases for solar power with capacity factors of 20 percent, 25 percent, and 30 percent.

Figure 2.4 depicts the water cost for a desalination plant running on RO technology and coupled with solar PV panels with varying capacity factors from 20 percent to 30 percent. The same plant is coupled with nuclear power for comparison purposes. We note that since we are studying the same desalination plant with the same output capacity of 100,000 m^3/d, the annualized capital cost

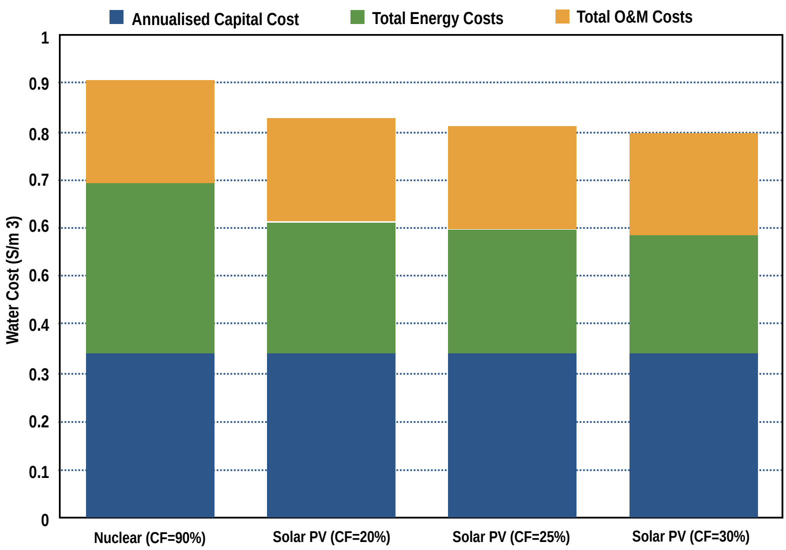
52. Ibid.

and the total O&M costs for all cases are the same. What differs is the total energy cost. Nuclear technology has the highest energy costs of 0.358 $\$/m^3$.

For solar PV, it is expected that as the capacity factor (or operational availability) increases, the water cost would decrease as it would mean the plant is run for more days per year and thus there is more water generation.

The most important conclusion to draw from the graph is that even at the lowest capacity factor of 20 percent, the water cost for solar PV is still less than nuclear.

Figure 2.4: Varying capacity factor for solar PV

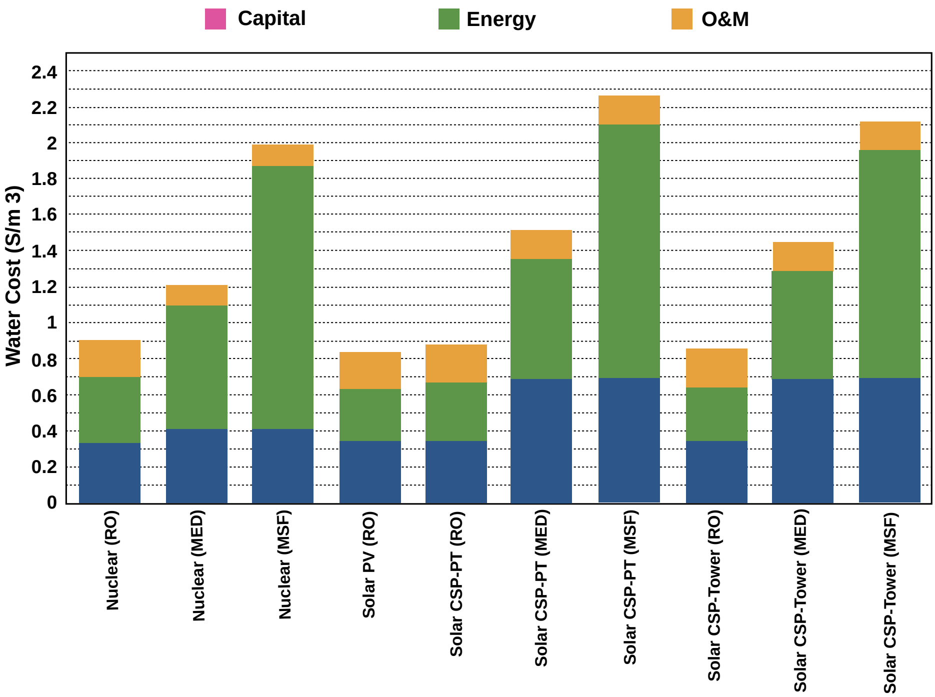


The capacity factor for solar CSP is known to be greater than that for solar PV. It is about 35 percent for CSP and 25 percent for solar PV.[53] However, it is noted in the International Renewable Energy Agency (IRENA) report of June 2012 that the capacity factor of solar CSP can reach values up to 53 percent if we introduce thermal storage units capable of storing energy for six hours.[54]

The challenge of lengthy construction time is not faced by solar powered plants, which can be built, in some cases, in less than a year. To study the effect of construction time on the cost of water and the power cost for nuclear power, we will vary the construction time from five years to ten.

53. Ahmad & Ramana, "Too Costly to Matter: Economics of Nuclear Power for Saudi Arabia."
54. International Renewable Energy Agency, "Water Desalination Using Renewable Energy."

Figure 2.5: Water desalination cost of different technologies



In total, we study ten combinations that are based on four energy sources and three desalination technologies. Nuclear power coupled with RO, MSF and MED, solar PV coupled only with RO, solar CSP and tower coupled with RO, MSF and MED. Figure 2.5 shows the water desalination cost ($/m^3) of the different combinations of energy sources and distillation technologies. It is apparent that energy cost is the major contributor to water desalination cost, especially when it comes to technologies such as MSF distillation. This technology, as well as MED, consume more energy than RO as a phase change takes place within their processes. Thus, out of all the distillation technologies, MSF has the highest water distillation costs, followed by MED and then RO. Other costs related to O&M comprise a small percentage of total water distillation costs. Nevertheless, O&M costs of RO are the highest (in comparison to other technologies) due to the fact that the RO process is more sensitive to fouling than MED and MSF.[55] Solar PV panels combined with RO seem to be the most economic option with a water desalination cost of $0.844/m^3. Compared to a nuclear powered RO desalination plant, whose

55. S. Ariyanto & S. Alimah, "Economic Aspect for Nuclear Desalination Selection in Muria Peninsula," Center for Nuclear Energy Development (PPEN) Batan, 2009.

cost is at \$0.911/m3, a solar PV desalination plant produces potable water at a cheaper rate. Moreover, it seems that the coupling between nuclear and thermal desalination processes results in higher water desalination costs. Nevertheless, these options still offer the advantage of larger desalination capacities.[56]

Figure 2.5 shows that for MSF desalination, nuclear and solar CSP energy sources are not competitive from an economic point of view. The reason is the high capital cost of the CSP systems. The high capital cost owes to the fact that the systems have thermal storage capacity up to six hours, with a capital cost of \$6,300/kWe and \$5,700/kWe for CSP parabolic trough and CSP tower, respectively. The water cost is broken down into three sub costs: capital, energy, and operation and maintenance costs. For CSP technologies, parabolic trough and tower both share the same capital cost and O&M cost of 0.694 \$/m^3 and 0.160 \$/m^3. What differs is the energy cost with parabolic trough being more energy intensive as it has an energy cost of 1.41 \$/m^3 whereas the CSP tower has an energy cost of 1.27 \$/m^3. Summing up these costs, we get a total water cost of 2.261 \$/m^3 for CSP parabolic trough and 2.127 \$/m^3 for CSP tower.

MSF coupled with nuclear, on the other hand, has a lower capital cost of 0.41 \$/m^3 and also lower O&M cost of 0.12 \$/m^3. Nuclear, however, does have a higher energy cost of 1.47 \$/m^3 resulting in a water of \$1.999/m^3.

Nuclear proves to be more economic than CSP in MED technology. When studying the costs for MED technology coupled with solar CSP, we note that the capital costs and O&M costs remain the same at 0.694 \$/m^3 and 0.160 \$/m^3, respectively. What differs now is the energy cost which is far less than MSF. Energy cost for CSP parabolic trough is 0.66 \$/m^3 and 0.60 \$/m^3 for CSP tower. These costs amount to a total of 1.515 \$/m^3 for CSP parabolic trough and 1.452 \$/m^3 for CSP tower. MED coupled with nuclear also has the same capital and O&M costs of an MSF plant of 0.41 \$/m^3 and 0.12 \$/m^3. Since MED is less energy intensive than MSF, the energy cost now is only 0.68 \$/m^3 making nuclear the most economical of all three options with a water cost of 1.221 \$/m^3.

56. H.S. Kim & H. Cheon, "Thermal Coupling of HTGRs and MED Desalination Plants, and its Performance and Cost Analysis for Nuclear Desalination," *Desalination* 303 (2012): 17-22.

Figure 2.6: Water costs with varying interest rates

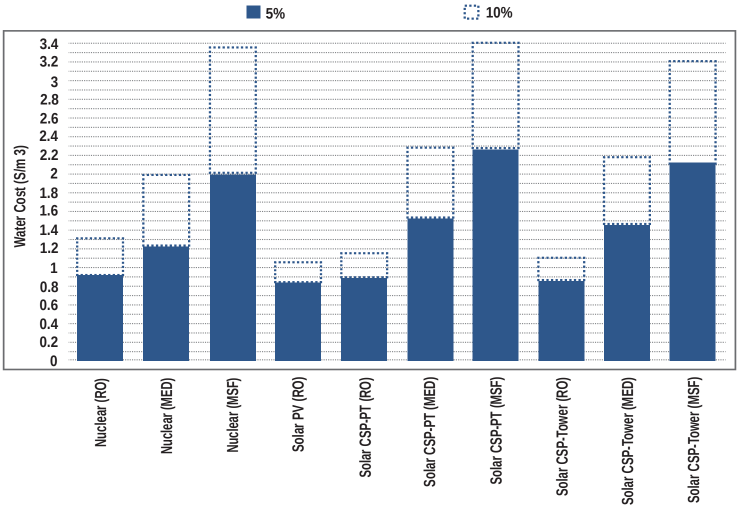


Figure 2.6 shows the effect of different discount rates on the water desalination costs. As witnessed with the hike in LCOE in Figure 2.3, increasing the discount rate affects the water desalination costs of nuclear powered technologies more than in solar powered technologies. This is because nuclear has high capital costs which makes it more sensitive to changes in discount rate.

Moreover, coupling nuclear power and MSF under a high discount rate results in very high water desalination costs.

Figure 2.7: Desalination cost range of different energy sources coupled with different desalination technologies

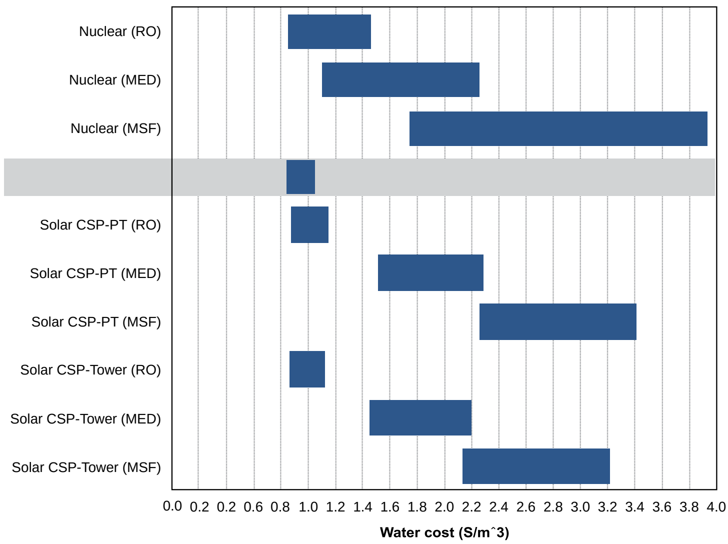


Figure 2.7 summarizes all the results of this study. It shows the water desalination cost in $\$/m^3$ of the different desalination and energy technologies. Each desalination technology is given a bandwidth which shows the lowest and the highest potential water desalination costs generated using that particular technology.

The lower value is based on low interest rates and capital costs and short construction periods, whereas the higher value is based on more conservative figures where the interest rates are high and construction periods are long.

In the case of solar energy, since the sun's radiation is varying through the day and completely absent at night, energy would need to be purchased should a night production of water occur. If no energy is purchased, then this will drive down the total energy costs. This is shown by the lower value of the cost band. This option is not needed in the case studies of nuclear because nuclear power is capable of generating a steady output of energy.

More importantly, the figure shows that the cheapest technology for producing potable water is RO running on solar PV panels. In fact, the maximum cost of using solar PV panels is still below the average cost of nuclear powered RO.

Discussion

Renewables, specifically solar PV, have great potential for technological improvement and cost reduction. Technological advancement in the material of PV panels could drive efficiencies higher creating breakthroughs in production lines and driving capital costs down. Potentially, this would decrease their levelized cost of electricity and water desalination costs even further. The levelized electricity costs for crystalline silicon solar panels for both utility and commercial scale were both projected with an 80 percent learning curve factor for module prices. In 2011, LCOE for Utility-Si was about ¢14/kWh, while the projected cost in 2020 is ¢8/kWh. For Commercial-Si, the cost in 2011 was ¢9/kWh and in 2020 it drops to about ¢5/kWh.[57] These costs are expected to drop even more in the future.

Economically speaking, if we compare the costs of all three desalination technologies, RO proves to be the cheapest. Nevertheless, there are several reasons why MSF and MED comprise a considerable part of the world's desalination capacity. The main advantage that MSF and MED have over RO is their capability to desalinate considerably larger volumes of water per day. Also, the desalinated

57. S. Reichelstein & M. Yorston, "The Prospects for Cost Competitive Solar PV Power," *Energy Policy* (2013):117-127.

water is usually of very high quality (less than 10 mg/L TDS) compared to RO systems (499mg/L TDS).[58]

Moreover, MSF and MED require minimal pre-treatment of the feedwater whereas in RO pre-treatment of feedwater is required to remove particulates in order for the membrane to last longer. Finally, since MSF and MED are thermal technologies which require heat to operate, they can be combined with other processes; for example, the heat energy from an electricity generation power plant can be used to evaporate the seawater.

On the other hand, lengthy construction and planning time is one of the main cost drivers in nuclear desalination projects. According to the *World Nuclear Industry Status Report,* the 62 reactors currently being built have been under construction for an average of 7.6 years, as of July 2015.[59] Historically, experts argued that the reasons for having such a long construction time include increased complexity of reactor systems as well as the need to spend more time on quality assurance processes. Furthermore, it is not unusual for a nuclear power plant to take 15 years to be constructed and, in some cases, even 20 years. Five reactors have been listed as “under construction” for more than 30 years. The US Watts Bar-2 project in Tennessee began construction in December 1972. Two Russian units (BN-800 and Rostov-4) and two units in Slovakia (Mochavce-3 and -4) have also witnessed more than 30 years in construction.[60]

Cost Difference and Cost Savings

Using the water cost results in this study, one can estimate the costs that can be saved by countries in the region if they rely on solar power for water desalination instead of using nuclear power. As discussed in the previous section, water cost for a SWRO coupled with nuclear power is \$0.911/m^3 and for solar PV it is \$0.844/m^3.

Concentrated solar power, on the other hand, did not prove to be more economical than nuclear power. An MSF desalination plant running on nuclear power has a water cost of \$1.999/m^3, whereas the same desalination plant coupled with CSP tower has a water cost of \$2.127/m^3, and for CSP parabolic trough it is \$2.261/m^3.

58. URS Australia, “Economic and Technical Assessment of Desalination Technologies in Australia: With Particular Reference to National Action Plan Priority Regions,” Detailed Report, 2002.
59. Schneider & Froggatt, *The World Nuclear Industry Status Report 2015.*
60. Ibid.

Table 2.5 shows the volume of desalinated water daily in countries of the Middle East in cubic meters. The adjacent columns show the annual savings that could be achieved if we utilize solar power instead of nuclear power for desalinating the required volumes of water. Two major findings can be drawn from the table. First, the highest savings are witnessed in column 6 when studying nuclear power versus solar PV. This is because the cost of desalinating water using solar PV is the lowest of all the technologies studied and this was shown earlier in Figure 2.7. Second, the annual savings for MSF & MED technologies (columns 4 & 5) are all negative proving that it would be more economically feasible to couple this technology with nuclear rather than CSP.

Table 2.5: Annual savings by country if solar desalination is implemented

Country Desalinated water volume (m^3/d)[61] Annual Savings using solar Technology (\$/y)						
	(1) MSF	(2) MED	(3) SWRO	(4) MSF	(5) MED	(6) SWRO
Egypt	32,574	25,202	321,318	(1,521,857)	(2,704,427)	7,857,832
Iran	27,570	90,558	26,134	(1,288,070)	(9,717,779)	639,107
Jordan	-	1,100	1,670	-	(118,041)	40,840
Kuwait	1,686,291	-	2,614	(78,783,516)	-	63,925
Saudi Arabia	4,621,230	973,551	1,190,035	(215,903,866)	(104,471,758)	29,102,306
Turkey	1,000	8,610	30,850	(46,720)	(923,939)	754,437
United Arab Emirates	4,733,417	555,707	578,836	(221,145,242)	(59,632,918)	14,155,434

Comparison and Validation of the Water Cost Model

Mansouri and Ghoniem in an article entitled "Does Nuclear Desalination Make Sense for Saudi Arabia?" did a comparative study on the economics of different power options for desalination purposes in Saudi Arabia.[61] The article examines different scenarios for fossil and nuclear-based desalination; however, it excludes solar power. The conclusion they reached, that nuclear power coupled with RO is the most economic among these options, is consistent with the findings reported in

62. N.Y. Mansouri, & A.F. Ghoniem, "Does Nuclear Desalination Make Sense for Saudi Arabia?" *Desalination* (2016), http://dx.doi.org/10.1016/j.desal.2016.07.009.

this work. Both studies show that nuclear power coupled with MSF is the costliest, followed by nuclear coupled with MED, and the cheapest option is nuclear with RO. However, there are differences when it comes to specific costs, as seen in Table 2.6, due to different cost assumptions.

Table 2.6: Comparison of water costs

Water Cost ($\$/m^3$)		
	Mansouri and Ghoniem	**This work**
Nuclear with MSF	1.58	1.999
Nuclear with MED	1.00	1.221
Nuclear with RO	0.78	0.911

The values Mansouri and Ghoniem used in their work were too optimistic towards nuclear power. For example, the construction duration for a nuclear power plant was taken as 60 months, whereas in our work we have used a more realistic 96 months.

Table 2.7 shows the different parameters used by Mansouri and Ghoniem along with our values.

Table 2.7: Comparison of parameters

Parameter	Mansouri and Ghoniem	This work
Construction duration	60 months	96 months
Specific construction cost	4,000 $/kW	5,530 $/kW
Technology efficiency	32%	33%
Specific fuel cost	5.9 $/MWh	10.12 $/MWh
Specific O&M cost	8.8 $/MWh	15.00 $/MWh
Production capacity	279,936 m^3/day	100,000 m^3/day

For the purpose of validating the water cost model we used in this work, the cases presented by Mansouri and Ghoniem were replicated. It is important to note that DEEP is a sophisticated software with hundreds of parameters to be input and Mansouri & Ghoniem's paper did not reveal all the parameters used; therefore, educated assumptions had to be made for certain parameters. The benchmarking analysis is displayed in Table 2.8. DEEP was used to generate three cases running on three different desalination technologies MSF, MED and RO. This study uses the same parameters assumed by Mansouri & Ghoniem to confirm the validity of the DEEP program.

Table 2.8: Common parameters used for benchmarking of DEEP's model between this work and Mansouri & Ghoniem's

Inputs	Units	MSF	MED	RO
Energy source		Nuclear	Nuclear	Nuclear
Thermal output	MWth	479	479	479
Elect. Production	GWh/y	977	977	977
Water capacity	m^3/d	279,936	279,936	279,936
Feed salinity	ppm	35,000	35,000	35,000

Table 2.9: Results of the benchmarking exercise between this work (Bitar) and Mansouri & Ghoniem's work (M&G)

Results		MSF (Bitar)	MSF (M&G)	MED (Bitar)	MED (M&G)	RO (Bitar)	RO (M&G)
Levelized capital costs	$\$/m^3$	0.46	0.46	0.41	0.41	0.34	0.34
Base plant overnight EPC	$\$/m^3$	0.36	0.36	0.32	0.32	0.29	0.29
Other	$\$/m^3$	0.10	0.1	0.09	0.09	0.05	0.05
levelized operating costs	$\$/m^3$	0.61	1.12	0.57	0.59	0.44	0.44
Heat	$\$/m^3$	0.31	0.81	0.29	0.3	0.00	0
Electricity	$\$/m^3$	0.19	0.19	0.16	0.18	0.23	0.24
O&M	$\$/m^3$	0.11	0.11	0.11	0.11	0.20	0.2
Transport	$\$/m^3$	0.00	0	0.00	0	0.00	0
Lifecycle Emissions	Mtn/yr	28	27	28	27	28	27
Thermal Utilization		94%	92%	89%	87%	18%	17%
Power lost	MWe	54	54	50	50	0	0
Power used for desalination	MWe	31	31	28	28	39	39
Power cost	$/MWh	67.4	69.5	68.5	69.5	67.4	69.5

The total water cost can be obtained by adding up the levelized capital costs and levelized operating costs. If we compare the water costs we obtained with the water costs of Mansouri and Ghoniem, it is clear that they are matching for RO and MED. For RO, the water costs we obtained was \$0.78/m^3 (=0.34+0.44) which is exactly the same as Mansouri & Ghoniem. For MED, the water costs we obtained was \$0.98/m^3 (=0.41+0.57) which is only 2 percent less than the water cost of Mansouri & Ghoniem which was \$1.00/m^3.

The results for MSF, however, are not as close as the results of RO and MED. The water cost generated by our simulation was \$1.07/m^3 whereas Mansouri & Ghoniem's value was \$1.58/m^3. A possible explanation for this difference in results is that one (or more) of the many unpublished parameters in this work of Mansouri & Ghoniem did not match the value(s) used in this work.

Conclusion

In this study, we focused on the three most used desalination technologies worldwide – Multi Stage Flashing, Multi Effect Distillation, and Reverse Osmosis. The aim was to conduct an economic study to see whether nuclear desalination or solar desalination is the best option for producing potable water from seawater. Further, the study seeks to provide reliable data for policy makers in the Middle East to make decisions on which technologies to opt for. In total, 10 combinations were studied and were based on four energy sources and three desalination technologies. The software DEEP was used to evaluate the levelized cost of electricity and the water cost of the different case studies.

Of all the desalination technologies and power options studied, it was found that the most economically feasible combination is solar PV panels coupled with RO technology. Water cost for a plant running on RO coupled with solar PV panels is \$0.844/m^3. A nuclear power plant running on the same technology would have a water cost of \$0.911/m^3. The next most economical combination is the coupling between solar CSP and RO with a water cost of \$0.863/m^3, followed by parabolic trough with a water cost of \$0.881/m^3.

MED and MSF, on the other hand, proved to be more economical when coupled with nuclear power rather than solar CSP. A MED plant coupled with nuclear power has a water cost of \$1.221/m^3; this is followed by a CSP tower with a water cost of \$1.452/m^3. The most expensive is CSP parabolic trough with a cost of \$1.515/m^3. MSF is the most energy intensive of all desalination technologies and, therefore, the water costs are the highest. An MSF plant running on nuclear power has a water cost of \$1.999/m^3, the same plant operated using CSP tower would have a water cost of \$2.127/m^3, and, as expected, a CSP parabolic trough has the highest water cost of \$2.261/m^3.

Manufacturing costs of PV panels will drop even further as solar technology develops, bringing down capital costs and consequently potential LCOE and water desalination costs of solar powered plants. In conclusion, integrating solar power with desalination technology could prove more cost effective than nuclear powered desalination plants.

3

Requirements for High Solar Penetration in Electricity Production in Saudi Arabia

Philippe Chite and Ali Ahmad

Abstract

The newly adopted Saudi national plan "Vision 2030" aims to reduce the country's dependence on oil and generate 9.5 GW of power from renewable energy sources. In this context, this chapter examines Saudi Arabia's requirements for high solar penetration in electricity production through utilizing the duration and residual curve concepts as a simple method in determining the optimal energy mix for the Kingdom in 2030. Simulations of different renewable energy systems based on different technologies were carried out, covering a number of locations in the country. Calculations of electricity generation costs of different technologies were made for different deployment scenarios. Moreover, investment and opportunity costs of renewable energy use were estimated and the policy changes needed for the suggested scenarios were examined too.

Introduction

Saudi Arabia has one of the world's largest proven reserves for crude oil and natural gas of around 266 billion barrels of oil and 8.3 trillion cubic meters of natural gas.[1]

1. Said Nachet and Marie-Claire Aoun, *The Saudi Electricity Sector: Pressing Issues and Challenges* (ifri Energie, 2015).

With the oil sector accounting for 42 percent of the country's GDP, it is evident that the Saudi economy is significantly dependent on the oil industry.[2] Oil revenues make up 87 percent of government revenues and account for 90 percent of the country's export earnings.[3] Thus, the downturn in the oil market, with prices falling from more than $100 per barrel in 2014 to around $50 in December 2016, has raised the country's budget deficit dramatically, and the Kingdom has been forced to tap into the global bond market to fix its finances.[4]

Coupled with this economic crisis, the country has been experiencing a surge in domestic energy demand. Electricity demand has been increasing in the Kingdom at a rate of 7.5 percent per year, while peak demand during summer has increased by 93 percent from 2004 to 2013.[5] Saudi Arabia has been relying on oil and gas to cope with its demand for electricity and desalinated water, missing out on opportunities to exploit the huge potential of renewable energy which could significantly contribute to electricity production. Recently, the Saudi government showed signs of an intention to change its domestic energy policies and focus on diversifying the country's energy mix.[6] In 2010, the King Abdullah City for Atomic and Renewable Energy (K.A.CARE)[7] was created to expand the Kingdom's power generation capacity through introducing solar, wind, geothermal, waste and nuclear power. According to K.A.CARE plans, nearly 50 percent of total electricity production in the Kingdom should come from non-fossil fuel sources, 17.6 GW from nuclear, and 41 GW from solar power (with 16 GW from PV and 25 GW from CSP) by 2030,[8] yet little has been done until now to execute these plans. Recently, the Deputy Crown Prince Mohammed bin Salman bin Abdulaziz Al-Saud launched

---

2. CIA, *The World Factbook 2016-17, Middle East, Saudi Arabia.* Central Intelligence Agency, 2016, https://www.cia.gov/library/publications/the-world-factbook/geos/sa.html.
3. Ibid.
4. *Financial Times,* November 9, 2015, https://www.ft.com/content/d1be572a-86fd-11e5-90de-f44762bf9896.
5. *Annual Statistical Booklet for Electricity and Seawater Desalination Industries* (Riyadh: Electricity & Cogeneration Regulatory Authority [ECRA], 2014).
6. Nachet and Marie-Claire Aoun, *The Saudi Electricity Sector: Pressing Issues and Challenges* (ifri Energie, 2015).
7. K.A.CARE was created by a Royal Order on April 17, 2010.
8. The date of the nuclear element of K.A.CARE's plans has been shifted to 2040. See World Nuclear Association, http://www.world-nuclear.org/information-library/country-profiles/countries-o-s/saudi-arabia.aspx. Also see K.A.CARE Vision, "Energy Sustainability for Future Generations," June 14, 2016, https://www.kacare.gov.sa/en/FutureEnergy/Pages/vision.aspx.

an ambitious plan: Saudi Arabia's "Vision 2030."[9] The plan aims to reduce Saudi Arabia's dependence on oil while simultaneously improving its investment status through opening up opportunities for the private sector, particularly in the energy sector. More importantly, the Saudi 2030 vision aims to redesign the energy subsidy system and promote the localization of the renewable energy value chain within the economy, with an initial target of generating 9.5 GW of electricity from renewable sources. The plan stipulates the local manufacture of parts of the renewable energy systems required by involving the private sector in research, development, and manufacturing. Moreover, a new city dedicated to energy will be created, and the legal and regulatory framework that allows the private sector to buy and invest in renewables will be reviewed as public private partnerships, and such activities will be encouraged.[10] Finally, according to the Saudi 2030 vision, the competitiveness of renewable energy shall be guaranteed through the gradual liberalization of the fuel market.[11]

Within the context of "Vision 2030," which highlights the Kingdom's willingness to add more and more renewable energies into the energy mix and signals the increasing need for conducting feasibility studies to support the energy transition within the country, this chapter presents a preliminary feasibility study for achieving high penetration of solar power in electricity generation in Saudi Arabia. Until now little has been done concerning renewable energy, with the total installed capacity not exceeding 17 MW, knowing that 125 MW is in the pipeline.[12,13]

In comparison, Germany's total installed capacity of solar power by 2014 was around 38.5 GW, where 1.4 million PV plants generated 35.2 TWh covering 6.9 percent of Germany's total demand. On sunny weekdays, PV was able to cover 35 percent of electricity demand. Moreover, the PV industry in Germany employed approximately 56,000 people in 2013.[14] Also, in the Arab world, Egypt is expecting to produce 20 percent of its needs from renewable sources with 12 percent coming from wind. In 2015, the Egyptian president declared that Egypt will pursue its strategies regarding implementation of renewable projects which include 4.3 GW

9. The "Vision 2030" document was approved by the cabinet on April 16, 2016. See K.A.CARE Vision, "Energy Sustainability for Future Generations."

10. K.A.CARE Vision, "Energy Sustainability for Future Generations."

11. Ibid.

12. Michelle Davis, et al., *Developing Renewable Energy Projects - A Guide to Achieving Success in the Middle East* (PwC, Eversheds, 2015).

13. Ibid.

14. Harry Wirth, *Recent Facts about Photovoltaics in Germany* (Fraunhofer ISE, 2015).

of generation capacity, 1.3 GW of solar, and 2.0 GW of wind using FIT (feed-in tariff)[15] schemes.[16]

Methodology

This chapter investigates the requirements and investments needed for high solar penetration in Saudi Arabia. An extensive desktop research was conducted covering the energy sector in general and electricity sector in particular. The data gathered included daily supply and demand patterns, weekly load patterns, demand increase rates, electricity demand by sector of activity, fuel and technology generation mix, and tariff structure. The research also looked at the institutional mapping of the energy sector, identifying all the key players, different organizations and institutions involved in production, transmission and sales, structure, regulating bodies if any, and governing laws and policies within the energy sector. The research also looked at Saudi Arabia's renewable energy plans including their quantitative goals and the technologies used and why they failed.

The second part of the research includes a technological review of renewable technologies in the world, mainly solar power, including PV (photovoltaics) and CSP (Concentrated Solar Power). This part focuses on usage, advancements in the technology in the last ten years, current and future cost projections, and adaptability to climatic conditions in Saudi Arabia. The current status of solar energy usage in different areas of the world is also investigated, with particular focus on countries like the United States for its PV and CSP projects, Spain for its fast deployment of CSP technology, and China for its high deployment of PV technology and manufacturing capacities. Special attention is given to the solar resources in Saudi Arabia, covering different regions, but also depending on availability of data regarding both DNI (Direct Normal Irradiance) optimal for CSP technology and GHI (Global Horizontal Irradiance) optimal for PV technologies (27 locations in the Kingdom are available from the ASHRAE website). This data was used for conducting the System Advisor Model (SAM) simulations which will be discussed later.[17]

15. Feed-in tariff is a scheme of offering long-term contracts to renewable energy producers.
16. Michelle Davis, et al., *Developing Renewable Energy Projects - A Guide to Achieving Success in the Middle East* (PwC, Eversheds, 2015).
17. *ASHRAE IWC2 Weather Files for International Locations,* White Box Technologies, 2008, http://ashrae.whiteboxtechnologies.com/.

Generally speaking, simulating the generation output of renewables is a complex process due to their variable nature and sensitivity to both location and time. However, the use of the SAM developed by the US National Renewable Energy Laboratory (NREL) can facilitate this task since it is one of the best available free software. It is designed to predict the performance and establish a business model of renewable energy systems. SAM does hourly calculations and predicts the energy output of the system, which can be viewed on different tables and graphs on an hourly, monthly, and yearly basis. Simulation can be applied to different technologies, photovoltaic systems (non-tracking, tracking, and concentrating) with battery storage, CSP including parabolic trough, tower using molten salt and direct steam, linear Fresnel and dish Stirling engine.[18]

For the purpose of this work, the simulations were carried out on imaginary solar plants in Saudi Arabia that are identical to currently operating plants around the world such as Noor I and II, solar CSP plants located in Morocco,[19] and the Cestas PV plant located in France, the largest European PV plant,[20] thus, simulating their energy output, the capacity factor, and the generation costs. Results are plotted on the estimated load duration curve (which is a sorted version of electricity load in 2030 estimated previously). Different deployment scenarios were studied, and the use of the duration and residual curves concept generally give a better visualization to renewable energy integration compared to conventional generation. Generation costs of different technologies were also calculated and compared, and screening curves of the different generation costs plotted. Screening curves are used to estimate the optimal generating mix for serving a load.

This chapter also examines the potential of coupling natural gas, which is available in large quantities in Saudi Arabia, and solar power to cover all of the electricity demand in the country by 2030, with a focus on technical feasibility and financial resources required. This scenario could offer a better alternative to other technologies including nuclear power, especially concerning cost, safety, and security. The study considers other impacting parameters such as advancements in storage technologies, interconnections with neighboring countries, and the deployment of

18. System Advisor Model (SAM) version 30.6.2015, National Renewable Energy Laboratory (NREL), https://sam.nrel.gov/, accessed June 20, 2016.
19. ACWA company website, "Projects around the World," http://acwapower.com/projects/, accessed June 20, 2016.
20. "France's 300 MW Cestas Solar Plant Inaugurated," *PV Magazine,* http://www.pv-magazine.com/news/details/beitrag/frances-300-mw-cestas-solar-plant-inaugurated_100022247/#axzz4Ncw8cZyf, accessed June 20, 2016.

smart grids on the electricity prospects in the Kingdom. Finally, the study puts forward the policy recommendations needed for an energy transformation in Saudi Arabia so as to enable high penetration of solar energy to cope with fast-growing energy demand, thus freeing more oil and gas for export.

