AMERICAN UNIVERSITY OF BEIRUT

PROSPECTS OF SMALL MODULAR REACTORS IN THE MIDDLE EAST

by
ROY ROOSEVELT GEORGE FATTOUH

A thesis
submitted in partial fulfillment of the requirements
for the degree of Master of Science
to the Department of Mechanical Engineering
of the Faculty of Engineering and Architecture
at the American University of Beirut

Beirut, Lebanon
March 2017

AMERICAN UNIVERSITY OF BEIRUT

PROSPECTS OF SMALL MODULAR REACTORS IN THE MIDDLE EAST

by
ROY ROOSEVELT GEORGE FATTOUH

Approved by:

Dr. Nesreen Ghaddar, Professor Advisor
Mechanical Engineering

Dr. Kamel Aboughali, Chairperson & Professor Member of Committee
Mechanical Engineering

Dr. Michel Kazan, Associate Professor Member of Committee
Physics

Dr. Ali Ahmad, Scholar In-Residence Member of Committee
Issam Fares Institute for Public Policy and International Affairs

Date of thesis defense: April 12, 2017

AMERICAN UNIVERSITY OF BEIRUT

THESIS, DISSERTATION, PROJECT RELEASE FORM

Student Name:	Fattouh	Roy Roosevelt	George
	Last	First	Middle

⊗ Master's Thesis ○ Master's Project ○ Doctoral
Dissertation

☒ I authorize the American University of Beirut to: (a) reproduce hard or electronic copies of my thesis, dissertation, or project; (b) include such copies in the archives and digital repositories of the University; and (c) make freely available such copies to third parties for research or educational purposes.

☐ I authorize the American University of Beirut, to: (a) reproduce hard or electronic copies of it; (b) include such copies in the archives and digital repositories of the University; and (c) make freely available such copies to third parties for research or educational purposes after : **One ---- year from the date of submission of my thesis, dissertation, or project.**
Two ---- years from the date of submission of my thesis, dissertation, or project.
Three ---- years from the date of submission of my thesis, dissertation, or project.

18.04.2017

Signature Date

ACKNOWLEDGMENTS

First and foremost, my deepest gratitude goes to my parents, sister and brother, whose continued encouragement, emotional, and financial support paved the way to a successful completion of my Master degree. I am greatly indebted to them.

I especially want to express my gratitude to Dr. Nesreen Ghaddar for her encouragement throughout this project. It has been a pleasure to work with you.

To Dr. Kamel Aboughali, a warm thank you for showing interest in my research and for his continuous support during both my undergraduate and postgraduate projects.

To Dr. Michel Kazan, a big thank you for his humble support. It has been a pleasure to work with him.

AN ABSTRACT OF THE THESIS OF

Roy Roosevelt George Fattouh for Master of Science
Major: Energy Studies

Title: Prospects of Small Modular Reactors in the Middle East

Small modular reactors are around one third the size of larger nuclear reactors having a capacity of 300 MW or less and in some cases, can be superior to the conventional reactors. The primary purpose of this paper is to determine the feasibility of installing small modular reactors (SMRs) in select countries in the Middle East region. The countries under study are Egypt, Iran, Jordan, Saudi Arabia, Turkey, and the United Arab Emirates.

SMR suitability will be measured using the GDP, electricity grid size, CO_2 emissions, population density, economic growth, nuclear capacity and Uranium resources of the 6 countries under study. From the results that will be obtained, SMRs will prove to be a feasible or unfeasible option for installation in these countries. Another focus of the paper will be on gathering extensive and thorough information from trusted sources on the complete history of small modular reactors in these countries.

