AMERICAN UNIVERSITY OF BEIRUT

SUPPLY AND DEMAND OF NUCLEAR FUEL IN THE MIDDLE EAST: OPTIONS AND OPPORTUNITIES

by
TEDDY ZADOUR KHACHADOURIAN

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By

TEDDY ZADOUR KHACHADOURIAN

Approved by:

Dr. Nesreene Ghaddar, Professor — Advisor
Energy Studies Program Director
Mechanical Engineering

Dr. Ali Ahmad, Visiting Fellow — Member of Committee
Issam Fares Institute for Public Policy and International Affairs

Dr. Hiba Khodr, Associate Professor — Member of Committee
Political Studies and Public Administration

Dr. Simon Neaime, Professor — Member of Committee
Department of Economics

Date of thesis/dissertation defense: April 28, 2016

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Several countries in the Middle East (Turkey, Jordan, UAE, Iran, Saudi Arabia, and Egypt) have set serious plans to build nuclear power plants for electricity generation in the upcoming years. The nuclear capacity to be added in the region could be as high as 40 Gigawatt by 2040.

These projections of nuclear power deployment in the region pose questions about the sources of nuclear fuel available and the security concerns associated with such a sensitive technology. This thesis proposes to study the options available for countries in the region to obtain the enriched uranium fuel. Since the process of enrichment is very costly and technically challenging to be done on a national level, special attention will be given to study the prospect of having a regional fuel bank from economic and security perspectives.

CONTENTS

ILUSTRATIONS

Figure Page

TABLES

Table Page

CHAPTER I

INTRODUCTION

A. Nuclear Energy Overview

Achieving energy security has become an ultimate goal for the world in general as an attempt to become more independent, and less reliant on other countries. A way to achieve energy security is through increasing the diversification of energy resources. The more diversified the resources the higher the level of energy security. A way to achieve energy security is through adopting resources and technologies that have high efficiency[1]. A type of energy source with such characteristics is the production of nuclear energy. Even though many are critical of nuclear power, it offers the advantage of high capacity factor, which is about 90 percent. In the Middle East, there are several countries such as Jordan, Iran, Saudi Arabia, United Arab Emirates, Turkey and Egypt, which have developed serious interest in nuclear energy. Iran has already connected its first reactor, the Bhusher reactor to the grid, and UAE will in mid-2016, or early-2017[2]. For the reactors to operate, uranium fuel is needed with a concentration of U-235 isotope of 3-5%[3]. Since U-235 isotope's concentration is 0.7% in natural uranium, it is expensive for each country to separately to build an enrichment plant in order to obtain enriched uranium fuel. This thesis will study the demand and supply options of enriched uranium fuel in the Middle East as well as examine the idea of building a joint enrichment plant in the region.

[1] (Cohen, ., Joutz, F., & Loungani, P.).
[2] (World Nuclear News).
[3] (Dr. Ulmer-Scholle, 2016).

However, the Fukushima nuclear accident in Japan on 11 March 2011[4], which was caused by a major earthquake, followed by a Tsunami**,** was given a rate 7 on the INES scale[5], the International Nuclear and Radiological Event Scale, which is a scale used to determine the technical size of damage to the public as a way of understanding the size of the damage. The maximum level on the scale is 7, which is termed as a *Major Accident*[6]*,* which was the case in Japan.

This rate was high, and it is considered very dangerous because of high radioactivity releases. In fact, it released around 940 PBq over a period of one week (I-131 equivalent)[7]**.** Ever since this incident, many countries have started to reconsider nuclear energy and their reliance on it as a source of energy**.** In fact, Germany has permanently shut down eight out of seventeen of its reactors and is planning to close the rest by the end of 2022. Moreover, Italy voted to keep their country nuclear-free. On a higher level, Spain and Switzerland have banned the construction of new reactors. However, there are sixteen European countries that still depend on nuclear power for at least a quarter of their electricity. In fact, France gets around three-quarters of its power from nuclear energy, while Hungary, Ukraine, Finland, Czech Republic, Switzerland, Slovakia, Slovenia, Sweden, and Belgium get around one-third or more of their energy from nuclear resources. Bulgaria, and South Korea get around one-third of their power from nuclear energy; while in the USA, Spain, Romania, Russia, and UK, almost one-fifth is from nuclear resources. Japan, the site of Fukushima incident, used to rely on nuclear power for more than one-quarter of its electricity and is expected to return to that level. Moreover, countries that do not host nuclear power plants, such Denmark and

[4] (World Nuclear Association, 2016).
[5] Ibid.
[6] (International Atomic Energy Agency, 2015).
[7] Ibid.

Italy, rely on nuclear energy to supply 10% of their total energy needs[8].

On the other hand, many countries' interests in nuclear energy for the purpose of electricity generation have continued to increase. In fact, some of them have reached advanced stages, such as UAE, Turkey, Saudi Arabia, Iran, and Egypt which are projected to produce up to 40 GWe by 2040. Some projects have been proposed and others are already planned. When we use the word "planned", we mean that it is approved by government officials or the parliament, that funding is available for the project, and that there is a commitment in place. This type of project is "planned" to take 8 to 10 years. However, the term "proposed" is used differently from "planned"; since "planned" is in more advanced stages, in a specific program or site proposals. The proposed projects are usually expected to be operating within 15 years. Hence, proposed projects might take longer periods of time than the ones "planned".

Today, we have 437[9] civil nuclear reactors that operate around the world, in addition to 62 under construction[10], including the ones that mentioned above. In 2014,2.411 million GWh.

Taking into consideration the number of new reactors that will be built, along with the sensitivity of enrichment of uranium technology by each country separately. This thesis will study building a common enrichment facility through answering three main questions:

1) How can we obtain the enriched uranium to fuel and then refuel the reactors?

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[8] (Nuclear Power in the World Today, 2016).
[9] Ibid.
[10] (IAEA).

2) How much of enriched uranium is needed?

3) If we should build one central enrichment facility, where should this facility be built?

The thesis is divided into five chapters. In the first chapter, it is discussed the overall situation of the nuclear energy world today. In the second chapter we will highlight the nuclear energy history of the countries that will enter will enter the nuclear world and their current status. The new entries countries are: Kingdom of Saudi Arabia, United Arab Emirates, Iran, Turkey, Jordan, and Egypt. In the third chapter, there is extensive literature review about the supply and the demand of uranium, along with discussing how the prices fluctuated in the 2000s. Also in the demand there are the minimum and maximum Projection of Nuclear Capacity. Through which the Enriched Fuel and Feed needed is calculated, along with SWU, Saparative Work Unit, and the cost of SWU is calculated.

In the fourth chapter, we will discuss Supply Options, through policy options of how we the enriched uranium can be obtained. And later discuss the host country of which the facility will be built in. In the final chapter, we will try to conclude, and suggest policies for this facility, based on the findings. The purpose of this thesis is to do a study the different aspects of building a central enrichment facility for the nuclear energy raisers in the Middle East, through qualitative and quantitative research.

CHAPTER II

HISTORY OF NUCLEAR ENERGY IN THE MIDDLE EAST

A. Islamic Republic of Iran

The Islamic Republic of Iran had started its nuclear activity before the revolution in 1975.The United States and Iran, as a part of the US Atoms for Peace program, signed a civil nuclear agreement in 1957[11]. Later, Shah of Iran, Mohammed Reza Pahlavi, had signed an agreement with a German company called Kraftwerk Union AG[12] to build its first reactor on the coast of the Persian Gulf, in an area called Bhusher.

After India's nuclear tests, the Shah of Iran says to a French magazine that Iran will have nuclear weapons in the future, "without a doubt and sooner than one would think"[13]. After the revolution, the supreme leader of the revolution, Ruhallah Khumaini passed away; and the president Hashemi Rafsanjani had already started efforts to attract the scientists back to the country in order to continue the nuclear program, as he knew that nuclear ambitions and goals couldn't be achieved unless there was foreign aid. Iran was able to provide its uranium ore supply and an enrichment plant plan by making deals with many countries, especially with China and North Korea. The Chinese supplied the uranium ore until 1997[14]. North Korea provided Iran with mining for uranium technology[15]. In addition to the Chinese and North Korean aid, in the early 1980s, Iran had also had nuclear activity with Pakistan. It is cited that A.Q Khan had

[11] (Jahanpour, 2007-2014).
[12] (Bernstein, 2014).
[13] (Gibney, 2015).
[14] (Bernstein, 2014).
[15] Ibid.

major role in the Iranian enrichment facility[16]. In 1993, Iran received a sample of the "P1" centrifuge after meetings with A.Q. Khan in Dubai. This was considered to be at very large cost since it was estimated to be of hundreds of millions of dollars. According to Jeremy Bernstein, Iran bought this plan to make metallic uranium hemispheres whose use was restricted to only proliferation and non-civic use of nuclear energy which was for weapon creation.

In April 2006, Gholam Reza Aghazadeh, the vice president of Iran's atomic energy back then, gave an interview about the Iranian nuclear program. In his speech, he claimed that due to lack of experience in the beginning some machines were breaking down often[17]. Then they, the Iranians, found out that this was due to using their bare hands which brought with it sweat and germs. Afterwards they started using fabric gloves.