The Energy Sector in Saudi Arabia

Oil prices have a huge influence on Saudi Arabia's budget. The oil price needed by the Kingdom to balance its budget has gone up during the last decade from $78 a barrel in 2012 to $89 in 2013, according to the IMF.[21] With oil trading around $40, Saudi Arabia's budget deficit for 2015 was estimated at 13 percent of GDP and should reach $87 billion in 2016. This would force the country to use its huge accumulated foreign currency reserves (estimated at $750 billion) to help it withstand the fiscal impact of low oil prices.[22]

Saudi Arabia produced an average of 11.6 million bbl/d of total petroleum liquids in 2013 of which 7.7 million bbl/d of crude oil were exported.[23] As for natural gas, production had reached around 102 billion cubic meters in 2013, growing at a rate of 6.8 percent during the last five years. Eighty six percent of the gas is associated gas, which exists as a joint product with oil (zero production cost),[24] providing 43 percent of Saudi electricity while oil provides the rest.[25] All the gas produced in the Kingdom is consumed domestically and is not exported.[26]

In order to meet the increasing demand for electricity, power generation capacity is expected to reach 120 GW by 2032.[27] This increase in electricity demand is driven by a number of factors. Firstly, since 1980, Saudi Arabia's population has increased by more than 180 percent.[28] Population growth has been a major contributor to energy demand since the residential sector consumes around 50

21. Said and Aoun, *The Saudi Electricity Sector.*
22. CIA, *The World Factbook 2016-17: Middle East, Saudi Arabia.*
23. EIA Country Analysis Brief: Saudi Arabia, US Energy Information Administration, http://www.eia.gov/beta/international/analysis.cfm?iso=SAU, accessed June 20, 2016.
24. Alyousef Yousef and Paul Stevens, "The Cost of Domestic Energy Prices to Saudi Arabia," *Energy Policy* 38 (2011): 6900-6905.
25. Christopher Segar, "Saudi Energy Mix: Renewables Augment Gas," International Energy Agency, November 3, 2014.
26. Rabia Ferroukhi, Arslan Khalid, Diala Hawila, Divyam Nagpal (IRENA), Laura El-Katiri, and Vasilis Fthenakis, *Renewable Energy Market Analysis: The GCC Region,* IRENA, 2016.
27. *Annual Statistical Booklet for Electricity and Seawater Desalination Industries.*
28. CIA, *The World Factbook 2016-17.*

percent of electricity production. Secondly, Saudi Arabia is a fast growing economy where large investments, encouraged by cheap energy prices, are made within the energy intensive industries which represent 9 percent of GDP.[29] Thirdly, a cheap energy market where electricity is sold at 0.09 $/kWh[30] has been one of the important economic factors behind rising energy consumption. Additionally, the Kingdom is known to be one of the largest subsidizers in the world with oil sector subsidies amounting to $46 billion and the electricity sector for $15 billion.[31]

The Electricity Sector

In 2014, the Saudi Electric Company (SEC) sold 274,503 GWh of power,[32] of which 50 percent was consumed by the residential sector, 21 percent by the industry, 15 percent by the commercial sector, and 12 percent by the government sector.[33] Between 2007 and 2014, peak load increased from 35 GW to 57 GW.[34] Energy consumption varies across the country with the highest rates in the western and central regions,[35] followed by lower rates in the eastern and southern regions that are less burdened by residential load.[36] This pattern originated with the setup of four distinctive companies for each region in the early days of electrification.

29. Nachet and Aoun, *The Saudi Electricity Sector.*
30. https://www.se.com.sa/en-us/customers/Pages/TariffRates.aspx.
31. Nachet and Aoun, *The Saudi Electricity Sector.*
32. *Annual Statistical Booklet for Electricity and Seawater Desalination Industries.*
33. Ibid.
34. Ibid.
35. Saudi Arabia is divided into four distinctive regions: East, West, Central and South.
36. *Annual Statistical Booklet for Electricity and Seawater Desalination Industries.*

Table 3.1: Electricity peak minimum and maximum and power sold in Saudi Arabia[37]

Year	Peak Max GW	Peak Min GW	Power Sold GWh
2008	37.15	20.46	187,163
2009	39.90	21.36	199,499
2010	43.90	23.60	218,254
2011	43.97	25.04	225,509
2012	50.75	28.10	246,610
2013	53.23	28.89	262,685
2014	56.83	31.88	281,155
2030	**120.00**	**60.00**	**560,000**

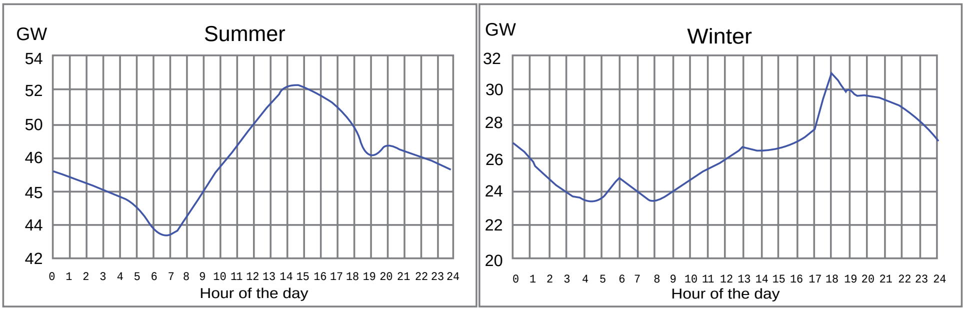
With the current pattern of consumption and no energy efficiency programs implemented, it is expected that the maximum peak power will reach 120 GW with the minimum peak power around 60 GW in 2030. The calculated ratio between low and high peak load for Saudi Arabia is 56 percent. This is considerably high compared to the US, for example, where peak load ratio now is between 27-33 percent.[38]

Peak and Hourly Load

The maximum peak load reached in Saudi Arabia was approximately 56.547 GW in 2014 occurring during week 36 of 2014 (September 1-7, 2014), while the minimum peak reached was 31.88 GW occurring during the first week of that same year (December 30-January 5, 2014). The high peak load occurred in summer and low peak load in winter. The difference between highest and lowest load in summer was 8.77 GW, the difference in winter was 7.55 GW.[39] The summer pattern is specific to a number of countries including the Gulf countries where air conditioning is widely used in summer and barely needed for heating in winter.

37. Ibid.
38. Shaalan Hesham, "Generation of Electric Power," in *Handbook of Electric Power Calculations,* edited by H. Wayne Beaty (McGraw-Hill Professional, 2001 Third Edition, Section 8).
39. *Annual Statistical Booklet for Electricity And Seawater Desalination Industries.*

Figure 3.1: Typical hourly load for summer (left) and winter (right)



This load configuration should offer an advantage for renewables, mainly solar, as the high load occurs in the summer, in step with the maximum output of solar PV or CSP systems. However, PV systems generally suffer from reduced power output during the summer due to high ambient temperature affecting the performance of solar cells. On the other hand, CSP systems are less affected by high ambient temperature but are more sensitive to weather conditions like haze or sandstorms which lower the performance of solar CSP plants.[40]

Generation Capacity and Technology

Saudi power generation capacity is built on conventional thermal plants fueled by a mix of crude oil, heavy fuel oil (HFO), natural gas, and other petro residuals.[41] Electricity generation in the kingdom is dominated by gas turbines, representing 60 percent of the total generation. Although they are less efficient (15-30 percent efficiency) than combined cycle or steam turbines, gas turbines offer a cheap alternative to cope with the increased energy demand, with the advantage of being able to run on different types of fuel (crude oil or associated gas) and operate without water for cooling which is a great advantage for Saudi Arabia.

SEC controls 71 percent of generation capacity while 16 other companies provide the remaining capacity.

40. "CSP Prospects in Saudia Arabia," www.csptoday.com/menasol2014, 2014.
41. Yousef and Stevens, "The Cost of Domestic Energy Prices to Saudi Arabia."

Table 3.2: Generation companies in Saudi Arabia

Producer	No. of Plants	Capacity MW	Percentage %
Saudi Electric Company	46	54,717	71%
Saline Water Conversion Corporation	6	4,761	6%
Hajr for Electricity Production Company	1	3,415	4%
Jubail Water & Power Company	1	2,875	4%
Saudi Aramco	8	1,927	3%
Durmah Electric Company	1	1,756	2%
Marafiq	1	1,589	2%
Rabigh Electric Company	1	1,320	2%
Shuaibah Water & Electricity Company	1	1,191	2%
Tihama Power Generation Company	4	1,083	1%
Shaqaiq Water & Electricity Company	1	1,020	1%
Rabigh Arabian Water and Electricity	1	600	1%
Jubail Energy Company	1	250	small
Saudi Cement Company	1	227	small
Tuwairqi Energy Company	1	73.5	small
Alaman Company	3	18	small
Obeikan Paper Industries Company	1	16	small
Total	**81**	**76,839**	**100%**

It is important to note that independent energy generation and water desalination companies as well as other industrial companies are sold fuel at a very low price. As shown in Table 3.3, the price of natural gas in Saudi Arabia was set around $0.75/million Btu in 2013, which was much lower than the average spot price set abroad.[42, 43] Such a very low price of oil influences the generation costs. The reference generation cost of the SEC in 2010 was 0.10 $/KWh[44] (see generation cost calculations in Appendix 1 and 2).

42. In comparison with an average of 3.75 USD/ MMBtu spot price at Henry Hub in the United States, 10.51 USD/MMBtu in the United Kingdom, and 15.96 USD/MMBtu in Japan.
43. EIA, "Country Analysis Brief: Saudi Arabia," US Energy Information Aministration, http://www.eia.gov/beta/international/analysis.cfm?iso=SAU, accessed June 20, 2016.
44. Yousef and Stevens, "The Cost of Domestic Energy Prices to Saudi Arabia."

Table 3.3: Prices for fuels paid by the power, water, and petrochemicals sectors

Type of fuel	Price in $/MMBtu
Methane and ethane	0.75 $/MMBtu
Arab light	4.24 $/bbl. (0.76 $/ MMBtu)
Arab heavy	2.67 $/bbl. (0.48 $/ MMBtu)
Diesel	0.65 $/MMBtu
HFO 360cst	0.36 $/MMBtu

Source: Council of Ministers Resolution No. 55 and Electricity & Co-generation Regulatory Authority (ECRA) and author calculations

Electricity Regulatory Framework

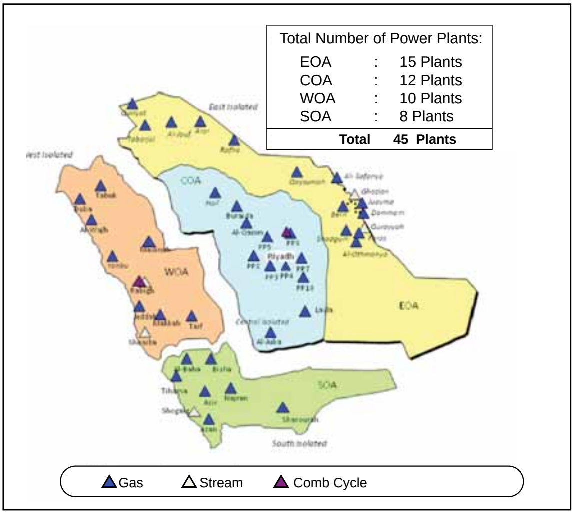
Saudi Arabia's electricity sector is essentially managed by SEC, a single, vertically integrated electricity company, which owns most of the generation capacity. SEC also controls the National Electricity Transmission Company (NETC) that is responsible for transmission and distribution of electricity in the Kingdom.[45]

As part of the restructuring efforts of the electricity sector in Saudi Arabia, the Electricity & Co-generation Regulatory Authority (ECRA) was created in 2002, with the aim of regulating the electricity and water desalination sectors, ensuring reliability, affordability, and quality of service and providing the regulatory framework for the energy sector according to Saudi laws and best practices.

The Saudi government's reforms in the electricity sector are pushing for the full unbundling of the sector into three parts: generation, transmission, and distribution. This could facilitate the entry of new producers including renewable energy producers thereby increasing efficiency and decreasing government spending in the sector.[46]

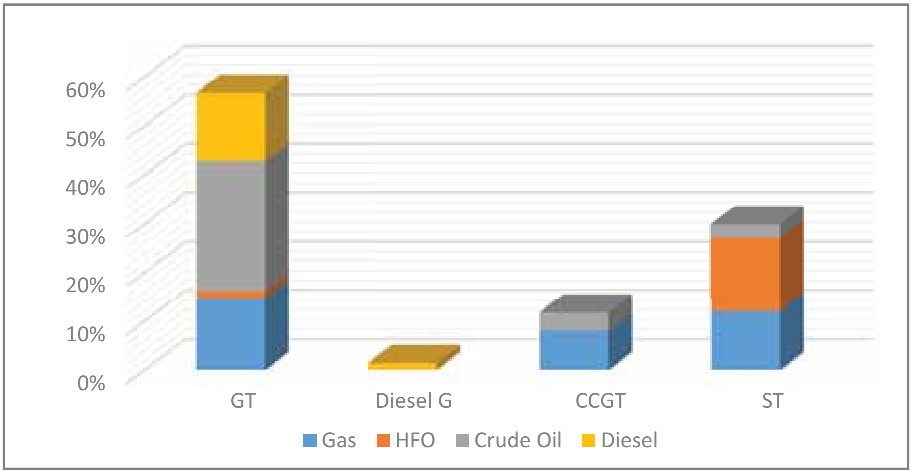
45. Nachet and Aoun, *The Saudi Electricity Sector*.
46. Shaalan Hesham, "Generation of Electric Power."

Figure 3.2: Power plants in Saudi Arabia in 2011



Source: Saudi Electricity Company. Annual reports 2011/2010/2009; 2011.

Figure 3.3: Electricity generation in Saudi Arabia by type of fuel and generation technology (ST steam turbine, CCGT Combined cycle gas Turbine, GT Gas Turbine, Diesel Generators)



Technology Overview

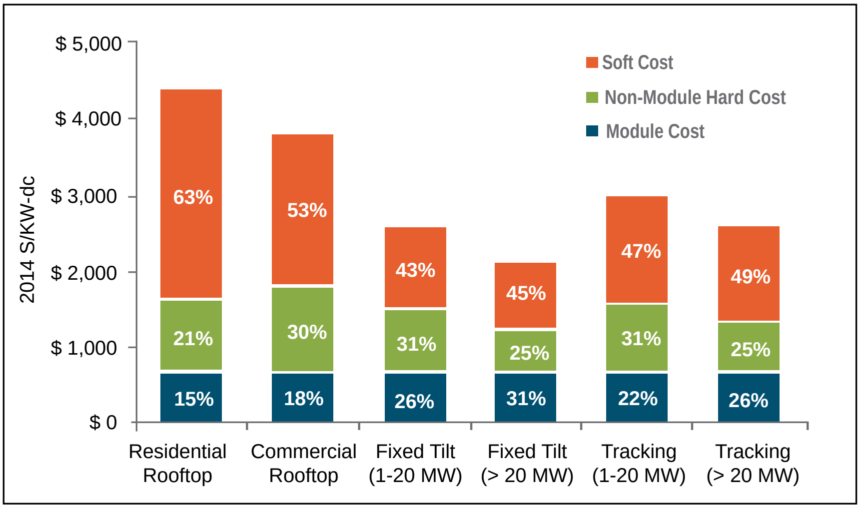
There are a number of technologies which can be used to generate electricity from the sun. The most widely used are solar PV and CSP:

Photovoltaics (PV)

Solar Photovoltaics is the most widely used solar technology directly converting sunlight into electricity.[47] There are different PV technologies commercially available, mainly those based on crystalline silicon cells (representing approximately 85 percent of the global market) and thin-film cells, including amorphous silicon (a-Si) and cadmium telluride (CdTe). A number of new technologies are being developed and commercially tested.[48]

A photovoltaic module is made up of several PV cells which are wired together and encapsulated to form PV modules. A typical PV project would include tens to thousands of modules connected in arrays generating DC (Direct Current), which is then converted to AC (Alternative Current) by an inverter which can be used with ordinary electric equipment.

Figure 3.4: Estimated breakdown of module and non-module "soft" and "hard" costs by solar PV segment



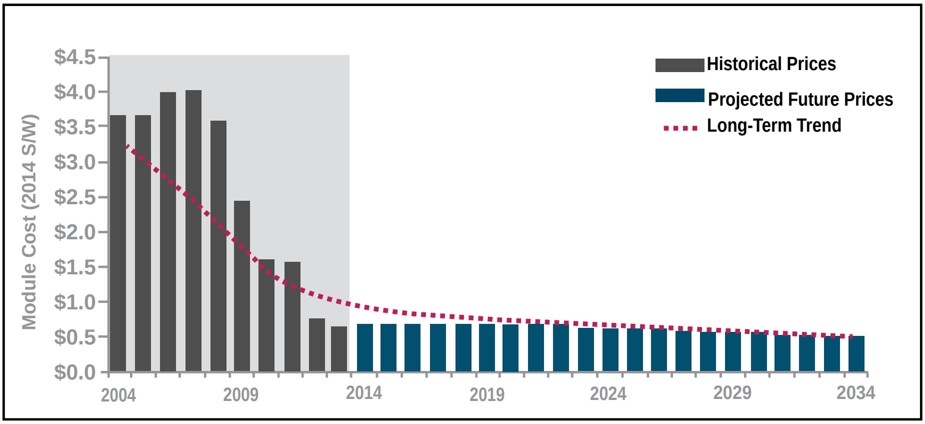
PV project costs are divided into module costs (direct cost of photovoltaic modules, non-module); "hard" costs (costs of inverter, racking, electrical equipment, etc.); and "soft costs" (labor, permitting fees, etc., as seen in Figure 3.4).[49]

47. "CSP Prospects in Saudia Arabia," www.csptoday.com/menasol2014, 2014.

48. "Renewable Electricity Futures Study," *Volume 2: Renewable Electricity Generation and Storage Technologies*, National Renewable Energy Laboratory, 2012.

49. Arne Olson, Nick Schlag, Kush Patel, and Gabe Kwok, "Capital Cost Review of power Generation Technologies," prepared for the Western Electric Coordinating Council, Energy

Figure 3.5: Historic and projected solar PV module prices based on observed learning curve



Module prices have followed a learning rate of 20 percent over the long term for the last 10 years, with price currently below the learning curve because of disruption in the demand and supply (in 2013, the European Union imposed anti-dumping and anti-subsidy duties on imports of solar cells and solar panels from China).[50] Non-module prices, which are also known as BOS (Balance of System), are also decreasing, nearly at the same rate. BOS costs are often higher than module costs, adding approximately $1/W to $4/W depending on system size, location, and project margins.[51] Future improvements in the PV technology cost should come from a combination of improving power electronics, reducing supply chain complexity and cost, and decreasing installation costs and margins as markets mature.[52]

Different capital costs of PV system were suggested with 3,080 $/kWac (for monocrystalline ordinary cell, 1.4 inverter loading and non tracking) and 25 $/kW-yr. for Operations & Maintenance.[53] Another older source suggests a capital cost for a PV system at 3,300 $/kWac with same specifications and 48 $/Kw-yr. O&M.[54]

and Environmental Economics, Inc. 2014.

50. http://trade.ec.europa.eu/doclib/press/index.cfm?id=1461.
51. "Renewable Electricity Futures Study," *Volume 2: Renewable Electricity Generation and Storage Technologies.*
52. Ibid.
53. Olson, Schlag, Patel, and Kwok, "Capital Cost Review of Power Generation Technologies."
54. "Renewable Electricity Futures Study," *Volume 2: Renewable Electricity Generation and Storage Technologies.*

Newer projects tend to use lower prices. For example, the Dewa project in Dubai (260 MW) is priced at $328 million giving a capital cost of 1,225 $/kW (thin film technology), and the plant is expected to produce electricity at a world record of 5.85 cent/kWh.

Prices are influenced by the project location just as the hard and soft non module prices are influenced by the country of origin. In Saudi Arabia, these costs should be less than those in the US and Europe. Costs should decrease even further as more PV projects are installed and some parts of the PV system are manufactured locally, and a capital cost between 2,000-3,000 $/kW should be within an acceptable range.

A lot of research is being conducted to increase the efficiency of the solar cells and modules, and solar module efficiencies could reach 21.5 percent in the near future, corresponding to an approximate cell efficiency of 24 percent. These achievements should help in increasing the energy yield and thus reducing prices.[55]

Concentrating Solar Power (CSP)

CSP technologies are indirect solar technologies as they use mirrors or lenses to focus sunlight onto a solar receiver containing thermal fluid that is used to transfer the thermal energy to a closed-cycle heat engine to drive the electrical generator. The presence of thermal fluid provides the possibility of adding an energy storage tank and/or a natural gas backup boiler to provide electricity even in the absence of the sun, thus improving the capacity factor[56] of the system. CSP systems with storage are operating in Spain (Andasol 1 and 2) with a storage capacity of 7 hours.[57]

CSP can be divided into different technologies: parabolic trough concentrators that use linear receiver with 1-axis tracking to collect concentrated sunlight; and solar power towers systems that use flat mirrors (heliostats) arrays with 2-axis tracking the sun into a fixed central receiver; linear Fresnel systems use a fixed linear receiver and an array of heliostats with 1-axis tracking system; and finally dish concentrators that use a dish with a 2-axis tracking system. Parabolic trough collectors were put into commercial use in 1984 and currently account for 96 percent of the global CSP deployment. CSP differs from PV systems (non-concentrating), firstly, in that

55. "CSP Prospects in Saudia Arabia." www.csptoday.com/menasol2014, 2014.
56. Capacity Factor of a power plant is the ratio of its actual output over a period of time to its potential output if it were possible for it to operate at full nameplate capacity.
57. "Renewable Electricity Futures Study," *Volume 2: Renewable Electricity Generation and Storage Technologies.*

it can only use direct solar radiation which makes it less effective in intermittent cloud cover or hazy skies. Secondly, CSP is very sensitive to scale which means that systems need to be large (tens of megawatts or larger) to be economically feasible in terms of maximizing efficiency and minimizing costs, in contrast to PV systems that can be installed anywhere at scales ranging from a few kilowatts to hundreds of megawatts. A third challenge for CSP deployment is the large land and water requirements of large scale CSP plants. Based on past projects and studies, three hectares (30,000 m^2) are needed per megawatt of CSP capacity.[58]

Different capital costs of the CSP trough system were suggested: 5,000 $kW for Trough/Tower without storage and 6,800 $/kW for Trough/Tower with storage, and 60 $/kW-yr. O&M costs[59] and for dry cooling the cost is multiplied by 1.4.[60] Other sources recommend a capital cost of 8,000 $/kW for CSP with six hours of storage. These values vary and are very much dependent on the technology used and project site (land, connection to grid, and labor).

CSP can still be improved significantly, with substantial opportunities for technology advances that would reduce the capital costs considerably. This can be achieved mainly through the use of heat transfer fluids that could operate at higher temperatures, which would improve efficiency (reducing collector area and storage volumes); better system design (including optimal mirror sizing, advanced receiver coatings; low cost foundations and support structures); and better storage systems that use higher temperature and phase change materials. Cost reduction potential estimates are in the range of 15 percent in the short term (five years) and 30 percent in the long term (20 years).[61]

Motivations for Solar Power Deployment in Saudi Arabia

Saudi Arabia has many reasons for deploying renewable energy systems. Aside from meeting the increasing energy demand, integrating renewables in the Kingdom's current energy mix would be both beneficial economically and from a sustainability point of view. Saudi Arabia has one of the highest potential of solar energy in the region where annual solar radiation is around 2,200 kWh/m^2, and the total

58. "CSP Prospects in Saudia Arabia."
59. Olson, Schlag, Patel, Kwok, "Capital Cost Review of Power Generation Technologies."
60. *Cost and Performance Data for Power Generation Technologies,* (Overland Park, KS: Black & Veatch, 2012).
61. Olson, Schlag, Patel, Kwok, "Capital Cost Review of Power Generation Technologies."

estimated potential energy that could be produced using CSP is 124,560 TWh which is by far greater than the country's annual energy demand.[62]

Moreover, renewable energy industries, in the case of high penetration (20 percent to 30 percent penetration till 2030), could drive economic diversification of the country and create employment opportunities and alleviate unemployment which is around 11.4 percent of the total population.[63] Moreover, introducing renewables into the Saudi market would further facilitate the implementation of climate change policies, which would allow the government to address the fact that the country is among the top 15 of the world highest carbon dioxide emitters per capita.[64]

Solar Resources in Saudi Arabia

Saudi Arabia is located in the Arab peninsula between latitudes 31 and 17.5-degree north, 50 and 36.6 degree east, with a variation of altitude between 0 and 2680 meters above sea level. Two seasons are observed in Saudi Arabia, winter and summer, and the vast areas of the country experience high solar intensities and long hours of sunshine with an average annual solar radiation of 2,200 kWh/m^2.[65]

Until 2013, only limited or outdated measures of the solar resource data were available for Saudi Arabia, and solar data for different locations were estimated using satellite observations. This type of data cannot be used for the design of large projects which generally require accurate long-term ground based data. However, Saudi Arabia has now equipped 30 meteorological stations and conducted more accurate measurements including one-minute measurements of Global Horizontal Irradiance (GHI), Diffuse Horizontal Irradiance (DHI), and Direct Normal Irradiance (DNI).[66]

Global Horizontal Irradiance ranged from 5,700 Wh/m^2 (average yearly totals of 2,080 kWh/m^2 yr.) to the highest 6,700 Wh/m^2 (average yearly totals of 2,445

62. A. Farnoosh, F. Lantz, & J. Percebois, "Electricity Generation Analyses in an Oil-exporting Country: Transition to Non-Fossil Fuel Based Power Units in Saudi Arabia," *Energy* 69 (2014): 299–308.
63. CIA, *The World Factbook 2016-17.*
64. Davies, *Developing Renewable Energy Projects.*
65. Arif Hepbasli and Zeyad Alsuhaibani, "A Key Review on Present Status and Future Directions of Solar Energy Studies and Applications in Saudi Arabia," *Renewable and Sustainable Energy Reviews* 15, no. 9 (2011): 5021–5050.
66. *Renewable Resource Atlas,* K.A.CARE King Abdullah City for Atomic and Renewable Energy, https://rratlas.kacare.gov.sa/RRMMPublicPortal/.

kWh/m^2 yr.) with higher values in inland areas and lower values found on the coast, showing the possibility of using PV systems anywhere in the country, though with decreased performance in areas subjected to high temperatures (over 30 degrees Celsius annual average). CSP technologies, which use DNI values, can be used effectively around the country, with the western inland area with average daily total of over 6,474 Wh/m^2 and an average yearly total of 2,400 kW h/m^2/yr. being better than eastern areas with an average daily total closer to 5,510 Wh/m^2 and average yearly totals of 2,000 kWh/m^2/yr.[67] For the purpose of this study, solar irradiance data was obtained from ASHRAE[68] weather data for 30 locations in the Kingdom.[69]

Renewable Energy Framework and Deployment Scenarios

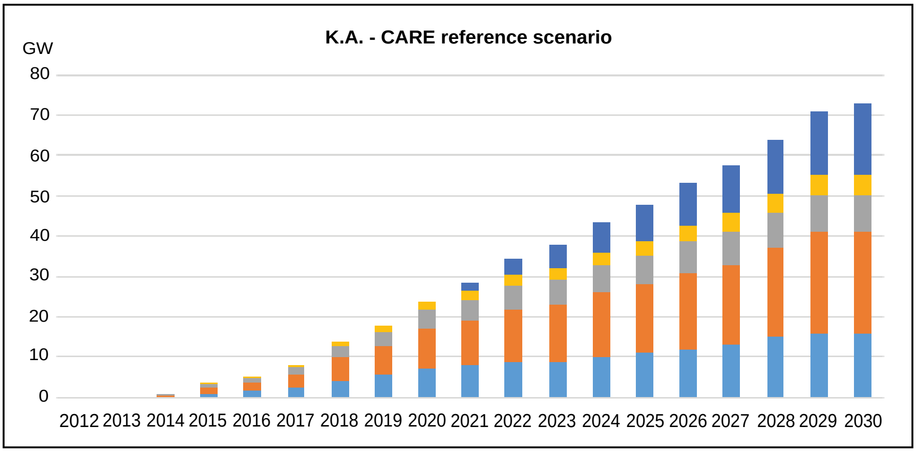
In order to benefit from the tremendous potential of renewable energy in Saudi Arabia, the King Abdullah City for Atomic and Renewable Energy (K.A.CARE)[70] was created in 2010, with the mission of being "the driving force for making atomic and renewable energy, an integral part of a national sustainable energy mix, creating and leveraging the competitive advantages of relevant technologies for the social and economic development of the Kingdom of Saudi Arabia."[71]

K.A.CARE produced an ambitious plan in 2012 to expand the country's power generation capacity through introducing solar, wind, geothermal, waste and nuclear power. By 2032, nearly 50 percent of total electricity production in Saudi Arabia should come from non-fossil fuel sources, 17.6 GW from nuclear, and 41 GW from solar power (with 16 GW from PV and 25 GW from CSP).[72]

---

67. Erica Zell et al. "Assessment of Solar Radiation Resources in Saudi Arabia," *Solar Energy* 119 (2015): 422-438.
68. "Issam Fares Institute for Public Policy and International Affairs"
69. *ASHRAE IWC2 Weather Files for International Locations.*
70. As mentioned earlier, K.A.CARE was created by a Royal Order on April 17, 2010.
71. "PV Guide to the MENA Region," www.pv-insider.com/mena, 2013.
72. Nachet and Aoun, *The Saudi Electricity Sector.*

Figure 3.6: K.A.CARE renewable scenario: Deployments of renewables and nuclear



In 2013, K.A.CARE published a white paper giving some details on the procurement process for renewable energy deployment and outlining an introductory round of 500–800 MW projects, then a first round of 2,000–3,000 MW projects, and a second round of 3,000–4,000 the MW and so on to reach the plan's targets.[73] Little has been done for the execution of the plan[74] and some argue that K.A.CARE's plan was intended as a scenario rather than an official target. The initial K.A.CARE plan was to produce 9.5 GW of power from PV and 54 GW from renewables by 2030. Reports say the first target has been postponed to 2030 and the latter to 2040.[75]

On April 25, 2016, Deputy Crown Prince Mohammad bin Salman Al Saud launched the "Vision 2030" plan with the aim of reducing the country's dependence on oil while simultaneously improving its investment status through opening up opportunities for the private sector and transforming the energy sector by increasing the capacity generated from renewable energy sources. The plan also aims to redesign the energy subsidy system and the localization of the renewable energy value chain within the economy, with an initial target of generating 9.5 GW of electricity from renewable sources.[76] The plan also stipulates local manufacture

73. Davies, *Developing Renewable Energy Projects.*
74. Nachet and Aoun, *The Saudi Electricity Sector.*
75. Ferroukhi, Khalid, Hawila, Nagpal (IRENA), El-Katiri, Vasilis Fthenakis, "Renewable Energy Market Analysis: The GCC Region," IRENA, 2016.
76. Vision 2030 Kingdom of Saudia Arabia, http://vision2030.gov.sa/en.

of parts of the renewable energy systems required by involving the private sector in research, development, and manufacturing. Moreover, a new city dedicated to energy is to be created.

In this context it, it is important to cite the different organizations and institutions involved in the field of renewable energy in the Kingdom like King Abdul Aziz City for Science and Technology (KACST), which is an independent scientific organization administratively reporting to the Prime Minister. KACST has been involved in the development of renewable energy in the Kingdom for a long time. It also acts as the national science agency of the Kingdom. The second important organization Saudi Arabia Solar Industries Association (SASIA) is a non-profit, non-governmental body promoting solar power in Saudi Arabia and across the Middle East.[77] There is a lack of coordination between the different organizations working in the field of renewables in Saudi Arabia, with overlapping objectives. For a fast renewable energy penetration in the country, better coordination and division of responsibilities will be needed. It is also important to emphasize that within the new energy framework, Saudi Aramco, which is the Saudi national petroleum company and the largest oil exporter company in the world, should play a major role in the transformation of the energy sector.[78]

Status of Current Renewable Projects in Saudi Arabia

The amount of electricity generated by solar technologies in Saudi Arabia is almost negligible, and renewable projects are still small in number and capacity. Initially, small scale PV projects were built to provide power for the petroleum industry in remote areas (cathode protection of petroleum pipelines).

Currently, total installed capacity of renewable energy does not exceed 17 MW. Projects of 125 MW are in the pipeline, not taking into account the projects stipulated in the K.A.CARE plan Round 1, which was put on hold. In comparison, Saudi Arabia's neighbor, the United Arab Emirates (UAE), which has only 3 percent of the kingdom's total area, has an installed capacity of 125 MW, 270 MW in the pipeline, and a planned capacity of 2,248 MW by 2020.[79]

77. "PV Guide to the MENA Region."
78. Vision 2030 Kingdom of Saudia Arabia, http://vision2030.gov.sa/en.
79. *Developing Renewable Energy Projects – A Guide to Achieving Success in the Middle East* (PwC, Eversheds, 2015).