CONTENTS

Chapter

ILLUSTRATIONS

TABLES

CHAPTER I

INTRODUCTION

The future of nuclear power is unknown since most existing nuclear plants have been operating for a long period of time and no data suggests that they will be replaced by newer plants. Nuclear power represents about 10 percent of the total electricity provided and has been falling since 1996 where it reached its peak of 17.6 percent. The debate regarding the future of nuclear power has given greater consideration to reactor size more specifically smaller reactors than the ones currently available. These small reactors should have a capacity less than 300 MW and are considered for deployment as single reactors in areas where typical large reactors are unsuitable, or as groups where several small reactors can act as a replacement for larger ones. The first strategy is best suitable in countries where total electricity capacity is limited to a few thousand megawatts. The capacity of a single power plant shouldn't exceed 10 percent of the grid's total capacity in order for the country not to be dependable on that single plant if malfunctions occur in the other plants connected to the grid. As for the second strategy, the disadvantage of a group of smaller reactors is the extra capital cost based on the concept of economies of scale; however, if the number of small plants becomes large enough, unit costs can decrease based on economies of serial production. These small reactors are called small modular reactors (Glaser, Ramana, Ahmad, & Socolow, Small Modular Reactors, 2015).

A. Why SMRs?

Small modular reactors have the possibility to be superior to the larger reactors. Conventional nuclear reactors are usually built on site and one-at-a-time and construction takes a long time. SMRs on the other hand can be built on an assembly line with a lower construction duration and then shipped to the dedicated site for commissioning.

Another advantage over conventional reactors is the location of deployment. Some of the SMR designs currently under study can be installed in underground concrete vaults or immersed in water which lead to enhanced safety and security. Also, some SMR designs do not require to be fueled for their entire lifetime unlike large reactors which typically need around 18 months to be refueled. (Abdulla, 2014)

Small modular reactors are particularly appealing in countries where the electricity grid system is not mature enough to support large reactors and where there isn't enough experience in nuclear power. Because of their relatively small generating capacity, they can easily be implemented in the electricity grid system of these countries (Earp, 2013).

Many SMR designs currently available show that these reactors, in addition to generating electricity, can be used for seawater desalination. The reason some of the Middle Eastern countries displayed interest in SMRs is due to the fact that they can be used for desalination (Small Nuclear Power Reactors, 2015).

B. Interest in Nuclear Energy in the Middle East, a Brief History

1. Egypt

As of May 2015, Egypt had a generating capacity of 31.45 GW. and the projected capacity for 2022 is 43.7 GW (Egypt: International energy data and analysis, 2015).

Egypt set up the Atomic Energy Commission in 1955 that became the Atomic Energy Authority in the following year which is in charge of licensing and regulation. In 1964 a nuclear plant with a generating capacity of 150 MW was proposed, then in 1974 a 600 MW plant was suggested for Sidi Kreir near Alexandria. In 1976 the government's Nuclear Power Plants Authority (NPPA) was established and in 1978 plans for constructing 10 plants by 1999 with 7200 MW capacity were proposed at different site locations.

The NPPA carried out a feasibility study between 1999 and 2001 and updating it in 2003 for a cogeneration plant for electricity and desalination. In 2004 and 2008 nuclear cooperation agreements were signed with Russia. In June 2009 contracts were signed with the NPPA to establish a 1200 MW nuclear plant with an aim to start generating electricity in 2017, but then in 2010 this proposal was expanded to include four plants operating by 2025. These plans were put on hold in 2011 when the political situation was not stable anymore.

In October 2013 the Minister for Electricity & Energy revived plans for a nuclear plant with eight reactors at El Dabaa, and Russia later announced their readiness to finance this project and in January 2015, Rosatom proposed to build four reactors with a combined capacity of 4800 MW at El Dabaa. Other proposals from South Korea and China were reported (Emerging Nuclear Energy Countries, 2015).

2. Iran

In 2013 Iran had a generating capacity of 68 GW. Demand is steadily growing at a rate of 8% per year which led the country to develop plans to increase capacity to 122 GW by 2022 also focusing on exporting some of this energy.

in 1957 and under the US Atoms for Peace program, a civil nuclear program was established. In 1967 the Teheran Nuclear Research Centre (TRR) was established and has a 5 MW research reactor supplied by the US. In 1974 the Shah of Iran declared that he was aiming to have 23 GW of nuclear capacity and in 1975 two units were being built in Bushehr province on the Persian Gulf; however construction was abandoned in 1979 due to the Islamic revolution with unit 1 basically complete and unit 2 half realized but later unit 1 was damaged by Iraqi air strikes between 1984 and 1988.