B. Saudi Arabia

KSA, one of the largest countries in oil production in the world, and being one of the six GCC countries, along with Bahrain, Kuwait, Oman, UAE, and Qatar started to consider nuclear program in December 2006[18]. However, in August 2009, Saudi Arabia announced to start its own nuclear program. In April 2010, a royal decree said: "The development of atomic energy is essential to meet the Kingdom's growing requirements for energy to generate electricity, produce desalinated water and reduce reliance on depleting hydrocarbon resources."[19] As a result, The King Abdullah City for Atomic and Renewable Energy (KA-CARE) was established in Riyadh as an agency

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[16] Ibid.
[17] Ibid
[18] (World Nuclear Association, 2016).
[19] (S. Jha, 2011).

responsible for treaties related to nuclear energy and signed by the kingdom. In addition to treaties, this agency is also responsible for radioactive waste management[20]. In summer 2010, Poyry Consulting, a Finnish-Swiss firm, was hired to assist the kingdom with strategies in nuclear and renewable energy with desalination. In June 2011 KA-CARE announced a plan to construct 16 nuclear power reactors over the next 20 years, of a total capacity of 17 GWe capacity by 2040. The costs were estimated at around 300 billion riyals, which is equivalent to $80 billion.[21] This way, around 20% of Saudi Arabia's electricity will be generated through nuclear energy.[22]

In March 2015, KA-CARE signed an agreement with the Korea Atomic Energy Research Institute (KAERI) to build at least two South Korean SMART reactors in the country, the preliminary study was expected to take three years. SMART reactors are relatively “smaller” in terms of capacity, with up to 100 MWe, and it is estimated to cost $1 billion for each unit. SMART has a life expectancy of 60 years, with 3 refueling cycles; in other words, refueling will take place every 20 years. [23]

Furthermore, the national Saudi Arabian Atomic Regulatory Authority (SAARA) was set up to commence activities early in 2014. In May 2014 KA-CARE signed an agreement with the Finnish Radiation and Nuclear Safety Authority (STUK) for assistance regarding nuclear safety and radiation by recruiting and training personnel. However, in January 2015, the Saudi Arabian government said that its target for 17 GWe of nuclear capacity would be more like for 2040[24].

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[20] Ibid
[21] Ibid
[22] Ibid
[23] (World Nuclear Association, 2016)
[24] Ibid

C. United Arab Emirates

UAE is a country rich in natural resources, most of which is gas and petroleum, with 198.5 trillion cubic feet, and 97.8 billion barrels of reserves respectively[25]. It is the second largest economy in the Middle East, after Saudi Arabia, with a GDP of $399.5 billion (2014)[26], and the third largest crude oil exporter in the region has developed interest in nuclear energy. What makes UAE significant, is that it started to build four commercial nuclear power reactors, producing a total 5.6 GWe, by 2020. This is under a contract of $20 billion signed with South Korean consortium. All the four reactors are currently under construction and the first reactor is expected to be completed, and put into operation by 2017[27]. In 1995, the UAE signed the Treaty on the Non-Proliferation of Nuclear Weapons (NPT) [28]. This Treaty is recognized as one of the largest international security agreements and focuses on three major aspects: non-proliferation, disarmament, and peaceful uses of nuclear energy. The UAE also signed safeguards agreement with the International Atomic Agency (IAEA) in 2003[29]. It also agreed to the IAEA Additional Protocol in 2010. In 2008, the UAE's electricity demand was growing by around 9% per year. By that rate of energy growth, the country's requirement for electricity to meet the demand should increase by 40 GWe by 2020. As an effort to meet the demand, the UAE released a policy document about its interest in developing a nuclear power program in April, 2008. Later, on September 29, 2009, the Federal Authority for Nuclear Regulation (FANR) was established, following federal law by a decree in 2009, concerning the civic uses of nuclear energy. FANR is an independent regulatory authority; its major role is ensuring long-term safety, security

[25] (U.S. Energy Information Administration, 2015).
[26] (World Bank, 2014).
[27] Ibid.
[28] (World Nuclear Association, 2015).
[29] (IAEA, 2013).

and sustainability in the peaceful uses of nuclear energy and ionizing radiation in the UAE by establishing world-class regulations and supervising their implementation.

D. Turkey

Turkey relies on importing its energy resources, in fact 98% of its natural gas and 93% of its oil is imported[30]. Turkey has been showing interest in nuclear energy since 1970[31] when it first conducted a feasibility study for a 300 MWe plant[32]. Three years later, the electricity authorities decided to build a relatively smaller plant of 80 MWe as a showpiece plant; however they did not achieve it.[33] In 1976, on the Eastern Mediterranean coast near the port of Mersin, Akkuyu was licensed for a nuclear plant. However, in 1980 this attempt failed again due to failure of the government in providing the needed financial guarantee for the development and construction the power plant. In 1993 a nuclear plant was included in the country's investment program following a request for preliminary proposals in 1992. Later in 1997, a biddings for a 2000 MWe plant at Akkuyu were received from Atomic Energy of Canada Limited (AECL), Framatome, Westinghouse, Mitsubishi, along with Siemens.[34]

After the final bid deadline in October 1997, the government delayed its decision many times between June 1998 and April 2000, where these plans were unrestrained due to financial and economic problems.

After 6 years another attempt was taken, this time in the province of the port city of Sinop, which is located on the Black Sea. This location was chosen because of

[30] (World Nuclear Association, 2015).
[31] Ibid.
[32] Ibid.
[33] Ibid.
[34] Ibid.

technical reasons. The main reason was due to the cooling water temperatures which had an average temperature of 5^{o}C less than that of the Mediterranean Sea, where Akkuyu is. This allows about 1% greater power output from any thermal unit. The plan was to build one 100 MWe showpiece, then to build a 5000 MWe of further plants to come into service from 2012. This involved hybrid partnership that included both the public and private sectors for the construction and operation. In mid-2006 the government had set a plan to build three nuclear civil power plants with a total generation of 4500 MWe operating by 2015. Discussions had been under way with AECL, which already had bid in 1997 to own two 750 MWe if CANDU type as an initial investment.[35] The first unit of the total 5000 MWe generation was planned to be built at Akkuyu site, as the license for building the plan at that location already existed, unlike Sinop, [36]which has the technical advantage that the license did not exist. In November 2007, the Turkish government had come up with a new law concerning the construction and operation of nuclear power plants and a decree regarding the sale of the energy. The decree was passed by parliament and later approved by the president. The bill had three major points. First it gave the Turkish Atomic Energy Authority (TAEK) the right to set the criteria to build and operate the power plants. Second, the Türkiye Elektrik Ticaret ve Taahhüt A.Ş (TETAS in English language), which is the Turkish Electricity Trade and Contracting Company, should buy all the power produced under 15-year contracts. Third, the bill provided the right for public institutions to build the plants for efficiency and cost minimization purposes. In May 2010, a deal was signed between Turkey and Russia for four 1200 MWe VVER units at the Akkuyu site

[35] Ibid.
[36] Ibid.

on Turkey's Mediterranean through BOO agreement,[37] built, operated, and owned by Rosatom, the Russian nuclear corporation[38]. This meant, that Russia was in charge to provide the reactors with the enriched uranium. However, after downing the Russian plane, on November 24, 2015, the Turkish-Russian relations have deteriorated, hence the nuclear project continuance is might have questionable[39]. However, on February 10, 2016,Rosatom'sdeputy director general, Kirill Komarov in his interview with Vestnik Atompromа, focused on the benefits of financing nuclear projects abroad, first benefit according to him is to promote the Russian technology abroad, in fact he stated:"… government support of projects such as in Turkey and Finland is logical in terms of promoting Russia's high-tech products". He also claimed that this helps in "creating a long chain of added value" for Russia.[40]This creates insecurity, in terms of the project achievement.

E. Jordan

Jordan, this country is unique in terms of owning low-cost uranium resources of 140,000 tU[41] plus another 59,000 tU in phosphate deposits, and plans to mine these resources. Jordan's nuclear power journey started in 1955, when it participated for the first time in an International Conference on the Peaceful Uses of Atomic Energy in Switzerland.[42] In 1988, Arab Atomic Energy Agency was created; of which Jordan was part of it, along with Lebanon, Saudi Arabia, Kuwait and others to organize the nuclear

[37] (World Nuclear News, 2016).
[38] (World Nuclear News, 2010).
[39] (Trenin, 2015).
[40] (World Nuclear News, 2016).
[41] (World Nuclear Association, 2015).
[42] (Tukan, 1955).

energy research within the Arab countries[43]. What alleviated Jordan's interest in 1990s, is the termination of Saudi Arabia's oil supply to Jordan[44]. In 2007, the Jordanian Committee for Nuclear Strategy was established, in order to put a strategy for nuclear power to be contributing 30% of Jordan's electricity by 2030. Later in 2007, Jordan Atomic Energy Commission (JAEC) was established by modifying the law[45]. JAEC started its strategy by conducting a feasibility study on nuclear power for Jordan, along with a CBA (Cost/Benefit Analysis). [46]In October 2008, a joint venture between JAEC and Areva was established to define uranium resources in central Jordan. In February 2010, this became the Joint Venture Company, Nabatean Energy. Areva made an agreement giving it exclusive uranium mining rights in central Jordan for 25 years. Areva's goal was "to create a full partnership with Jordan on training and obtaining nuclear technology".[47]

In 2008, the Jordan French Uranium Mining Company (JFUMC) was set up as a joint venture between Areva and Jordan Energy Resources Inc. (JERI) and traded as Jordan Areva Resources.

This company would carry out a feasibility study on mining by August 2012. The Minister for Energy and Mineral Resources earlier announced that development of an open pit mine would begin in 2013, for operation starting from 2015. However, in October 2012 JAEC terminated the JFUMC joint venture mining license due to JFUMC failing "to submit its report on time"[48].

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[43] (International Institute for Strategic Studies , 2008).
[44] (Ibrahim, 1990).
[45] (World Nuclear Association, 2015).
[46] (Hibbs, 2007).
[47] Ibid.
[48] Ibid.

Since 2009, Jordan has been working on constructing and developing a modern nuclear reactor capable of producing 10 MW[49]. The plan has involved the cooperation of multiple Western, Arab, and East Asian countries. Jordan has made deals with these countries for the numerous tasks involved in constructing a functional nuclear reactor: uranium mining, desalination, designing, and environmental safety. In November 2009, JAEC signed a contract with Worley Parsons worth $11.3 million for pre-construction consultation of Jordan's first nuclear plant[50].

However, in October 2013, JAEC's chairperson, Khaled Toukan, announced that Russia will build the Jordanian nuclear reactor, based on BOO scheme. According to Toukan, the project costs $10 billion. The Russians will contribute 49% of the total cost, and the Jordanian government will be financing the remaining 51%. However, the major challenges that the Jordanians might face is that most countries have plans for nuclear energy, they have high GDP. Although GDP is not the only condition to own nuclear power plant, however it contributes to indicate the inability to finance the project, as for Jordan there is no clear source for funding the project, due to relatively low GDP, decline in tax revenues since 2008, and weak credit rating. This might fail in providing guarantees to the countries that loans will take from.[51] In terms LCOE, Ahmad also suggests that PV will be less costly than that of the nuclear in coming decade, given that the PV prices will continue decline at the same rate[52].