Table 3.4: Status of renewable energy projects as of 2014[80]

Project	Technology	Status	Size	Location
SEC - Duba Integrated Solar Combined Cycle (ISCC) Power Plant Phase I	CSP	Under construction	50 MW	Dubai
Saudi Aramco - KAPSARC	PV	Complete	3.5 MW	Riyadh
KAPSARC II	PV	Complete	1.8 MW	Riyadh
SEC - Farasan Island Solar Project	PV	Complete	500 kW	Farasan Island
KAUST	PV	Complete	2 MW	Thuwal
North Park	PV	Complete	10 MW	Dhahran
Tabuk KJC CPV	PV	Execution	1 MW	Tabuk

The System Advisor Model (SAM)

As discussed earlier in the methodology section, the System Advisor Model (SAM) was used to simulate the energy output for two imaginary solar power plants located in different regions of the country. Ten locations were chosen covering all the regions as shown in Table 3.5.

Table 3.5: Regions in Saudi Arabia with available weather data

	City	North°	West°	Altitude m	Zone
1	Abha	18.233	42.65	2093	South
2	Al Baha	20.3	41.65	1652	South
3	Al Madinah	24.55	39.7	636	West
4	Arar	30.9	41.13	549	East
5	Dhahran	26.267	50.167	17	East
6	Hail	27.433	41.683	1002	Middle
7	Jeddah(King Abdul)	21.7	39.183	17	West
8	Makkah	21.433	39.767	240	West
9	Riyadh Obs(Oap)	24.7	46.733	620	Middle
10	Tabuk	28.383	36.6	768	West

Simulations for the PV system were carried out on a 300 MW PV plant with the following parameters (Standard PV module, DC to AC ratio 1.4, fixed open track installation, and losses amounting to 16.1 percent). Simulation results for the PV system showed that there is little disparity in energy output between the different regions of the Kingdom; Abha showed better results than other areas as

80. Davies, et al. *Developing Renewable Energy Projects.*

the solar irradiance was higher and the daily mean temperature lower because of altitude. Also, there is little difference in the energy output between summer and winter. Capacity factor for the PV systems varied from 18.9 percent for Abha and 15 percent for Makkah, confirming the effect of temperature and weather conditions (see Figure 3.7).

For the CSP system, a 160 MW generic system with six hours of storage was chosen. Simulation results showed that the CSP system performed better than the PV system in general, with a capacity factor ranging from 37.3 percent to 26.4 percent for a CSP system with no storage. These values increased when six hours of storage was added to reach 63.5 percent in the best case and 47.5 percent for the worst, showing clearly that CSP systems are superior to PV in terms of providing higher energy output and a higher capacity factor.

Figure 3.7: Simulation results of PV system and monthly output for different locations in the Kingdom, SAM simulation

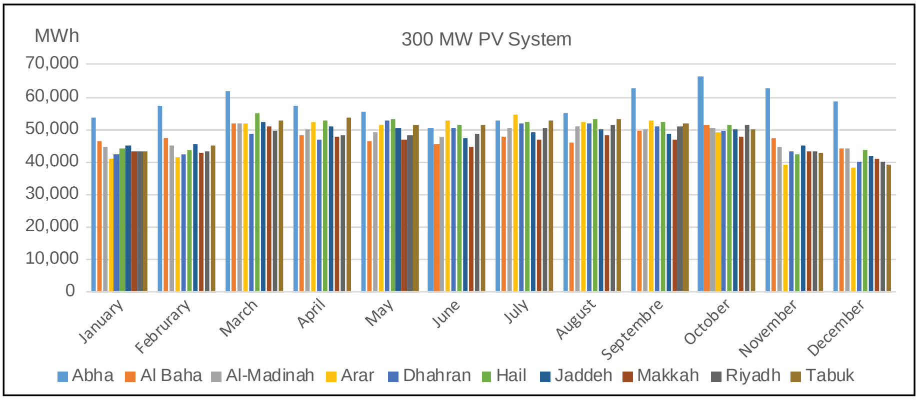
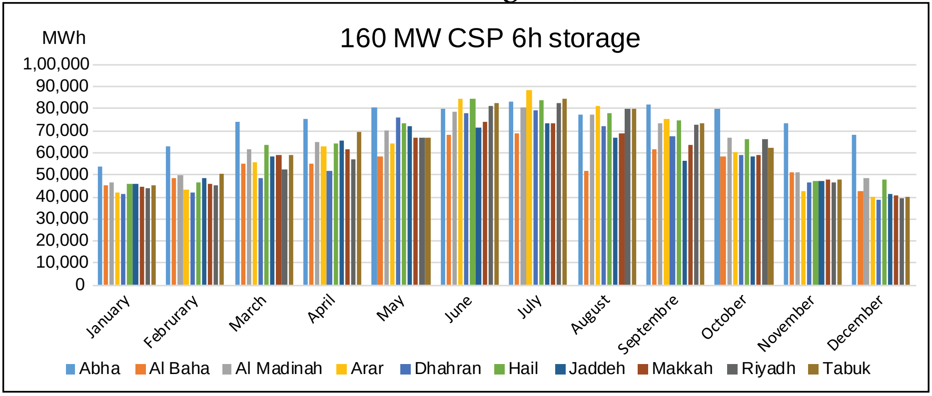


Figure 3.8: Simulation results of 160 MW CSP plant and monthly output for different locations in the Kingdom, SAM simulation



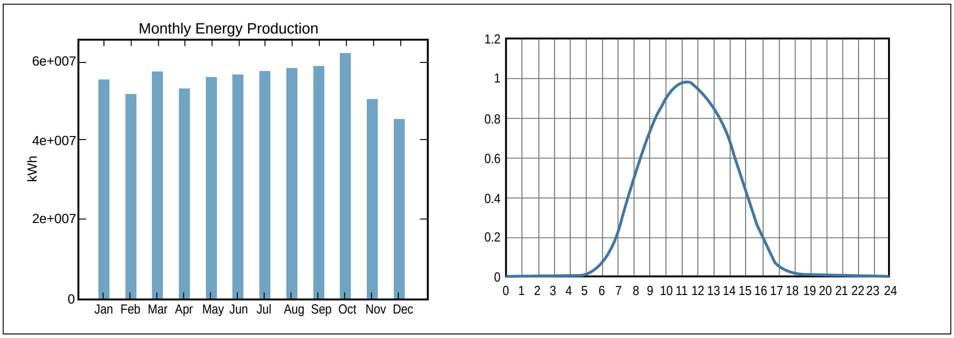
To conduct further simulations and calculate the levelized cost of electricity (LCOE), the Riyadh region was taken as reference (as it represents the average energy output among the different studied regions). For the financial calculations, a capital cost of 2,500 $/kW for 300 MWe PV plant with no tracking was used, 2,800 $/kW for one-axis tracking, a fixed operating cost of $25/kW-yr. for both systems, and an interest rate of 4 percent. These values represent the average capital cost from now until 2030.[81]

Table 3.6: Simulation results for 300 MW PV plant located in Riyadh region using SAM

	Non tracking	One-axis tracking
Annual energy produced MWh	568,951	656,871
Capacity factor %	15.5	17.9
LCOE cent / kWh	9.23	7.98

The results show that adding one-axis tracking, despite being more expensive, increases the annual energy output while reducing the LCOE (see Table 3.9).

Figure 3.9 Monthly (left) and daily (right) energy output from 300 MW PV plant, SAM simulation

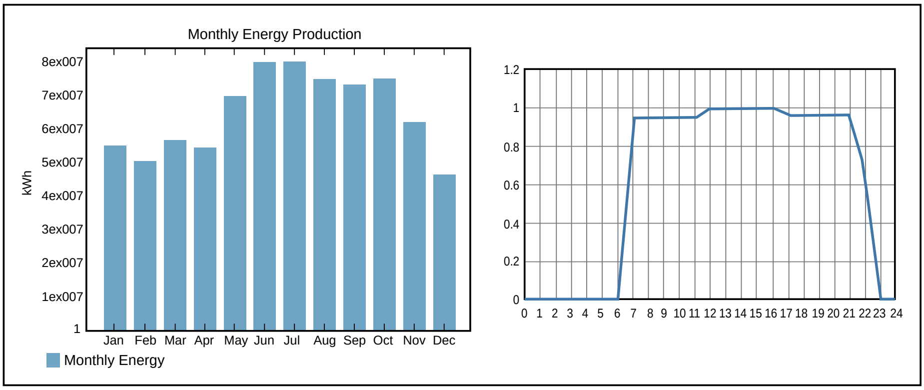


81. Olson, Schlag, Patel, and Kwok, "Capital Cost Review of Power Generation Technologies."

Table 3.7: Simulation results for 160 MW CSP 6 hour storage plant located in Riyadh using SAM

	CSP with no storage	CSP with 6 hour storage
Annual energy produced MWh	516,053	734,356
Capacity factor %	36.8	52.4
LCOE cent /kWh	12.07	9.67

Figure 3.10 Monthly (left) and daily (right) output from 160 CSP plant 6 hour storage, SAM simulation



For CSP systems, a capital cost of 5,000 $/kW for a plant with capacity of 160MWe with no storage was used (and 10,000 $/KW for six hours' storage) and the interest rate used was 4 percent. These values represent the average capital cost from now until 2030.

Load Duration Curve

Any electric power system should always match the electricity demand which is the total consumption of thousands of users, from individual households to the large commercial and industrial enterprises. The electricity is generated by large power plants which use different types of technologies with different fixed and running costs. Thus, the aim of any electricity company is to optimize the overall cost of production of these different technologies and rank them accordingly.

Electricity demand (defined as load) fluctuates across the year. It never drops to zero as there is always a minimum load known as the baseload. The baseload is usually covered by baseload power plants, such as steam plants and nuclear power plants characterized by high capital costs and low variable costs (fuel costs). On the other hand, the peak load which occurs for shorter periods than the baseload needs to be instantly and continuously covered by peak power plants, such as gas turbines, characterized by low capital costs and high variable costs.[82]

Unlike dispatchable[83] fossil fuel generators, power generation from renewable sources such as wind and solar power vary continuously depending on weather conditions. As the penetration of renewable technologies increases within the electrical system, the variable nature of their output will become a more important feature of power systems and will have an impact on the capacity needed to be installed to meet peak system demand taking into account the variability of renewable sources.[84] To visualize the interaction between the two types of generation, the load duration and residual curves are used.

A load duration curve (LDC) is a representation that shows the number of hours of the year at which the load is equal to or above a given value. To build a load duration curve, the peak loads of the system in percentage or in GW are sorted in a decreasing order which makes it easy to see when the load exceeds a certain level. A flat load duration indicates a better grid where less dispatchable generation will be needed.

From the load function, it is easy to derive the duration curve which represents the cumulative amount of time during which demand exceeds a certain level, while the area under the curve represents the total energy produced in kWh/yr., MWh/yr. or GWh/yr.[85]

$$LDC(t) = sort\ [(Load\ (t)]$$

Adding renewables to the load curve poses some challenges in dealing with the variability. However, using a method derived from the duration curve, it is possible to define a residual load duration curve for residual demand:

$$ResLDC(t) = sort[Load(t) - Generation\ RES(t)]$$

This residual function is obtained by sorting the output of the renewable plants and the load duration curve, with the area between the two curves representing the demand fulfilled by generation from renewable sources. The resulting curve

82. Hesham, "Generation of Electric Power."

83. Dispatchable generation is a source of electricity that can be started or dispatched upon the request of the power grid or the plant owner.

84. P. Sullivan, K. Eurek, and R. Margolis, "Advanced Methods for Incorporating Solar Energy Technologies into Electric Sector Capacity-Expansion Models: Literature Review and Analysis," NREL, 2014, NREL/TP-6A20-61185.

85. Masters M. Gilbert, *Renewable and Efficient Electric System* (John Wiley & Sons, Inc., 2004).

represents the new duration curve which must be met through other sources of generation.

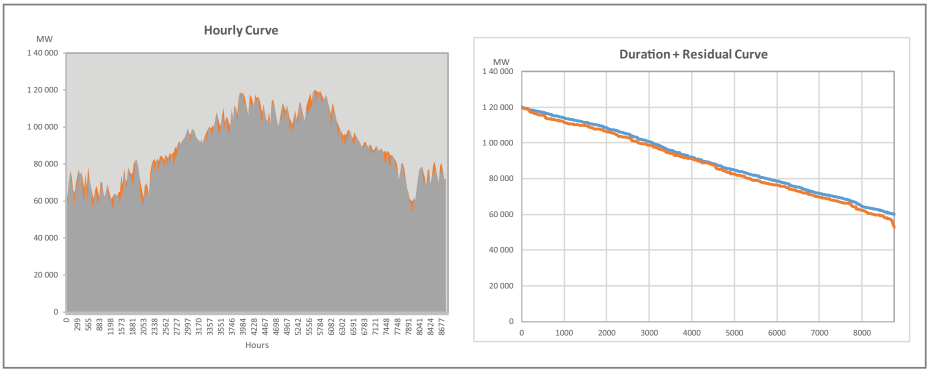
Screening Curves with Merit-Order Dispatch

Screening curves are generally associated with load duration and residual curve and are used to estimate the optimal generating mix for serving a load assuming the lowest-cost units sufficient to meet demand are always selected for dispatch (merit-order). Screening curves are very useful tools for capacity expansion planning[86] and determining the costs of generation of different technologies. This simplified approach does not take into consideration the starting cost, ramping constraints, and other system considerations like transmission losses.

Results

To study the different high penetration scenarios of solar energy in the Saudi electricity sector, the duration curve for Saudi Arabia was plotted using the hourly load variations of 2009 to represent the 2030 load[87] assuming no change in the consumption patterns and no implementation of an energy efficiency program and maximum peak load for 2030 as 786,484 GWh. Then, the residual duration curve for 2030 is the duration curve minus the power generated by renewable sources simulated on hourly basis.

Figure 3.11: Duration and residual curve for 9.5 GW PV "Saudi Vision 2030"



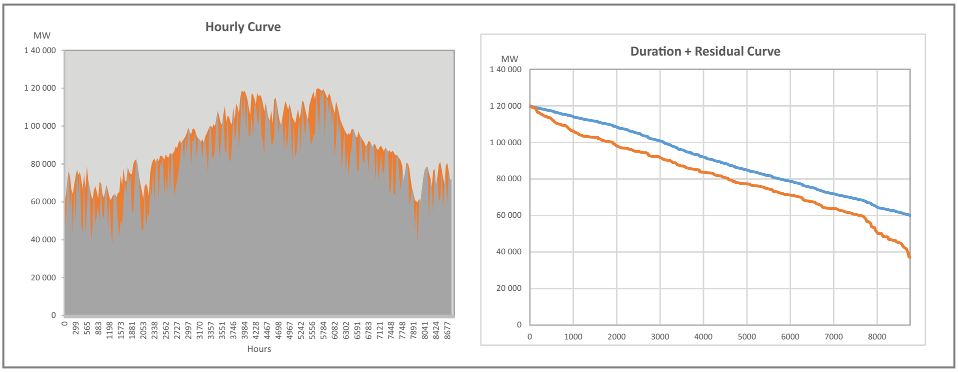
Source: Author calculations

86. Sullivan, Eurek and Margolis, *Advanced Methods for Incorporating Solar Energy Technologies into Electric Sector Capacity-Expansion Models:* "Literature Review and Analysis."
87. Farnoosh, Lantz, & Percebois, "Electricity Generation Analyses in an Oil-Exporting Country."

The effect of the deployment of 9.5 GW of PV, which represents 7 percent of the peak load of 2030, on the duration curve is minimal (see Figure 3.11), with 18,685 GWh of electricity generated from renewables representing only two percent of total electricity needs, representing a saving of 68,049 barrels of oil daily (using actual heating rate for the calculation).

Another deployment scenario, which offers a compromise between the very ambitious K.A.CARE deployment plan and the Saudi Vision 2030's modest targets, is the deployment of 16 GW of PV and 10 GW of CSP with six hours of storage (see Figure 3.12). For this deployment, the effect on the duration is still significant with 75,692 GWh generated by renewables sources representing nearly 9 percent of electricity needed, which represents 275,661 barrels per day.

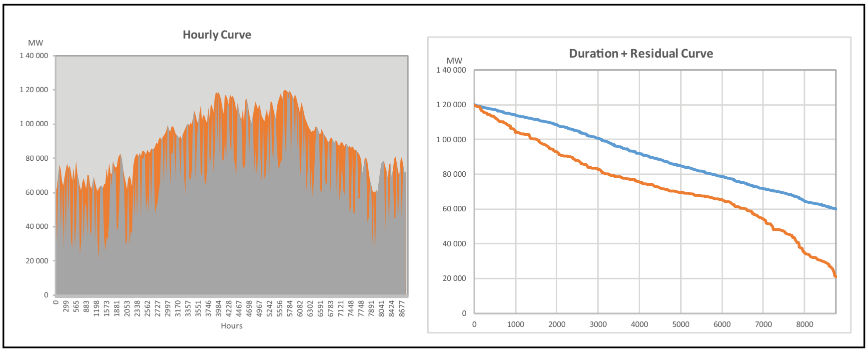
Figure 3.12: Duration and residual curve for a modified plan 26 GW of solar renewables (16 PV and 10 GW CSP with 6 hours' storage)



Source: Author calculations

The third scenario is the implementation of the solar part of the K.A. CARE plan, which stipulated the generation of 41 GW of electricity from solar resources with 16 PV and 25 CSP, plotting the results on the 2030 duration curve. The effect on the duration curve is huge (see Figure 3.13), with 141,934 GWh of the electricity generated from solar representing 18 percent of the total electricity needs, which represents 516,906 barrels per day.

Figure 3.13: Duration and residual curve for K.A.CARE plan 41 GW of solar renewables (16 PV and 25 GW CSP with 6 hours' storage)



Source: Author calculations

Cost of Generation

After studying the output and the cost of different renewable resources, it is important to understand the cost of electricity generation using conventional systems in Saudi Arabia. As predicting the oil prices in 2030 is difficult, calculations were made taking the 2014 average prices of petroleum products and using different capital costs of generation, operation maintenance costs, and heat rate of different generation technologies. The results are shown in Appendix 1, 2 and in Figure 3.12.

In 2014, the prices of oil and gas were relatively high compared to 2016, with the average price of a barrel of oil averaging $96.24.[88] However, these prices do not reflect the real price paid by the Saudi operators and SEC to the government for subsidized fuel (see Table 3.3) resulting in very low generating prices where renewables cannot compete.

Table 3.8: Cost of generation in Saudi Arabia of different technologies using subsidized prices

Fuel/ Technology	Gas-light oil / GT	Gas-light oil/ CCGT	Heavy Oil/ ST	Diesel/ Diesel
Fixed Cost ($/MWh)	10.37	17.35	14.77	66.98
Var. Cost(US$/MWh)	37.69	8.70	8.23	21.50
LCOE (cent/kWh)	4.81	2.60	2.30	8.85

88. International prices of imported raw materials - Brent crude oil (London) - Prices in US dollars per barrel - Information, *Insee Instut national de la statistique et des etudes economiques.* http://www.insee.fr/en/bases-de-donnees/bsweb/doc.asp?idbank=000455743, accessed June 20, 2016.

These results show that renewable energy sources within the context of government subsidies cannot compete with conventional sources as the latter's generation costs are lower. It also shows that gas fired CCGT and heavy oil steam turbine (despite heavy environmental burden) offer the best baseload option even when compared to nuclear energy.

Any new investments in the power sector in Saudi Arabia should be directed towards more efficient fuels (gas) and technologies to compensate for the higher prices needed to introduce renewable energy to the market. Saudi Arabia should gradually switch to gas fired power plants and build more efficient combined cycle plants. Cheap energy can compensate the higher prices of renewable energy.

On the other hand, Saudi Arabia has large quantities of gas reserves mainly in the form of associated gas, but the country lacks the infrastructure needed for exporting natural gas. More gas usage in generation will allow more oil to be freed for export. If renewables and solar energy are integrated into Saudi Arabia's energy mix, then, the lifetime of its natural gas reserves could be extended by about 10 to 15 years depending on the technology used.

Table 3.9: Number of years needed to deplete Saudi gas reserves using different technologies

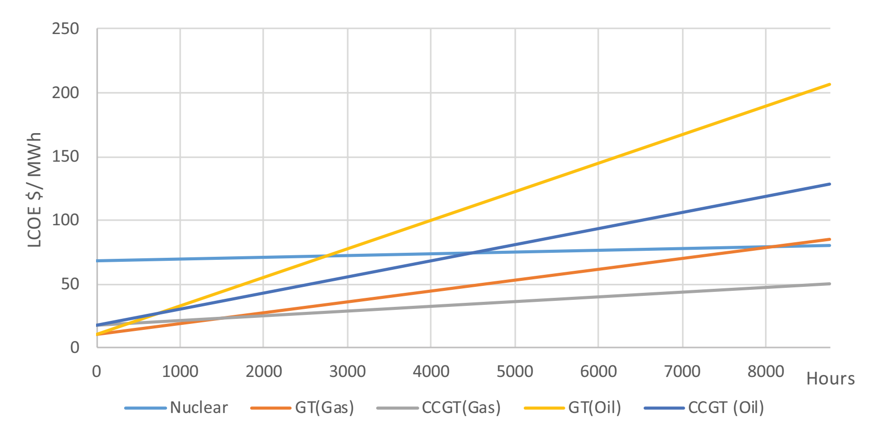
	GT	CCGT	Actual [89]
No Renewables	37	55	52
9.5 GW PV	38	57	53
16 GW PV 10 GW CSP 6H storage	41	61	57

Investment Needs

To complete the study, investment needs until 2030 were calculated using different deployment scenarios. Implementing the K.A.CARE plan will require large investments (16 GW PV, 25 GW CSP, and 17.6 GW of nuclear power). For the calculation of the investments required, the following capital costs of technologies were taken: 2,500 $/ kW for PV, 6,800 $/kW for CSP with six hours storage,[90] and $5,530 for nuclear reactor[91] (see Figure 3.13).

89. Actual Saudi generation mix is composed of 57% gas turbine, 1% diesel, 12% combined cycle, and 30% steam turbine (author calculations).
90. Olson, Schlag, Patel, and Kwok, "Capital Cost Review of Power Generation Technologies."
91. Ali Ahmad and M.V. Ramana, "Too Costly to Matter: Economics of Nuclear Power for Saudi Arabia," *Energy* 69 (2014): 682-694.

Figure 3.14: Screening curve for generation cost of different technologies in $/MWh using 2014 fuel prices



For the K.A.CARE deployment scenario, the total investment is expected to reach around $360 billion by the end of 2030, which is a considerable amount in the current financial situation.

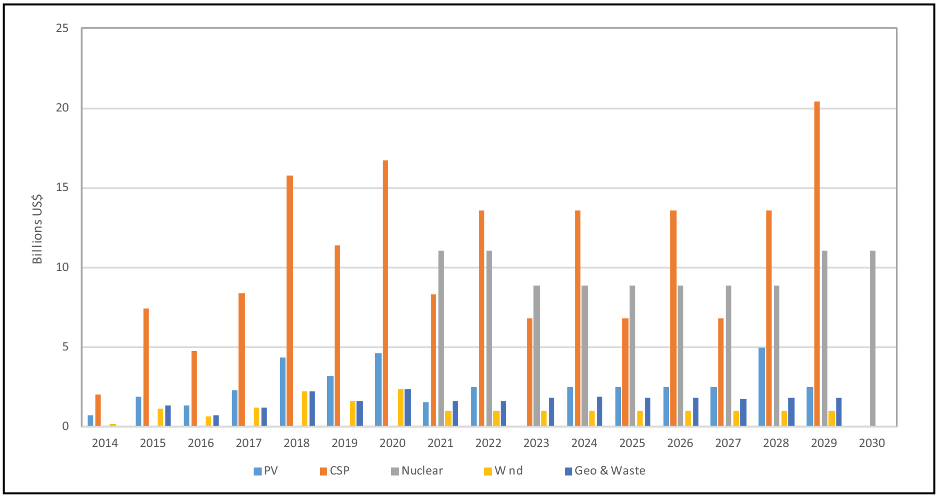
According to the calculations, CSP investments represent the highest part of the investments needed in the plan as its capital cost is the highest compared to other technologies. Despite being more expensive, solar CSP offers many advantages: it is less sensitive to the harsh climatic conditions in the desert, including high temperatures during the day which decrease energy output of PV systems.[92] CSP technologies offer the possibility of storage and can be coupled to the fuel back-up systems which improves the dispatchability. The 50 MW CSP project in Duba is an example of such an initiative (600 MW combined cycle plant coupled with backup system 50 MW CSP).

A cheaper and more feasible scenario will be to replace nuclear reactors with CCGT power plants, as besides being cheaper, the construction time for CCGT plants is shorter (60 months for a 1,000 MW reactor compared to 41 months for a 580 MW CCGT power plant).[93] Nuclear power reactors generally overrun their construction period.

92. "CSP Prospects in Saudia Arabia," www.csptoday.com/menasol2014, 2014.

93. "Renewable Electricity Futures Study," *Volume 2: Renewable Electricity Generation and Storage Technologies.*

Figure 3.15: Investment in billion US$ needed to implement the original K.A.CARE plan (16 GW PV, 25 CSP and 17.6 GW Nuclear)



Using renewables will require another 30 GW of gas turbines to cover the intermittency of the renewable resources (16 GW PV and 10 GW CSP which are equivalent to 9.6 GW of full dispatchable source). The total investment needed for this scenario amounts to about $150 billion, which represents nearly half of what was needed by the K.A.CARE plan initially.

Deployment of renewable energy in Saudi Arabia should be accompanied by the localization of some part of the value chain of renewable technology. For PV systems, the localization of BOS activities can be the first step; this could include manufacturing support structures, trackers, mounting hardware, electric protection devices, wiring, monitoring equipment, and installation.[94]

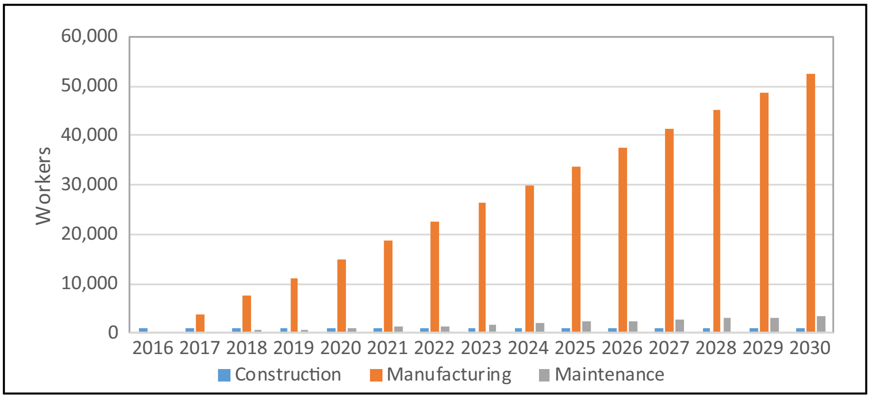
As a second step in localization of renewables in the country, Saudi Arabia can build a PV manufacturing facility in the country (the capital cost required to build a 1 GW/yr. PV manufacturing facility would range between $1 billion and $2 billion per plant). Starting with a 500 MW plant and increasing the plant capacity by 500 MW yearly, the size of the plant should reach a capacity of 7 GW by 2030. A typical PV plant will need two persons/ MW in the construction stage, 7.5 persons/ MW in the operation stage, and 0.5 person/ MW for maintenance. By the end of the project, 57,000 persons should be employed directly.[95]

94. Ibid.

95. *Energy from the Desert: Very Large scale PV Plants for Shifiting to Renewable Energy Value,* IEA - PVPS T8-01, 2015.

In 2012, the PV industry created 3-7 direct jobs and 10-20 indirect jobs per MW produced. With a 7,000 MW planned capacity in 2030, around 21,000-50,000 direct jobs and 70,000-140,000 indirect jobs should be created. Being a more complex technology, localization of CSP manufacturing in Saudi Arabia would be more difficult and take more time.

Figure 3.16: Number of persons employed in PV manufacturing plant starting with 500 MW plant with a yearly increase of 500 MW/yr. reaching 7 GW of manufacturing capacity by 2030



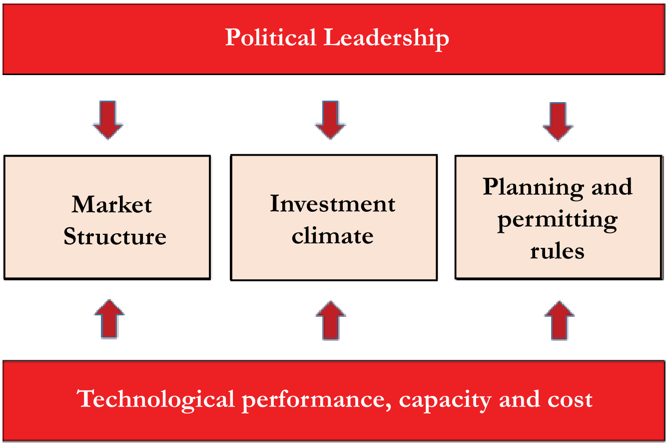
Energy Transformation Framework

Besides discussing the benefits of adding renewable energy to Saudi Arabia's electricity grid from an economic point of view, it is important also to discuss the policies needed to promote renewable energy in the Kingdom. High penetration of renewable energy will need an important transformation in its energy sector, which is often the case when a new technology is introduced in any country or market. History shows that for new technologies to move from a niche to the mainstream depends on events and elements at three levels. At the top level, a supportive political leadership is needed to facilitate the implementation of the new technology, while a second factor is related to the type of technology introduced and its capacity to perform the job at the desired cost. On the middle level, three issues are to be addressed,[96] such as the market structure in which power is bought and sold, the investment climate within which project developers obtain financing, and finally the permitting rules and regulations.[97]

96. *Moving towards 100% Renewable Electricity in Europe & North Africa by 2050: Evaluating Progress in 2010,* PricewaterhouseCoopers, 2011.

97. "Energy from the Desert: Very Large scale PV Plants for Shifiting to Renewable Energy Value,"

Figure 3.17: Elements of the power system transformation



Within this context, the recent restructuring in the electricity sector in Saudi Arabia through the unbundling of SEC and creation of K.A.CARE, and the objectives laid out in "Saudi Vision 2030," show that Saudi political leaders are showing a growing interest in renewable energies and a more sustainable approach to the energy sector which is still dominated by a strong oil sector. Saudi Arabia was slower in starting this transformation as compared to the UAE which rapidly initiated a number of renewable projects and plans in favor of renewable energy.

The underdevelopment of renewable energy in Saudi Arabia is due to the heavy dependence on oil, a highly subsidized energy sector with very low fuel prices paid by the private sector generating companies, and very low electricity prices that are among the cheapest in the world which encourages high consumption. Despite some restructuring efforts within the Saudi electricity sector by bringing together the companies in four regions under the authority of the SEC, and establishing the National Electricity Transmission Company, there is still room for restructuring the sector to become more competitive and facilitate the entry of renewables.

Saudi Arabia is still in the process of establishing the regulatory framework to support generation of electricity from renewable resources by the private sector. For example, Germany's high penetration of PV power was boosted by favorable tariffs for renewable energy generating companies and individuals.[98] All the existing entities needed for leading the energy transition are still new or yet to be established in Saudi Arabia. K.A.CARE was established in 2010 with the aim of formulating

IEA - PVPS T8-01, 2015.

98. Wirth, *Recent Facts about Photovoltaics in Germany.*

an ambitious plan for renewable deployment. Unfortunately, these plans never materialized. It is apparent that after adopting "Saudi Vision 2030," Saudi Aramco will play a more important role in implementing the "Vision 2030" goals concerning renewable energy.[99]

Until recently, renewable energy was never considered a serious competitor to conventional generation in Saudi Arabia, and consequently, very little was done in field of research and development. Further research on the effect of sandstorms, soiling, aging, and high temperature effects (mainly on PV systems) will be required. There is also the need to develop solar equipment standards specific to Saudi Arabia.

The localization of renewable technology should be viewed by Saudi policy makers as a top priority. Saudi Arabia can rely on many countries to develop its renewable energy sector such as China and Germany for PV (China is the world leader in solar photovoltaics manufacturing and installation with 13 GW of capacity installed 2013),[100] Denmark and India for wind power (the Indian wind energy sector had an installed capacity of 23,439 MW by March 2015 and is ranked among the top five in the world),[101] and the US and Spain for CSP systems (Spain deployed 2.3 GW of CSP plants in less than five years, with an average of 300 MW financed every year between 2006 and 2012).[102] Nuclear power, on the other hand, involves complicated technology and is subject to international nonproliferation treaties. The Saudi private sector should be effectively involved in the energy transition efforts. ACWA Power, a Saudi company, is involved in important projects outside the Kingdom and is leading a consortium which signed a $900 million worth power purchase agreement for the net electricity output of the Noor I CSP IPP (Independent Power Producer) with a capacity of 160 MW located approximately 200 km south of Marrakesh, Morocco.[103]

It is important for Saudi Arabia to promote energy efficiency programs, as the cost of saving a kWh is generally cheaper than producing the equivalent amount of energy. Energy storage schemes must be promoted, smart grid systems introduced,

99. Vision 2030 Kingdom of Saudia Arabia, http://vision2030.gov.sa/en.

100. *Energy from the Desert: Very Large scale PV Plants for Shifiting to Renewable Energy Value. s.l. : IEA - PVPS T8-01, 2015.*

101. Indian Wind Energy Association, http://www.inwea.org/, accessed June 20, 2016.

102. Gianleo Frisari and Jacobo Feas, "The Role ef Public Finance in CSP: How Spain Created a World-leading Industry Then Shattered Investor Confidence," Climate Policy Intiative, 2014.

103. Energy from the Desert: Very Large scale PV Plants for Shifiting to Renewable Energy Value. IEA - PVPS T8-01, 2015

and interconnection with neighboring countries developed.