In January 1979 two units were being constructed at Darkhovin, on the Karun River but were cancelled in April of that same year. In 1992 the Islamic Republic of Iran arranged with China to build 300 MW reactors at Darkhovin, but China withdrew from the project.

The original plan of 1974 was to construct four units at Bushehr, followed by two units at Isfahan and two units at Saveh. The units at Isfahan and Saveh would have been the first large nuclear reactors that used dry cooling.

In 1992 Iran and Russia agreed on building two units in Bushehr and the Atomic Energy Organization of Iran (AEOI) which was established in 1974 and is responsible for nuclear and radiation safety, licensing facilities, and supervising insisted that the already existing structures and equipment in Bushehr were to be fully used in the project. The project was almost abandoned in 2007. In September 2009, reports showed that the reactor was 96% complete and fuel loading was expected by October, but the date was pushed to 2010 but fuel was finally loaded in December 2011. Due to a pump failure, start up was delayed until 8 May 2011 and finally entered into commercial operation in September 2013.

in 2004 the Nuclear Power Production & Development Company of Iran (NPPD) was established which is responsible for Bushehr. In May 2012 a second unit in Bushehr was announced with construction to start in March 2014, but AEOI later gave the starting date as April 2014 or in the following months. In March 2014 AEOI agreed with Rosatom to construct two more nuclear reactors at Bushehr and then in November 2014 further agreements with Rosatom and AEOI covered construction of four reactors at Bushehr and another four at a different not yet determined site. Iran has also been building a heavy water reactor at Arak with a 40 MW capacity with plans to be used only for research and development. An announcement in February 2013 declared that 16 sites to build new nuclear plants over the next 15 years were selected.

It is worthy to note that the Iran Nuclear Regulatory Authority (INRA) was established within AEOI and is responsible for regulation, safety, monitoring, and management of radioactive waste. The Nuclear Science & Technology Research Institute (NSTRI) was established in 2002 to take over the research role of AEOI (Nuclear Power in Iran, 2015).

3. Jordan

Jordan faces serious problems when it comes to its energy needs. It imports about 97% of its energy needs which amounts to one-fifth of its GDP. In 2013 the available generating capacity was 3.2 GW (NEPCO Annual Report 2013, 2013) and is expected to need 8000 MW by 2030. Jordan's 2007 national energy strategy estimated nuclear power to contribute to 6% of total generating capacity by 2020.

Also set up in 2007 was Jordan's Committee for Nuclear Strategy which has a goal of providing 30% of electricity from nuclear power by 2030, and to provide for exports. The Jordan Atomic Energy Commission (JAEC) and the Jordan Nuclear Regulatory Commission (JNRC) were set up in the same year, in addition to radiation protection and environmental roles.

JAEC focuses on safety and security, nuclear science and technology, and safeguards and verification. Its mission is to transform Jordan into a net electricity exporter by 2030 by ending dependence on fossil fuels. It aims in exploiting national uranium assets, promoting public and private partnerships, providing for water desalination, and enabling competitive industries that are energy-intensive.

In mid 2008, a feasibility study between JAEC and Atomic Energy of Canada Ltd with SNC-Lavalin was to be conducted. The study focused on building a 740 MW reactor using natural uranium fuel. In December 2008, JAEC signed a memorandum of understanding with Korea Electric Power Corporation to conduct a feasibility study on nuclear power and site selection. In September 2009 JAEC signed a contract with Tractabel Engineering to conduct a two-year siting study for a new plant about 25 Km south of Al Aqabah and 12 Km east of the Gulf of Aqaba coastline, but this site was later changed in 2010. The new site was to be in Qasr-Amra in Al-Azraq province some 70 Km south east of Amman. In April 2014 the International Atomic Energy Agency sent a team of experts to evaluate the proposed site.

In 2009 JAEC evaluated seven offers and in May 2010 three designs were short-listed. In October 2013 JAEC announced that Rosatom's reactor export subsidiary AtomStroyExport would be the one to supply two nuclear units. JAEC expected construction of one 750-1200 MW nuclear reactor to start and to become fully functional by 2020 and a second one to operate by 2025. On the longer term, four nuclear reactors are being considered (Nuclear Power in Jordan, 2015).