[49] Ibid.
[50] (MacLachlan, 2009).
[51] (Ahmad, 2015).
[52] Ibid.

F. Egypt

Egypt has been considering owning a nuclear plant in the area of Daba'a since the 1980s[53]. However, after the Chernobyl disaster 1986, they chose to freeze the plan. It was not until 2006 when the former President Hosni Mubarak planned to revive the program back. However, in 2011, a revolution started, and the president resigned. In 2014, when Abdel Fattah El Sisi became the president of the country, he announced that Egypt had signed a memorandum of understanding to adopt the nuclear energy program for the country. With a population of 90 million inhabitants, there are vast energy requirements. Given the situation, the Egyptian government is seeking to diversify its energy sources. Along with the nuclear facility, Sisi has talked about other renewable energy sources, such as building solar and wind energy facilities in the coming three years to generate around 4,300 megawatts of power[54].

According to a Russian spokesman, Egypt's first nuclear power plant would be built in Daba'a, in the northern part of the country, and will be completed by 2022[55]. The plant will be 'third-generation' plant with four reactors. Noting the cost was not announced, President Sisi assured that the loan from Russia would be paid off over 35 years[56].

[53] (World Nuclear Association, 2016).
[54] (Reuters , 2015).
[55] Ibid.
[56] Ibid.

CHAPTER III

SUPPLY AND DEMAND OF URANIUM

A. Uranium Mining Production

Almost 66% of the world's uranium production is concentrated in three countries[57]: Kazakhstan where it produced 23,127 tU in 2014 [58],second largest is Canada, where it contributed 9134 tU[59] to the supply, and Australia in third place with 5001 tU [60]. Kazakhstan has the largest share of uranium production from mines with 41% of world supply, followed by Canada 16% and Australia 9%[61]. Although production had decreased continually till 1993, it has risen back again meeting 90%[62] of the of the nuclear power generation, while the other 10% was secured from the existing stockpiles.

B. The Cost of Extraction

There are two types of uranium resources that are identified: Reasonably Assured Resources (RAR) and Inferred Resources (IR). Both types are recoverable for a cost less than $260/kgU[63], which is equivalent to $100/lb$U_3O_8$.[64]Resources recoverable for less than $260/kgU increased by 538 600 tU[65], which is around 7.6%, reaching to a total supply of 7 635 200 tU[66]. This makes the supply of Uranium relatively affordable.

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[57] (World Nuclear Association , 2015).
[58] Ibid.
[59] Ibid.
[60] Ibid.
[61] Ibid.
[62] Ibid.
[63] (IAEA OECD, 2014).
[64]Ibid.
[65] Ibid.
[66] Ibid.

Themines in 2013 supplied around 70,800 tU[67] of uranium oxide concentrate U_3O_8 containing 59,370 tU, which makes 91% of utilities' annual requirements. However, thanks to the secondary sources, including stockpiled uranium held by utilities, the balance is regained and in the last few years of low prices those civil stockpiles have been built up again following their depletion between 1990 and 2005. At the end of 2013, the stockpiles were estimated to be more than 90,000 tU[68] in Europe and USA, and a bit less in East Asia, particularly concentrated in China.

C. Uranium Prices

Nuclear utilities purchase uranium primarily through long-term contracts. There was fear of forthcoming scarcity in Uranium 2007, after a huge flood hit the Cigar Lake Mine in Canada in 2006.[69] Cigar Lake Mine is the world's second largest undeveloped high grade uranium deposit in the world. This drove the "spot price" for un-contracted sales to around US$ 135 U_3O_8/lbsin 2007.[70] However, the prices decreased back, and the spot price per pound of U_3O_8began to decrease, in fact on March 1, 2014, it reached US$35.50/lbs.[71]. Taking into consideration that uranium supply contracts are signed on long-term basis, these contracts are put into action and start deliveries in two to four years after they are signed. The contracts are valid for delivery from four to ten years thereafter[72]. Therefore even though the prices got settled, it reflected a premium of at least $10/lbs[73]. above the spot market, until the current contracts reach to their maturity. In addition, the prices which utilities are likely to be paying for current delivery, only

[67]Ibid
[68] Ibid
[69] (Topf, 2015)
[70] (Carter, June, 2014)
[71] (Uranium Participation Corporation , 2015)
[72] (Denison Mines Corporation, 2015)
[73] Ibid

one third of the cost of the fuel loaded into a nuclear reactor is the actual ex-mine (or other) supply. However, most the cost is for enrichment and fuel fabrication, with a small element for uranium conversion. It is estimated that uncovered demand is projected to increase significantly during the period between 2016 and 2018. According to UxCo, the uncovered demand in 2015 is only 6.7 million pounds of U_3O_8,[74] but is expected to increase to 17.6 million pounds of U_3O_8 in 2016 and up to 49.4 million pounds in 2018, which should result in increased contract activity in 2015 and into 2016[75].

Figure 1 Uranium Prices, Source: UxC.com

D. The Suppliers of the Market (Enriched Uranium)

Currently there are many suppliers of enriched Uranium such as Areva in France, Germany, Netherlands, and UK. Urenco.[76] Global Laser Enrichment, USEC in USA, Tenex in Russia, Areva CNNC in China, JNFL for Japan, along with others in Argentina, Brazil, India, Pakistan, Iran. Some of these companies mentioned above are dedicated to specific power plants. JNFL in Japan, for example is dedicated to

[74] Ibid.
[75] (Uranium Market, 2015).
[76] (World Nuclear Association Nuclear , 2015).

Rokkaasho Nuclear Fuel Reprocessing Facility.[77] Areva in France for example, is dedicated to Georges Besse I and II enrichment facilities. On the other hand, Tenex in Russia supplies for Angarsk, Novo Uralsk, Zelenogorsk, and Severskenrichment plants.[78]

Table 1: World Enrichment Capacity. Data: World Nuclear Association Nuclear Fuel Report 2013 & 2015, information paper.

World Enrichment Capacity – Operational and Planned (thousand SWU/yr)				
Country	**Company and plant**	**2013**	**2015**	**2020**
France	Areva, Georges Besse I & II	5500	7000	7500
Germany-Netherlands-UK	Urenco: Gronau, Germany; Almelo, Netherlands; Capenhurst, UK.	14,200	14,400	14,900
Japan	JNFL, Rokkaasho	75	75	75
USA	USEC, Piketon	0*	0	0
USA	Urenco, New Mexico	3,500	4700	4700
USA	Areva, Idaho Falls	0	0	0
USA	Global Laser Enrichment, Paducah	0	0	0
Russia	Tenex: Angarsk, Novouralsk, Zelenogorsk, Seversk	26,000	26,578	28,663
China	CNNC, Hanzhun & Lanzhou	2200	5760	10700+
Other	Various: Argentina, Brazil, India, Pakistan, Iran	75	100	170
Total	Total SWU/yr approx	51,550	58,600	66,700
	Requirements (WNA reference scenario)	49,154	47,285	57,456
	Excess	2,396	11,315	9,244

1. Tenex

In terms of Saparative Work Unit (SWU) produced, in 2013, 2015 and projection of 2020 Tenex, the Russian company is largest contributor of SWU. In fact, in 2013, it was able to supply 26 million SWU[79], which made 52.8% of the total supply needed. In 2015, Tenex was estimated to produce 26.578 million SWU, which constituted 56.2%, even though the supply increased only by 2.2% (from 26 million to 26.578 million SWU)[80]; however its contribution has impacted by 3.4%.This is due to decrease in demand for SWU in 2015 by 3.8%. In 2020 projection, Tenex will produce 28.663 million SWU, which will contribute 49.8%. Noticing the increase in supply by Tenex,

[77] Ibid.
[78] Ibid.

[79]Ibid.
[80] Ibid.

the contribution is relatively lower than the previous years because of the dramatic increase in demand, by 21% between 2015 and 2020, from 47.285 million SWU to 57.456 million SWU.[81]

2. CNNC

Another interesting case is CNNC, which is located in China. CNNC supplied 2.2 million SWU in 2013 and contributed 4.47%, however it doubled its production to 5.76 million SWU in 3 years' time and had a market share of 12.18%.This way CNNC's market share increased by around 300%. In 2020, CNNC is estimated to produce more than 10.7 million SWU, which is four times the initial production in 2013. This way, CNNC will contribute at least 18.6% of the total demand in 2020. [82]

3. Urenco

Urenco is located in different European countries and in the United States. In 2013, Urenco produced 17.7 million SWU throughout Europe and the US.[83] They contributed 36% of the total demand, making Urenco the second largest contributor after Tenex. In 2015, Urenco increased its production 7.91% from 17.7 to 19.1 million SWU.[84] In 2020, the projection shows that Urenco's production will increase by 500,000 SWU in Europe, keeping the Urenco's production in the USA constant, reaching to 19.6 million SWU.[85] This way Urenco will end up having 34.11% of the total demand.[86]

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[81] Ibid.
[82] Ibid.
[83] Ibid.
[84] Ibid.
[85] Ibid.
[86] Ibid.

4. Areva

Areva currently is focused mainly in France, in 2013; Areva produced 5.5 million SWU[87] and contributed 11.18% of the total SWU. In 2015, it increased its production by 1.5 million SWU[88]or 27.27%. Hence it had 14.8% of the total required SWU, and 11.94% of the total SWU produced per year. In 2020 projection, Areva will contribute 13.5% of the total demand.

5. JNFL

JNFL or Japan Nuclear Fuel Limited is located in Rokkasho, Aomori Prefecture, Japan. It has relatively small impact and contribution in the total demand needed, as it produced only 75,000 SWU[89], which made barely 1.5% of the total in 2013. Moreover, in 2015 the supply stayed constant; however, due to decrease in demand its contribution increased to only 1.6%. Japan has these low contributions due to suspension of the nuclear power plant operations after the 2011 Fukushima incident. In the projection of 2020, this remained as it is, as the government suspended its nuclear activities. It was not until August 11, 2015[90]when they restarted the nuclear operations.