Conclusion

The Saudi electricity sector is not sustainable. Relying heavily on its abundant oil and gas resources, and with its current electricity demand growth rates, Saudi Arabia may become a net importer of oil in the coming years. This study examined the status of country plans regarding renewable energy, particularly solar power. The K.A.CARE plan was probably too ambitious to be executed, though the recently articulated "Saudi Vision 2030" is perhaps more attainable. A modified target was suggested, which if executed, will provide 9 percent of the electricity needs of the Kingdom from solar resources. All these scenarios were simulated using NREL SAM software and plotted on the load duration curve to obtain the residual curve. It was also found that reaching 25 percent solar energy penetration by 2030 will represent the technical limit for the Saudi grid to handle without massive storage facilities. The levelized cost is not the main obstacle for the high penetration of renewable energies in the Kingdom, despite the record low prices of photovoltaics system offered worldwide; the huge subsidies offered to the energy producers, with fuel at 10 percent of the international prices make the generation costs so low that they are beyond any competition. Simulation results confirmed the impact of climatic conditions like soiling on the performance of PV systems. Unfortunately, the lack of hourly data prevented addressing this issue in detail. Finally, it was found that under the current energy framework, it will be difficult to implement high penetration of renewable projects, as heavy subsidies distort generation costs in favor of conventional generation systems, affecting the feasibility of renewable projects which prevents the private sector from investing in the sector. Schemes such as Feed-in-Tariff should be developed along with strong political backing to promote investments in renewable energy. Transfer of technology and international partnerships can help the Kingdom in achieving its energy transformation plans. It is important to note that only utility scale solar power systems were covered in this study and that there is great potential for roof mounted PV systems, which in many areas are used to provide electricity to the national grid.

Appendix 1

Table 3A1: Cost of generation in Saudi Arabia of different technologies using 2014 fuel prices

Type	Nuclear	GT Gas	CCGT Gas	GT Oil	CCGT Oil
Unit Capital Cost ($/kW)	5,530	651	1,230	651	1,230
Fixed O&M ($/kW -yr.)	93.28	5.26	6.31	5.26	6.31
Variable O&M ($/MWh)	2.14	29.90	3.67	29.90	3.67
Heat rate (BTU/kWh)		10390	6705	10390	6705
Capacity Factor	90%	90%	90%	90%	90%
Gas used (MMBtu/MWh)					
Gas cost ($/MMBtu)		4.36	4.36	16.00	16.00
LEU Fuel Cost ($/kg)	$3,211				
Fuel consumption (kg/kWh)	3.15E -06				
Fueling costs ($/MWh)	10.11	45.30	29.23	166.24	107.28
Economic life	60	20	30	20	30
Auxiliary Consumption	0%	0%	0%	0%	0%
Discount Rate	8%	10%	10%	10%	10%
CRF (method 1) NREL	0.081	0.117	0.106	0.117	0.106
CRF (method 2)	0.081	0.117	0.106	0.117	0.106
FC cost levelized ($/MWh)	68.50	10.37	17.35	10.37	17.35
VC	12.25	75.20	32.90	196.14	110.95
LCOE ($/MWh)	80.76	85.57	50.25	206.51	128.30
LCOE (cent/KWh)	8.08	8.56	5.03	20.65	12.83

Appendix 2

Table 3A2: Cost of generation in Saudi Arabia of different technologies using subsidized prices

Type	Nuclear	GT Gas	CCGT Gas	GT Oil	CCGT Oil
Unit Capital Cost ($/kW)	5,530	651	1,230	651	1,230
Fixed O&M ($/kW -yr.)	93.28	5.26	6.31	5.26	6.31
Variable O&M ($/MWh)	2.14	29.90	3.67	29.90	3.67
Heat rate (BTU/kWh)		10390	6705	10390	6705
Capacity Factor	90%	90%	90%	90%	90%
Gas used (MMBtu/MWh)					
Gas cost ($/MMBtu)		4.36	4.36	16.00	16.00
LEU Fuel Cost ($/kg)	$3,211				
Fuel consumption (kg/kWh)	3.15E -06				
Fueling costs ($/MWh)	10.11	45.30	29.23	166.24	107.28
Economic life	60	20	30	20	30
Auxiliary Consumption	0%	0%	0%	0%	0%
Discount Rate	8%	10%	10%	10%	10%
CRF (method 1) NREL	0.081	0.117	0.106	0.117	0.106
CRF (method 2)	0.081	0.117	0.106	0.117	0.106
FC cost levelized ($/MWh)	68.50	10.37	17.35	10.37	17.35
VC	12.25	75.20	32.90	196.14	110.95
LCOE ($/MWh)	80.76	85.57	50.25	206.51	128.30
LCOE (cent/KWh)	8.08	8.56	5.03	20.65	12.83

4

Nuclear Energy for the Middle East: Technology Choices and Considerations

Abdalla Abou Jaoude and Anna Erickson

Abstract

Nuclear power has been proposed in several Middle Eastern countries as a way to meet increased demand for electricity and achieve energy security through diversification of energy sources. Past studies have focused on assessing the need for nuclear power, either for specific countries or for the region as a whole, and the economic challenges associated with it. However, little research has been done so far on assessing the technology supply side. This chapter reviews a number of available nuclear reactor technologies that are ready to be exported to the Middle East and discusses their respective merits and drawbacks. It also provides an overview of more advanced reactor designs and their respective characteristics. The main objective is to provide states interested in pursuing nuclear energy with a map of options that will guide their decision-making process. The study concludes that the Russian VVER reactors have the highest potential for deployment due to their financing and fuel leasing options. Small modular reactors, although better suited for countries with smaller electricity grids, are still not ready for deployment. In addition to the technological characteristics of available reactor designs, economic and political factors are likely to play an important role in the decision-making process.

Introduction

The Middle East is at the center of a global wave of nuclear new build, with ambitious plans in Egypt, Iran, Jordan, Saudi Arabia, Turkey, and the United Arab Emirates (UAE). The official rationale to build nuclear power plants in the Middle East is based on a set of common challenges that face countries across the region. These challenges include rising demand for electricity and water desalination due to economic and population growth, the need to achieve energy security through reducing reliance on energy imports or through diversification of energy sources, and the opportunity cost associated with burning oil and gas to generate electricity instead of diverting these resources for export.[1] Nuclear power has also been advocated as a means to promote localization, by building a highly skilled local workforce and industrial capacity that can induce economic growth.[2]

In light of the surging interest in nuclear power in the Middle East, this chapter examines the supply side of this market, i.e., the nuclear reactor technologies that are currently available for export. It conducts a comparative analysis between the various reactor designs and studies their suitability for the region in general and for the Gulf Cooperation Council (GCC) region in particular. The suitability analysis extends beyond technical elements to cover vendor-related features such as ease of financing and localization potential. Obtaining help with financing of capital-intensive nuclear power plant projects is considered a priority in countries such as Turkey, Jordan, and Egypt, while achieving high level of localization is perceived to be a requirement in Iran and Saudi Arabia.

Overview of Current Status and Projected Demand

The supply side of nuclear power technologies available for countries in the Middle East is dependent on the status of regional nuclear programs and their corresponding expansion plans. It is therefore important to review the current standing of regional programs in order to define the market size and potential.

Currently, there are six countries in the Middle East pursuing nuclear power: Egypt, Iran, Jordan, Saudi Arabia, Turkey, and the UAE. However, these countries are at different levels of advancement towards acquiring nuclear power plants. Iran has the most advanced nuclear program with the only operating reactor in the region (Bushehr-1). Iran also possesses a relatively advanced research and human capacity

1. M. Kamrava (ed), *The Nuclear Question in the Middle East* (Oxford University Press, 2012).
2. Jordan Atomic Energy Commission, "White Paper on Nuclear Energy in Jordan," 2012.

in the nuclear field, including a controversial uranium enrichment program. The UAE is also at an advanced stage with four reactors currently under construction, each with an installed capacity of 1400 MWe. Among other countries, Turkey is the closest to starting the construction of its power plants. It has already signed final project contracts with Russia's Rosatom to build four reactors at the Akkuyu site and another contract with a Franco-Japanese consortium to build another four reactors at the Sinop site at the Black Sea.[3,4]

In the GCC, only the UAE and Saudi Arabia are interested in acquiring nuclear power. Bahrain, Kuwait, Oman, and Qatar decided to abandon or suspend their nuclear power ambitions in the wake of the accident at Japan's Fukushima nuclear plant.[5] Jordan and Saudi Arabia have committed plans and are currently developing the legal and regulatory framework, as well as acquiring the required infrastructure and human resource capacity.[6] Of the six Middle East states currently planning for nuclear power, only Egypt has not yet fully committed to reactor construction, even though plans have been in place since the 1960s.[7]

Table 4.1 summarizes the national nuclear programs that currently exist in the region in terms of their status, as of May 2016, and perceived priorities for vendor selection factors. Clearly, different countries in the region have different priorities when selecting nuclear vendors, depending on their political and economic profiles. For instance, the UAE's decision to purchase the APR1400 reactor from South Korea, in preference to vendors from France, Japan, and the United States, while

3. Turkish Atomic Energy Authority, "Akkuyu Nuclear Power Plant," 2014, accessed November 8, http://www.taek.gov.tr/en/institutional/akkuyu-nuclear-power-plant.html.
4. Turkey signed and ratified an intergovernmental agreement with Japan to build the four reactor "Sinop plant" in which ownership will be split between Japan, France, and Turkey. http://www.world-nuclear-news.org/NN-Erdogan-approves-Turkey-Japan-nuclear-agreement-1041501.html
5. Anton Khlopkov, "Prospects for Nuclear Power in the Middle East after Fukushima and the Arab Spring," United Nations Institute for Disarmament Research (UNIDIR) Resources, 2012, http://www.unidir.org/files/publications/pdfs/prospects-for-nuclear-power-in-the-middle-east-after-fukushima-and-the-arabic-spring-402.pdf.
6. Ali Ahmad, "Civilian Nuclear Programs in the Middle East: Analysis and Evaluation," *Gulf Year Book,* 2016
7. Ibid.

unexpected by some at the time,[8] is believed to have been based on the already strong commercial and trade ties between the UAE and South Korea.[9]

Table 4.1: Status of nuclear power programs in the Middle East and perceived selection priority in each country

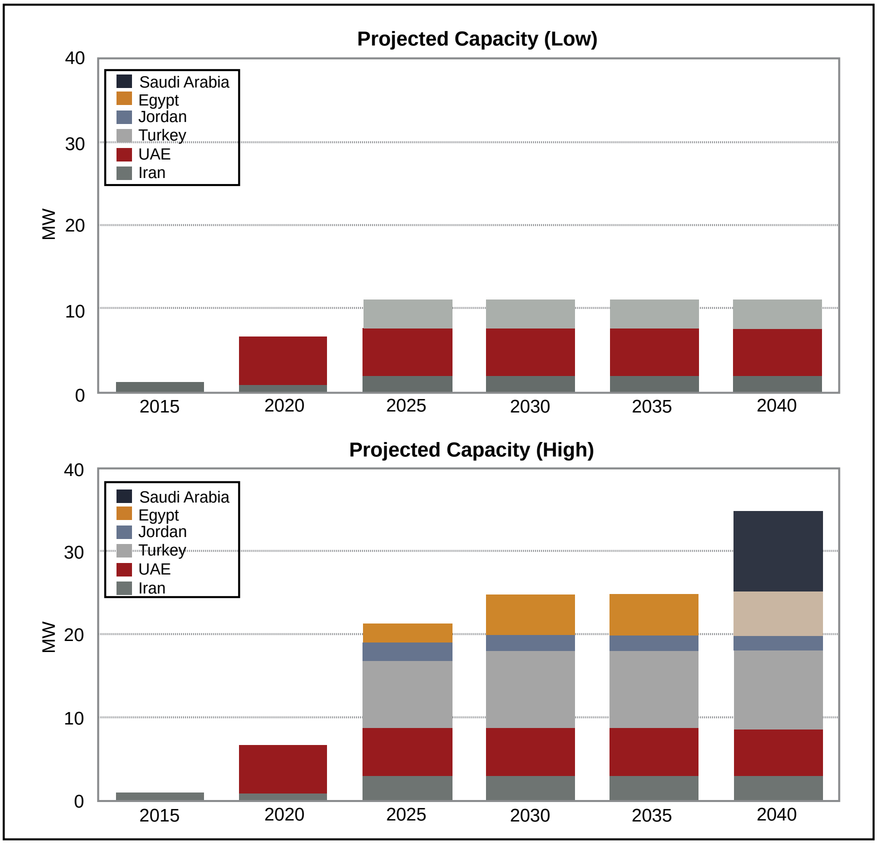
	Status	Perceived major choice factor(s)
Iran	Reactor operating	Political ties + localization
UAE	Reactors under construction	Commercial advantage
Turkey	Contracts signed, legal and regulatory infrastructure well developed	Ease of financing + diversification
Egypt	Developed plans but commitment pending	Ease of financing
Saudi Arabia	Developed plans but commitment pending	Political ties + localization
Jordan	Committed plans, legal and regulatory infrastructure developing	Ease of financing

In terms of projections for nuclear capacity additions in the next 20-25 years in the region, Figure 4.1 shows the possible expansion plans in the six countries with ambition to acquire nuclear power. There are two, low and high, estimates for projected capacity of nuclear electricity for each country as well as for the Middle East region as a whole. The low estimates assume that not all of the planned nuclear plants will materialize, depending on the country and whether final contractual agreements exist. For example, the low estimate for Egypt, Jordan, and Saudi Arabia is zero since no final construction agreement has been signed yet, despite the presence of well-developed plans to build at least one nuclear power plant in these countries. On the other hand, the high estimates assume regional policies that are favorable to nuclear power. The low and high estimates for added nuclear capacity in the Middle East as a whole by 2040 are 11 and 35 GWe, respectively. Assuming that, on average, the capacity of a single reactor unit is 1 GWe, the market size is

8. A. Bakr and C. Mee-Young, "South Korea Wins Landmark Gulf Nuclear Power Deal," Reuters, December 27, 2009, http://www.reuters.com/article/us-emirates-korea-nuclear-idUSLDE5BQ05O20091227.
9. F. Kane, "UAE and South Korea – Old Friends that Can be Winners Together," *The National*, 2015, retrieved May 29, 2016, from http://www.thenational.ae/business/economy/uae-and-south-korea--old-friends-that-can-be-winners-together.

between 11 to 35 reactor units. The large discrepancy between the low and high estimates is driven by Saudi Arabia's huge projections (18 GWe by 2040) coupled with their high level of uncertainty.

Figure 4.1: The projected capacity of nuclear power programs in the Middle East



Overview of Reactor Designs

Currently Available Reactor Technologies and Reactor Comparisons

The nuclear reactor market has become increasingly internationalized with reactor manufacturers from across the world collaborating and forming consortiums. This allows them to share project risks and enhance their credibility by promoting their expertise in the various fields required to establish nuclear power plants.[10] Toshiba

10. D. Finon and F. Roques, "Financing Arrangements and Industrial Organizations for New Nuclear Build in Electricity Markets," EPRG Working Paper, University of Cambridge,

acquired Westinghouse in 2006,[11] GE formed a joint venture with Hitachi in 2007,[12] and Areva formed a consortium with Mitsubishi called ATMEA that same year.[13] In the past, countries have favored developing their own indigenous reactors, normally with some initial external assistance. Presently, states are more willing to directly import external technology. This can be attributed to the increasingly high barriers to enter the nuclear power market such as the high level of sophistication designs have reached. It is becoming exceedingly difficult for newcomers to develop their own affordable, safe and economically competitive solution. Middle Eastern countries that are showing interest in building nuclear power plants are overwhelmingly considering external reactor technology suppliers rather than developing indigenous technologies. If a country in the Middle East wants to build a nuclear reactor today, what are the currently available options in the market?

Table 4.2 shows the reactor technologies that are available for deployment in the Middle East; these reactors are at different levels of readiness; some have already been built while others are still under construction. Reactor designs under construction but without any exporting plans (e.g., Chinese and Indian designs) are not included here, but are discussed in following sections; similarly for advertised designs that do not have any unit under construction (e.g., ESBWR, APWR and Canadian designs). The only exception is the ATMEA1 reactor, which is expected to begin construction in Turkey in 2017 and is discussed in this section.[14]

March 2008.

11. Toshiba Corporation, "Toshiba Acquires Westinghouse form BNFL," Press Release, February 6, 2006, http://www.toshiba.co.uk/innovation/NEWSARCHIVE/archived_news_article.jsp?ID=0000006709.
12. Hitachi, "GE, Hitachi Sign Formation Agreement for Global Nuclear Energy Business Alliance," Press Release, May 16, 2007, http://www.hitachi.com/New/cnews/f_070516a.pdf.
13. ATMEA, "MHI and Areva Confirm Official Start of ATMEA," Press Release, December 7, 2007, http://www.atmea-sas.com/scripts/ATMEA/publigen/content/templates/Show.asp?P=114&L=EN.
14. World Nuclear News, "Turkey Ratifies Agreement for New Plant at Sinop," April 2, 2015, http://www.world-nuclear-news.org/NN-Turkey-ratifies-agreement-for-new-plant-at-Sinop-02041502.html.

Table 4.2: Current reactor designs that are currently available for the export market*

	Vendor	Reactor	Capacity (MWe)	Status
US/Japan	Westinghouse	AP 1000	1,110	Under construction
France	Areva	EPR	1,650	Under construction
South Korea	KEPCO KHNP	APR1400	1,400	Constructed
Russia	Rosatom	VVER (AES 92) VVER (AES 2006)	1,000 1,200	Constructed Under construction
US/Japan	GE Hitachi	ABWR	1,380	Constructed
France/Japan	Areva Mistubishi	ATMEA1	1,200	Planned

* All of the reactors are PWR-type (Pressurized Water Reactors) with the exception of the ABWR, which is a BWR-type (Boiling Water Reactor)

With a wide range of different designs currently being pursued, it is useful to provide an overview of their design characteristics. Table 4.3 compares some characteristics of the seven reactor designs listed in Table 4.2. Three metrics were investigated with the goal of providing analysts and policy makers with an overview of the mains strengths and weaknesses of the different designs. The focus was on design maturity, the level of interest in the Middle East, and technological sophistication. Each reactor is given a score based on the criteria defined in the Appendix. Design maturity can be a good indicator of how proven a design is and how much experience has been acquired in its development. The amount of interest in the Middle East can be a useful parameter for states considering nuclear power in the region by virtue of looking at what designs their neighbors are favoring. Lastly, technological sophistication indicates the level of advancement of some designs and the extent of reliance on innovative features. As shown in the table, no standout design scores at the highest level on each aspect. This illustrates the need for compromise in selecting reactors; decisions are more likely to be based on what aspects are deemed more important by policy makers, as well as other considerations, notably contractual arrangement (see following sections).

Table 4.3: Comparison of the modern reactor designs in the global market*

	Design Maturity	Middle East Interest	Technological Sophistication
AP1000	Medium	Low	Highest
EPR	Medium	Medium	Highest
APR1400	Very high	Highest	High
AES -92	Highest	Medium	Medium
AES -2006	Medium	Very high	Highest
ABWR	Highest	Low	High
ATMEA1	Low	High	Very high

*The ranking decision is based on the data compiled in the Appendix.

The reactor designs in the market have reached various level of maturity. Some, such as the APR1400 and ABWR, are proven and have already been built, while others, such as the AP1000 and AES-2006, are nearing the end of construction. The least proven design currently is the ATMEA1 reactor, which was only reviewed by the French Nuclear Safety Authority 2012.[15] Design maturity can often be an indicator of likelihood of cost and time overruns. However, it should be noted that there is empirical evidence that costs have actually increased as knowledge and experience have accumulated.[16] The impact of learning on costs in the nuclear industry has been a controversial issue. Nevertheless, Far Eastern manufacturers demonstrated the ability to build reactors reliably and at a competitive cost relative to their counterparts.[17]

Inside the global nuclear industry, the reactors that have been receiving the most attention are the advanced and innovative ones, namely the AP1000 and the EPR. However, they have gained limited traction in the Middle East. In the GCC itself, the South Korean APR-1400 technology is the only reactor currently under construction (in the UAE). So far, however, the Korean consortium has not managed to replicate its UAE success in other countries in the region or elsewhere.

15. World Nuclear News, "Atmea1 Safety Features Meet French Requirements," www.world-nuclear-news.org/, February 07, 2012.
16. A. Grubler, "The Cost of the French Nuclear Scale-up: A Case of Negative Learning by Doing," *Energy Policy*, 38 (2010): 5174–5188.
17. J. Lovering, A. Yip, & T. Nordhaus, Historical Construction Costs of Global Nuclear Power Reactors," *Energy Policy* 91 (371-382), retrieved from http://www.sciencedirect.com/science/article/pii/S0301421516300106.

Saudi Arabia's interest in nuclear power has attracted a number of nuclear vendors. As part of a $12 billion deal signed with France in 2015, the two nations would conduct a feasibility study for two EPRs while also cooperating on the training of a Saudi nuclear workforce.[18] On the other hand, Russian reactors are also proving to be very attractive to the region, with four AES-2006 commissioned by Turkey[19] and two AES-92 by Jordan.[20] Turkey has also made plans to construct ATMEA reactors.[48]

The technological sophistication of a reactor can be a difficult parameter to gauge. Here, the ranking was based on accident frequency, a proxy for evaluating the safety of nuclear reactor designs. The AP1000, EPR, and AES-2006 are considered "Generation III+" reactors, meaning they can withstand severe accident scenarios, including core meltdown. Their core damage frequency and large release frequency – two parameters used in assessing the likelihood of severe accidents – are among the highest in the industry. These reactors are believed to be an order magnitude safer from the other designs such as the APR1400, AES-92, and ABWR. They employ many innovative features such as reliance on passive safety, or advanced safety components such as "core catchers" and "hydrogen recombiners.". Such features will be discussed in greater detail in the next section.

Standout Technological Features

In light of some of the technological advancements in some reactors, it is useful to provide a broad overview of their standout design characteristics. Emphasis is given to the distinguishing aspects of the seven reactors rather than a comprehensive listing of features. The majority of designs offer a 60-year core lifetime, a burnup of the order of 50 GWd/t, a thermal efficiency of around 35 percent, earthquake resistance as well as a high capacity factor (around 90 percent). Most of the outlined innovations relate to safety features, although some designs have focused more on optimizing and streamlining manufacturing in order to reduce costs.

---

18. World Nuclear News, "France to Study Reactor Construction in Saudi Arabia," June 26, 2015, http://www.world-nuclear-news.org/NP-France-to-study-reactor-construction-in-Saudi-Arabia-2606154.html.
19. World Nuclear News, "Ground Broken for Turkey's First Nuclear Power Plant," April 15, 2015, http://www.world-nuclear-news.org/NN-Ground-broken-for-Turkeys-first-nuclear-power-plant-1541501.html.
20. World Nuclear News, "Jordan Selects its Nuclear Technology," October 29, 2013, http://www.world-nuclear-news.org/NN-Jordan-selects-its-nuclear-technology-2910134.html.

AP-1000

The Westinghouse AP1000 is often considered as one of the flagship Generation III+ reactor. It received certification from the US Nuclear Regulatory Commission (NRC) in 2005,[21] and multiple units are currently under construction in the US and China. The reactor is a two-loop PWR generating 3,415 MWt (1,100 MWe). The design philosophy was to increase reliance on passive features that depend on physical phenomena, for instance gravity-driven emergency cooling and natural circulation, rather than human intervention. The design is based on the earlier AP600 and can withstand extreme accident scenarios, including core meltdown, without any release of radioactivity to the environment. Emergency water tanks provide enough water, without any human intervention, to last up to seven days during a severe accident. Westinghouse also drove simplifications across the plant, reducing the number of components and raw material needed for construction. The AP1000 is constructed in a modular fashion with the majority of components fabricated at a centralized facility in order to reduce the risk of cost and time overruns.[22]

EPR

AREVA went in a different direction with its EPR than Westinghouse. Instead of simplifying the design, the vendor opted to increase redundancy by having four independent safety trains that provide emergency cooling and a double containment building. A core catcher allows the EPR to withstand meltdown scenarios and the reactor is safe even from aircraft crashes. To counter the cost incurred from the additional safety systems, the EPR generates a massive 4,590 MWt (1,630 MWe). The EPR is capable of load following and of employing a variety of fuels in the core, including MOX fuel. Units are under construction in Finland, France, and China, but have been bogged down by cost overruns and technical issues. As a result, interest in the EPR appears to be waning, leading AREVA to shift focus to a modified EPR NM and the ATMEA reactors.[23]

---

21. US Nuclear Regulatory Commission, "Issued Design Certification – Advanced Passive 10000 (AP1000)," April 13, 2016, http://www.nrc.gov/reactors/new-reactors/design-cert/ap1000.html.
22. Westinghouse Electric Company, "AP1000 Design, Safety Technology, Operability Features and Current Deployment Projects," Interregional Workshop on Advanced Nuclear Technology, IAEA, Vienna, July 2011.
23. World Nuclear Association, "Advanced Power Reactors," May 2016, http://www.world-nuclear.org/information-library/nuclear-fuel-cycle/nuclear-power-reactors/advanced-nuclear-power-reactors.aspx.

APR14000

The South Korean APR1400 is the only design currently being built in the Middle East. The KEPCO-KPNH consortium obtained a design certification in South Korea in 2003 and began construction of a unit in the UAE in 2012. Modular construction of the reactor allows for shorter and more reliable build schedule of roughly 48 months, a feat in the industry. Different variants of the reactor are under development, notably the APR-1000 that is targeting the Middle East. It can operate at a higher heat sink temperature than in more typical markets.[57]

VVER

Multiple design variants exist for the Russian VVER reactors. The main three are the AES-92, AES-2006, and the VVER-TOI; the latter is the most advanced and least proven concept. The 1,200 MWe AES-2006 is the most innovative variant that is currently under construction; it is largely based on the established, 1,000 MWe AES-92. The AES-2006 touts more passive safety features than its predecessor, quadruple redundancy in safety trains, double containment, a core catcher, hydrogen recombiners, as well as "leak-tight" water pumps. The reactor is able to sustain core meltdown conditions and aircraft impact.[24] However, the most attractive features of these reactors have little to do with actual design. Russian consortiums are offering to finance, regulate, and manage the waste produced by the reactors, under what is being referred to as Build-Own-Operate (BOO) model.[25,26] This is one of the main reasons why these reactors are receiving considerable attention from newcomers to the nuclear market.

ABWR

The ABWR is heavily based on preceding versions of the reactor. It is the only Boiling Water Reactor (BWR) out of the seven reactors, meaning that there is no need for a secondary loop. Steam is generated inside the reactor pressure vessel and fed directly to a turbine, without an intermediary steam generator. Multiple variants

24. Rosatom Overseas, "The VVER Today," *Technical Brochure,* http://www.rosatom.ru/en/resources/b6724a80447c36958cfface920d36ab1/brochure_the_vver_today.pdf.
25. Reuters, "Rosatom Offers Emerging Nations Nuclear Package – Paper," May 13, 2013, uk.reuters.com.
26. I. Hore-Lacy, "Russian Proposal for Nuclear Fuel Leasing and Recycling," *World Nuclear News,* April 26, 2016, http://www.world-nuclear-news.org/V-Russian-proposal-for-nuclear-fuel-leasing-and-recycling-2604166.html.

of the ABWR exist with both Toshiba and GE-Hitachi advocating their own. The reactor technology is relatively conventional; the more radical design iteration promoted by GE-Hitachi is the ESBWR. Nonetheless, the ABWR is a highly simplified, compact, cost-effective, and proven BWR design. The reactor also touts enhanced active safety features over previous models, notably its integrated pressure vessel that hosts the pumps inside it.[27]

ATMEA1

Based on the EPR, the ATMEA1 reactor aims to address some of the shortcomings of its predecessor. The outcome of a joint venture between AREVA and Mitsubishi Heavy Industries, the ATMEA is a smaller and simplified version of the EPR. The reactor generates 3,150 MWt (1,100 MWe) and has three independent safety systems (instead of four for the EPR). ATMEA1 retains many of the other standout EPR features including a core catcher, ability to use MOX fuel, load-following capability, and flexible fuel cycle length.[28] The French nuclear regulating authority, ASN, approved the design in 2012.[29]

Advanced Reactors

Small Modular Reactors

Small Modular Reactors (SMRs) have been gaining significant traction in the nuclear industry. These smaller designs are intended to be factory-produced, transportable, and readily deployable. Mass-producing them at a centralized location allows for better quality controls, reducing the risks of cost and time overruns; it also allows vendors to benefit from learning curve effects, driving down costs as more and more units are churned out. A number of nuclear vendors have argued that there are multiple motivations to pursue smaller designs, directed both at large industrialized countries and developing countries. One motivation is the high upfront capital cost of standard reactors, which is beyond the financing capacities of many utilities and countries. Additionally, installing SMR modules incrementally allows utilities

27. Hitachi-GE Nuclear Energy Ltd, "Advanced Boiling Water Reactor," *Technical Brochure,* 2013, http://www.hitachi-hgne.co.jp/en/download/abwr.pdf.
28. ATMEA, "The ATMEA1 Reactor: a Mid-sized Generation III+ PWR," Interregional Workshop on Advanced Nuclear Technology, IAEA, Vienna, July, 2011.
29. Areva, "Avis positif de l'autorité de sûreté nucléaire française sur les options de sûreté du réacteur atmea1," Press Release, February 26, 2012, www.areva.com.

to start reaping returns from electricity production before reaching the maximum installed capacity at a site. Another motivation is to expand nuclear power to countries with relatively small electrical-grid capacities; a gigawatt-scale reactor could destabilize a small grid. Other factors that have been offered as motivations for SMRs are claims to potentially greater safety due to the reliance on passive features and resulting enhancement in public acceptability.

While the term SMR is widely used, it actually does not represent just one kind of a reactor. Rather, there are a very wide variety of SMR designs with distinct characteristics that are being developed. These designs vary by power output, physical size, fuel type, enrichment level, refueling frequency, site location, and spent fuel characteristics. They are also at different stages of development, with some that are in the process of being constructed (e.g., the Russian KLT-40 floating plant) and others that still face major technical challenges that are unlikely to be overcome over the next decade or longer.

The "price" for accruing some of these potential benefits of SMRs is the loss of economies of scale. There is a reason why the current nuclear reactors are much larger than the early prototypes were: smaller nuclear reactors are typically more expensive on a per unit cost basis. SMR proponents contest this by claiming that the new reactor designs are different and the comparison with traditional reactor costs is invalid. Further, they argue that even if there are diseconomies of scale, these can be compensated by the economic advantages accruing from modular and factory construction, learning from replication, and co-siting of multiple reactors.[30]

The suitability of SMRs for the Middle East region in general, and to the GCC countries in particular, will depend on their capacity to host small reactors as opposed to large reactors. The two key indicators are the size of the economy, in terms of gross domestic product (GDP), and the electricity grid's size. In principle, other criteria including the nature of the demand (peak load versus base load) and regulatory capacity should also be relevant. All things being equal, a country pursuing nuclear power generation with sufficient capacity to host a large reactor, would prefer to opt for standard designs rather than SMRs due to the aforementioned economic disincentives. However, if the grid size is less than about 10 GW, then a large reactor is not recommended, but with one caveat: this criterion implicitly assumes that each country is taken individually. However, two or more countries

30. M. Carelli et al., "Economic Features of Integral, Modular, Small-to-Medium Size Reactors," *Progress in Nuclear Energy* 52, no. 4 (2010): 403-14; Mario Carelli et al., "Economic Comparison of Different Size Nuclear Reactors," in 2007 International Joint Meeting of the Latin American Section of the American Nuclear Society (Cancun, 2007).

could integrate their grids thereby providing electricity to each other when the nuclear reactor is shut down for maintenance or refueling.

In some cases the grid is suitably large, but the state under question – or any private utility within the country – may not have the requisite economic capacity to purchase a reactor. This is what is measured through the GDP and GDP per capita. Historically, no country starting a nuclear power program has had a GDP below $13 billion ($2,000) at the time of construction of their first reactor.[31] Likewise, the GDP per capita has never been below $700 per capita in purchasing power parity (PPP) terms. None of the GCC countries fall below these limits. Therefore, it is unlikely that any of them will have to avoid purchasing a large reactor simply because their economy is too small, making electricity grid size the crucial variable. On this basis, if they were to go nuclear, Saudi Arabia and the UAE are better off with purchasing large reactors whereas Bahrain, Kuwait, Oman, and Qatar are better suited for SMRs.

The question that follows would be: If a decision is taken to build SMRs in a country where they are suitable, what are the SMR technologies available? There are currently dozens of SMR designs under development. Some of these are in the conceptual phase, many are in the R&D phase, and only four have been licensed or are under construction.[32] The details of these four SMRs are summarized in Table 4.4. Thus far, there is little evidence that any of the smaller GCC countries are considering any of these reactors.

---

31. Jessica Jewell, "Ready for Nuclear Energy?: An Assessment of Capacities and Motivations for Launching New National Nuclear Power Programs," *Energy Policy* 39, no. 3 (2011): 1041–55.

32. WNN, "Reactors Ready for Floating Plant," *World Nuclear News,* August 7, 2009, http://www.world-nuclear-news.org/NN-Reactors_ready_for_first_floating_plant-0708094.html; Alexandr Nikitin and Leonid Andreyev, *Floating Nuclear Power Plants* (Oslo: Bellona Foundation, 2011); M. Hadid Subki, "Global Trends, Prospects and Challenges for Innovative SMRs Deployment" (presented at the "Long-term Prospects for Nuclear Energy in the Post-Fukushima Era," Seoul (Korea), August 29, 2012), http://www.iaea.org/INPRO/5th_Dialogue_Forum/Wednesday,_29.08.2012/Session_IV_Nuclear_Safety_and_Innovation/2._Hadid_Subki_IAEA_0829_no_distribute.pdf; Yuliang Sun, "HTR Development Status in China" (presented at the 23rd Meeting of the IAEA Technical Working Group on Gas Cooled Reactors (TWG-GCR), Vienna, Austria, March 5, 2013), http://www.iaea.org/NuclearPower/Downloadable/Meetings/2013/2013-03-05-03-07-TWG-NPTD/Day_1/3.Sun.pdf.