4. Saudi Arabia

Saudi Arabia had a generating capacity of 58 GW in 2014 (Today in Energy, 2014). There is an 8% yearly increase in demand and 70 GW of generating capacity is expected by 2020 and 120 GW by 2032. The Ministry of Water & Electricity (MOWE) is mainly responsible for power in the country. Plans to supply 18 GW of generating capacity from nuclear by 2032 have been put back to 2040.

The King Abdullah City for Atomic and Renewable Energy (KA-CARE) was set up in Riyadh to advance the plan of Saudi Arabia advancing the nuclear power program on its own. KA-CARE plans to set nuclear as an alternative to oil and to be the competent agency for treaties on nuclear energy signed by the kingdom. It also has a role of supervising works related to nuclear energy and waste management.

In 2013, three sites were short-listed where nuclear plants could be built: Jubail on the Gulf, Tabuk and Jizan on the Red Sea. The Nuclear Holding Company was being set up in 2013.

Over the next 20 years, KA-CARE introduced plans to construct 16 nuclear power reactors which would generate about 20% of total electricity production. Construction was planned to begin in 2016. In September 2013 GE Hitachi Nuclear Energy and Toshiba/Westinghouse signed contracts with Exelon Nuclear Partners (ENP) to pursue construction deals with KA-CARE.

In March 2015 the Korea Atomic Energy Research Institute (KAERI) signed an agreement with KA-CARE to evaluate building of at least two potential south Korean

SMART reactors (generating capacity up to 100 MW, with a 60-year design life and three-year refueling cycle) (Nuclear Power in Saudi Arabia, 2015).

5. Turkey

Turkey's generating capacity in 2012 was 57 GW (Turkey: International Energy Data and Analysis, 2015). It imports most of its energy, including 98% of its natural gas and 92% of its oil. Demand is growing at about 8% per year. In order to decrease its reliance on Russian and Iranian gas for electricity, a key aspect of the country's aim for economic growth is including nuclear power to the electricity grid. Plans are to have 4.8 GW of nuclear capacity by 2023.

Several nuclear power projects have been proposed throughout the years: in 1970 a feasibility study focused on a 300 MW plant, in 1973 the electricity authority was about to build a 80 MW demonstration plant but was not carried out, then in 1976 the Akkuyu site on the eastern Mediterranean coast was licensed for a nuclear plant. In 1980, lack of government financial guarantee led to a failed attempt to build several plants. In 1992 preliminary proposals for a nuclear plant were proposed but revised tender specifications were not released until December 1996. in 2000 and due to economic circumstances, plans for a 2000 MW plant at Akkuyu were abandoned. Early in 2006, the province of a port city of Sinop on the Black Sea was adopted for implementation of a commercial nuclear power plant. In August 2006 the government announced plans to build three nuclear plants with a capacity of 4500 MW to be operational by 2012-15 at Akkuyu. In 2007 the Turkish Energy

Authority (TAEK) was appointed to set the criteria for building and operating the plants. The Turkish Electricity Trade & Contract Corporation (TETAS) would then buy all the power for 15 years following the contracts set. The Atomic Energy Commission (AEC) oversees all nuclear activities, sets TAEK's program and submits budgets to the ministry. Also, the National Radioactive Waste Account (URAH) and a Decommissioning Account (ICH) were appointed to take care of waste management and decommissioning respectively.

In May 2008 a civil nuclear cooperation agreement with the USA was signed, also agreements with both South Korea and China were signed in 2010 and 2012 respectively. In 2013 the government announced intentions for two new nuclear plants each constituting of four reactors to be operational by 2030. In March 2015 the first unit in Akkuyu was suggested for commissioning in 2022 and construction is planned to begin at the end of 2016. As for the nuclear plants in Sinop, construction is planned to begin in 2017 and commissioning in 2023.

New plans to build additional nuclear capacity at other sites are under study. TAEK has identified Igneada in Kirklareli province on the Black Sea and Akcakoca as possible third nuclear plant sites. Ankara and Tekirdag on the Sea of Marmara were also identified as possible sites (Nuclear Power in Turkey, 2015).