6. Others (Argentina, Brazil, India, Pakistan, Iran)

These countries had the same impact in 2013, as JNFL, with 75,000 SWU[91], which is around 1.5% of the total demand in 2013. However in 2015, this increased by 25%

[87] Ibid.
[88] Ibid
[89] Ibid
[90] (Martin, 2015)
[91] Ibid

reaching to 100,000 SWU.[92] In 2020, it is projected to be 170,000, [93] which is almost the double that of 2015.

E. Current Capacity

The total electricity connected to the grid using nuclear energy is above 380GWe[94], through with444 civil nuclear reactors operating in 31 countries in addition to Taiwan reaching to a capacity of over 384 GWe**.**In 2014, these reactors provided 2411 billion kWh, which contributed to over 11% of the world's total electricity.[95]

F. Post-Fukushima Impact

After the Fukushima incident, on March 11, 2011, many countries started to diverge their interest from nuclear energy, and decided to shut down their reactors. This was because public opinion was raised against using nuclear energy because of fear of potential accidents. Consequently, Germany shut down 9 of its 17 nuclear reactors[96] which used to constitute 9611MWe. However, on the other hand, there are currently 65 reactors under construction in 20 countries of which 35 are being either constructed or under studies in the Middle East. [97]

Currently Middle East has only 1 GWe capacity, which is considered to be relatively low compared to the EU, European EU countries, East Asia and North America. However, this might change in the upcoming years as there are serious plans in the Middle East to start generation of electricity through nuclear energy.

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[92] Ibid
[93] Ibid
[94] (European Nuclear Society, 2016).
[95] (World Nuclear Association, 2015).
[96] (Reuters, (2011).
[97] (World Nuclear Association, 2016).

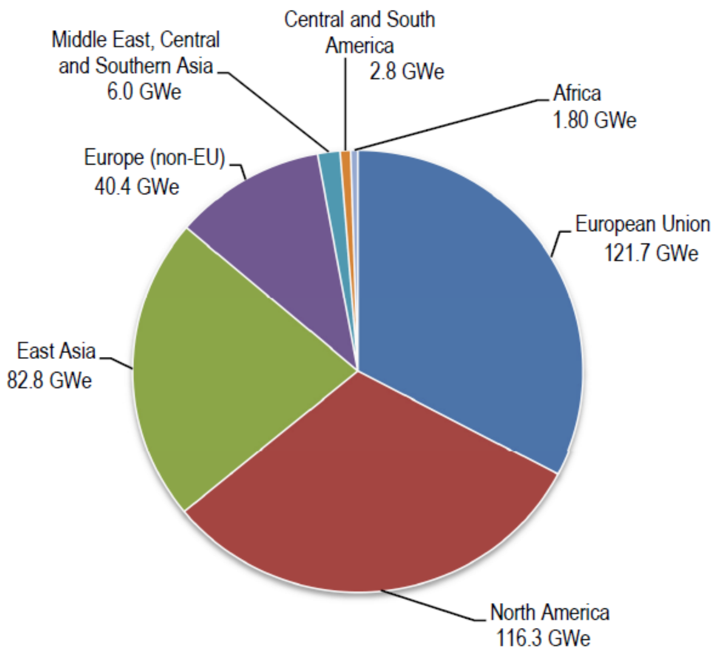

Figure 2: Nuclear Energy production as of January 2013. Source: Uranium 2014: Resources, Production and Demand.

G. Projected Capacity of Nuclear Electricity for the Middle East

There are currently 5 countries in the Middle East that are planning to have their first civil nuclear plants: Egypt, Jordan Saudi Arabia, Turkey and the United Arab Emirates (UAE). This is in addition to Iran it already has the Bhusher reactor connected to the grid and producing electricity. Each of these countries has set a certain number of nuclear reactors that they are planning to build (see Figure 2). The earliest reactor that will be connected to the grid is Barakah ***1*** in the UAE in 2017.[98]

[98] (Emirates Nuclear Energy Corporation, 2016)

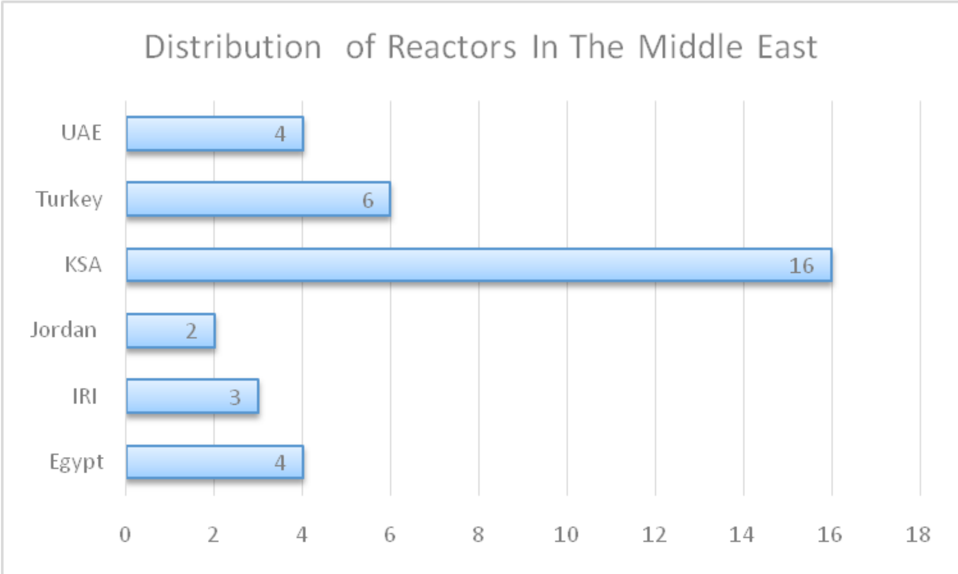

Figure 3: Distributions of Reactors in the Middle East.

1. The Projection

Using the current official announced data, a projection is done for the nuclear capacity in the Middle East till 2040. Based on the maximum projection, Saudi Arabia will have the largest capacity by 2040, with a total of 17 GWe which makes up to 42% of the total projections in the region; however, this will start in 2032, Turkey comes second with a total of 7.1 GWe, noting that Turkey's first reactor will be connected to grid by 2023. Third place goes to the United Arab Emirates (UAE), with a total capacity of 5.6 MWe. However, what makes UAE significant is that its four reactors are currently under construction and the first reactor will be connected to the grid by the end of this year or starting 2017. The UAE is the first country between the 5 non-experienced countries to start producing electricity through nuclear energy. Fourth is Egypt with a total capacity of 4.8 GWe, however they will not start operation before 2025, and fifth is Jordan, with 2120 MWe. They have the smallest capacity between all countries, but they might plan to build addition reactors, when the demand of electricity increases further and the trial of the previous reactors be successful. Iran was not mentioned in this part since it has already started its nuclear program and has been producing electricity since 2015.However, what makes Iran's case significant is the production of electricity using nuclear energy, with a projection of only 3 MWe by 2040, which relatively low compared to the other countries in the Middle East.

On the other hand, based on the minimum projection, Saudi Arabia will not own any nuclear power plants, along with Jordan and Egypt. This leaves Turkey, the UAE, and Iran. With this scenario, Turkey will have the largest share in electricity production, with almost 50%, (48.3%) to be precise. Second comes UAE with 5.6 MWe, and Iran third with 2 MWe.

Table 2 Minimum Capacity Expected of Nuclear Energy

Projected Capacity of Nuclear Electricity (megawatt)					
Iran	UAE	Turkey	Saudi Arabia	Jordan	Egypt
1000	0	0	0	0	0
1000	0	0	0	0	0
1000	1400	0	0	0	0
1000	2800	0	0	0	0
1000	3200	0	0	0	0
1000	5600	0	0	0	0
1000	5600	0	0	0	0
1000	5600	0	0	0	0
2000	5600	3550	0	0	0
2000	5600	5900	0	0	0
2000	5600	7100	0	0	0
2000	5600	7100	0	0	0
2000	5600	7100	0	0	0
2000	5600	7100	0	0	0
2000	5600	7100	0	0	0
2000	5600	7100	0	0	0
2000	5600	7100	0	0	0
2000	5600	7100	0	0	0
2000	5600	7100	0	0	0
2000	5600	7100	0	0	0
2000	5600	7100	0	0	0
2000	5600	7100	0	0	0
2000	5600	7100	0	0	0
2000	5600	7100	0	0	0
2000	5600	7100	0	0	0
2000	5600	7100	0	0	0

Table3 Maximum Capacity Expected of Nuclear Energy

Projected Capacity of Nuclear Electricity (megawatt)					
Iran	UAE	Turkey	Saudi Arabia	Jordar	Egypt
1000	0	0	0	0	0
1000	0	0	0	0	0
1000	1400	0	0	0	0
1000	2800	0	0	0	0
1000	3200	0	0	0	0
1000	5600	0	0	0	0
1000	5600	0	0	0	0
1000	5600	0	0	0	0
2000	5600	3550	0	0	0
2000	5600	5900	0	1060	0
3000	5600	7100	0	1060	4800
3000	5600	7100	0	2120	4800
3000	5600	7100	0	2120	4800
3000	5600	7100	0	2120	4800
3000	5600	7100	0	2120	4800
3000	5600	7100	0	2120	4800
3000	5600	7100	0	2120	4800
3000	5600	7100	1900	2120	4800
3000	5600	7100	3800	2120	4800
3000	5600	7100	5700	2120	4800
3000	5600	7100	7600	2120	4800
3000	5600	7100	9500	2120	4800
3000	5600	7100	11400	2120	4800
3000	5600	7100	13300	2120	4800
3000	5600	7100	15200	2120	4800
3000	5600	7100	17000	2120	4800