Table 4.4: Small modular reactors currently under construction or licensed

	SMART	KLT 40S	HTR PM	CAREM
Country of Origin	South Korea	Russia	China	Argentina
Reactor Technology	PWR	PWR	HTR	PWR
Status	Licensed	Under Construction	Under Construction	Under Construction
Electrical Power (MWe)	90 100	35	2x 105	27

Jordan was often considered to be a fitting case for the deployment of SMRs. Indeed, the country was considering bids by vendors but ultimately decided against the option.[33] It appears that Saudi Arabia is the only country in the Middle East forging ahead with SMR plans; the country signed a memorandum of understanding in 2015 with South Korea.[34] The two countries intend to collaborate closely on the new SMART reactor and undertake a feasibility study for the construction of two units in the Saudi Arabia. The country also signed an agreement with China to develop the advanced SMR based on HTR technology.[35] While Saudi Arabia is not limited by the constraints to opt for SMRs, it appears that the country's decision is primarily rooted in the objective of gaining a foothold in the development of future technologies.[36]

33. M.V. Ramana and Ali Ahmad, "Wishful Thinking and Real Problems: Small Modular Reactors, Planning Constraints and Nuclear Power in Jordan," Energy Policy, 93 (2016): 236–245.
34. World Nuclear News, "Saudi Arabia Teams up with Korea on SMART," March 4, 2015, http://www.world-nuclear-news.org/NN-Saudi-Arabia-teams-up-with-Korea-on-SMART-0403154.html.
35. World Nuclear News, "China, Saudi Arabia Agree to Build HTR," January 20, 2016, http://www.world-nuclear-news.org/NN-China-Saudi-Arabia-agree-to-build-HTR-2001164.html.
36. K.A. CARE, "Regarding the Signing of King Abdullah City for Atomic and Renewable Energy (K.A.CARE) Agreements with the Korean Nuclear Energy Research Institute (SMART) for the Reactor of Compact Small Units (SMART)," Press Release, September 2, 2015, https://www.kacare.gov.sa/en/mediacenter/news/Pages/news166.aspx.

New Reactor Designs

Water-Cooled Reactor Designs
Chinese Designs

China, through its state-run companies (such as CNNC and SNPTC), has been actively expanding its nuclear program. The country is projected to double its nuclear power capacity to at least 58 GWe by the early 2020s.[37] The expansion relied initially on Russian designs, then on French and American ones, notably the EPR and the AP1000, but now intends to develop its own indigenous designs.[38] The main three variants are the Hualong One, the CPR, and the CAP1400. The Hualong One design came from a "merger" of the other two, in an effort to drive a unified Chinese front to export the technology abroad. In March 2016, the main Chinese reactor vendors, CGN and CNNC officially launched a joint international entity to market the reactor abroad. The entity is already in talks with Pakistan, the UK, and Argentina for potential projects. There are currently four Hualong One units under construction in China.[39] The design is a typical 3-loop PWR configuration, with double containment as well as a combination of active and passive safety features.

ESBWR

GE-Hitachi's ESBWR is one of the newer design additions to the so-called "Generation III+" designs. It is a BWR-type reactor, meaning it has only a single coolant loop (no intermediary loop). Following the Westinghouse approach, the reactor is a significantly simplified version of its predecessors, relying primarily on passive safety features. The designers eliminated the need for primary pumps in the system, relying only on natural circulation for heat extraction, a novelty for commercial reactors. The ESBWR is even being touted by GE-Hitachi as "the world's safest," by virtue of having the lowest core damage frequency and large

37. World Nuclear Association, "Nuclear Power in China," *Country Profiles,* February 2016, http://www.world-nuclear.org/information-library/country-profiles/countries-a-f/china-nuclear-power.aspx.

38. *The Economist,* "Nuclear Power – A Glowing Future," September 24, 2016, http://www.economist.com/news/china/21707576-china-wants-its-nuclear-industry-grow-dauntingly-fast-glowing-future.

39. World Nuclear News, "Hualong One Joint Venture Officially Launched," March 1, 2016, http://world-nuclear-news.org/C-Hualong-One-joint-venture-officially-launched-1703164.html.

release frequency.[40] GE-Hitachi believes that modular construction coupled with fewer overall components will substantially reduce construction and maintenance cost. The refueling interval is also extended from 18 months to 24 months. The ESBWR is based on the ABWR, which is still being marketed by the consortium.[41] While it may hold much promise, the reactor is currently one of the least proven designs; it was only awarded NRC certification in 2014 with no current plans to build any unit.[42]

CANDU-type Reactors

Heavy-water cooled reactors, commonly referred to as CANDU reactors, are being most actively pursued by Canada and India. The main difference with typical water cooled technology is the use of a heavier isotope of hydrogen in the water molecule. This allows the reactors to run on natural uranium without any enrichment whatsoever, greatly simplifying fuel sourcing and fabrication. On-line refueling is also possible in these reactors, with fuel reloaded in the core without requiring a cold shutdown. The Canadian AECL is developing two new designs, the EC6 and the ACR. The first is amore incremental design iteration, while the latter is more advanced. However, development of both reactors has stalled, with the ACR believed to have been shelved.[43] India, on the other hand, is pushing ahead with its smaller designs. Its PHWR variants have already been built with more being planned for local projects. The country has even expressed hope of exporting the design abroad, to little fruition thus far.[44] A more advanced variant, the AHWR, is currently under development and touts advanced features such as reliance on natural circulation driven by coolant boiling. One additional notable feature of the Indian designs is their ability to be partially fueled by thorium.

40. GE-Hitachi, "ESBWR Nuclear Power Plant," https://nuclear.gepower.com/build-a-plant/products/nuclear-power-plants-overview/esbwr.html, accessed May 24, 2016.
41. D. Hinds and C. Maslak, "Next Generation Nuclear Energy: The ESBWR," *Nuclear News*, American Nuclear Society, January 2006.
42. World Nuclear News, "Design Approval for the ESBWR," www.world-nuclear-news.org/, September 17, 2014.
43. World Nuclear Association, "Nuclear Power in Canada," November 2016, http://www.world-nuclear.org/information-library/country-profiles/countries-a-f/canada-nuclear-power.aspx.
44. World Nuclear News, "India Ready to Export Reactors," September 23, 2010, http://www.world-nuclear-news.org/NN-India_ready_to_export_reactors-2309107.html.

US SMR Designs

SMR designs have garnered significant interest in the US recently, albeit at a slightly reduced rate than the pre-2014 hype. Many competing manufacturers as well as newcomers to the field have proposed different designs. The most notable were Babcock & Wilcox's mPower, the Westinghouse-SMR, the Hotec SMR-160, and the NuScale Power Module. The US Department of Energy has been playing an active role in supporting their development, awarding a $200 million contract to the mPower and Nuscale projects.[45] Recently, however, interest from manufacturers appears to have waned, with NuScale being the only company still planning on submitting their design through the regulatory approval process.[46] The design is relatively innovative with the containment building and pressure vessels built into a single module that is loaded inside of a water-filled pool below ground to provide quick and reliable access to water. The reactor itself relies completely on natural circulation and has an integral design configuration (all of the primary components are located inside the pressure vessel).[47] The company is already eyeing international export, with talks being held for potential plants in the UK.[48]

Unconventional Reactor Designs

While some of the highlighted designs propose relatively new solutions, they do not depart from the water-cooled technology of current reactors. Radical new technologies under development are proposing to completely alter the inner workings of the reactor or change how it can be used. The six so-called "Generation IV" reactors do away with using water as a coolant and promise a paradigm shift in reactor performance. Not all of these reactors are gaining the same level of traction nor are at the same level of maturity. We outline the trends that are likely to be of interest to the Middle East. The High Temperature Gas-cooled Reactor (HTGR) is gaining attention in the region following the aforementioned agreement signed

45. World Nuclear News, "NuScale SMR Wins Second DoE Funding Round," December 13, 2013, http://www.world-nuclear-news.org/NN-NuScale-SMR-wins-second-DoE-funding-round-1312137.html.
46. US Nuclear Regulatory Commission, "NuScale," March 31, 2016, http://www.nrc.gov/reactors/advanced/nuscale.html.
47. J. N. Reyes, "Overview of NuScale Technology," Workshop on Technology Assessment of Small and Medium-sized Reactors, IAEA, Vienna, December 2011.
48. World Nuclear News, "Preferred Site Chosen for NuScale SMR," August 11, 2016, http://www.world-nuclear-news.org/NN-Preferred-site-chosen-for-NuScale-SMR-1108167.html.

between China and Saudi Arabia.69 In addition, fast and salt-cooled reactors are receiving renewed interest at a global level.

The HTGR is a relatively proven technology, with multiple reactors previously built in Germany, the USA, UK, Japan, and now China. It relies on a novel type of fuel known as TRISO; this consists of uranium micro-spheres, wrapped by multiple layers as silicon and graphite. The protective layers ensure no radioactive material escapes to the outside during operation or even in the case of an accident. This has led many to consider this reactor design "meltdown-proof" since it is able to withstand extreme temperature environments without any release of radioactivity.[49] These properties allow the reactor to operate at a much higher temperature than a conventional reactor, translating to a thermal efficiency of around 45-50 percent (as opposed to 30 percent for conventional reactors). The higher operating temperature opens up the possibility of using the reactor for industrial heat production, an invaluable option for the petrochemical industry. Furthermore, the reactor can be "dry-cooled" and wouldn't consume any water during operation, an important added value for the Middle East.[50]

Two main variations of the HTGR are currently being pursued in the industry. "Prismatic" fuel arrangements are advocated by established reactor manufacturers such as General Atomics and Areva. On the other hand, "Pebble-bed" designs are pushed by China and X-Energy, a newcomer backed by the US Department of Energy.[51] While the different US companies are still at the design stage, China already has a 10 MW pebble-bed design at its Tsinghua campus since 2003. The country is currently building a twin unit commercial-scale facility in the Shandong province. Each reactor would produce 250 MWth of power and are claimed to be immune to core meltdowns.83 Construction is nearly complete and the coming 18 months will be spent installing final components, running tests, and loading the fuel. This prototype project will be followed by a full scale 600 MW facility in the Jiangxi province.

49. Richard Martin, "China Could Have a Meltdown-Proof Nuclear Reactor Next Year," *MIT Technology Review,* February 2016, https://www.technologyreview.com/s/600757/china-could-have-a-meltdown-proof-nuclear-reactor-next-year/.

50. IAEA, "Advances in High Temperature Gas Cooled Reactor Technology," IAEA-TECDOC-CD-1674, Vienna, 2012, http://www-pub.iaea.org/MTCD/Publications/PDF/TE_1674_CD_web.pdf.

51. US Department of Energy, "Energy Department Announces New Investments in Advanced Nuclear Power Reactors to Help Meet America's Carbon Reduction Goal," Press Release, January 15, 2016, http://www.energy.gov/articles/energy-department-announces-new-investments-advanced-nuclear-power-reactors-help-meet.

The fast and salt-cooled reactors both tout similar advantages to the HTGR. They can operate at higher temperatures than conventional reactors (albeit not as high as the HTGR) and can be dry- cooled. The main advantage of fast reactors is that they can burn fuel much more efficiently than their counterparts. Nuclear engineers have often proposed to use them to close the nuclear fuel cycle and recycle nuclear waste, although this is expected to be at great economic cost and proliferation concerns. Russia hosts the most aggressive fast reactor R&D program, having recently begun operation of its BN-800.[52] Terrapower, a US firm backed by Bill Gates, has also made plans to build its first prototype fast reactor.[53] China is also active in the field, turning on an experimental facility in 2011.[54] However, there are no concrete plans to export these reactors as of yet.

The salt-cooled reactor is even further away from commercial deployment. No reactor has been in operation since the 1960s. Despite this, the design has been gaining substantial interest in the nuclear community. China is ahead of the pack in this field as well; it is planning to build a 10 MW prototype reactor by 2020, with a commercial one to follow before 2030.[55] The main advantages of this reactor type are its higher coolant temperature, operation at atmospheric pressure, and solubility of radioelements in the coolant. Multiple variants of the design exist with some using the same TRISO fuel as the HTGR, and others dissolving the fuel inside the coolant (known as the Molten Salt Reactor or MSR). Many technical barriers remain before these reactors can enter the market.[56]

While all of these technologies are still in their nascent stages, certain features may be of strategic value to Middle Eastern countries (e.g., co-generation). In these instances, states should identify and engage with the R&D efforts early on in order

52. World Nuclear News, "Russia Connects BN-800 Fast Reactor to Grid," December 11, 2015, http://www.world-nuclear-news.org/NN-Russia-connects-BN800-fast-reactor-to-grid-11121501.html.

53. World Nuclear News, "Terrapower, CNNC Team up on Travelling Wave Reactor," September 2015, http://www.world-nuclear-news.org/NN-TerraPower-CNNC-team-up-on-travelling-wave-reactor-25091501.html

54. World Nuclear News, "Chinese Fast Reactor Starts Supplying Electricity," July 21, 2011, http://www.world-nuclear-news.org/NN-Chinese_fast_reactor_starts_supplying_electricity-2107114.html.

55. R. Martin, "China Details Next-Gen Nuclear Reactor Program," *MIT Technology Review,* October 2015, https://www.technologyreview.com/s/542526/china-details-next-gen-nuclear-reactor-program/.

56. D. Holcomb, "Molten Salt Reactors Today: Status & Challenges," Workshop on MSR Technologies, Oak Ridge, October 15, 2015.

to establish links providing preferential access to the technology developed, similar to what Saudi Arabia has done. In most cases, reactor development progresses at a timid pace due to demand uncertainty. Committing to reactor orders before they are ready can go a long way in encouraging, even accelerating their development; this would then give a state added leverage during collaboration negotiations. At this stage, it appears that the HTGR is the most mature of the advanced reactor concepts and has already started to gather interest in the region. This is likely due to two main factors: (1) the technology promises significant added value to requirements of the region, (2) early movers will be able to establish supply chains that can then be relied upon in future reactor deployments. The latter point is especially important to nuclear programs that emphasize the need for localization. Nevertheless, it should be noted that the HTGR is not without its challenges. Critics have pointed to a German report detailing technical difficulties and questioning the "meltdown-proof" perception.[57] Furthermore, it remains to be seen if these plants are economically competitive with conventional ones.

Economic Considerations for the Middle East Market

Project Financing

The main component of the cost of generating power at a nuclear plant, no matter what the size of the plant, is the capital cost of constructing the nuclear reactor. The other cost components—fueling the reactor with uranium, operating costs, dealing with the radioactive waste products, and setting aside money to clean up the site after the reactor has been retired—are smaller but highly uncertain. Most of the capital cost is incurred prior to the commencement of electricity generation. Economics has been an important barrier to the construction of new reactors around the world. The problem posed by high construction costs is compounded by uncertainty. Historical analyses of reactor construction and operation cost show significant variations among different reactors.[58] Another problem has been a history of time overruns.

Traditionally, nuclear power projects have been financed through public funds via tax revenues or electricity tariff subsidies. Recent trends, however, have shown

57. S. Thomas, "The Demise of the Pebble Bed Modular Reactor," *Bulletin of the Atomic Scientist,* June 22, 2009, http://thebulletin.org/demise-pebble-bed-modular-reactor.

58. Nathan E. Hultman and Jonathan G. Koomey, "The Risk of Surprise in Energy Technology Costs," *Environmental Research Letters* 2 (2007): 1-6; Jonathan G. Koomey and Nathan E. Hultman, "A Reactor-Level Analysis of Busbar Costs for US Nuclear Plants, 1970–2005," *Energy Policy* 35 (2007): 5630-42.

a surge of interest in private sector assistance in nuclear financing. In developed nations, this is mostly attributed to the deregulation and privatization of the electricity grid market. In regions such as the Middle East, the lack of government funds has played a more important role. As nuclear plant costs range from $2 to $9 billion, it can be difficult for countries with GDP around $20 billion or less to invest in a project whose costs can escalate to one third of the GDP. This is all the more an issue for countries with a gross debt to GDP ratio above 50 percent. This explains why many governments have been more willing to pursue nuclear energy on the basis that vendors would be charged with sourcing a significant portion of the financing through private means.[59] These private/public financing arrangements are expected to prove very attractive in the Middle Eastern market. Table 4.4 highlights how countries with high GDP and low debt ratio (Saudi Arabia) are able to drive energy policies based solely on public funding, while others, in less robust financial situations, are pursuing external private assistance.

Table 4.5: Economic status of Middle Eastern countries interested in nuclear energy vs. the financing agreement pursued (or obtained in the case of UAE)

	GDP Nominal (2016) *	Debt/GDP*	Nuclear Financing Agreements
UAE	$375 billion	15%	Public/Private
Turkey	$735 billion	32%	Public/Private & Private
Egypt	$346 billion	90%	Public/Private
Saudi Arabia	$637 billion	5.9%	Public
Jordan	$39 billion	89%	Public/Private

Source: International Monetary Fund

While the UAE deal with KEPCO is the only financing agreement that has been followed through, it is worth emphasizing that the deal is a special case, and one cannot come to any conclusions about the relative economics of nuclear power from this case. The primary aim of the deal with the UAE appears to have been

59. Nadira Barkatullah and Ali Ahmad, "Current Status and Emerging Trends in Financing Nuclear Power Projects," working paper (submitted to Energy Strategy Reviews).

to introduce South Korean nuclear exports to the region and gain more market confidence. For this reason, South Korea seems to have subsidized the project substantially; some have estimated the deal with the UAE at being about 20 per cent beneath the industry average.[60] Not surprisingly, the deal was criticized within South Korea as commercially weak and that future customers will demand similar terms.[61] It is therefore difficult to use the agreement as a basis for further financing agreements in the region. While there is a long history of systematic under-bidding in nuclear projects, especially true in the case of countries with ambitious nuclear programs, this sort of subsidization can be done only for the first one or two projects and cannot be the basis of a large-scale expansion of nuclear power in a region.

The issue of financing is of paramount importance for countries with limited or strained budget such as Egypt, Jordan, and Turkey. These countries have, on multiple occasions, expressed their need for financing arrangements that would make it easier to establish their nuclear programs. As such, these three countries have opted for Russia as their major technology supplier due to Russia's flexible Build-Own-Operate (BOO) business model. In the case of Turkey, Russia has agreed to fully sponsor the project, while it has agreed to cover 49 percent of the costs of Jordan's nuclear project as an equity shareholder.[62] Russia's ability to meet its commitments to Egypt, Jordan, and Turkey, however, is challenged by the recent decline in its economy and its fiscal power due to the decline in oil revenues. Possibly, Russia may have to prioritize investing in the least risky projects in its global portfolio, leading to withdrawing or suspending its commitment to help with the financing of the nuclear project of Jordan. Since the Russian BOO model has garnered so much interest in the region, it is worth discussing it in further detail in the following section.

Contractual Arrangements and the Build-Own-Operate Model

The decline in interest in public financial arrangements for nuclear power plants has given rise to new types of agreements, most notable of which is the Russian-

60. Joshua Chaffin, "Seoul's Nuclear Ambitions Wane," *Financial Times,* April 26, 2011, http://www.ft.com/intl/cms/s/0/0d0122de-7030-11e0-bea7-00144feabdc0.html#axzz2qp4ikcVj.

61. Lee Tae-hoon, "Senior DP Official Says President Lied about UAE Nuclear Deal," *The Korea Times,* February 16, 2011, http://www.koreatimes.co.kr/www/news/nation/2014/05/116_81531.html.

62. World Nuclear Association, "Russia and Jordan Agree $10 Billion Construction Project," March 25, 2015, http://www.world-nuclear-news.org/NN-Russia-and-Jordan-agree-10-billion-construction-project-25031501.html.

proposed Build-Own-Operate scheme. Not many reactor vendors are able to offer these types of agreements, but many Middle-Eastern countries are seeking them actively. Under these new types of arrangements, the government forfeits a majority stake in the project in return for transferring different types of risks to an external entity. Raising funds, construction, operation, maintenance, decommissioning, fuel procurement, waste management, and in some case, regulation, is essentially outsourced. The host country only needs to provide a suitable site and interconnection with the national grid. BOO arrangement incentivizes lowering costs and increases synergy between construction and operation. In the case of the Akkuyu agreement, the plant is fully funded by Russian capital. Rostaom has a 75 percent share in the project, Atomstroyexport, the contractor, has 2.3 percent, and Rosenergoatom holds 22 percent for handling operation and maintenance. The majority of the electricity generated is sold to the Turkish government-owned wholesale company via a Power Purchase Agreement (PPA).[63]

The main advantages of the BOO model are a reduction in financial risks on the host country, expedited construction, and lowered burdens of setting up indigenous supporting entities for such large projects. These contracts bring several advantages to nuclear newcomer nations but may not be attractive to countries seeking to develop their own indigenous industry. Countries that, for instance, prioritize energy security as their main rationale for pursuing nuclear power, will be less inclined to pursue such models. Similarly, countries with burgeoning nuclear industries, such as Iran and the UAE, will have little incentive to forfeit this level of control over their facilities. An alternative version of the BOO model is the Build-Own-Operate-Transfer (BOOT) variant whereby the power plant is later on sold back to the host nation and ownership rights are transferred.

One aspect of BOO agreements that is not given much emphasis is their proliferation resistance. Since nuclear fuel is sourced locally, this removes the imperative to enrich uranium. The region as a whole is projected to need substantial amounts of low-enriched uranium (LEU) in the coming years. Even under the conservative low estimate (11 GWe by 2040), the region would require about 242 tons of low-enriched uranium per year, and thus, more than a million separative work units (SWU) per year, rising to about 4.4 million SWUs in the high estimate case.[64] Countries committing to exclusively obtaining external uranium would

63. Sinan Ulgen, *Managing the Risks of Nuclear Energy: The Turkish Case,* EDAM Report, 2016, ISBN: 978-605-66923-0-7.

64. Ali Ahmad and Ryan Snyder, "Iran and Multinational Enrichment in the Middle East," *Bulletin of Atomic Scientists* 71 (1): 52-57, 2016.

alleviate such concerns. The case of Iran may be the only exception as the Islamic Republic has reiterated its need to produce LEU fuel for its reactors domestically. This issue has been a central point in the negotiations between Iran and the P5+1 over Tehran's nuclear program.

Similarly, the BOO agreement provides security advantages in the back-end of the fuel cycle as well. Managing spent nuclear fuel is a cause for proliferation concern due to the large quantities of plutonium contained within them, not to mention the challenges associated with providing a final repository for radioactive waste. The estimated annual spent fuel production is equivalent to the annual amount of LEU needed, which is about 22 tons per megawatt. Many contracts will likely have the vendor supplying fuel and taking it back for waste storage. In fact, Russia offers a "take-back" option for spent fuel in its business model; this option is currently in place for Iran's Bushehr-1 reactor and is part of the agreement with Jordan[65] The question of whether fuel from the Akkuyu site will remain in Turkey has not been settled.[66]

These proliferation concerns explain why the US has been so insistent on "Gold Standard" agreements under which a country renounces its right to enrich and reprocess nuclear fuel. This is an added requirement to so-called "123 Agreements" that ensure nuclear cooperation conforms with US export control laws and meets Nuclear Regulatory Commission and Nuclear Supplier Group guidelines. The intent is to ensure that nuclear technology is used exclusively for peaceful purposes. A typical 123 Agreement does not require a country to foreswear enrichment and reprocessing, but doing so would meet the Gold Standard agreement. Middle Eastern countries interested in US reactors (or consortiums including US companies) will likely need to adhere to these requirements, as the UAE did.[67]

Conclusion

Nuclear energy is currently part of the energy mix of two countries in the Middle East and is being considered in four other countries. This chapter aimed at analyzing the supply side of the market, i.e., the nuclear reactor technologies available for

---

65. Rosatom, "Russia and Jordan Signed Intergovernmental Agreement on NPP Construction in Jordan," Communications Department, March 25, 2015, http://www.rosatom.ru/en/presscentre/highlights/a2689f8047c4f233ae2bfefd303c2ae3.
66. World Nuclear Association, "Nuclear Power in Turkey," October 2015, http://www.world-nuclear.org/info/Country-Profiles/Countries-T-Z/Turkey/.
67. Arms Control Association, "Strengthening Congressional Oversight of 123 Agreements," *Issue Briefs,* Volume 7, Issue 8, July 2, 2015.

countries in the region to choose from. Multiple vendors are courting policy makers in the region and are trying to gain a foothold to tap into this new market. Although there are more than fifteen reactor design options being advertised by vendors, the choice is more limited in reality, since not all of them have gained the same level of maturity. From those completed or under construction, a select group is ready for export to the global market. We reviewed seven of those designs, which originate from Russia, France, US, South Korea and Japan. The American AP1000 appears to be a favorite if safety concerns are deemed primordial, though it has gathered little interest in the region as of yet. Russian and South Korean designs have more attractive economic aspects, with the former offering flexible financing arrangements and fuel "take-back" option and the latter promising the shortest construction time for its reactors. The nuclear industry is also promoting small modular reactors for the region. Advocates believe they will be attractive to countries with smaller grids or where financing larger reactors is an issue. However, due to their higher cost per unit of energy, and their relatively unproven design, it remains to be seen if demand for them materializes. Advanced reactors are also receiving attention in the Middle East, notably the High Temperature Reactors. These reactors promise to be able to produce industrial heat for co-generation and be dry-cooled, two attractive features for the region. However, because advanced reactors are still under development, Middle Eastern countries can do little more than cooperate with relevant R&D efforts at this stage. Countries which intend to "go nuclear" will need to take special issues into consideration. Financing will be one of the largest challenges and countries lacking resources will likely be tempted by Russia's Build-Own-Operate model. It is clear that the decision to select one reactor technology over another cannot be solely tied to the reactor technology itself due to the role played by commercial, economic, and political factors.

Appendix

The four tables listed here detail how the ranking scheme of 4.2 was established. Each table provides the background for the values of each of the four metrics: design maturity, Middle East interest, and technological modernity. While the analysis tries to rely on quantitative data, this is not always possible, due to lack of information or qualitative aspects that need to be taken into consideration. In such instances, the authors' judgment was used to provide a score for the given parameter.

Table 4A 1: *Design Maturity* metric scoring scheme for each reactor
(The metric is mostly based on whether these reactors have already been constructed, if they are under constructions or whether they are still at the planning stage.)

	Status	Score
AP1000	Under construction	Medium
EPR	Under construction	Medium
APR1400*	Constructed	Very high
AES -92*	Constructed	Highest
AES -2006	Under construction	Medium
ABWR*	Constructed	Highest
ATMEA1	Planned	Low

** Although all three of the AES-92, ABWR, APR1400 have been constructed, the latter was only completed recently, while the other two are much older designs. As such, the APR1400 is given a lower score of very high.*

Table 4A2: The Middle East Interest metrics scoring scheme for each reactor (The APR1400 are under construction in the UAE. The EPR is planned for Saudi Arabia. The AES-92 is planned for Jordan while the AES-2006 is planned for Turkey and Egypt. The ATMEA1 is planned for Turkey. Reactor that are under construction receive a higher score than those only at the planning stage.)

	Under construction	**Planned**	**Score**
AP1000	0	0	Low
EPR	0	2	Medium
APR1400	4	0	Highest
AES -92	0	2	Medium
AES -2006	0	8	Very high
ABWR	0	0	Low
ATMEA1	0	4	High

Table 4A3: Technology Modernity for each reactor was based on the touted "safety" advantages of the reactor. (A strong indicator of the safety levels reached is the Core Damage Frequency and the Large Release Frequency. These paramaters are taken to be proxies to the level of technological sophistication in reactor designs. Note that the lower frequencies correspond to the safer designs.)

	Core Damage Frequency (per reactor year)	**Large Release Frequency (per reactor year)**	**Score**
AP1000[68]	2.41E 7	1.95E 8	highest
EPR[69]	8.6E 7	1.8E 7	highest
APR1400[70]	1E 6	10E 6	high
AES -92[71]	3.4E 6	N/A	medium
AES -2006[72]	10E 7	1.8E 8	highest
ABWR[73]	<1E 5	<1E 6	high
ATMEA1[74]*	<1E 5	<1E 6	very high

* The ATMEA1 received a higher ranking than the ABWR and the APR1400 due to its advanced safety features such as the core catcher and three independent safety trains.

5

Iran, Uranium, and Future Proliferation Dynamics in the Middle East

Ryan Snyder

Abstract

Roughly one year after the implementation of the 2015 Iran nuclear deal, security structures in the Middle East are collapsing due to weak states and overlapping revolutions. The current driver of the region's instability remains the Syrian Civil War, which in addition to attracting the involvement of outside powers such as Russia, is the latest regional conflict involving the proxy struggle for regional dominance between Iran and Saudi Arabia. This Iran-Saudi dynamic, and the role played by the United States within it, will likely determine the prospects for bringing stability to the region and for establishing a more proliferation-resistant multinational arrangement to replace Iran's temporarily restricted national nuclear program. This chapter discusses how historical and current dynamics between the US, Iran, and Saudi Arabia will affect the possibility of such an arrangement, and why the three states must agree upon a concept of stability for the region. The evolution of these dynamics may not only determine the future of Iran's nuclear program, but may also affect whether other states seek a nuclear weapons option in their own national enrichment programs. An argument is advanced for multinational over national enrichment as a more proliferation-resistant arrangement, and the conditions for regional stability to advance this arrangement are presented at the end.

Introduction

The July 2015 agreement between Iran and the six countries known as the P5+1 established limitations and transparency measures on Iran's nuclear program.[1] These restrictions are to remain in place for a decade or more, limiting Iran's use of enrichment and reprocessing technologies that are needed to make the fissile materials—highly-enriched uranium (HEU) and plutonium—required for nuclear weapons.

While these restrictions on Iran's program remain in place, other states in the Middle East plan to establish their own civilian nuclear power programs. These plans raise concerns about whether other states may follow Iran's example and build their own national uranium enrichment programs, giving them a potential nuclear weapons capability. The decision by regional powers about whether to establish such programs will likely be influenced by multiple factors, including unwanted dependencies on other states for the supply of reactor fuel or technological expertise, or even the national prestige associated with mastering nuclear technology. Concerns about national security, however, will most likely dominate these decisions, and the collapsing security structures across the region due to weak states, overlapping revolutions, and Iran's regional ambitions may play a role in whether states seek a nuclear weapons option. Perhaps most importantly, the evolution of Iran's nuclear program upon the expiration of restrictions on it may be the deciding factor.

The Iran deal known as the Joint Comprehensive Plan of Action (JCPOA) limits Tehran's enrichment capacity for ten years and the size and enrichment level of its uranium stockpile for fifteen.[2] By then, Iran intends to have an enrichment capacity at least sufficient to fuel its Bushehr-1 nuclear power reactor.[3] This would provide the country with an enrichment capacity capable of producing a significant quantity of HEU for inclusion in a nuclear weapon in about one week.[4] A crisis

1. The P5+1 includes the United States, the United Kingdom, France, Russia, China, and Germany.
2. Joint Comprehensive Plan of Action, Vienna, 2015, http://collections.internetmemory.org/haeu/content/20160313172652/http://eeas.europa.eu/statements-eeas/2015/150714_01_en.htm.
3. Arash Karami, "Chief of Iran's Atomic Energy Organization Clarifies Nuclear Needs," Al-Monitor, July 9, 2014, http://www.al-monitor.com/pulse/originals/2014/07/iran-nuclear-chief-clarifies-nuclear-needs.html. The head of the Atomic Energy Organization of Iran, Ali Akbar Salehi, has said that Iran's program will need 190,000 separative work units (SWUs) to annually fuel Bushehr-I. This figure, however, is based upon the flow of uranium hexafluoride. When only the flow of uranium is considered, the required capacity becomes ~120,000 SWUs.
4. A significant quantity is defined by the IAEA as "the approximate amount of nuclear material

over this "breakout time" could occur again unless relations between Iran and its neighbors and the US improve. The most worrying consequence is that other states decide to develop their own enrichment capacities, making the region's security concerns vastly more challenging to manage.

This chapter is an attempt to lay out the challenges associated with managing the dynamics of nuclear proliferation in the Middle East. It first outlines the history of clandestine nuclear programs in the region, and uses this history—and some examples of programs from outside the region—to outline the future challenges associated with detecting them. A history of the struggle between Iran and Saudi Arabia is then discussed, as the motivations that drive each of these powers' actions may be important in stabilizing the region. A brief discussion of US foreign policy in the Middle East over the past several decades is used to provide context for how the United States has analyzed its interests and responsibilities, and how more creativity may be necessary in bringing stability to the regional chaos. Next, the motivations that states have for acquiring nuclear weapons are placed into the regional context, and dynamics are identified that risk further proliferation. The fifth section advances an argument for multinational control of Iran's nuclear program that would provide regional states and the P5+1 with more assurance about its peaceful use after current JCPOA restrictions expire. Lastly, the conditions for successfully aligning the political factors to advance the idea for multinational control of Iran's program are discussed.

Technology and Proliferation in the Middle East

Proliferation has a long history in the Middle East, beginning with Israel's nuclear program in the 1960s and continuing with clandestine programs in Iraq, Libya, and Syria that violated commitments each state made under the Nonproliferation Treaty (NPT).[5] This history reveals the challenges associated with detecting the

---

for which the possibility of manufacturing a nuclear explosive device cannot be excluded." For an enrichment facility with a capacity of ~120,000 SWUs to fuel a 1 GW reactor such as Bushehr-I for a year, a significant quantity of 27.8 kg of uranium enriched to 90 percent in the uranium-235 isotope could be produced in approximately one week.