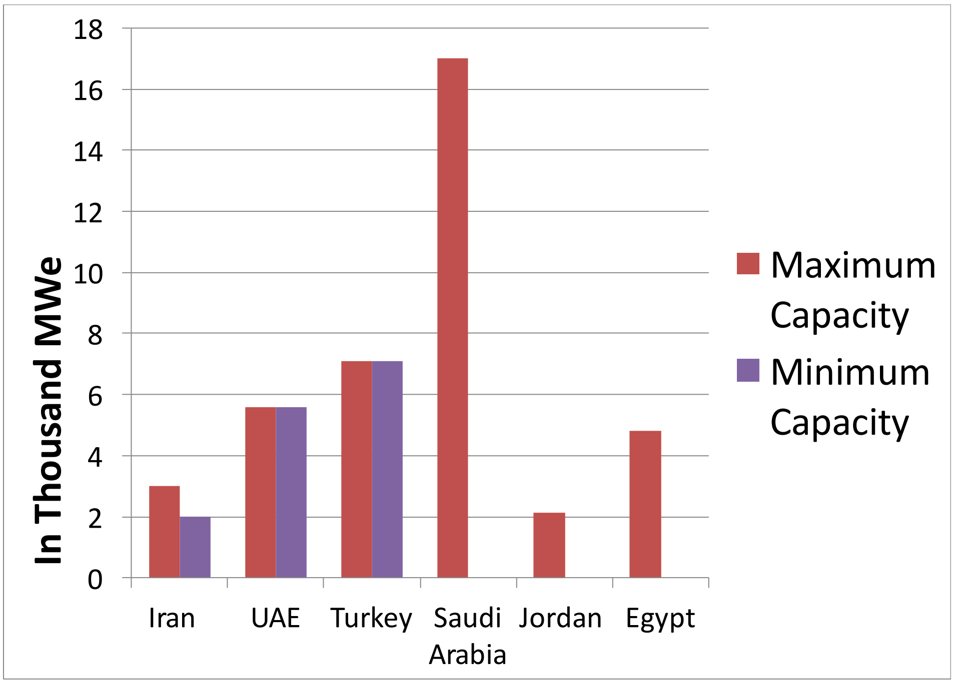

Figure 4: Maximum capacity expected in Nuclear Energy

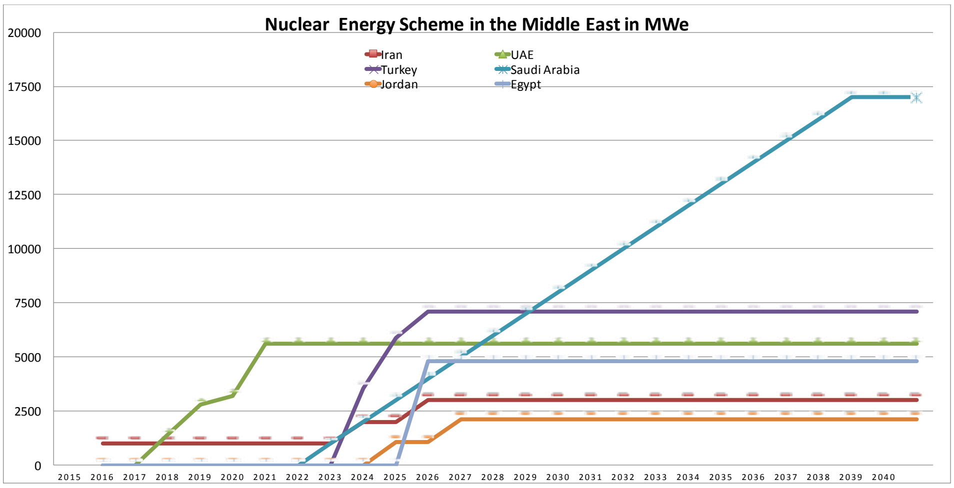

Figure 5: Nuclear Energy Projection in the ME and Gulf

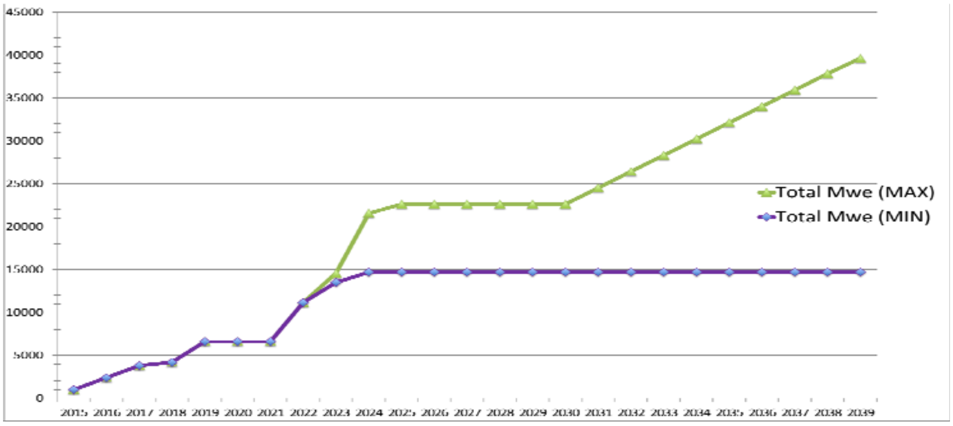

Figure 6: Nuclear Energy Trend Labeled for ME and the Gulf

2. Calculations of Feed and Enriched Fuel with Assumptions:

In order to estimate the actual demand of uranium, many assumptions should be taken into account in order to have real estimates.

a. <u>Enriched Fuel Demand</u>

We calculated the total enriched fuel demand per year, for both capacities at maximum and minimum, in order to calculate the actual amount of mined uranium needed. For the enriched uranium to be calculated, we need to define the capacity, thermal efficiency, capacity factor, along with the fuel burn up. The results are in (figure 6). The assumptions are found in the table below, (table-5).

Formula:

$$EnrichedFuel = \frac{1}{B} \times \frac{capacity\ (MWe)}{th} \times CF \times 365$$

Where,

Enriched Fuel: Mass of uranium loaded annually μ_{th}: Thermal Efficiency B: Burn up of the fuel

CF: Capacity Factor

Capacity: Installed electric capacity

365: Number of days per year

Year	Enriched Fuel MIN (TONS)	Enriched Fuel MAX(TONS)
2015	19.909	19.909
2016	39.818	39.818
2017	87.6	87.6
2018	163.255	163.255
2019	246.873	246.873
2020	378.273	378.273
2021	509.673	509.673
2022	641.073	660.982
2023	863.059	922.786
2024	1131.832	1272.39
2025	1424.495	1781.266
2026	1717.159	2331.155
2027	2009.823	2900.954
2028	2302.486	3490.661
2029	2595.15	4100.277
2030	2887.814	4729.803
2031	3180.477	5379.237
2032	3473.141	6048.581
2033	3765.805	6737.834
2034	4058.468	7446.995
2035	4351.132	8176.066
2036	4643.795	8925.046
2037	4936.459	9693.935
2038	5229.123	10482.734
2039	5521.786	11271.532
2040	5814.45	12060.33

Table 4: Enriched Fuel Data for Max and Min Capacities

b. Feed Demand

For the feed to be calculated, we needed the enriched fuel amount, both at minimum and maximum capacities. In order to calculate the total feed per year, we have made assumptions for the product assay, tail assay, and feed assay we want to have. The assumptions are found in (figure-8) below.

Formula:

$$Feed = \frac{Enriched\ Fuel\ (nP - nT)}{(nF - nT)}$$

Where,

nF: Feed array

nP: Product array

nT: Tail array

Assumptions	
nF	0.007
nP	0.0367
nT	0.003
B	50
CF	90%
µth	0.33

Table 5: Assumptions for the formulae of Enriched Uranium and Feed

Year	FEED min	FEED max
2015	167734.0909	167734.0909
2016	335468.1818	335468.1818
2017	738030	738030
2018	1375419.545	1375419.545
2019	2079902.727	2079902.727
2020	3186947.727	3186947.727
2021	4293992.727	4293992.727
2022	5401037.727	5401037.727
2023	7271272.841	7271272.841
2024	9535683.068	9713481.205
2025	12001374.2	13329828.2
2026	14467065.34	17123973.34
2027	16932756.48	20918118.48
2028	19398447.61	24712263.61
2029	21864138.75	28506408.75
2030	24329829.89	32300553.89
2031	26795521.02	36094699.02
2032	29261212.16	40207538.93
2033	31726903.3	44639073.61
2034	34192594.43	49389303.07
2035	36658285.57	54458227.3
2036	39123976.7	59845846.3
2037	41589667.84	65552160.07
2038	44055358.98	71577168.61
2039	46521050.11	77920871.93
2040	48986741.25	84566496.61

Table 6: Feed Max and Feed Min Data

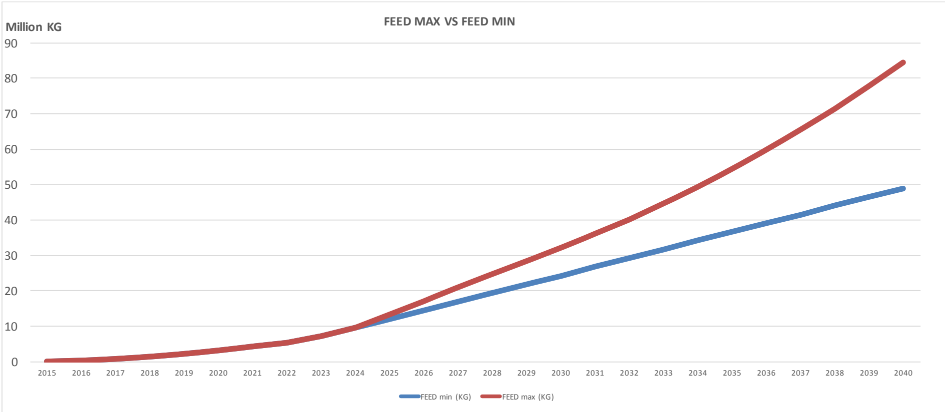

Figure 7: Feed Max vs Feed MinTrend

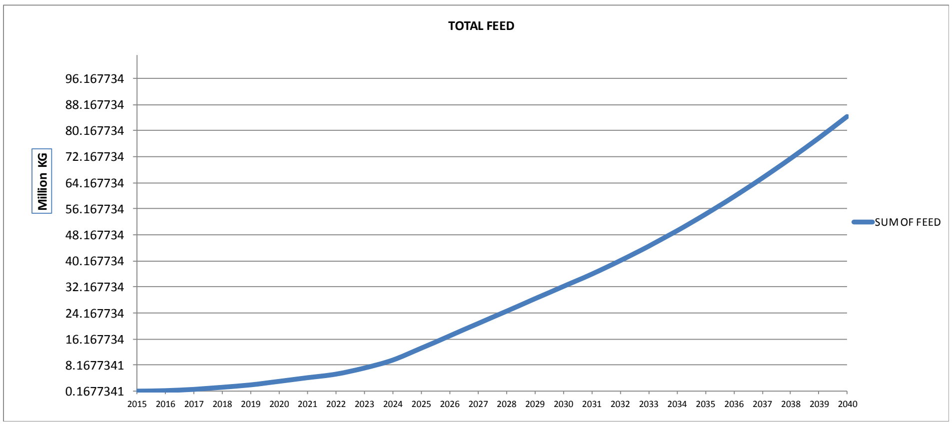

Figure 8: Total feed needed by 2040

3. Saparative Work Unit SWU:

The work done to enrich uranium, which corresponds to the change in entropy is measured with SWUs. In this part it used to determine the total amount of SWUs needed to enrich the 6 countries combined.

a. <u>Formula</u>

SWU can be calculated using the WISE Uranium Method, which is used in to do the calculation in (Figure-12 and 13):

$$W_{\mathrm{SWU}} = P \cdot V(x_p) + T \cdot V(x_t) - F \cdot V(x_f)$$[99]

Where,

- F : Mass of Feed (Tons)
- x_f : Feed assay (%)
- P: Mass of product (Tons)
- x_p: Product assay (%)
- T : Mass of Tail (Tons)
- x_t : Tail assay (%)
- $V(x)$: Value function.

[99] (WISE, 2009).

Year	SWU per year (Miliion)	cost of SWU per year (Million$)
2015	0.094	5.638
2016	0.094	5.638
2017	0.226	13.532
2018	0.357	21.425
2019	0.395	23.681
2020	0.62	37.212
2021	0.62	37.212
2022	0.62	37.212
2023	1.048	62.867
2024	1.269	76.116
2025	1.381	82.882
2026	1.381	82.882
2027	1.381	82.882
2028	1.381	82.882
2029	1.381	82.882
2030	1.381	82.882
2031	1.381	82.882
2032	1.381	82.882
2033	1.381	82.882
2034	1.381	82.882
2035	1.381	82.882
2036	1.381	82.882
2037	1.381	82.882
2038	1.381	82.882
2039	1.381	82.882
2040	1.381	82.882

Table 7: SWU: Minimum Capacity with cost

Year	SWU per year (Million)	cost of SWU per year (Million$)
2015	0.094	5.638
2016	11.276	5.638
2017	21.31	15.672
2018	36.21	20.538
2019	43.236	22.698
2020	58.374	35.676
2021	71.352	35.676
2022	71.352	35.676
2023	95.946	60.27
2024	138.972	78.702
2025	195.246	116.544
2026	238.818	122.274
2027	244.548	122.274
2028	244.548	122.274
2029	244.548	122.274
2030	244.548	122.274
2031	244.548	122.274
2032	254.82	132.546
2033	275.358	142.812
2034	295.896	153.084
2035	316.44	163.356
2036	336.996	173.64
2037	357.534	183.894
2038	378.066	194.172
2039	398.61	204.438
2040	427.812	223.374

Table 8: SWU maximum capacity with cost

CHAPTER IV

SUPPLY OPTIONS, ENRICHMENT FACILITY & THE HOST COUNTRY

A. Overview

In this chapter, we will discuss three scenarios that concern the Middle Eastern countries, through which these countries will guarantee supply of enriched uranium for their reactors**,** and later estimate the cost of Scenario 3. After we did the cost study of the enrichment plant, in this chapter we do a study to choose the host country. There are two countries that we chose to do discussion about, Turkey, a major NATO power, a pro-western country and the Sultanate of Oman, a GCC member, and pro- Eastern alliance. We then chose the best alternative between the two, based on different indicators (table-5).

B. Policy Option One

The "client" country that is planning to own nuclear power plants in the future has many options and alternatives to secure the Uranium fuel needed for the nuclear power plant to run. A scenario could be the host country itself building an enrichment plant facility, through buying natural uranium from the international market, and
enriching it in their enrichment plant.

Owning an enrichment plant will make the host country self-sufficient and more energy secure, in terms of supply of enriched Uranium, since the host country itself is in charge of providing the fuel for the power plant. However, on the other hand, owning an enrichment facility, especially if there were no previous infrastructure for the very reason, might cause the host country to bare high costs. Moreover, once a country owns the technology, starts to have expertise, and trains high skilled workforce, the host country will be interested and have the intention, desire, and tendency to go a “step further” and start the trial of enrichment on higher levels. This would be an incentive. On the long run, the host country will consider as a “natural right” the ability to own nuclear weapons due to their nuclear technological capacity and skilled workforce, under the constraint of defense from the surrounding countries, especially if there are tension among them. The host country will tend to own nuclear missiles, not necessarily having the intentions to attack an enemy, but as a sign of prestige for the country to own nuclear weapons in an attempt to become more influential and a rising power in the region. Yet, having the expertise and technology can never eliminate the possibility of accidents that can occur as mechanical and human errors are probable which could end up as a catastrophe.

In terms of security, it is very important for a host country that owns enrichment facility to own a robust security intelligence to prevent any type of terrorism and attempts of enriched uranium theft. The International Atomic Energy Agency says there is "a persistent problem with the illicit trafficking in nuclear and other radioactive materials, thefts, losses and other unauthorized activities[100]. However, if the host country has been put into action, without actually declaring the start of the program and without the IAEA approval, it might lead to international economic and political sanctions for long periods of time.

[100] (IAEA, 2007).

C. Policy Option Two

Another option could be the assistance of the vendor country, of which country the host country bought the power plant from. The vendor country can be in charge of providing the enriched Uranium. Adopting this option could save the host country from many problems, including the experience that is required to enrich the uranium. Moreover, there will be lower risks of spreading enrichment technologies for non-proliferation purposes, as the country will not have the access or control over the enrichment, this might help the host country to have access to enriched Uranium for electricity generation purposes. On the other side, the host country might possibly be facing some problems in terms of being under the vendor country's political reliance and subordination. This is because the vendor country could cut the supply of enriched uranium, as means of pressure when the host country's political vision is not similar to that of the vendor. Moreover, the host country might not be able to buy enriched Uranium from other countries or companies such as URENCO or other fuel banks due to fuel design restrictions. Hence, energy security will not be achieved since there is no alternative to buying supplies in case there is cut in supply which will lead to electricity shortage. Moreover, once these countries have the incentive to build several other reactors to increase their energy supply, they will ask for their own enrichment plant construction based on economy of scale.

D. Policy Option Three

A third scenario, which is similar to the previous scenario, could be the host country buying enriched uranium fuel from countries other than the vendor. The supply could come from URENCO or LEU fuel banks which are in partnership with IAEA. The aim of this LEU bank is to serve countries which have no previous experience in nuclear energy, and which are willing to build their first nuclear power plants. The IAEA's main goal for such banks is to discourage countries building their own enrichment technology as it could be used for weapon construction. Having many sources to buy from, this could increase the security of supply since there are many sources to have access to. This would limit the chance of enhancing nuclear weapon construction due to the absence of enrichment plant. In terms of supply, it is a relatively better option from the second option in terms of having alternatives.

Based on the scenarios mentioned above, a hybrid alternative could be a solution for the supply of enriched Uranium. This alternative could secure enriched Uranium supply and at same time lower chances for High Enriched Uranium (HEU, that could be used to weapon construction. This alternative might give the rise to a safer system in terms of security, and energy security. This might be achieved through construction of a joint enrichment plant, a plant that could be shared and used by countries that have no previous experience with nuclear power plants. At the same time there will be relatively lower chance of weapon construction, as there will be no control by a single country over the enrichment plant.

E. Geography

1. Turkey

Turkey is located in between Southeastern Europe and Southwestern Asia. It has borders the Black Sea, Bulgaria, Georgia, the Aegean Sea, the Mediterranean Sea, Greece, and Syria. It has a strategic advantage over other countries in terms of natural resources (water), location, however what makes Turkey a concrete candidate, is its membership in NATO.[101] This creates an incentive for many countries to have good diplomatic relations with Turkey since Turkey is the doorway from Asia to Europe through the Bosphoreand Dardanelles Straits.

2. Oman

The Sultanate of Oman is the “Horn” of Middle East. It has borders with the Arabian Sea, the Persian Gulf, the Gulf of Oman, Yemen, and UAE. What makes Oman special is that access to seas throughout the entire costal boarder from the South to the North; from the South it has the Arabian Sea, and from the North it has the Gulf of Oman.

F. Polity

Polity is a very important indicator because, by definition, polity is “political organization: civil order, or a specific form of political organization in which the whole body of the people govern for the good of all and that constitutes a fusion of oligarchy and democracy”.[102]In other words, the more democratic the system is, the less the chance for revolutions and chaos. This is because people tend to have slight changes periodically through elections, rather than a drastic, radical change through revolution. This criterion is very crucial since any serious security flaw or a revolutionary step might put the enrichment facility in a big risk. This effects not only the host country, but also the countries that rely on the host country to provide enriched uranium.

[101] (North Atlantic Treaty Organization, 2015).
[102] (Webster).