5. Israel is believed to have obtained about 337 kg of weapon-grade uranium from a Nuclear Materials and Equipment Corporation (NUMEC) in Apollo, PA, during the 1960s either before its Dimona reactor began producing plutonium or for use as a driver fuel to increase Dimona's plutonium production. For more details, see V. Gilinsky, "Sometimes Major Violations of Nuclear Security Get Ignored," *Nuclear Weapons Materials Gone Missing: What Does History Teach?* edited by Henry Sokolski (The Strategic Studies Institute Publication Office, United States Army War College, November 2014).

uranium compared to plutonium weapon routes and the successes, or lack thereof, of detecting assistance provided by foreign suppliers being watched versus those unwatched by the intelligence community. The history of clandestine programs in countries outside the region suggests even less likelihood of successful detection.

One pathway to a nuclear weapon involves the separation of plutonium—a fissile material needed to sustain a chain reaction in a nuclear weapon—from spent nuclear fuel by chemical means known as reprocessing.[6] The plutonium must be produced in a reactor, which is relatively easy to spot with reconnaissance satellites, and reprocessing activities can be detected by monitoring the emissions of krypton-85, a gaseous fission product released when spent nuclear fuel is cut open during the first stage of reprocessing. Because this gas is nonreactive, it remains the best indicator of clandestine plutonium separation, as capturing it appears challenging and energy intensive.

With the exception of Israel, previous programs using the plutonium route have been disrupted by first detecting and then destroying reactors under construction. Israel, the region's only nuclear-weapon state, is the only Middle Eastern country that has separated plutonium from spent nuclear fuel, while Syria's reactor was destroyed by an Israeli air strike in 2007 after analysis by US and Israeli intelligence agencies agreed that its sole purpose was to produce plutonium for a bomb.[7] Previous to that, Iraq's Osirak reactor was also destroyed by the Israeli Air Force in 1981.

Uranium enrichment plants with centrifuges, by contrast, have proven more challenging to detect, and those challenges only appear likely to grow. First, these plants emit very few signatures, and detection of clandestine uranium hexafluoride production may prove more effective than monitoring any centrifuge plant emissions.[8] The concern about these plants is that they can be quickly reconfigured to produce HEU, and this explains the focus on Iran's enrichment facilities and activities.

---

6. Alexander Glaser, Zia Mian, Seyed Hossein Mousavian, and Frank von Hippel, "Building on the Iran Deal: Steps toward a Nuclear-Weapon-Free-Zone," *Arms Control Today,* December 2015.
7. David Makovsky, "The Silent Strike," *The New Yorker,* September 17, 2012, http://www.newyorker.com/magazine/2012/09/17/the-silent-strike.
8. R. Scott Kemp and Clemens Schlusser, "Initial Analysis of the Detectability of UO2F2 Aerosols Produced by UF6 Released from Uranium Conversion Plants," *Science & Global Security* 16, no. 3 (2008): 115-125; R. Scott Kemp, "Source Terms for Routine UF6 Emissions," *Science & Global Security* 18, no. 2 (2010): 119-125.

Libya provides an interesting case because it received assistance from the A.Q. Khan network beginning in 1984, but its program was not detected until 2000 when US intelligence detected a Libyan order for a full-scale centrifuge plant from the Khan network.[9] This network, now widely blamed for the centrifuge programs in Libya, Pakistan, Iran, and North Korea, began being watched by the intelligence community in 1975 after establishing a link between Pakistan's centrifuge ambitions and its procurement channel. Libyan contact with another foreign agent, however, who was working to provide Libya with centrifuge capability prior to 1984, was not detected.[10] It is believed that Iraq was also offered assistance from the Khan network, but opted instead for assistance with centrifuges from German engineers.[11] This program, along with an electromagnetic isotope separation (EMIS) program, went undetected until inspections in Iraq following the 1991 United Nations Gulf War ceasefire resolution revealed an extensive clandestine nuclear weapons program.[12]

Despite Libya's program being so disorganized that it made little progress between 1984 and 2000,[13] and the gap between receiving and detecting assistance and Iraq's activities that were revealed only following a war, provide little comfort about the future. Had Libya been more organized and received better technical assistance earlier, or had Saddam Hussein not invaded Kuwait in 1990 triggering US military action, this history may have been very different. It does suggest that detection of clandestine nuclear weapons activity appears more likely when a monitored supply network—here the A.Q. Khan network—provides assistance, and that unmonitored foreign suppliers are more likely to escape detection.[14]

Beyond the Middle East, North Korea's first contact with the Khan network appears to be around 1986, with a few dozen procurements related to centrifuges observed over the decades that followed. The US intelligence community assessed

---

9. R. S. Kemp, "The Nonproliferation Emperor Has No Clothes: The Gas Centrifuge, Supply-Side Controls, and the Future of Nuclear Proliferation," *International Security* 38, No. 4 (Spring 2014): 39-78.

10. Ibid.

11. Ibid.

12. "Nuclear Proliferation Case Studies," World Nuclear Association, updated September 2016, accessed December 21, 2016, http://www.world-nuclear.org/information-library/safety-and-security/non-proliferation/appendices/nuclear-proliferation-case-studies.aspx.

13. IAEA, Implementation of the NPT Safeguards Agreement of the Socialist People's Libyan Arab Jamahiriya, GOV/2008/39 (Vienna: IAEA, September 12, 2008), para. 26, as cited by Kemp, "The Nonproliferation Emperor Has No Clothes."

14. Kemp, "The Nonproliferation Emperor Has No Clothes."

that North Korea had an interest in centrifuges and may have had a development program, but not a capability. It was therefore a surprise when the North Koreans revealed a full-scale centrifuge plant in Yongbyon in 2010.[15]

The most glaring case of non-detection was the centrifuge program in the Soviet Union, which the intelligence community knew had been in development since 1955. While intelligence assessments concluded that this program had not developed beyond the laboratory stage, satellite reconnaissance showed that older gaseous diffusion plants were being shut down and disassembled. Without concluding that they must be using centrifuges instead, both the US and United Kingdom concluded that the Soviets must be reducing their enrichment program.[16] After the Soviet Union collapsed in 1991, Russia disclosed to the United States that it had operated centrifuge plants for thirty-four years, then the largest program in the world by nearly a factor of ten.[17]

If anything, this history suggests that past successes may not repeat themselves and that new arrangements are needed. While previous detection successes occurred when states sought assistance from a network being monitored by the intelligence community, these successes were limited but too often inaccurate. In addition, while the Soviet Union was already equipped with the technical expertise to isolate its program and develop it indigenously, the prospect that other countries may be able to do the same is rising. Workforces around the world are becoming more technically sophisticated, opening up the possibility of pursuing multiple technical routes, not only with a wide variety of centrifuge designs procured through either multiple foreign channels or indigenously developed, but perhaps laser uranium enrichment technologies as well.[18]

This track record, and the possibilities imagined given Iran's growing indigenous capabilities and history of engaging in clandestine uranium enrichment activities,[19] raises questions about verifiable assurances that Iran's program will remain peaceful.

15. Ibid., 54.

16. Ibid., 50.

17. Mark Hibbs, "MAPI Official Says All Four Soviet SWU Plants Are in Russian Republic," *Nuclear Fuel* 16, no. 23 (November 11, 1991): 4, as cited by Kemp, "The Nonproliferation Emperor Has No Clothes."

18. R. Snyder, "A Proliferation Assessment of Third Generation Laser Uranium Enrichment Technology," *Science & Global Security* 24, no. 2(2016): 68-91, http://www.tandfonline.com/doi/full/10.1080/08929882.2016.1184528?scroll=top&needAccess=true.

19. Paul K. Kerr, "Iran's Nuclear Program: Tehran's Compliance with International Obligations," Congressional Research Service, September 26, 2016, https://fas.org/sgp/crs/nuke/R40094.pdf.

This concern only adds to suspicions of a region currently experiencing political upheaval.

The Iranian-Saudi Struggle for Regional Dominance

The current chaos in the Middle East—wars in Syria and Yemen and upheaval in Iraq, Lebanon, and Bahrain—reflects a broader struggle for regional dominance by Iran and Saudi Arabia. These two powers support dictators, militia violence, and religious extremism that fuel a Sunni-Shiite sectarianism that suggest a future of civil wars and unstable governments. Societies divided along sectarian lines may persist for many years.[20] The history of this struggle deserves consideration as the motivations that drive it may be reflected in responses to the future of Iran's nuclear program and the United States' role in managing this struggle to stabilize the region.

The 1979 Iranian Revolution, also called the Islamic Revolution, threatened the religious legitimacy of Sunni Islam upon which Saudi Arabia had built its state since its founding in 1932. The revolutionaries in Iran encouraged Muslims in other states to overthrow their rulers, raising Saudi fears of unrest within its own Shiite population, which make up 10 percent of its citizens.

When Saddam Hussein's Iraq invaded Iran in 1980, Saudi Arabia's fear of the Iranian Revolution led them to back Iraq in an attempt to bring the revolution to an end. The Iran-Iraq war lasted for eight years until 1988 and was often waged through Iranian-Saudi proxies that would occasionally prompt the involvement of the US, whose dominant concern was ensuring the flow of oil and gas from the region to the world market.

The US policy of providing security to the energy-rich Arabian Gulf pushed the US-Saudi relationship closer after Saudi Arabia nationalized its oil industry in the late 1970s. The Saudis then became a partner of the US in the Cold War with the Soviet Union, and the latter's "Twin Pillar" policy of stabilizing the region by relying on both Saudi Arabia and Iran, ruled by the Shah, ended with Iran's Islamic Revolution in 1979. The chaos of the Iran-Iraq war brought the interests of the US and Saudi Arabia into closer alignment.

Iran's concern about the US-Saudi relationship given the American-backed order in the region was likely one that it considered an existential threat; it may have even provided the impetus for Iran's missile and nuclear programs. American

20. Much of the history recounted in this section was supplied by the following article: Max Fisher, "How the Iranian-Saudi Proxy Struggle Tore Apart the Middle East," *New York Times,* November 19, 2016.

military bases that were installed in the region following the1990-91 Gulf War to protect US allies from Iraq only tilted the power balance further against Iran. During this period, Saudi Arabia was also promoting anti-Shia sentiment in schools and the media, contributing to this sectarian rift.

Following the US invasion of Iraq in 2003, Iran raced to fill the post-war vacuum and influence Baghdad's politics by using its leverage with Shia groups. Saudi Arabia struggled to check Iran's influence with Sunni groups, but many had turned towards jihadism. This struggle eventually moved to Lebanon in 2005 where Iran supported Hizbollah, the Shia militia and political movement previously used to harass or fight Israel, and Saudi Arabia supported the Lebanese military and other Sunni political allies. Both sides chose to oppose each other rather than build a functioning state.

In response to the fall of governments during the Arab Spring beginning in 2011, Saudi Arabia financially aided numerous states, sent troops to Bahrain to support a Sunni king, and supported a general in Libya resisting the Salafist Islamist militia group Ansar Al Sharia. This may have been an attempt to stabilize areas in turmoil to prevent any divisions from being exploited by Iran. Concerns about increasing Sunni radicalism across the region that might threaten the Saudi state may have played a role in these actions as well.

Yet Saudi Arabia is also positioning itself as a national security threat to Iran given its recent actions. The Saudis have been secretly engaged for a few years in strategies with Israel to curb Iran's gains in regional influence,[21] and they recently convinced the Arab League to adopt stances against Iran,[22] which have previously only been used to mobilize Arab countries against Israel. Saudi Arabia has also bolstered cooperation with Egypt and Turkey to recruit Sunni political actors to confront Iran,[23] and they have also increased contact with the People's Mujhadeen of Iran or Mujahideen-e-Khalq (MEK), a Shia Iranian national liberation organization, to confront the perceived Iranian threat more directly.[24]

21. David A. Graham, "Israel and Saudi Arabia: Togetherish at Last?" June 5, 2015, http://www.theatlantic.com/international/archive/2015/06/israeli-saudi-relations/395015/.
22. Tamer El-Ghobashy, Ahmed Al Omran and Asa Fitch, "Arab League Statement Backs Saudi Arabia in Diplomatic Fight with Iran," *The Wall Street Journal,* January 10, 2016, http://www.wsj.com/articles/arab-league-statement-backs-saudi-arab-in-diplomatic-fight-with-iran-1452457521.
23. Hussein Ibish, "Saudi Arabia's New Sunni Alliance," *The New York Times,* July 31, 2015, http://www.nytimes.com/2015/08/01/opinion/hussein-ibish-saudi-arabias-new-sunni-alliance.html?_r=0.
24. Joseph Hammond, "Is Saudi Arabia Pivoting Toward Iranian Radicals?" *The National Interest,*

Finally, the civil war in Syria between Bashar al-Assad's government and insurgents that begin in 2011 was eventually fueled by Saudi Arabia, Turkey, and Qatar aiding rebel groups, including Sunni Islamists, and Iran sending officers and Hizbollah to fight on behalf of Syria's government. The US and Russia have more recently interfered in the conflict, and these cumulative actions have killed over 400,000 people.[25] In addition is the 2015 Iran nuclear agreement, which has raised questions not only regarding its effectiveness in monitoring Tehran's program, but also about the program's future and the role of the US in the Middle East and its relationship with the two competing regional powers.

Addressing these concerns will likely depend upon the US advancing a concept of stability for the region that is accepted by both Iran and Saudi Arabia. Both this and a better arrangement that hinders Iran from establishing a clandestine facility, the most important concern regarding its program, deserve more reflective thinking and wider consideration.

US Foreign Policy in the Middle East

For more than half a century, US policy in the Middle East has been guided by three core security objectives: preventing the emergence of a hegemon in the region; ensuring the flow of energy resources that are vital to the world economy; and attempting to broker a peace between Israel and its neighbors. The US has more often concluded that Iran threatens these interests and that its alliance with Saudi Arabia strengthens them.

Consider first US interests in the region's energy resources. It is true that the security of America's oil supply has played a role in national strategic thinking since Franklin Roosevelt met with Saudi Arabia's King Abdul Aziz in the Suez Canal near the end of World War II. It is also true that the US government has never been indifferent to the concerns of major oil companies. But the security of America's domestic oil supply plays a small role in US policy in the Middle East, and the interests of American companies do not drive strategic thinking.

The US today depends on the Middle East for only a small portion of its energy supplies. This dependence is also decreasing due to the application of hydraulic fracturing (also known as "fracking") and horizontal drilling that have made US

August 9, 2016, http://nationalinterest.org/feature/saudi-arabia-pivoting-toward-iranian-radicals-17294?page=show.

25. Max Fisher, "Syria's Paradox: Why the War Only Ever Seems to Get Worse," *New York Times,* August 26, 2016.

domestic supplies of oil and natural gas, particularly in shale rock, economically recoverable. Imports account for only 24 percent of US energy consumption[26] versus 54 percent for the European Union[27] and 94 percent for Japan.[28] Well more than half of all oil and natural gas imported by the US comes from the Western Hemisphere, with most of the remainder supplied by sub-Saharan Africa.[29] Only 16 percent of US oil imports and less than 0.3 percent of its natural gas comes from the Middle East,[30] whereas 84 percent of Japan's oil[31] and 52 percent of China's[32] (and rising) come from the same source. Should the energy supply from the region to world markets be disrupted, global energy prices would rise and affect the US economy. The security of its domestic energy supply, however, is not the prime driver of US interests in the Arabian Gulf.

Those core interests can be understood by considering the global economic and political system that has been developing for centuries, first under British leadership, and then inherited by the US following World War II and led by it to this day. The US—with the help of its allies and other partners—maintains the security of world trade by ensuring that economic transactions take place in an orderly fashion. This system can only work if the US prevents another power from dominating the Arabian Gulf and maintains the ability to protect the safe passage of ships through

---

26. "Total Energy," Independent Statistics and Analysis–2015 data, US Energy Information Administration, http://www.eia.gov/totalenergy/data/browser/ - /?f=A&start=1949&end=2015&charted=4-6-7-14.
27. "Energy Production and Imports," Eurostat Statistics Explained, data from 2014, accessed December 23, 2016, http://ec.europa.eu/eurostat/statistics-explained/index.php/Energy_production_and_imports.
28. "Japan's Energy Supply Situation and Basic Policy," The Federation of Electric Power Companies of Japan, accessed December 23, 2016, http://www.fepc.or.jp/english/energy_electricity/supply_situation/.
29. "U.S. Imports by Country or Origin," Petroleum and Other Liquids–2015 data, Independent Statistics and Analysis, US Energy Information Administration, https://www.eia.gov/dnav/pet/pet_move_impcus_a2_nus_ep00_im0_mbbl_a.htm, and "U.S. Natural Gas Imports by Country," Natural Gas–2015 data, Independent Statistics and Analysis, US Energy Information Administration, https://www.eia.gov/dnav/ng/ng_move_impc_s1_a.htm
30. Ibid.
31. "Japan–International Data and Energy Analysis," US Energy Informational Administration, data from 2014, January 30, 2015, http://www.eia.gov/beta/international/analysis_includes/countries_long/Japan/japan.pdf.
32. "China–International Data and Energy Analysis," US Energy Informational Administration, data from 2014, May 14, 2015, http://www.eia.gov/beta/international/analysis_includes/countries_long/China/china.pdf.

its waters. Due to the American security umbrella, European states, China, India, Japan, and others do not need to maintain militaries capable of projecting force into the Middle East to access energy. If America's ability to safeguard the Gulf and the trade routes around it would ever end, defense budgets would grow in every global power center and Middle Eastern politics would be further destabilized as every country sought political influence in the region to gain access to energy.

It is remarkable that the US-Saudi relationship has endured for so long despite all that has occurred: the conflicts between Israel and other Arab states; the 1973 Arab oil embargo, which saw the rise of Saudi Arabia as an energy superpower; the rise of Islamic extremism; and Saudi Arabia's restrictive domestic politics regarding human rights. With occasional adjustments in the amount of oil it supplies to world markets to manipulate prices in accordance with its domestic needs, Saudi Arabia has continued to believe that supplying energy to world markets aligns with its own security interests. Reciprocally, the US has always regarded Saudi Arabia's energy supplies as important enough to not pressure the Saudis in areas where there is strong disagreement. How long this lasts given the ongoing shale energy revolution in the US and the future status of Saudi Arabia's energy reserves is an open question. The US, however, should carefully consider the consequences of drastic changes in this relationship: volatile energy markets, a weak or collapsing state with a radicalized population, and a worsening security environment that suggests imagined benefits in acquiring nuclear weapons cannot be ruled out.

The 1979 Iranian Revolution not only pushed the US closer to Saudi Arabia due to concerns about disruption in global energy supplies, but the repudiation by the new Iranian regime of Israel's right to exist challenged another core US security interest. Iran-Israel relations prior to 1979 reflected Iran's geostrategic obligations as a non-Arab, non-Sunni state in a mostly Arab and Sunni dominated region; this period is summarized nicely by F. Rezaei and R.A. Cohen.[33] Israel's "periphery doctrine" called for building ties with non-Arab states, and the idea was welcomed by the Shah of Iran, who had a common interest with Israel in resisting the spread of pan-Arabism promoted by Egyptian President Gamal Abdel Nasser. Iran perceived an investment in relations with Israel as outweighing the benefits from supporting its radical Arab rivals, and the Shah likely believed that such an alliance would be welcome by Washington. It is important to note that Iran provided Israel with oil during the Suez crisis in 1956 and with both needed support and oil during the Yom

33. Farhad Rezaei and Ronen A. Cohen, "Iran's Nuclear Program and the Israeli-Iranian Rivalry in the Post Revolutionary Era," *British Journal of Middle Eastern Studies* 41, no.4 (2014); 442-460, http://www.tandfonline.com/doi/abs/10.1080/13530194.2014.942081.

Kippur War of 1973. Iran was the only Islamic country that rejected demands to destroy Israel and expressed support for recognizing the Jewish state as a sovereign and independent state. With the 1979 Islamic Revolution, however, Ayatollah Khomeini severed diplomatic relations with Israel, and a primary objective of Iran's foreign policy has been to undermine Israel's legitimacy and right to exist ever since. Iran eventually took the lead in regional hostility against Israel by training, funding, and equipping organizations such as Hamas, Hizbollah, and Islamic Jihad to carry out attacks against it.[34] Iran's nuclear program, while a challenge to the effectiveness and acceptance of the global nonproliferation regime, is considered by many in Israel to be directed against them.

The terrorist attacks on September 11, 2001, alerted the US to a different threat from the region: Islamic radicalism. It was revealed that fifteen of the nineteen hijackers were citizens of Saudi Arabia, and questions regarding why have been asked in the US, but no consensus that explains the connection or for effectively dealing with the problem has formed. Three rationales for the Saudi connection are typically advanced: (1) Saudi Arabia's government promotes a virulent form of Islam known as Wahhabism, whose radical Islamic interpretation aligns its adherents against the secular and capitalist West, the leader of which is the US; (2) The US military bases installed in Saudi Arabia after the Gulf War to protect US allies from Iraq were a humiliation to local citizens and considered a desecration of the Muslim Holy Land (the bases have since been removed); and relatedly but perhaps more generally true throughout the region, (3) when citizens from theological societies such as Saudi Arabia interact with Western, secular cultures, they may respond with revulsion when interpreting what is valued in a complicated, modern society. This is certainly exacerbated by the dominance of American cultural and military power, which people from the region feel they are powerless to control. Each of these factors interacts with an unemployment rate that in Saudi Arabia was over 29 percent among young men in 2013.[35] This lack of hope makes people more susceptible to radicalism.

In response to the September 11 attacks, the US launched a war against the Taliban in Afghanistan, which was then providing a safe haven for Al-Qaeda, the terrorist organization led by Osama bin Laden, who was responsible for the attacks. These attacks also renewed focus on Saddam Hussein in Iraq, who it was feared may

34. Ibid.

35. Ismaeel Naar, "Saudi Arabia Launches Committee to Tackle Unemployment," Al Arabiya, October 15, 2015.

supply weapons of mass destruction—particularly nuclear weapons—to terrorists who would use them in even more devastating attacks against the US. However, the US failed to bring stability to the country after the 2003 invasion—Afghanistan remains unstable today as well—and Iraq's Shia government today is backed by Iran. The refusal of this Iranian-backed Shia government to make political compromises with Sunni groups within Iraq, and the civil war waged by Bashar al-Assad's regime in Syria against mostly Sunni groups who oppose him, created a political vacuum that gave rise to the Sunni jihadist group, the Islamic State in Iraq and Syria (ISIS).

Iran's current position in Iraq and its support for Assad's regime in the Syrian Civil War—and other regional proxies—plus a possible closer relationship with the US following the nuclear negotiations, have raised fears in Saudi Arabia about its rival's regional ambitions. The US has focused most on trying to weaken ISIS, but it is the ongoing crisis in Syria that appears to drive recruitment to the organization. The US has struggled with how to manage Islamic radicalism since the attacks of September 11, and now the dynamics between Iran and Saudi Arabia threaten to exacerbate the problem.

ISIS, however, and Islamic radicalism more generally, is not the most serious threat to the US. In its main stronghold of Mosul, Iraq, ISIS has between 3,000–5,000 fighters[36] and is without an air force or any meaningful air defense. It is the Syrian civil war, with Iran and Russia backing Assad, that has the potential to dramatically alter the balance of power in the region and thereby threaten a long-standing core US security interest: preventing a hegemon from dominating the region. The use of massive US military power in the region to weaken ISIS, followed again by military occupation of certain areas as was attempted after the invasion of Iraq, would only come with counterproductive and long-lasting effects. It would also serve the interests of Russia and Iran, who would then benefit with even more influence over territory and people,[37] in addition to the gains they have already achieved. Thus while criticism of US actions in the Middle East since the 2003 invasion of Iraq is warranted, certain US actions could yet produce even worse outcomes, and paralysis due to limited policy options and complexities threatens

36. Robert Burns, "US Says 2,000 IS fighters Killed, Gravely Wounded in Mosul," Associated Press, December 11, 2016, https://www.yahoo.com/news/us-defense-secretary-arrives-iraq-assess-mosul-fight-062837721.html.

37. Massive US military action attempting to weaken ISIS could also weaken Turkey given Russia's history of manipulating Kurdish independence. This could weaken Iran as well. These complicated regional dynamics go beyond the scope of this essay, but the United States must be aware of what effects military action could have.

to undermine core US interests, and by extension, the lives of millions of innocent people.

The US must focus on a political settlement to the Syrian civil war in Damascus, by raising the costs to the Syrian regime and its Iranian and Russian supporters for their continued killing; it should also pressure Saudi Arabia to moderate its activities against Iran and engage them in a broader dialogue on regional security issues. Lastly, the US must soon return focus to Iran's nuclear program within a new and broader regional framework. Not only does Iran still threaten all three US security interests outlined at the beginning of this section, the Syrian civil war and Saudi Arabia's actions risk both further radicalization of the region's population and inflaming the Iran-Saudi rivalry. The possibility of more complicated challenges related to nuclear proliferation may be the consequence of these dynamics if not managed well.

What Are the Motivations for Acquiring Nuclear Weapons?

It would be a mistake to interpret the nuclear agreement and the future of Iran's program in isolation from this broader struggle between Iran and Saudi Arabia, or from the relationship of each country with the US. While the deal contains restrictions and monitoring arrangements to verify them, key restrictions are temporary, and concern about a clandestine nuclear weapons program in Iran will persist.

Academic research focused on why states build nuclear weapons has centered on three models that affect the decision: (1) increased security against foreign threats; (2) advance narrow domestic or bureaucratic interests; and (3) a symbol of national identity or prestige.[38] These motivations should be placed within the current Middle East political context to better consider what may drive nuclear weapons acquisition among the regional powers, or at least the decision to build a national uranium enrichment facility like Iran has today. Given the numerous security threats that exist in the region, however, the focus will primarily be on how states perceive foreign threats, with some analysis on how the other two factors may relate to them.

Iran's nuclear program may be understood with respect to the security threat posed to it by the US. After the September 11 attacks, it was reported that Iran cooperated with the US in capturing Al-Qaeda operatives in Afghanistan, but

38. S. D. Sagan, "Why Do States Build Nuclear Weapons?: Three Models in Search of a Bomb," *International Security* 21, no. 3 (Winter 1996-97): 54-86.

after Iran was labeled along with Iraq and North Korea as an "Axis of Evil" in George W. Bush's 2002 State of the Union address, assistance ceased.[39] After the US invasion of Iraq, Iran then had two neighboring countries that were both at war with the US, and acquiring a nuclear weapon to deter a military attack appears to be a likely calculation. In December of 2002, as the debate about using military force against Iraq was dominating American politics, the US accused Iran of having two clandestine facilities that could be part of a nuclear weapons program.[40]

It is likely that Iran developed sufficient capability over the period 2002–2015 to deter a military attack by the US, and that its demonstrated technical expertise is one of the primary reasons it decided to agree to restrictions—with the lifting of economic sanctions—in the July 2015 agreement. The US-Iran relationship will likely need to show improvement for Iran to agree to a more proliferation-resistant multinational arrangement.

The current question is whether with the election of Donald Trump, the nuclear agreement will still be honored by the United States. As it considers its options, the Trump administration must be careful not to empower factions within the Iranian government who want nuclear weapons. For instance, if the US imposes new sanctions designed to complicate Iran's procurement of ballistic missile technology that effectively result in re-establishing the nuclear sanctions, those groups could again be strengthened. If the US pulls out from the deal, there is negligible prospect that Iran will trust the United States again anytime soon.

Saudi Arabia has seen its regional influence diminish since, inevitably, Iraq's Shia population began playing a dominant role in their politics following the US invasion. The collapse of other Sunni regimes following the Arab Spring added to this sense of dwindling power. The Kingdom also has doubts about what future regional role the US will play following the Iran deal, and the Syrian civil war has strengthened Iran even further. An internal threat to the Saudi royal family's hold on power may also materialize due to the radicalization of Saudi citizens. The question is how the evolution of these uncertainties affects whether Saudi Arabia imagines providing for its defense requires a national enrichment facility, or whether convincing Pakistan to supply them with nuclear weapons is the better strategy.

39. Dexter Filkins, "The Shadow Commander," *The New Yorker,* September 30, 2013, http://www.newyorker.com/magazine/2013/09/30/the-shadow-commander.

40. David Sanger, "Threats and Responses: Weapons Programs; U.S. Says Russia Helped Iran in Nuclear Arms Effort, Adding to Concerns About Allies," *The New York Times,* December 16, 2002.

Any sectarian tension also has the potential to raise the desire for nuclear weapons for reasons of national prestige. Saudi Arabia's national identity as the leader of Sunni Islam, and its strategy over many decades of fostering sectarian identity to align with the region's Sunni majority had much success until Sunni populations turned to jihadism in the wake of the chaos in Iraq. Whether Saudi Arabia would attempt to align Sunni Muslims behind a nuclear weapon capability, ostensibly for reasons of national prestige, is something that would likely be a desperate attempt at preserving the government in the face of other security threats. Such a possibility could be imagined in Turkey in reaction to threats of Kurdish nationalism, or in Egypt to unite the country due to the serious current economic problems, but those seem remote.

The proliferation risk in Turkey may occur if President Recep Tayyip Erdogan succeeds in deconstructing the Turkish constitution. Such a move by Erdogan could end any participation in the NATO alliance, and European and American reactions to his move toward authoritarianism could alter Turkey's security strategy. The risk, of course, is that Erdogan's new defense strategy involves a nuclear program.

Regarding the Iran-Saudi struggle, it is important that the US not appear to take sides. The history of intervention by both powers seems to be driven by fears that each conflict presents a threat to their existence. The US must avoid letting either power believe it is siding with one against the other, as future challenges to stability—and relatedly proliferation—may result. For now, Saudi Arabia probably calculates that its security is best served if it remains a US partner. Its ability to sell oil to world markets is unaffected, and no better option exists for their security.

Why Multinational Enrichment?

If Iran intends to expand its enrichment capacity to fuel its Bushehr-I reactor, it should seek an arrangement that provides additional assurance of peaceful use. Such an expansion under its own control may trigger other regional powers to begin their own national enrichment programs and would likely bring another crisis with P5+1 countries, particularly the United States. If Iran agreed to give up national control and convert its nuclear program to a multinational arrangement, the political acceptance of such a facility in the region could be viewed as a confidence-building measure within the context of other security challenges.

Ali Akbar Salehi, the head of Iran's Atomic Energy Organization, even suggested some sort of regional cooperation in September 2016: "We would like to reiterate our readiness to share our valuable accumulated experience in the nuclear industry with our Persian Gulf neighbours through establishing a regional nuclear scientific contact group."[41]

A precedent for multinational enrichment exists with Urenco, a multinational company that combined the national enrichment programs of Germany, the Netherlands, and the United Kingdom in 1970.[42] While Urenco today is the world's second largest provider of enrichment services behind Russia, it was in part originally established due to concerns that Germany may want to acquire nuclear weapons. A multinational facility established in Iran today could allow full access to facilities previously controlled by Tehran and a say in how they are managed. Any management could be designed to control access to proliferation-sensitive knowledge and technology by the workers in the plant.

Regardless of whether regional states feel they need a secure source of fuel from a multinational facility for their nuclear energy programs, they would want confidence that the plant could not be used for weapons production as Iran expands capacity. For instance, Israel has no current plans for civilian nuclear energy, but would almost certainly have an interest in further assurance about Iran's program as more centrifuges are added and the flow of enriched uranium increases at Natanz. Alternatively, Saudi Arabia has very ambitious nuclear energy plans, but may never consider any dependence on a facility located within the territory of its main regional adversary for reactor fuel. One condition for Iran agreeing to multinationalize its program, however, would be that other regional states agree to forgo their own national enrichment ambitions.

There are three reasons why multinational enrichment deserves consideration as a more proliferation-resistant option following the JCPOA. First, the transparency provided by a multinational workforce would provide more assurance that "breakout" attempts from declared facilities are caught in a timely manner. Second, it would complicate the establishment of a clandestine enrichment plant by control and monitoring of proliferation sensitive equipment and knowledge. Lastly, a multinational enrichment facility would provide a solution to the problem of national enrichment plants that the existence of Iran's program currently presents.

41. "Iran Ready to Share Nuclear Experience," *World Nuclear News,* September 16, 2016, http://www.world-nuclear-news.org/NP-Iran-ready-to-share-nuclear-experience-1609167.html.

42. Treaty of Almelo, 1970. "Agreement between the United Kingdom of Great Britain and Northern Ireland, the Federal Republic of Germany, and the Kingdom of the Netherlands on Collaboration in the Development and Exploitation of the Gas Centrifuge Process for Producing Enriched Uranium," accessed March 4, 2016, http://fissilematerials.org/library/urenco70.pdf.

Declared Facility

The advantages of a multinational facility versus a national one depend upon an arrangement that provides a clear and timely warning about attempts to breakout from a declared facility can before a quantity of HEU leaves the facility. A list of the benefits could include:

- Transparency within the facility because of a multinational workforce that would be more capable of monitoring changes in cascade connections to produce HEU within the facility. This would allow more timely detection than IAEA safeguards.
- Any enrichment to higher levels could be detected in a timelier manner than IAEA safeguards with either regional inspectors or on-site analysis of enrichment levels. If the IAEA can implement continuous enrichment monitoring, this advantage of multinational control may not exist; but this capability would provide more assurance against breakout from either a national or multinational facility.
- Any attempt to nationalize the plant would provide a clearer signal that there was a crisis, prompting an international response. Such an attempt would, of course, be less likely if Iran (or another state or non-state group, for that matter) did not view the facility as a viable route to HEU production. The tolerance for taking this risk by Iran should still be much greater than that from various manipulations of the breakout time under IAEA safeguards, and therefore, more preferred.
- There may be controls possible in a multinational plant to stop centrifuge operation in an emergency that a national plant would not allow. For instance, instead of mere detection of HEU by IAEA safeguards, a multinational plant could enable a shutdown of centrifuge operation upon such detection.