1. Electoral System and the Government

The Republic of Turkey adopts the republic parliamentary system.[103] In this system, the citizens elect their deputies. Then the deputies themselves vote on legislation. Turkey has a political system in which the legislatures, in this case the parliament, selects the government cabinet and the prime minister. This is done according to party strength as expressed in elections, as the elections in Turkey is based on proportionality. However, the major criticism is that if a party does not get 10% of the total popular vote, it cannot enter the parliament. This happened with True Path party (DYP)in 2002, where it had won 40 seats, but got 9.55% of the total votes. Hence, it forfeited the 40 seats.[104]Adopting this system, the government acquires a dual responsibility both to the citizens as well as to the parliament. Adopting this system, the government acquires a dual responsibility both to the citizens as well as to the parliament. However, in 2007, a constitutional amendment changed the presidential electoral process to direct popular vote. After the elections, the president appoints the prime minister from among members of the Grand National Assembly of Turkey (parliament). [105]

On the other hand, the Sultanate of Oman is a monarchy and it has the bicameral Council of Oman or Majlis Oman. There is the Council of State or Majlis al-Dawla and Consultative Council or Majlis al-Shura. The sultan and the prime minister is the head the government, which is the sultan himself, Qaboos Bin Said Al-Said.[106]

In terms of democracy, citizens elect the Consultative Council or Majlis al-Shura by simple majority popular vote to serve renewable 4 years; while the Council of State is appointed by the Royal Family. In 2011, when the Arab spring started, the Royal

[103] (CIA Factbook, Updated on 2016).
[104] (Louter & Lyons, 2015).
[105] (CIA Factbook, Updated on 2016).
[106] (CIA Factbook, Updated 2016).

Family made reform decrees by granting the Consultative Council legislative and regulatory rights. [107]In order to numerically evaluate the level of democracy, we use the democracy index as a tool.

2. Democracy Index

According to The Economist's Democracy Index 2015, Turkey was put under the hybrid regime category, and ranked 14th in that category out of 37,[108] and it was ranked 97thout of all countries,[109] with respect to being ranked 89th in year 2010.[110]As for Oman, the Sultanate of Oman is categorized under the monarchy category and is ranked 26th out of 51 in that category, andit is the 142ndout of all countries, while it was 143rd in 2010.[111] For this index, the higher the rank, the better off the country. In this case Turkey is better off, which makes it a better candidate to become the host country.

G. Distance & Infrastructure

Another important indicator is the infrastructure. Infrastructure is important for transportation purposes for two main reasons. The first reason is because of the delicacy of the transported cargo, which in this case is enriched uranium. The second reason is the distance. Some countries are far distant from each other. Turkey for example has an average distance of 2466 km away from UAE, 1918 km from Saudi Arabia, 1815km from Iran, 937 km from Jordan, 1414 km Egypt. For this case, Turkey will not be considered as the host country. On the other hand, if we take Oman as the host country,

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[107] (Katzman, 2011).
[108] (The Economist Intelligence Unit, 2016).
[109] Ibid.
[110] (The Economist Intelligence Unit, 2010).
[111]Ibid.

there is a 2767 km away from Turkey. It is only 301 km from UAE, 1144 km from Saudi Arabia,1235 km from Iran, 2208 km from Jordan, and 2614 km from Egypt.[112] In terms of infrastructure, the GCC railway project has been started and will continue for the next 10-year period with a budget estimated to be $110 B.[113] The Omani railway will be constructed by 2017. What makes this railway important is the link between the important GCC countries, including Oman, UAE, Saudi Arabia and Kuwait. The significance of this railway is that it includes Saudi Arabia, which has the demand and largest bulk of the total demand of enriched uranium, along with UAE, which has the third highest demand in the maximum capacity and second in the minimum range. In this case, Oman is better off in terms of logistics and transportation especially for these 2 important countries. Both have very large container ports; however, in the 2015 report, Oman's Khor Fakkan/Sharjah Port had 3.8 million TEU (Twenty-Foot Equivalent Units) of cargo, and ranked 36th. On the other hand, Turkey's Ambarli port ranked 40th, with 3.488 million TEU of cargo.[114] Both are close, however Oman is better off in this criteria.

1. Logistics Performance Index

This index is very important as logistics play a very important role in order to have the knowledge of how countries face challenges in trade with neighboring countries, with the help of the country's infrastructure. This is important in order to have a vision of how the performance of the countries will be with the enriched uranium. According to World Bank's 2014 report, Turkey ranked 30th position, with an

[112] (Distance calculator using google maps, 2009-2016).
[113] (Intec Export Intelligence Limited, 2015).
[114] (International Association of Ports and Harbors, 2015).

LPI Index of 3.5, and Oman 59th with an index of 3. [115]

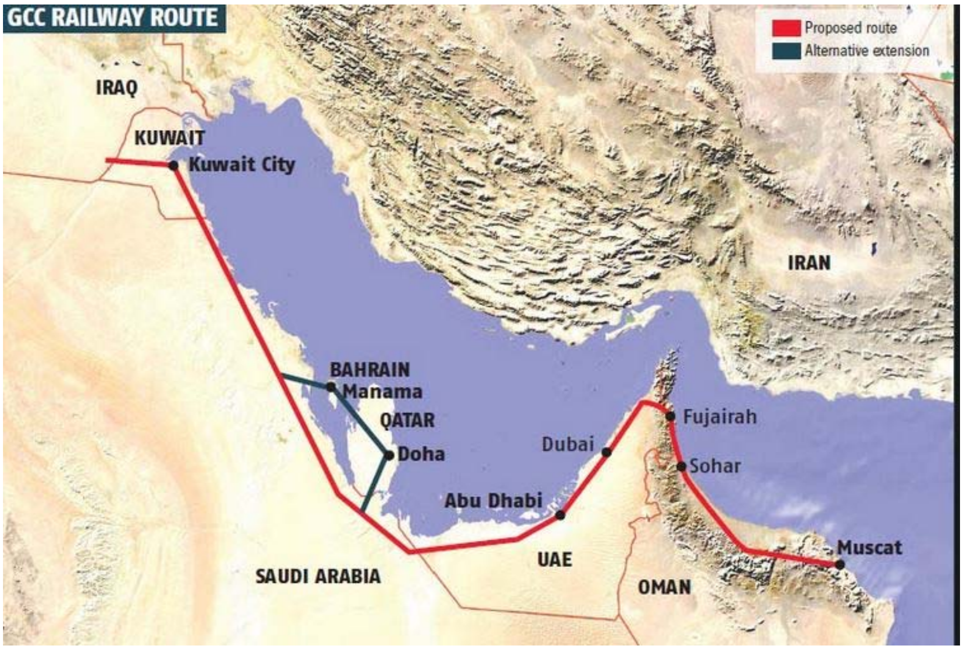

Figure 9 GCC Railway Route. Source: Consultancy.uk

[115] (World Bank, 2015).

H. Military

Military strength is a very important indicator, as this could show to what extent is the host country capable of keeping the security under control, including the nuclear enrichment plant. The stronger the military and intelligence capabilities, the less the risk of nuclear terrorism. According to the business insider, Turkey ranked in the top eight for the world's 20 strongest militaries, [116]with an expenditure of $18.18 Billion,[117] which makes Turkey a major NATO power. On the other hand, Oman was ranked 69th.[118]

I. Wars on Borders

Regional conflicts are very important measure as the host country's security is affected by the neighboring countries' security. The more wars on the borders and in the neighboring countries, the higher the risk for having war in the host country. This does not only create security threat, but also creates economic and social problems. This makes the host country not qualified to host the enrichment facility; this criterion will be seen through GPI, RPRI & TI indices.

1. GPI: Global Peace Index

According to Institute for Economics and Peace, the 2015 Global Peace Index in 2015, showed that for Turkey and Oman were 2.363 and 1.947, respectively, the criteria is found in (Table-6). This index is measured based on 23 qualitative and quantitative indicators. With this index, the lower the measure, the better.[119]

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[116] (Bender, October 2015).
[117] (Macias, Bender , & Gould, 2014).
[118] (CIA Factbook, Updated on 2016)
[119] (Institute for Economics and Peace, 2016).

2. RPRI: Regional Political Risk Index

According to PRS, Political Risk Services group, the global average risk index was 73. Turkey had an average below the global index with an average of 71,[120] and Oman above the average with an average of 84. [121]This result was relatively predictable due to the wars and instability around Turkey more than that around Oman.

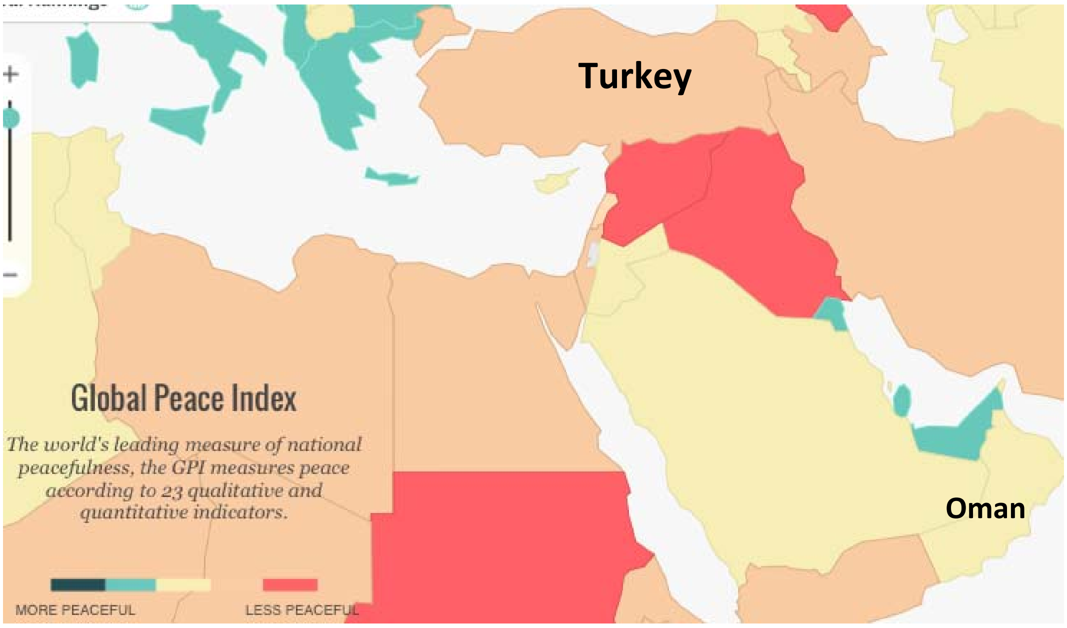

Figure 10: Global Peace Index map

[120] (Political Risk Services , May 2015).
[121]Ibid.

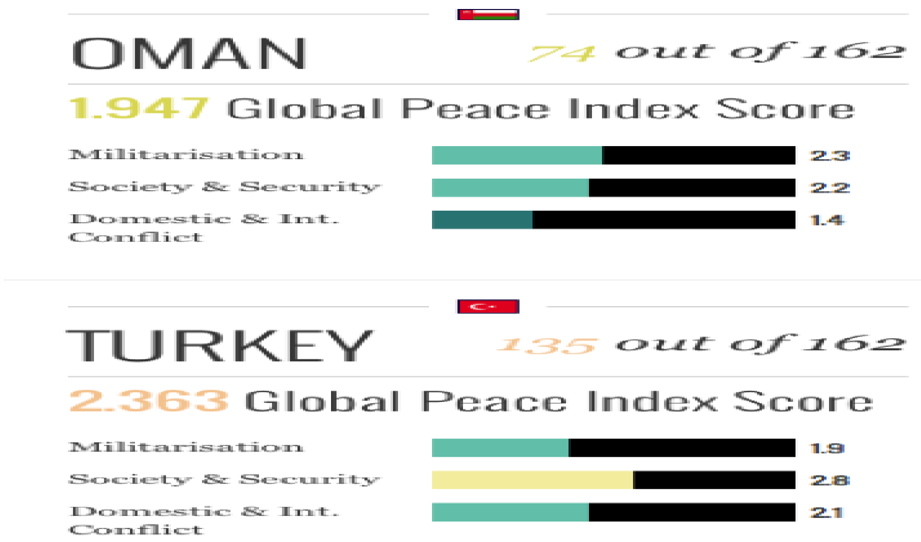

Figure 11: Global Peace Index. Source: Institute for Economics and Peace

3. TI: Terrorism Index

According to Institute for Economics and Peace, the Terrorism Index in 2015, which is measured based on five year weighted average, showed that for Turkey and Oman were 5.57 [122]and 0, respectively[123]. For this index, the lower the measure, the better (check figure 16). [124]

Figure 12: Terrorism Index. Source: Institute for Economics and Peace

[122] (Institute for Economics and Peace, Global Peace Index, June. 2015).
[123] Ibid.
[124] Ibid.

4. Global Opportunity Index

This index is also important, and included in the war on borders, since it includes Economic Fundamentals, Ease of Doing Business**,** Quality of Regulations and Rule of Law.

Taking into consideration that foreign investment attraction is directly related to the status of the country in terms of war, the more regional conflicts, the less the stability and hence the ability to attract investments. Giving equal weights to these criteria, Oman ranked 25th and Turkey ranked 54th.[125]

Country	Turkey	Oman
Composite	5.8	6.79
Economic Fundamentals	4.82	5.54
Ease of Doing Business	5.79	7.73
Quality of Regulations	6.8	7.5
Rule of Law	5.8	6.4

Figure 13 Global Opportunity Index Data: Milken Institute

Indicators	*Turkey*	*Sultanate Oman*
GDP (Billions)	$798.4	$77.78
Population (millions)	75.93	4.236
per capita	$19,700	16,870
Average Growth %	3.73	3.2
Life Expectancy (years)	75	77
Climate (°C)	0-22	20-30
Wars on the boarder	Syria	Yemen
Sea Access	Black Sea + Medit.	Arabian Sea
International Organization Participation:	G-20, IAEA, NATO,UN	GCC, IAEA,UN
Unemployment Rate %	10	15
Inflation %	8.9	1
Central Bank Discount Rate 2009-2011	5.25% (decreased by 185%)	2% (increased by 390%)
Population Below Poverty Line	16.9	N/A
Litaracy Rate %	98.65	97.7
Military Ranking	10	69
Geopolitics	Pro-Western Countries	Pro- Eastern Countries

Table 9: Stats Turkey vs S. Oman. Sources: CIA Fact book, World Bank, and Global fire power.

[125] (Milken Institute, 2015).

Country	Turkey	Oman
Global Peace Index	2.363	1.947
Perceptions of criminality	4	2
Security officers & police	3.5	4.5
Homicide	2	1
Incarceration	2.4	1.1
Access to weapons	3	4
Intensity of internal conflict	3	2
Violent demonstrations	3	3
Violent crime	3	2
Political instability	2.8	3
Political terror	4	3
Weapons imports	1	2.5
Terrorism impact	3	1
Deaths from internal conflict	2	1
Internal conflicts fought	1.6	1
Military expenditure	1.3	4.6
Armed services personnel	1.5	1.5
UN peacekeeping funding	1	2.3
Nuclear and heavy weapons	3.5	1.2
Weapons exports	1	1
Displaced people	1	1
Neighbouring countries relations	3	2
External conflicts fought	2	1
Deaths from external conflict	1	1

Table 10: Peace Indices for Turkey and Oman. Source: Institute for Economics and Peace

CHAPTER V

POLICY RECOMMENDATIONS&RESEARCH LIMITATIONS

Energy security is a major challenge to be achieved. Especially when countries rely on importing sources of energy. In the projections done above, even though we can see the huge difference between the minimum and maximum capacities, we are sure that a minimum 11 GWe of nuclear energy will be added to the world total supply and a maximum of 40 GWe. But is it worth it? This question is hard to be answered with certainty, due to many reasons. As for some countries, even though they have plans and deals with the vendor countries, there is no assurance of funding their nuclear program, which might make them unable to contribute to the facility as well. If this happens, the cost on the other countries will increase, as some of these countries will be unable to pay this large amount, which at the end might stop this enormous project. In addition, once these countries stop their nuclear programs, the demand on enriched uranium will decrease further; this is found in the minimum capacity projection. However, being more optimistic and considering the funding is available, and none of these problems is risen. Choosing the host country is another major challenge as well. Since both countries have many advantages and disadvantages. In terms of GPI, important elements that could determine the host country would be: political instability, political terror, terrorism impact, death from internal conflict, internal conflicts fought, nuclear and heavy weapons. Based on this, it would go to the advantage of Oman. However, in terms of other indicators, such as GDP, unemployment, per capita, and environmental index, and sustainability, the advantage will go to Turkey to be the hosting country. In terms of logistics even though Turkey has a higher index, as mentioned above, Oman is part of the GCC railway project, which could facilitate the transportation of enriched uranium throughout the GCC. Taking into consideration the fact that Saudi Arabia will have the largest demand, if we take the maximum capacity scenario by 2040. This factors give Oman the advantage. However, in case a war takes place between any of the GCC countries that use the railroad for uranium transportation, targeting this railroad, could put all the GCC-nuclear countries at risk of not being able to receive the supply of uranium on time. However, the major concern security, as the railroad could not be secured enough, and as a result, burglary could occur. As small as 1 kg of 5% enriched uranium is more than enough to build a bomb, given having the capabilities. Hence this railroad could be a blessing, and at the same time a curse. In addition to this, Oman has the Hurmuz strait. This strait is very important because, the largest percentage of oil is transported through it at an estimated 17 million bbl/d of the total 90 million bbl/d of the world, while only 2.9 million bbl/d pass through the Turkish straits.[126] It should be noted that oil is one of the most tradable commodities and is the second most important source energy for electricity production after coal. Moreover, Oman is a neighboring country for the UAE which has the third largest demand in the maximum scenario, making up 57.04% of the total demand with Saudi Arabia gives. Again, the advantage goes to Oman to be the host country. In addition to this, from the strategic view, even if Iran closes, due to war, or any other reason, the Hurmuz strait, Oman won't be affected as it has access from south as well, due to its geography. In the minimum capacity, even though Turkey itself has the highest capacity and hence the highest demand, the second and the third countries combined have larger demand than Turkey and these two border Oman. Other two important factors that would put a

[126] (Energy Information Administration U.S Department of Energy, 2014).

country in front of the other are a) wars in neighboring countries and b) the capability of attracting foreign investment. Turkey is surrounded by the highest terrorism indexed countries, along with the currently least peaceful countries; that is a reason why Turkey has to own a strong military. Not only Turkey is surrounded by those dangerous countries, but it also has to help its allies during times of war, such as Azerbaijan, which itself has conflicts with countries, such as Armenia, the most recent ceasefire was on April 4, 2016. Also having Iraq, Syria, medium indexed Iran, Georgia, along with a relatively high indexed Turkey itself. However, on the other hand, Oman has an index of zero, or no sign of any terrorism within the country, and only Yemen from Oman's neighboring countries has a high rate of terrorism index. Furthermore, being part of the NATO, and in order to have influence in the region, it a natural strategy for Turkey to have such a large spending on military ($18.2 billion). On the other hand, Oman has adopted a neutral position, is part of the GCC, and hence it does not need a huge military capability rather than focusing on the economic growth.

After all, nuclear enrichment facility is a vast investment, and it needs time to be constructed within the upcoming years, as soon as possible as most of the countries all of the countries will own nuclear power plants by 2023, based on our projections at both minimum and maximum capacities. The region surrounding Turkey is facing not only external wars, but also internal civil wars, along with some terrorist attacks within Turkey. On the other hand, till the date of writing this thesis, no single attack happened inside Oman, even though there is war on its boarder. For around the upcoming 20 to 30 years, citerous paribus, and taking into account the GOI index, the Global Opportunity Index, Oman's 25th ranking and Turkey's 54th ranking,along with the experience of oil transportation. Oman will have a better chance of hosting this facility. However, if the minimum capacity projection scenario occurred, where Turkey has the largest capacity of nuclear power, will Turkey accept the enrichment facility to be built in Oman or claim since it has the largest capacity, hence the largest demand of enriched uranium, it is their natural right to ask for the facility to be built in their country?

Some limitations of the current study need to be further examined and addressed in future research works. They include the following:

- This project is purely based on assumptions, where we are basing our conclusions based on it.
- The conclusion is based on indices that can change in upcoming years, hence the decision of the location of building the enrichment facility might change based upon it.
- The need of having very high security during transportation of uranium might be a major challenge.
- The model used is an estimation hence the there is a chance of not being accurate (5% chance of error).
- Time constraint and having a limited time to produce such a project, by not being able to tackle all the aspects.

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