These scenarios deserve careful thinking, as Iran intends to increase its enrichment capacity to fuel Bushehr-I, and other states may wish to use the plant to obtain fuel for their planned reactors. The breakout time could then be shortened greatly compared to that with Iran's current capacity.

Of additional concern is whether the plant should be designed to be economically profitable, as the goal of making a profitable plant may change the incentives that Urenco may have to become a partner as well as which countries may be willing to join the multinational workforce. This would also affect the size and duration of monetary subsidies until the plant became profitable, and how to incorporate a desire for and the benefits of profitability with assurances of peaceful use may prove challenging. Additionally, Germany (a P5+1 country) and the Netherlands (both Urenco countries) may be the most trusted as partners in a multinational facility due to their commitment to the nonproliferation regime and lack of conflicting political interests in the region. It should be noted that Russia's state nuclear energy company Rosatom has nuclear fuel supply and "take-back" in its current supplier contracts with Middle Eastern countries, and Russia's interests in preserving this aspect of their business model may need to be accommodated.

If the scale of the plant requires a large enrichment capacity, however, there is no reason why the entire capacity should be located in Iran. The plants could be broken up into two with slightly different arrangements for a plant inside Iran versus one located outside the country. It deserves recognizing, however, that one very large enrichment plant even under multinational control may present justifiable concerns about breakout that could prove unworkable. Iran should also be aware of this, as a threshold breakout capability within the country—no matter who controls the facility—could provoke another crisis.

Clandestine Facility

The most important justification for a multinational facility, however, is the additional assurance it would provide against the establishment of the most likely route to nuclear weapon production by Iran: a clandestine facility. A multinational arrangement that complicates this route would also most likely prove the most politically challenging to produce agreement.

The primary rationale behind why a multinational facility would complicate the establishment of a clandestine enrichment plant is that it would provide an arrangement that controls proliferation-sensitive technology, skills, and knowledge. For example, technology, skills, and knowledge that aids in the construction of a plant in some other location could occur through unmonitored transfers between scientists and engineers in a national plant. In theory, the scientists and other workers accepting the transfer, if possessing the technical sophistication and confidence, could alone construct and operate another plant in isolation from the declared facility. This may be unlikely because scientists trained in the declared facility would likely move between that facility and the clandestine one, and the detection of highly-enriched nuclear material by safeguards in the declared facility would indicate the existence of a separate plant (the current assumption under the JCPOA). Yet successful clandestine HEU production with this route would still be more likely than with the controls of a multinational plant. Consider the following options in a multinational enrichment plant:

- Centrifuge Research & Development: In-depth knowledge of the hydrodynamics of uranium hexafluoride centrifuge gas flow and engineering construction could require a multinational overlay. This would allow such skills to be monitored for transfer to others not required to have them. Telephone calls, electronic messages, and downloaded documents could all be monitored to better protect against important transfers.
- Centrifuge Manufacturing: Monitoring the transfer of centrifuge components and the knowledge about how to manufacture them could also be controlled. These skills may be very different from the skills involved with research and development, so scientists that have only one or two skills may not be as likely to successfully enrich uranium as multiple scientists that collectively have acquired all of the necessary skills. Again, in a national plant, bringing people together with all of the required skills would not be nearly the obstacle as having to do it under observation of a multinational workforce and other agreed upon controls. The JCPOA indicates that centrifuge manufacturing is monitored for twenty years, but it is unclear from its text exactly how effective this monitoring may be at verifying undeclared production of centrifuge components. Even if it is, the question is how could multinational controls complicate the establishment of a separate centrifuge manufacturing facility beyond that offered by current JCPOA monitoring?
- Centrifuge Assembly: It is possible that assembling the centrifuges requires a separate set of skills. How proliferation-sensitive is this skill, and is there any benefit to isolating the people who have it from others who do not?
- Centrifuge Installation & Operation: Here the question is exactly what skills and knowledge might advance clandestine programs if not properly monitored. What is required to install and operate a centrifuge? Are there proliferation-sensitive skills involved in properly balancing the centrifuge upon installation? Is there proliferation-sensitive information about various running parameters during centrifuge operation that could be controlled? Would having knowledge in only one area and not the other complicate success? Is it possible to control the transfer between these two areas?
- Centrifuge Dismantlement: When centrifuges are removed from operation and ultimately dismantled, what proliferation-sensitive knowledge is

disclosed? Is it possible to control this to make a more proliferation-resistant arrangement?

Consideration should be given to supplying centrifuges in a black-box format to an enrichment facility. Could the most important proliferation-sensitive components and knowledge be contained within the black box and have a feature that would prevent their operation if a seal was broken? If the research, development, manufacturing, and assembly required to manufacture black-box centrifuges were all multinationalized, such an arrangement would likely be much more proliferation-resistant. Iranian scientists working along with scientists from countries with centrifuge expertise would likely acquire more advanced technology, but Iran is currently doing research on advanced centrifuges and is likely to acquire these designs by its own efforts. This concern is likely outweighed by the benefit of multinationalizing these processes.

One last question is whether Iran would agree to have all declared centrifuge manufacturing facilities outside the country? This would likely require much more trust between Iran and the US but would certainly be the most proliferation-resistant arrangement. A concern would then be what happens to the Iranian scientists with knowledge about centrifuges. Where would they go every day after having been shut out from the process of supplying centrifuges to the enrichment plant? How to ensure their safety, as well as how to maintain confidence that they are not enriching uranium in a separate facility, requires deeper consideration.

National Enrichment Proliferation

Beyond a more proliferation-resistant arrangement, converting Iran's nuclear program to a multinational one would reduce the risk that other countries around the world—and not just in the Middle East—will make plans for a national enrichment plant of their own. Some US allies could argue that their close relationship with the US suggests that they should be allowed to acquire one, and that it would be of no undue concern if they did. It is difficult for the US to win this argument, as denying the wishes of close allies when it had to accept Iran's program is a risky arrangement unlikely to be sustained for long. South Korea is one US ally with ambitious nuclear energy plans that may lobby for a national enrichment plant of its own.

Conditions for Political Alignment

Given this analysis, there are some conditions that will need to be established for charting a pathway forward. It is possible that Iran offering some multinational control of its facility could be viewed as a confidence building step in resolving other regional issues; but other conditions will likely need to be in place for a multinational arrangement to provide sufficient assurance of Iran's peaceful intentions.

- The US must work towards a political solution to the Syrian civil war by raising the costs on the Syrian regime, Iran, and Russia for their continued killing. This conflict is the main source of regional instability.
- Iran and Saudi Arabia will need to restrain their involvement in regional conflicts and engage in a broader dialogue about regional security issues; this will likely require the involvement of the US.
- The US must avoid being perceived by either Iran or Saudi Arabia as aligning with one side against the other. Given their history of viewing every regional conflict as an existential threat, the perception that the US is siding with one could drive nuclear ambitions in the other.
- The US and its partners should return focus to Iran's nuclear program and work towards a more proliferation-resistant multinational arrangement of Iran's enrichment facility.
- All regional powers must agree to forgo any ambitions to acquire their own national enrichment plants; Iran will not give up national control of its facility unless other states make commitments not to acquire their own.

There is no doubt that establishing these conditions will be a daunting challenge. It is up to Iran, Saudi Arabia, and the US to search for a way to manage the region's security problems, while avoiding the possibility of regional states looking for their own nuclear weapons option in national enrichment plants. The spread of nuclear technology throughout the Middle East can only add more human tragedy to a region that has experienced too much already.

6

Confidence Today, Weapons of Mass Destruction Free Zone in the Middle East Tomorrow

*Marianne Nari Fisher**

Abstract

First proposed by the governments of Iran and Egypt, the United Nations General Assembly (UNGA) adopted Resolution 3263 to deweaponize the Middle East over four decades ago; the move formally idealized the establishment of a regional nuclear weapon free zone (NWFZ) in the Middle East. While the scope of the zone has since widened to include all weapons of mass destruction, progress on a Weapons of Mass Destruction Free Zone Middle East (WMDFZME) agenda has stalled entirely since its initial proposal in 1974. Additional support for regionally driven initiatives by non-governmental organizations or entities, with an emphasis on rising institutions in the Gulf, could build up expertise across the region and support other necessary confidence-building measures towards a verifiable zone. To move the agenda forward on such a zone, three key actions could better facilitate the ideals of a WMDFZME: First, widening Track I efforts alongside Track II and Track III diplomatic efforts in the region could further advance an achievable WMDFZME; second, convening key international organizations and domestic institutions to discuss pathways forward and act as extensions of "official" or Track I

* Disclaimer: All views expressed here are explicitly those of the author alone and do not in any way represent the views of her employer, affiliated institution, or any other entity of the United States government.

diplomacy could facilitate a successful WMDFZME, and third, localizing efforts to the region in support of a WMD-free zone could effectively indigenize new approaches on security affairs into discernible policy options, especially in countries that are on the path to acquire nuclear power, such as in the United Arab Emirates and Jordan.

Confidence Today; Weapons of Mass Destruction Free Zone in the Middle East Tomorrow

The question of a Weapons of Mass Destruction Free Zone in the Middle East (WMDFZME) is longstanding, though progress towards a feasible WMDFZME has yet to be realized despite its initial proposal nearly forty years ago. Decades of debate have surrounded the deweaponization process in the Middle East, yet discernible ways forward on a zone remain stagnant. The 2015 Non-Proliferation Treaty (NPT) Review Conference provision on the WMDFZME proved that the issue remains ever relevant; however, the meeting was unable to produce tangible results or next steps towards a verifiable zone.[1] In a follow up to the 2015 meeting alone, Israel, Canada, the United Nations (UN), Algeria, and Iran, among others, submitted official papers in support of the zone, reiterating the strong regional commitment and global initiative to support a nuclear weapons free zone in the Middle East.[2,3]

Ongoing circumstances in the region have led to rising difficulties in unilateral or direct government-to-government interaction, further obstructing the WMDFZME agenda. Despite that, as governments continue to transition across the region, the international community could look to engage non-governmental organizations (NGOs) and other entities as an extension of official diplomacy to generate progress through a multitrack process. NGOs, especially those geographically located in the Gulf that continues to be a bedrock of regional stability, could be particularly instrumental in shaping the conversation, leading to discernible steps towards deweaponization and greater cooperative security of the region. These entities, often endowed with top-tier professionals and facilities,

---

1. Emily Landau and Shimon Stein, "2015 NPT RevCon: WMDFZ Conference off the Table, for Now," Institute for National Security Studies (2015), accessed May 2015, http://www.inss.org.il/index.aspx?id=4538&articleid=9716.
2. "Final Report of the Preparatory Committee for the 2015 Review Conference of the Parties to the Treaty on the Non-Proliferation of Nuclear Weapons," United Nations Secretariat, 2015.
3. "Establishment of a Middle East Zone Free of Nuclear Weapons Report Submitted by the Islamic Republic of Iran," United Nations Secretariat, 2015.

are well-positioned to pursue back channel options towards a more realizable WMDFZME, advancing candid conversations on a more multilateral approach that will support other regional cooperative prospects. Certainly, bolstering the technical readiness of academic institutions, professional associations, and research centers alongside official initiatives could certainly further a peaceful nuclear agenda, an ideal first step to gain the political will needed for the adoption of the zone.

Despite limited progress on a zone since its proposal, confidence-building measures could further the conversation on a WMDFZ in the Middle East, especially by pursuing alternative diplomatic paths through multilateral engagement with professionals, officials, and others across the region. Numerous initiatives are already in strong support of these ideals, such as the Middle East Next Generation of Arms Control Specialists Network that actively supports development of emerging specialists on the issues or an ongoing task force hosted by the University of California-Los Angeles's (UCLA) Center for Middle East Development that supports a special focus on the biological weapons dimension, in the process uncovering the fact that there is greater regional consensus on such issues, as opposed to nuclear or chemical counterparts. While these efforts are enormously helpful in furthering the agenda, there is still lack of agreement on even the definition of a WMFDZ.[4] This chapter will largely focus on the nuclear aspect of such a zone, as the successes of similar zones have revolved around denuclearization matters – a necessary and integral step towards an eventual, larger encompassing WMDFZME. Overall, to move the agenda forward on such a zone, three key actions could better facilitate a WMDFZME: First, widening Track I efforts alongside Track II and Track III diplomatic efforts in the region could further advance an achievable zone; second, convening key international organizations and domestic institutions to discuss pathways forward and act as extensions of "official" or Track I diplomacy

4. The US Code of Law, as adopted by the Federal Bureau of Investigations, defines Weapons of Mass Destruction to be: "Weapons of Mass Destruction (WMD) are defined in US law (18 USC §2332a) as: Any explosive, incendiary, or poison gas, including the following: a bomb; grenade; rocket having an explosive or incendiary charge of more than four ounces; missile having an explosive or incendiary charge of more than one-quarter ounce; mine; or device similar to any of the previously described devices; Any weapons that is designed or intend to cause death or serious bodily injury through the release, dissemination, or impact of toxic or poisonous chemicals, or their precursors; Any weapon involving a disease organism; Any weapon that is designed to release radiation or radioactivity at a level dangerous to human life. WMD is often referred to by the collection of modalities that make up the set of weapons: chemical, biological, radiological, nuclear, and explosive. These are weapons that have a relatively large-scale impact on people, property, and/or infrastructure." See: https://www.fbi.gov/investigate/wmd.

could facilitate a successful WMDFZME; and third, localizing efforts to the region in support of a WMD-free zone could effectively indigenize new approaches on security affairs into discernible policy options, especially in countries that are on the path to acquire nuclear power, such as the United Arab Emirates (UAE) and Jordan. Despite the inevitable difficulties in rallying consensus on a nuclear weapons free zone or weapons of mass destruction free zone in the Middle East, delay on the issue will likely only exacerbate ongoing security challenges facing the region.

The governments of Iran and Egypt at the United Nations General Assembly (UNGA) first proposed the zone, aiming to demilitarize the Middle East over four decades ago. The resulting Resolution 3263 formally idealized the establishment of a regional nuclear weapon free zone (NWFZ) in the Middle East. The scope of the zone has since widened to include all WMD due to an additional proposal by Egypt, though general progress on a WMDFZME agenda has stalled entirely since its initial proposal in 1974. Although progress is not readily evident, there are some successes worth celebrating: the pursuit of nuclear weapons programs in Iraq, Syria, and Libya were effectively ended, demonstrating that some headway has already been made towards a deweaponized zone.[5] Further, no regional states are actively pursuing nuclear weapons programs. On the other hand, Egypt, Iran, Jordan, Saudi Arabia and Turkey are actively pursuing nuclear power as effective "nuclear newcomers", making the precedent for a WMDFZME ever more pressing. The UAE nuclear power program is expected to go live as early as 2017.[6] The transition to strictly peaceful uses of nuclear capabilities in the Gulf, as highlighted by the UAE, showcases an important change in perceptions towards valuation of collective security and peripheral confidence-building measures towards a verifiable zone. Moreover, the development of applications of nuclear power presents a rare opportunity for states in the Gulf to take a more active role to further the agenda.

Yet, the overall stagnation of the formal WMDFZME process in recent years is also paralleled by the call for increased public participation and civil society in decision-making and political processes, including more transparent processes even in disarmament and security policy affairs.[7] In 2015, the UN noted the special "role

5. John Bolton, "Radio Sawa Interview with Under Secretary John Bolton," Bureau of International Information Programs, US Department of State, 2003,
6. Matthew Cottee and Hassan Elbahtimy, "Russia's Nuclear Ambitions in the Middle East," Foreign Affairs (2016), accessed May 2016, https://www.foreignaffairs.com/articles/middle-east/2016-05-20/russias-nuclear-ambitions-middle-east.
7. Sameh Aboul-Enein, "A Nuclear Free Zone for the Middle East: Implications for NATO," NATO Defense College 2016.

played by civil society in contributing to the implementation of the 1995 Resolution 41. Civil society has continued to play a significant role in hosting Track II diplomacy meetings and producing papers, reports and books. NGOs in the region and in other parts of the world have assisted in building expertise, knowledge and capacity on the topic of the implementation [of a WMDFZME]."[8] Thus, there is much more international awareness and even active encouragement of international, regional, and state support for the role of NGOs and citizens in furthering the WMDFZME agenda. In addition, the head of the Gulf Research Center, Dr. Abdulaziz Sager, wrote in 2012 that the "Arab Spring" has given rise to the phenomenon of "people power," an outcome that will undoubtedly affect the policy making process in Arab governments, and specifically, foreign policy decision-making, and steer it in directions that are aligned with popular preferences."[9] The WMDFZME provides a prime opportunity to better engage civil society to complement the official and formal Track I negotiations that have largely stagnated due to regional uncertainty and the rise of complicated adversaries, highlighting the potential of multitrack diplomacy on making discernible progress towards a deweaponized region.

Historical Factors of a WMDFZME

The push for a WMDFZ agenda was launched in the 1970s, as the ideals of the landmark Non-Proliferation Treaty (NPT) gained support.[10] Iran had worked with Egypt in 1974 to appeal to the UNGA to propose a Nuclear Weapons Free Zone in the Middle East that would draw from the 1967 Latin American Nuclear Weapons Free Zone as a model. When progress on a zone stalled, the NWFZ ideal was expanded to encompass all weapons of mass destruction (WMD) in 1990.[11] Despite strong support across the board for a deweaponized Middle East, it was not enough to attain tangible results and no real progress was made on the proposal until the 1995 NPT Review Conference.

---

8. "Implementation of the Resolution on the Middle East adopted by the 1995 Review and Extension Conference of the Parties to the Treaty on the Non-Proliferation of Nuclear Weapons: Background Paper Prepared by the United Nations Secretariat," United Nations Secretariat, 2015.
9. Bilaal Saab, "The 2012 Conference on a Weapons of Mass Destruction-Free Zone in the Middle East," Center for Non-Proliferation Studies, 2012.
10. Zia Mian, Alexander Glaser, Frank von Hippel, Seyed Mousavian, Emad Kiyaei, and Harold Feiveson, "Fissile Material Controls in the Middle East: Steps Toward a Middle-East Nuclear-Weapon-Free Zone," Princeton University, 2014.
11. "NWFZ Postcard," United Nations Office for Disarmament Affairs, accessed 2014.

Alongside the indefinite extension of the NPT in 1995, a "Resolution on the Middle East" was produced to encourage states in the region to pledge and pursue a feasible WMDFZME.[12] With the exception of Israel, most regional states became early signatories to the NPT and supporters of the WMDFZME, and the resolution was in step with Article VII of the NPT, stipulating that "nothing in this Treaty affects the right of any group of States to conclude regional treaties in order to assure the total absence of nuclear weapons in their respective territories."[13] However, it was not until 2003, when Syria proposed the implementation of an official WMDFZME, that the discussion was renewed. In April 2004, the United Nations Security Council (UNSC) adopted Resolution 1540, reaffirming international consensus "for a call on all nations to commit to the principles of nonproliferation and disarm any weapons of mass destruction," in line with WMDFZME ideals.[14] Further, this positive international momentum demonstrated global commitment to non-proliferation and the use of nuclear technologies for peaceful purposes, including the growth of weapons free zones.[15]

At the 2010 NPT review conference, the WMDFZME call was revived yet again for a conference on the matter to be convened in 2012, in this round to be headed by the NPT depositary states and conference co-facilitators, including Russia, the United Kingdom and the United States, with efforts led by Finnish Undersecretary of State Jaakko Laajava.[16] However, final arrangements of the conference failed to materialize, and the Finnish delegate was unable to secure the necessary parties in time for a 2012 deadline. As a consequence, the plans for a WMDFZME conference collapsed, and the topic has seemingly been put on hold indefinitely.[17] As an NPT-led initiative, disappointment over the failure to convene the meeting prompted Egypt to walk out in protest at the NPT Preparatory Committee Meeting in Geneva in April 2013 and has also damaged the credibility

12. "Resolution on the Middle East, the Conference of the Parties to the Treaty on the Non-Proliferation of Nuclear Weapons," United Nations Office for Disarmament Affairs, 1995.
13. "NPT: The Non-proliferation Treaty Text," US Arms Control and Disarmament Agency, 1994.
14. "Resolution 1540 (2004) Adopted by the Security Council at its 4956th Meeting, on 28 April 2004," United Nations Security Council, 2004.
15. "Building a Weapons of Mass Destruction Free Zone in the Middle East: Global Non-Proliferation Regimes and Regional Experiences," United Nations Institute for Disarmament Research, 2004.
16. Oliver Meier, "The 2015 NPT Review Conference Failure: Implications for the Nuclear Order," Stiftung Wissenschaft und Politik (2015): WP No 4.
17. "Banning WMD from the Middle East," Bulletin of the Atomic Scientists (2013).

of the NPT states to uphold their bargain on credibly pursuing the zone.[18] Following the walkout by Egypt, the call for the conference and political efforts to further the agenda have been put on indefinite hold by regional states. However, a large part of the breakdown in progress can be attributed to the lack of consensus on the parameters of collective security and discernible next steps of a zone. The lack of a central regulatory authority on WMDs or regulatory entity to oversee the spread and use of related technologies in the Middle East, furthered by inequitable distribution of capabilities across the region, has left limited room for agreement and cooperation. These concerns, intensified by ongoing events stemming from the Arab Spring, has stalled official Track I diplomacy and direct engagement between governments on the WMDFZME question.

In other words, political will on the WMDFZME agenda has been exhausted, especially following the collapse of the 2012 conference proceedings. Yet, building technical capacity across the region can support human capacity development from the ground up, and regional initiatives towards a zone may not require widespread official support to restart or enable political will on the topic. The Comprehensive Test Ban Treaty (CTBT), a multilateral treaty to ban nuclear explosions, had faced a similar dilemma upon its proposal. For decades, the CTBT had remained in political limbo with little progress until a majority of the UNGA adopted its ideals in 1996. This support was garnered despite a lack of political will from several key states for its ratification. Since then, the international community has looked to build up international technical capacity and verification methods in conjunction with the CTBT Organization in support of the treaty so that developed capabilities can match political will when additional official channels are ready. Although binding political commitments at the official or Track I level are sometimes constrained, building up technical capacity furthers the conversation and can even build up political will, as was done through the successes of the CTBT Organization's In-Field Exercise (IFE) that took place in Jordan in Fall 2014. Therefore, there is utility in multitrack successes such as the IFE that support development of technical capabilities so that these capacities can match or even surpass political will in the future.

Despite the activities of several regional organizations such as the Arab Maghreb Union, the Organization of the Islamic Conference (OIC) and the Gulf Cooperation Council (GCC), discernible goals to deweaponize the region or promote regional security is often not within the purview of these entities and their

18. Paolo Foradori and Martin B. Malin, "A WMD-Free Zone in the Middle East: Regional Perspective," Belfer Center, Harvard University, 2013.

ability to coordinate support for related initiatives is limited. The Arab League, a loosely organized pan-Arab body that convenes on regional issues, now supports a Committee of Senior Arab Officials on Nuclear and other Weapons of Mass Destruction. The Gulf has taken leadership of the forum, with the UAE chairing the 37th proceedings in 2017 and Qatar heading the 38th event in August 2016.[19,20] Furthermore, regional institutions often comprise of "sub-regional countries" such as the Gulf and do not encompass a majority of "regional" countries, diminishing "collective legitimacy" and rendering the decisions of such authorities ineffectual or non-representative of the region as a whole. While the GCC appears to be taking an unprecedented lead on other political mechanisms such as pursuing economic cohesion through establishment of one currency[21] or furthering talks on relaxed restrictions on inter-GCC travel for nationals,[22] among others, there is still space to expand the role of the GCC to more adequately coordinate on security questions. With the UAE ready to produce electricity using nuclear energy in 2018 and Jordan and Turkey slated to follow within the next decade, the WMDFZME agenda could not be a more pressing goal. The need for a successful zone is also amplified by the blessing of capabilities in Iran due to the implementation of the Joint Comprehensive Plan of Action (JCPOA) and Saudi Arabia's vague nuclear ambitions. In the following sections, this chapter will summarize previous efforts and the ongoing scope of multitrack diplomacy in a WMD security context in the region, in addition to describing how these efforts will serve to advance a WMDFZME.

Multitrack Diplomacy in the WMDFZME Context

While official channels are at a standstill on the WMDFZME agenda, non-official conflict or back channel conflict resolution efforts could help fill emerging security gaps across the region; further, deweaponization efforts to support WMDFZME

19. "UAE Chairs Arab League's Committee on WMD," Emirates News Agency, 2016, https://www.wam.ae/en/news/emirates/1395292367038.html.
20. "Qatar Takes Part in Meeting of Senior Arab Officials in Charge of Nuclear Weapons Issues Committee," Qatar News Agency, 2016, http://www.qna.org.qa/en-us/News/16080114160045/Qatar-Takes-Part-in-Meeting-of-Senior-Arab-Officials-in-Charge-of-Nuclear-Weapons-Issues-Committee.
21. Esteban Jadresic, "On a Common Currency for the GCC Countries," International Monetary Fund, 2012.
22. "GCC Citizenship Workshop Recommends Equality in Movement and Residency," Emirates News Agency, 2014. http://www.wam.ae/en/news/arab/1395269497414.html.

ideals could build confidence towards an achievable zone in the years to come. At the very least, engaging NGOs by bolstering the work of academic institutions, professional associations, training or research centers in the region could certainly further a more peaceful agenda, an ideal first step. These entities, and especially Gulf-based institutions, are typically endowed with top-tier professionals and facilities. This strategic advantage signals that a number of already established organizations could be well positioned to pursue back channel options towards a more realizable WMDFZME, advancing candid conversations on a more multilateral approach that will support other prospects for greater regional cooperation.

Certainly, bolstering back channel talks or Track II or III diplomacy through institutes not formally affiliated with the government is not a new concept in the Middle East. Although many institutions, private or public, still fall under strict government purview, existing and informal relationships can leverage greater private-public cooperation and be paralleled with more formal efforts to prevent proliferation of weapons of mass destruction across the region. For example, institutions could facilitate informal, candid discussions through short-term projects, initiatives, or other programs towards a WMDFZME, including nuclear energy collaboration or cooperation. Through multitrack diplomatic efforts over the years, deweaponization principles could be socialized among high-ranking officials or influential academics, then filtered and transmitted into realizable policy.[23,24]

Additional support for regionally driven initiatives by non-official entities could increase expertise across the region and build up other necessary confidence-building measures towards a verifiable zone. Multitrack-oriented organizations in the Middle East already have a strong awareness of key nonproliferation ideals and have the ability to bring together key stakeholders from across the government, academic, and other sectors to drive policy-directed initiatives. In recent years, a number of prominent think-tanks have emerged across the region, including Brookings Doha Center in Qatar and the Carnegie Middle East Center in Lebanon that engage sectors on a variety of issues. Engagement on the issues will require

23. Dalia Dassa Kaye, "Rethinking Track Two Diplomacy: The Middle East and South Asia," Netherlands Institute of International Relations (2005): Paper 3.

24. The United States Institute for Peace describes multitrack diplomacy as "a term for operating on several tracks simultaneously, including official and unofficial conflict resolution efforts, citizen and scientific exchanges, international business negotiations, international cultural and athletic activities, and other cooperative efforts. These efforts could be led by governments, professional organizations, businesses, churches, media, private citizens, training and educational institutes, activists, and funders." See: "Tracks of Diplomacy," United States Institute for Peace, accessed May 2016, http://glossary.usip.org/resource/tracks-diplomacy.

extensive coordination with governmental bodies, international agencies and other key stakeholders, and a multitrack approach would greatly support all-inclusive participation and shared standards. Besides, through multifaceted diplomatic channels, international and regional bodies can continue the momentum on a WMDFZME by pursuing Track I, II and III channels in tandem.

Track I: Official Diplomacy

To date, Track I diplomacy has typically encompassed high-level, official discussions between political, royal, or military leaders. From among international organizations, the Comprehensive Test Ban Treaty Organization (CTBTO), European Union (EU), UN, and IAEA, among others, have historically headed deweaponization and related diplomatic efforts in support of the WMDFZME under the auspices of NPT ideals in cohorts with member states or by leveraging multilateral and bilateral initiatives. Yet, the events of the Arab Spring following 2011 have made it increasingly difficult to reach consensus among high-level or official channels, especially when dealing with transitory governments across the region. While official talks and political will can never be substituted, multitrack diplomacy could effectively supplement outlined Track I principles and further the conversation. Indeed, the lack of a regional roadmap or achievable next steps in pursuit of a WMDFZME has led to decades of inaction, and it is evident that layers falling outside the purview of official channels may be needed or could better help the process along.

Track II: Non-official Diplomacy

Track II diplomacy is dominated by dialogue carried out by non-officials or several convening parties in non-official settings. In recent years, Track II efforts have grown to include civil society participation in formal discussions. In 2013, Princeton University published a report on Track II diplomacy in the Middle East, outlining that such "dialogues can offer creative or original proposals about what steps are necessary to resolve a conflict and lay the groundwork for pre-negotiation [and that] Track II dialogues can generate discussion on issues too sensitive for official negotiations."[25] Certainly, in light of political stagnation at the high levels of

25. Nate Allen, Rashad Badr, Chris Brown, Thomas Burns, Lindsey Einhaus, Kathleen Merki, Mayank Misra, Travis Sharp, Seth Smith, Alexandra Utsey, and William Wagner, "Bridging Divides: Track II Diplomacy in the Middle East," Princeton University, 2013.

government, there is space for off the record discussions that could lead to verifiable steps to deweaponize the region as part of a WMDFZME.

There is also little doubt that the role of social media and mobilization of regional populations following changes in governance has made citizen participation in rule-making ever more crucial. Dialogue in support of the zone from a non-official stance could set the stage for pre-negotiation and promote voluntary socialization of issues that may be non-traditional, including security or deweaponization matters.

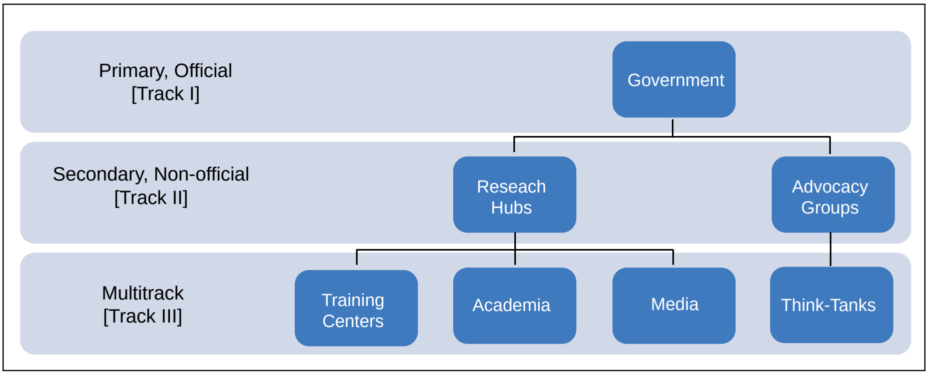
Track III: Multitrack Diplomacy

Sometimes referred to as Track 1.5 diplomacy, in policy circles multitrack diplomacy is designed to complement formal processes that have been historically dominated by high-level officials by taking a multilateral approach. In addition to the participation of non-officials in influencing rule-making and security affairs, greater inclusion of civil society, the general public, and the media are also supplements to official tracks. These non-official parties are able to disseminate and effectively translate disarmament ideals towards a realizable WMDFZME, promoting peaceful conflict resolution in the region.

To avoid further stagnation on a zone, officials could complement high-level or official meetings with multitrack diplomacy that weaves together all layers of civil society, including intellectuals, professionals, and academics, among others. In a 2014 bilateral meeting, the UN and the OIC produced a final document that "agreed on the need to work together for promoting the objectives of nuclear disarmament and non-proliferation and the establishment of a world free of weapons of mass destruction…and establishment of additional such zones including the establishment of a zone free of nuclear weapons and all other weapons of mass destruction in the Middle East."[26] Leveraging multitrack support of this type across governmental and non-governmental sectors is key to furthering the agenda and securing the political will from the appropriate parties towards progress on a WMDFZME.

26. "Final Document of the General Meeting on Cooperation between the United Nations and the Organization of Islamic Cooperation," United Nations and Organization of Islamic Cooperation, 2014, accessed May 2016, http://www.oic-oci.org/oicv2/upload/pages/un/2014/UN-OIC_Report_2014_final.pdf.

Figure 6.1: Primary Track I, II & III entities and projected levels of influence towards the success of a zone.



These three tiers of proposed engagement for the multitrack diplomacy approach were determined on loose metrics assessing disarmament goals, organizational or institutional structure, and relative influence in the MENA region. Primarily, official or high-level talks headed by governments and international organizations have dominated the conversation, yet would benefit from greater inclusion of other entities. Secondary, research hubs such as national laboratories and fundamental research centers or think-tanks that impact policy and progress on security matters will be especially important in influencing the conversation and implementing measures in deweaponizing the region. Third and finally, civil society efforts by academia, training centers, the media, and other professional or research groups also have a key role in influencing WMDFZME efforts through social support and shaping the discussion. Different examples of these institutes are examined in greater detail later.

In particular, six nuclear energy "newcomer" states are emerging in the Middle East, including Saudi Arabia, the UAE, Egypt, Turkey, Jordan, and Iran which are equipped to take the lead on multitrack diplomatic efforts in support of the peaceful use of nuclear energy and securing weaponizable materials.[27] In recent years, these countries have built up their technical and research capabilities significantly in regard to training, nuclear cooperation, and promoting opportunities for regional nationals. For example, the UAE now supports a range of education and training opportunities for both nationals and regional Arab nationals to pursue careers in the nuclear field such as the Gulf Nuclear Energy Infrastructure Institute (GNEII)

27. Cottee and Elbahtimy, "Russia's Nuclear Ambitions in the Middle East."

in Abu Dhabi and Simulator Training Center (STC) near Barakah on the southern coast of the UAE. These institutions look to develop a responsible nuclear culture and view themselves as a regional hub for the development of human resources in direct support of their own and other regional nuclear energy programs based on a three-pillar system revolving around education, research, and technical demonstrations. Institutions such as GNEII are well equipped to support safety and security measures that could further deweaponize the region, leading to greater cooperative or mutual security over the coming years. The GCC is particularly well positioned to take the lead on the agenda, as the process has largely been led by other regional states. Although the GCC cannot be expected to divorce its approaches from regional considerations, growing institutional and human resources of the Gulf can usher in new voices and perspectives to the WMDFZME conversation.

Key Organizations in Advancing the Agenda

This section will outline the key international organizations in instrumenting a WMDFZME and regional organizations that could act as extensions of "official diplomacy" through multitrack pursuits. Partnering with regional and multilateral entities could strengthen efforts to prevent the proliferation of weapons of mass destruction and related materials, in addition to formalizing and coordinating agreements with all levels of institutions beyond official channels. In short, despite limitations due to their non-official status, NGOs present an excellent opportunity to expand current programmatic goals and reach to increase awareness and movement on the WMDFZME ideals.

Table 6.1: Highlighting the roles of different types of institutions in multitrack diplomacy given a MENA context.

Type of Institution	Description	Impact
Government	Official organizations already address and prevent WMD - material proli feration threats emanating from security concerns across the region, but are constrained by internal and regional politics. These entities are typically specific in approach, sometimes in coordination with international agencies, and often take the lead on high -level negotiations in support of critical mission objectives.	High Impact

Research Centers or National Laboratories	Crucial in identifying key mission space and building long-term engagements, these entities can also identify critical partner government contacts and facilitate introductions, but are restricted by funders or governmental directives. Research centers can also facilitate technical reach - back for specialty enterprises or government.	High Impact
Policy Think - Tanks	Given the unofficial political reach of these institutions, these organizations can convene governmental officials to discuss key concepts and influence paths forward but are still restricted in their technical capabilities. Supported research and discussions often carry forward objective dialogue on critical issues.	Medium Impact
Academia	Nearly every country in the region maintains at least one university department that strongly lends itself to safety and security issues. "Nuclear newcomer" countries are particularly at the forefront of building up education and training centers, with prospects to better include WMDFZME ideals through education and training opportunities.	Medium Impact
Media	Serves as an important springboard to educate the public, though is sometimes constrained in its messaging capabilities, especially those that may contend with the views or policies of respective governments. Its central role lies in engaging and informing civil society on the latest developments and producing opinion pieces on particular issues.	Limited Impact
Advocacy Groups, Training	These types of institutions are vital to the visibility of issues, translate the needs into the security and protection realms, and are more informal, often acting as regional hubs for best practices. The numerous associations or centers typical specialize in a subset of topics and offer access to a variety of participants across the government and professional sectors.	Limited Impact

All of the mentioned entities are well-positioned to engage domestic, regional, and the international communities, as their missions are connected to WMDFZME objectives. Indeed, engagement with these institutions could expand the breadth and scope of engagement on limiting WMD across the region, further fostering collaborations that will increase the sustainability of such programs well into the future. As such, trainings, workshops, tabletop exercises, and ongoing diplomatic efforts could all contribute to raising awareness on the benefits of a zone and ridding the region of nefarious materials.

Bolstering the work of academic institutions, professional associations, training or research centers in the region could certainly further a more peaceful agenda, an idyllic first step. Yet, while indigenization or localization of the process could go a long way, these entities are sometimes restricted in assessing sponsors, including host governments, or criticisms of regional decision-making. There is limited flexibility in actual influence of policy-making, but efforts can still frame the security debate towards WMDFZME ideals. It should be noted that significant buy-in from regional and state leadership within the organization or government would be eventually needed for any developments to be truly impactful and would require years of rigorous work. Certainly, the "autonomy dilemma" arises when regional entities could be influential in instrumenting efforts toward WMDFZME, but the same institutions are also constrained in pursuits of sensitive research or political efforts.

Further, additional support for regionally driven initiatives by non-governmental institutions, with an emphasis on rising institutions in the Gulf, could increase expertise across the region and build up other necessary confidence-building measures towards a verifiable zone. To parallel efforts in demilitarizing the region, other emerging, potential areas of cooperation could also be discussed, such as the growing call for peaceful applications of nuclear energy development in the region. In particular, opportunity for a regional, shared nuclear fuel cycle is becoming ever more plausible. Similarly, there are options for the region to support a state-based division of labor in the fuel cycle, including uranium enrichment or management of nuclear waste, potentially to mirror the URENCO model or participation in a fuel bank such as the IAEA fuel bank under development in Kazakhstan. The time is ripe for regional entities beyond official governmental entities to push for the WMDFZ agenda, given the political climate and realities of the region.

Localization of Efforts towards a WMD-free Zone

Numerous institutions in the Middle East already have a high awareness of key nonproliferation and disarmament affairs and often have the ability to bring together key stakeholders from different sectors. Many of these institutes that work on arms control already exist in the Middle East, including the Center for Middle East Development (CMED), Gulf Research Center (GRC), Consortium of Middle Eastern Research Institutes, and the International Institute for Strategic

Studies (IISS), though a number of others have phased out.[28] These institutions are tangentially connected to the rulemaking or governance realms, but are instrumental in facilitating multitrack diplomacy. Other initiatives include annual or periodic meetings on the topic at the Center for Nonproliferation Studies, Stockholm International Peace Research Institute (SIPRI), and the United Nations Institute for Disarmament Research (UNIDIR). For example, the Cooperative Monitoring Center initiated by Sandia National Laboratory was successfully developed into the Middle East Scientific Institute for Security (MESIS) in Jordan. Other entities such as the European Union Chemical, Biological, Radiological, and Nuclear Risk Mitigation Centers of Excellence (EU CBRN CoE) already aim to build and strengthen nonproliferation capacity through international partnerships. At present, three EU CBRN CoEs are based in Algeria, Jordan, and the UAE, though additional support for regional entities and initiatives could further the WMDFZME agenda. Another example includes the University of California-Los Angeles's Center for Middle East Development that supports a task force comprising participants from across the region to meet with regular frequency in recent years. For the most part, participants have explored the fundamentals of biological weapons, biological safety and security, and other confidence-building measures that surround the Biological and Toxin Weapons Convention (BWC), a good start to further efforts that are directly in support of a WMDFZME.[29] If possible, more investigation on the need for a regionally-led initiative or regulatory body dedicated to WMD related issues could be useful, or at the very least could determine if the expansion of an already existing entity could fill the gap.

For example, the Middle East Scientific Institute for Security (MESIS) in Amman already focuses on bringing together government and industry on both a state, regional, and international level on security issues. Supporting a multitrack approach by facilitating high-level discussions, trainings, workshops, and other related events, MESIS is a regional leader in its ability to gather professionals and politicians to liaise on nonproliferation issues. The head of this institute, Al-Sharif Nasser bin Nasser has published on the importance of culture in support of scientific or security ideals, because even "though terms such as 'local ownership' and 'partnerships' have become commonplace in the world of scientific cooperative

28. Peter Jones, "Filling a Critical Gap, or Just Wasting Time? Track Two Diplomacy and Regional Security in the Middle East," Arms Control in the Middle East (2008): Chapter 2, accessed May 2016.
29. Benjamin Bonin, Amir Mohagheghi and Michael Yaffe, "Implementing a WMD-Free Zone in the Middle East," The Nonproliferation Review 20, no.1 (2013): 137-144.

engagements, it is rare to see them translated successfully into policy," demonstrating the importance of full regional participation and localization of regional initiatives.[30] More generally, greater indigenous research and participation in the social and organizational structures of pursuing WMDFZME ideals could better serve these ideals. Other regional hubs are also already supporting deweaponization principles, such as the Khalifa University in the UAE that supports human capacity development and familiarization of MENA-based professionals with the applications of nonproliferation concepts. Other entities include the Arab Center for Research and Policy Studies in Qatar and the Emirates Center for Strategic Studies and Research, institutions that are contributing to regional security research. The Arab Institute for Security Studies (ACSIS) based in Jordan hosts the annual WMD Security Colloquium, an incredibly instrumental tool in furthering multitrack diplomacy in support of a WMDFZME.[31] Additional confidence-building measures and safeguards associated with a WMDFZ will lead to increased disarmament and would greatly benefit from multitrack participation.

Multitrack Diplomacy Could Support Possible Confidence-Building Measures

Paralleling support for deweaponization, it is imperative to encourage regional states to fully participate in existing international verification regimes. For example, Resolution 1540 legally binds states to actively enforce measures against proliferation, dedicating use and procurement of potentially sensitive technologies only for peaceful and civilian purposes. Besides, fine-tuning policies to include non-proliferation and disarmament at the state and regional levels will be monumental to rally regional states to sign onto such agreements, a move that would put the Middle East on the path towards denuclearization and a WMDFZ. Nonetheless, dialogue will only improve if fostered through smaller steps and confidence-building measures, rather than large bargains that are politically tied to other long-standing issues.

In the meantime, there are a number of feasible measures that could build confidence among states in the Middle East towards a WMD free zone. These

30. H.H. Nasser Bin Nasser, "A Social Science Perspective on International Science Engagement," Federation of American Scientists 68, no. 3 (2015).

31. "Implementation of the Resolution on the Middle East Adopted by the 1995 Review and Extension Conference of the Parties to the Treaty on the Non-Proliferation of Nuclear Weapons: Background Paper Prepared by the United Nations Secretariat," United Nations Secretariat, 2015.

recommendations could be orchestrated through multilateral, cooperative efforts to enhance regional security. The following list is non-exhaustive, but may offer attainable ways forward on a WMDFZME:

International Efforts: Track I

- **Encourage states to ratify IAEA safeguards.** Specifically, states such as Saudi Arabia, Yemen, and the UAE could support confidence-building measures by amending and updating their modified small quantities protocols. Alternatively, Israel could pursue additional or more stringent safeguards measures, beyond facility-type INFCIRC/66 agreements, due to the fact that a traditional comprehensive safeguards agreement is not possible without signing onto the NPT. The detailed Additional Protocol is still awaiting ratification by Qatar, Saudi Arabia, Egypt, Sudan, Oman, Syria, Iran, Lebanon and Yemen as of December 2015.[32] Canada, among other states, have actively called on states that have not ratified or fulfilled broad safeguards obligations to do so as soon as possible to signal good faith to regional states.[33],[34]
- **Localize the WMDFZME agenda before the 2020 NPT Review Conference.** First, the international community could consider moving beyond the failed Finnish conference that regional states have already politically dismissed. Second, the lead on the zone could instead be passed to a regional country or entity to rally support. Third, multitrack support for entities based in the region to further training, technological support, and other programs could facilitate deweaponizing the region and building up expertise to combat potentially nefarious actors. These measures would demonstrate that the NWFZ/WMDFZME has not lost relevance in today's security climate and would give greater ownership of the agenda to the region.

32. International Atomic Energy Agency, "Conclusion of Safeguards Agreements, Additional Protocols and Small Quantities Protocols," Updated December 31, 2015, https://www.iaea.org/sites/default/files/16/04/status_list_sg_agreements_31_december_2015.pdf.
33. "Steps to Promote the Achievement of a Nuclear-weapon-free Zone in the Middle East and the Realization of the Goals and Objectives of the 1995 Resolution on the Middle East Report Submitted by Canada," United Nations Secretariat, 2015.
34. "Implementation of the Resolution on the Middle East Adopted by the 1995 Review and Extension Conference of the Parties to the Treaty on the Non-Proliferation of Nuclear Weapons."

- **Support Article VI of the 1995 UN Resolution on the Middle East.** Parties to the NPT that are willing and able could pledge security guarantees or provide aid for the disposal of weapons of mass destruction in exchange for country-specific incentives. The language of the Resolution on the Middle East stipulates:

> "all States party to the Treaty on the Non-Proliferation of Nuclear Weapons, and in particular the nuclear-weapon States, to extend their cooperation and to exert their utmost efforts with a view to ensuring the early establishment by regional parties of a Middle East zone free of nuclear and all other weapons of mass destruction and their delivery systems."[35]

To extend good faith to the peaceful use of nuclear power, countries could also support the right of newcomer states "to participate in, the fullest possible exchange of equipment, materials and scientific and technological information for the peaceful uses of nuclear energy," as outlined by the NPT.[36] Bolstering nuclear newcomers in the Middle East to take the lead on the zone could enable states coordinate greater regional support of the zone, especially as Gulf-based countries such as the UAE are slated to start up the second regional nuclear energy program as early as 2017. Matthew Cottee and Hassan Elbahtimy write, "Middle Eastern governments are on the lookout for nuclear technology providers, regulatory best practices and training opportunities," and could be further encouraged to pursue peaceful uses buy-in.[37]

- Support ratification of international and multilateral treaties that would result in deweaponization, including the Non-Proliferation Treaty (NPT), Chemical Weapons Convention (CWC), Biological and Toxic Weapons Convention (BTWC), and the Comprehensive Test Ban Treaty (CTBT). Already, progress has been made on the contentious question of the BTWC, where a UCLA task force has already brought technical experts from the region to outline an ambitious agenda and draft a working framework to build regional confidence on the biological weapon dimension; subgroups of this nature tailored to each treaty could be framed in a broader context

35. "Resolution on the Middle East, the Conference of the Parties to the Treaty on the Non-Proliferation of Nuclear Weapons,."
36. "NPT: The Non-proliferation Treaty Text," US Arms Control and Disarmament Agency, 1994.
37. Cottee and Elbahtimy, "Russia's Nuclear Ambitions in the Middle East."

towards a greater WMDFZME agenda.[38] Certainly, all these treaties are the bedrock of any potential successful WMDFZ, and regional states could sign onto treaties that have not yet been adopted. There is still progress to be made on other fronts, and as such, the CTBT awaits ratification by Egypt, Iran, Yemen, and Israel.[39]

Regional Efforts: Track I & II

- Champion a regional verification or regulatory body. A new entity or consortium could potentially take the lead on bilateral or multilateral initiatives, such as managing enrichment and reprocessing questions to balance regional anxieties over the JCPOA or coordinating other programmatic endeavors such as education and training.[40] Pursuing this on the Track I level, regional officials could look to start an initiative, almost mirroring the Brazilian-Argentine Agency for Accounting and Control of Nuclear Materials (ABACC), highlighting possibilities for regional powers to collaborate and manage dual-use or radioactive materials in a safe and secure way. From the perspective of Track II and Track III pursuits, regional think-tanks could reproduce a linkage of research firms such as EU Nonproliferation Consortium to encourage greater cooperation among Middle Eastern entities, professionals, and officials. Meanwhile, the IAEA already supports the Arab Network of Nuclear Regulators (ANNuR), a group of member states from the Arab region, to collaborate on the applications of nuclear sources for medical, research or energy purposes; this group could potentially be expanded in scope.[41] In line with the 38th meeting of the Arab League's Committee of Senior Arab Officials on Nuclear and other Weapons of Mass Destruction, the Secretary-General of the organization has "set up an Arab elders committee for arms control and non-proliferation to

38. Bonin, Mohagheghi and Yaffe "Implementing a WMD-Free Zone in the Middle East."
39. "Status of Signature and Ratification," Comprehensive Nuclear-Test-Ban Treaty Organization, last modified April 9, 2012, https://www.ctbto.org/the-treaty/status-of-signature-and-ratification/.
40. Mian, Glaser, von Hippel, Mousavian, Kiyaei, and Feiveson, "Fissile Material Controls in the Middle East.".
41. "Strengthening Arab Network of Nuclear Regulators," International Atomic Energy Agency, last modified May 29, 2014, https://www.iaea.org/newscenter/news/strengthening-arab-network-nuclear-regulators.

participate in the meetings of the first preparatory committee of the 2020 NPT Review Conference, to be held from 2-12 May 2017," presenting a rare opportunity for the group to push for progress at official levels.

- Endorse regional "no first-use" pledges. Countries outlined in the zone as a collective or one-by-one could pledge a "no first-use" of weapons of mass destruction as a confidence-building measure to other regional powers. This move would reiterate peaceful purposes and also provide some security assurance to partner states, the region, and the international community. Along similar lines, there could be utility in exploring other non-binding commitments or even declarations or public statements to signal support for WMDFZME ideals.

Multinational Efforts: Track I, II & III

- First pursue a controlled Nuclear Weapons Free Zone (NWFZ) or a smaller, limited zone. This step could take place before pursuing ambitious plans of a Middle East free of weapons of mass destruction, facilitating initial consensus on a NWFZ. Other measures include starting with a smaller zone that could grow out as regional powers buy in to the larger NWFZ or WMDFZME. Regionally based entities could band together and promote peaceful ideals and outline a potential initial zone, whether or not that would include Iran or Israel.
- Consider a Regional Joint Comprehensive Plan of Action. Unintentionally, negotiation of the JCPOA and legitimization of peaceful uses in Iran's nuclear program has a great potential to contribute to a better non-proliferation regime, regionally and globally. In a way, the JCPOA fills the gaps left intentionally in the NPT, especially in securing commitments by states to forego reprocessing and limiting enrichment. Perhaps, a first step towards a comprehensive WMDFZME is to agree on a "regional JCPOA," either for a limited time or indefinitely.
- Support the ban on separation of plutonium and use of HEU as a reactor fuel. Guidance proposed by researchers at Princeton University outlines that certain limitations on reprocessing and stricter measures on HEU would ensure that uranium cannot be repurposed or used in a non-peaceful manner.[42] Although discussions on this level are difficult to directly

42. Mian, Glaser, von Hippel, Mousavian, Kiyaei, and Feiveson, "Fissile Material Controls in the

negotiate, multitrack diplomacy could better push for a HEU-free future in the region.

Immediate Complications to a Zone

Ongoing circumstances in the region and conflicts have resulted in a deep mistrust that permeates diplomatic and political relations between regional countries, rendering official Track I diplomacy nearly impossible in many cases. In 2012, Prince Turki bin Faisal Al Saud of Saudi Arabia wrote there is still a need for "public commitment by Israel in support of the Zone. Iran, while paying lip service to the Zone, is more committed to pursuing enrichment of uranium and other suspicious activities that raise doubts about their commitment to the Zone," highlighting mistrust and perceptions among the regional leadership that make diplomatic success difficult.[43] Though decreased regional conflict and deweaponization of the Middle East could reduce perceived dangers and therefore any need for WMD capabilities, behavioral uncertainties and political considerations in Iran, Israel, Syria, and Yemen all pose complications to a WMDFZME.[44]

Factoring Iran, Israel, and the Conflicts in Syria and Yemen

Iran is the first state in the region to acquire nuclear energy capabilities; however, the program has been widely criticised in recent decades. Although it was an early proponent of the WMDFZME, Iran has been accused of noncompliance in the past by the IAEA, which has broken down trust with regional states.[45] The JCPOA commits Iran's capabilities to peaceful purposes, yet uncertainties remain when factoring historical compliance affairs.[46] UNSC Resolution 1803 states that "a solution to the Iranian nuclear issue would contribute to global non-proliferation efforts and to realizing the objective of a Middle East free of weapons of mass

Middle East."

43. Ayman Khalil and Marc Finaud. "The Conference for a Middle East Weapons of Mass Destruction Free Zone: A Synopsis of Engagement of International and Regional Organisations, and Civil Society," Arab Institute for Security Studies, 2012.
44. Robert Einhorn and Richard Nephew, "The Iran Nuclear Deal: Prelude to Proliferation in the Middle East?" Brookings Institution, 2016, accessed May 2016, http://www.brookings.edu/research/reports2/2016/05/iran-deal-regional-proliferation.
45. Michael Adler, "The Iran Primer: Iran and the IAEA," United States Institute of Peace, 2015, http://iranprimer.usip.org/resource/iran-and-iaea.
46. Michael Adler, "The Iran Primer

destruction, including their means of delivery."[47] Without doubt, resolution on the scope of capabilities in Iran is essential to remedying relations with its neighbors and building trust towards a realizable WMDFZME.

Second, misconstrued perceptions of WMD capabilities in Israel remain a major concern to its neighbors. Above all, the lack of transparency in Israel poses a significant hindrance to achieving trust in the region that would put the Middle East on track towards a verifiable zone. While Israel bases itself on a "peace before disarmament" mantra in regards to its capabilities, there are still measures that could build confidence with neighboring states. As such, between October 2013 and June 2014, Israel participated in five rounds of multilateral consultations with states in the region to seek consensus on the essential aspects of a zone, breaking much needed ground in more than two decades despite the conclusion of the talks.[48] There is little doubt that Israel has much to gain from pursuing additional cooperative and trust-building efforts in support of a WMDFZME.[49]

Third, ongoing conflicts in the region, especially in Syria and Yemen, present enormous obstacles to progress on the WMDFZME agenda. The current crises in Syria and Yemen are issues causing grave regional concern as permeable borders are easily exploited. In Syria, the use of chemical weapons by the Assad government was also a humanitarian catastrophe and a major setback in achieving a WMDFZ.[50] Although Syria has made strides in securing and disposing of its chemical weapons, destroying "98 percent of [its] declared category 1 and 89 percent of its category 2 chemicals" before 2015, the egregious use of such weapons highlights the dire need for immediate progress on a WMDFZME.[51] In Yemen, ongoing strife between the Houthi rebels and government forces is compounded by sectarian violence and decreased security of weaponizable materials that could pose dangers in the future.[52]

47. "Resolution 1803 (2008) Adopted by the Security Council at Its 5848th Meeting, on 3 March 2008," United Nations Security Council, 2008.
48. "Towards a Regional Dialogue in the Middle East: an Israeli Perspective Submission by Israel," United Nations Secretariat, 2015.
49. Saab, "The 2012 Conference on a Weapons of Mass Destruction-Free Zone in the Middle East."
50. British Broadcasting Corporation, "Syria: The Story of the Conflict," http://www.bbc.com/news/world-middle-east-26116868.
51. Chen Kane, "Planning ahead: A Blueprint to Negotiate and Implement a Weapons-Of-Mass-Destruction-Free Zone in the Middle East," Center for Nonproliferation Studies Occasional Paper No. 22 (2015).
52. British Broadcasting Corporation, "Yemen Crisis: Who is Fighting whom?" http://www.bbc.com/news/world-middle-east-29319423.

Moreover, for either country, it would be nearly impossible for the respective governments of Syria or Yemen to be adequately represented on the international, regional, or even state level on moving the zone forward to pursuing confidence-building measures towards deweaponizing the region. The lack of consensus thus far in the region on the Syria and Yemen conflicts only highlights the potential benefit of establishing a regulatory authority or lead in the region to coordinate and manage security concerns, including pathways forward on a WMDFZME.[53] Uncertainty due to changing circumstances in the region has hindered movement in arms reductions and disarmament measures, but the pursuit of a NWFZ/ WMDFZME remains an important step in fortifying regional and global security as a whole.

Additional Considerations and Potential Limitations for a WMDFZME

Between 1991 and 1995, the Arms Control and Regional Security Working Group (ACRS) that was formed at the Middle East Peace Process in Madrid failed to reach consensus due to exclusion of states such as Iran, Iraq, Lebanon, Libya and Syria and focusing too strongly on the Israel-Palestine paradigm.[54] However, this is not to say that no progress has been made despite hurdles throughout the last four decades; Iraq disarmed in 1998, and Libya gave up its nuclear weapons capabilities in 2005, among other examples. Nonetheless, other sizeable debates remain in regard to measurable steps towards the success of this zone, and measures of success continue to be hotly debated. Is the framework of success of a zone contingent on a finalized, legally mandated area free of weapons or can it be met in degrees through ensuring contentious sides such as Egypt and Israel hold bilateral meetings and pursue "small step" disarmament. Multitrack meetings remain necessary, but there is also a need for a clear agenda and a clear signal of political will as displayed in Table 6.2:

53. Foradori and Malin, "A WMD-Free Zone in the Middle East: Creating the Conditions for Sustained Progress,"

54. Jones, "Filling a Critical Gap, or Just Wasting Time?"

Table 6.2: Systematic approaches to be addressed before pursuit of a comprehensive zone.

Non-Proliferation vs. Total Disarmament: Consensus should be reached on the preferred outcomes of a WMDFZME, deciding on whether *non-proliferation* (dealing with the prevention of acquisition of nuclear weapons) or *disarmament* (referring to the act of reducing, limiting, or abolishing weapons) should take precedence as long-term goals.
Prevention vs. Dismantlement: Similar to non-proliferation vs. disarmament, the region should decide whether or not states should seek to prevent the acquisition of any new technologies or continue to systematically dissolve capabilities in the region that could be used for nefarious purposes.
'Top Down' vs. 'Bottom Up': The international community has largely led the efforts for a WMDFZME to this point, yet greater indigization of the process across the Middle East could foster a bottom-up approach towards a regional consensus; an executive way forward on a lead or multidimensional approach could be paved.

Conclusion

In a recent working paper, the co-convening states of the 2015 NPT Review conference wrote that hosting "a successful, inclusive Conference will be a practical first step towards the long-held, common goal of the establishment of a Middle East zone free from nuclear weapons and all weapons of mass destruction."[55] Further, even as the region awaits the successful, long-term implementation of regional agreements such as the Joint Comprehensive Plan of Action with Iran (JCPOA) – advancing the first full nuclear fuel cycle in a regional state – it is worthwhile to pursue ideals that could lead to a WMDFZME. In February 2016, the foreign minister of Egypt noted that the world had moved closer to an achievable zone, contingent on Iran meeting its JCPOA obligations and forgoing a nuclear weapons program. Given the current regional political and security environments of the Middle East, focus on non-proliferation and preventing acquisition of weapons of mass destruction in the region is ambitious, but not outside the realm of possibility. Nilsu Goren of the Center for International and Security Studies at the University of Maryland wrote in the Bulletin for Atomic Scientists that nuclear terrorism and radiological vulnerability is still a high concern in the region, citing the 2016 Nuclear Security Index, where "Middle Eastern nations rank poorly when it

55. "Working Paper Submitted on Behalf of the co-convening States (Russian Federation, United Kingdom of Great Britain and Northern Ireland and United States of America)," United Nations Secretariat, 2015.

comes to safeguarding their nuclear materials from theft" and also rank lower on nuclear sabotage, highlighting the need for immediate action on the topic.[56,57] Yet, in the two cases of Libya and Iraq, the IAEA was able to successfully dismantle nuclear capabilities that had been repurposed for non-civilian use. The success of dismantlement in the region demonstrates the ability of coordinated regional efforts to successfully hedge against potential pursuit of the bomb that could then lead towards a verifiable NWFZ or WMDFZ.

Historically, Track I diplomacy limited to governmental and official channels had dominated the WMDFZME conversation, even on the international stage, in large part supported by initiatives led by the UN or IAEA. Due to shifting circumstances in the region, it appears unilateral or direct government-to-government interaction has become more difficult, further obstructing the WMDFZME agenda. Indeed, as regional governments continue to transform, the international community would benefit by engaging other NGOs as an extension of official diplomacy to generate progress and further continuity on deweaponizing the region, especially rising nuclear newcomers such as the UAE. Existing NGOs could be particularly instrumental in shaping the conversation and establishing back channels to support the WMDFZME agenda.

Although the path towards a WMDFZME is a slow one, having just passed the 40-year mark from its first proposal in 1974, small confidence-building measures in addition to multitrack diplomacy with greater regional participation and leadership can further the WMDFZME agenda. Options to support ways forward outlined in this chapter are not exhaustive. Informal, candid discussions through short-term projects, initiatives, workshops, or other programmatic work towards a WMDFZME, including nuclear fuel cycle collaboration or technical cooperation, could all contribute to raising awareness on the benefits of such a zone and downsizing nefarious materials in the region. First, the scope of Track I efforts could be widened and be complemented by Track II and Track III diplomacy to advance an achievable WMDFZME. Second, international and regional organizations could act as extensions of "official diplomacy," further indigenize efforts towards a WMDFZME, and effectively support new tactics to translate

56. Nilsu Goren, "The Middle East: Culprit for My Nuclear Security Insomnia," Bulletin of Atomic Scientists (2016). Accessed May 22, 2016, http://thebulletin.org/what-path-nuclear-security-beyond-2016-summit/middle-east-culprit-my-nuclear-security-insomnia.

57. Nuclear Security Index, "Building a Framework for Assurance, Accountability, and Action," Nuclear Threat Initiative, http://ntiindex.org/wp-content/uploads/2016/03/NTI_2016-Index-Report_MAR-25-2.pdf.

cooperative security measures into discernible policy options for the region. And third, the localization of regional efforts in support of a WMD-free zone could promote innovative approaches.

About the Contributors

Ali Ahmad is a Scholar In-Residence at the American University of Beirut (AUB) and director of the Energy Policy and Security in the Middle East Program at AUB's Issam Fares Institute for Public Policy and International Affairs. Ahmad's research and teaching cover nuclear security, energy policy, and economics. Prior to joining AUB, he was a research fellow in Princeton University's Program on Science and Global Security where he worked on studying the prospects of nuclear energy in the Middle East and informing nuclear diplomacy with Iran. Besides his academic activities, Ahmad is also involved with government and investment advisory firms on energy issues. He holds a degree in physics from the Lebanese University and a Ph.D from Cambridge University.

Abdalla Abou Jaoude is a PhD candidate in the Nuclear and Radiological Engineering department of the Georgia Institute of Technology. His research interests are at the intersection of advanced reactor technology and nonproliferation issues. His thesis focuses on how to design proliferation-resistant long-lived fast reactors. Jaoude was also a temporary research assistant at Oak Ridge National Laboratory, Argonne National Laboratory, and EDF in France. He is a Sam Nunn Security Fellow and an alum of the TI:GER Entrepreneurship program. He holds a master's in Mechanical and Nuclear Engineering from Imperial College London.

Rami Bitar is a graduate student at the American University of Beirut where he is enrolled within the Energy Studies Program. He is expected to graduate in the spring of 2017. As part of his master's degree requirements, Bitar studied the economics of water desalination with a focus on the Middle East region for his thesis project, which led him to write his chapter in this book. Bitar's research interests cover interdisciplinary topics related to energy economics, energy policy, and energy management. He graduated with high distinction in June 2014 with a bachelor's degree in Mechanical Engineering from the American University of Beirut (AUB).

Anna Erickson is an Assistant Professor of Nuclear & Radiological Engineering in the Woodruff School of Mechanical Engineering at Georgia Tech. She received her MS and PhD from the Massachusetts Institute of Technology, where she was a NNSA Stewardship Science Graduate Fellow. Prior to her position at Georgia Tech, she was a postdoctoral researcher at the Advanced Detectors Group at Lawrence Livermore National Laboratory. Dr. Erickson's research focuses on advanced nuclear reactor design and nuclear security and nonproliferation, connected by the current need for proliferation-resistant nuclear power. On the experimental side, her group is involved in large-array imaging applications for homeland security and antineutrino detection.

Philippe Chite is team leader of Reconstruction and Economic Recovery, for the National Agenda for the Future of Syria, a project hosted by UN-ESCWA since 2012. He is also an affiliated researcher with the Energy Policy and Security in the Middle East Program at the American University of Beirut. Previously, he worked at the Aleppo Chamber of Industry, Syria, in addition to working for more than ten years at the Syrian European Business Center, an EU-funded project for upgrading the SME sector in Syria. He has also worked as a freelance engineer. His expertise includes the SME sector, export, policy formulation, business incubation, and renewable energy. He holds a BSc in Mechanical Engineering and is currently studying for an MSc in Energy Studies at AUB.

Marianne Nari Fisher is a Graduate Research Associate and Fellow working on global security and technology policy issues in the Washington, D.C. area. She is a former Kuwait Programme Scholar from Sciences Po in Paris, France where she completed her MA in international energy. She holds a BA in international studies from the University of Washington.

Ryan Snyder is a Visiting Fellow at the Arms Control Association in Washington, D.C. His focus is on the intercontinental ballistic missile (ICBM) modernization debate, and how US conventional weapons lethality may affect strategic stability, the future of nuclear arms control, and extended deterrence. As a postdoctoral research associate with Princeton University's Program on Science and Global Security, he worked on the proliferation risks of laser isotope separation and multinational uranium enrichment in the Middle East. He was previously a Fellow for Energy Studies at the Federation of American Scientists and an adjunct lecturer in physics at American University, both in Washington D.C. In graduate school, he worked at the Thomas Jefferson National Accelerator Facility as part of a collaboration that used parity-violating electron scattering to measure the strange-quark contribution to the structure of the nucleon. He received a PhD in physics from the University of Virginia and a BA in physics from Kenyon College.

Energy Transitions in the Gulf:
Key Questions on Nuclear Power

Several countries in the Middle East, including the United Arab Emirates and the Kingdom of Saudi Arabia, are in the process of planning, establishing, or expanding their nuclear power programs. The official rationale for investing in nuclear energy differs from one country to another, but broadly speaking, it seems to emerge from the need to improve energy security through reducing the reliance on oil and natural gas to generate electricity and desalinated water. This volume aims to examine the challenges as well as the opportunities associated with the deployment of nuclear power in the region. The key focus areas of this book are the economics of nuclear power; nuclear security and potential for regional cooperation; and technology overview.

Gulf Research Centre Cambridge
Knowledge for All

ISBN 9781909864207

9 781909 864207

1866 AUB
American University of Beirut
الجامعة الأميركية في بيروت
Issam Fares Institute for Public Policy and International Affairs
معهد عصام فارس للسياسات العامة والشؤون الدولية