6. United Arab Emirates

The United Arab Emirates had more than 27 GW of generating capacity in 2013 (United Arab Emirates: International Energy Data and Analysis, 2015). Electricity demand is steadily growing by 9% per year and a capacity of 40 GW is expected to be required by 2020.

UAE independently published in April 2008 an extensive policy regarding nuclear energy. Nuclear power proved to be an environmentally promising and commercially competitive option which led to the establishment of a regulatory framework. Also, a site at Barakah between Abu Dhabi city and Ruwais has been selected for possible installation of a nuclear power plant. Another possible site mentioned then was Al Fujayrah on the Indian Ocean coast.

Nuclear Energy Program Implementation Organization set up the Emirates Nuclear Energy Corporation (ENEC) as an Abu Dhabi public entity, which was initially funded with $100 million, in order to assess and implement nuclear power plants in the UAE.

Nine companies expressed interest for construction of the first nuclear power plant. ENEC short-listed the companies and sought bids by mid 2009. In December 2009, ENEC announced KEPCO to be the one to build four reactors at a single site. By 2020, UAE hopes to have four 1400 MW nuclear plants to be functional and producing electricity at quarter of the cost of electricity produced from gas.

In November 2013, the Dubai Electricity & Water Authority announced that by 2030, plans were to have 12% of total electricity supplied to be nuclear mainly from Abu Dhabi's Barakah plant, but also possibly from another plant to be situated in Dubai (Nuclear Power in the United Arab Emirates, 2015).

C. Interest in SMRs in the Middle East Region

Of the six countries under study, Iran, Jordan and Saudi Arabia showed interest in small reactors. In May 2007 the Atomic Energy Agency of Iran had plans to build a 360 MW light water reactor at Darkhowin on the Karun River and in May 2012 AEOI completed the design of the light water reactor. In May 2013 Iranian experts were underway to design a 300 MW light water reactor for Darkhowin according to a senior government official and in May 2014 AEOI confirmed that progress is being made on the project (Nuclear Power in Iran, 2015).

The Jordan Atomic Energy Agency has plans to install small reactors but after construction of the first large nuclear reactor takes place. In November 2013 JAEC put a plan to build several small reactors with a capacity of around 180 MW each (Nuclear Power in Jordan, 2015).

In March 2015 agreements were signed between Korea Atomic Energy Research Institute (KAERI) and KA-CARE to determine the feasibility of constructing at least two South Korean SMART reactors in Saudi Arabia with a capacity of about 100 MW per reactor and which are designed for thermal applications such as seawater desalination. This

SMART unit has an estimated cost of USD 1 billion and has a 60-year design life and three-year refueling cycle. Further agreements were made in September 2015 to implement knowledge infrastructure in SMART technology fields.

Also in March 2015, a joint venture company called Invania was set up between the state-owned INVAP in Argentina and the state-owned Taqnia in Saudi Arabia to develop nuclear technology in Saudi Arabia with a strong focus on small modular reactors such as CAREM for desalination (Nuclear Power in Saudi Arabia, 2015).

CHAPTER II

ENERGY PROFILE OF THE SELECTED COUNTRIES

A. Egypt

As of May 2015, generating capacity in Egypt was 31.45 GW and is expected to be 43.7 GW by 2022 (Egypt: International energy data and analysis, 2015).

in 2013 Egypt's electricity production was 167817 GWh of which 167412 GWh was used domestically. 76.8% of Egypt's electricity is fueled from natural gas, 14.5% from oil, 7.7% from hydroelectricity, 0.8% from wind power, and 0.2% from solar energy.

After subtracting losses and electricity used by the energy industry itself, we are left with a final consumption of 143204 GWh of which 40725 GWh was consumed by the industry, 517 GWh consumed by the transport sector, 61012 GWh for Residential use, 34589 GWh used for commercial and public services, and 6361 GWh consumed by the agriculture sector (Egypt: Electricity and Heat for 2013).

Electricity demand growth is about 7%/year. The country is targeting to increase its reliability on renewable energy by 2020 to 20%, of which 12% from wind, 6% hydro, and 2% solar (Egypt: International energy data and analysis, 2015).

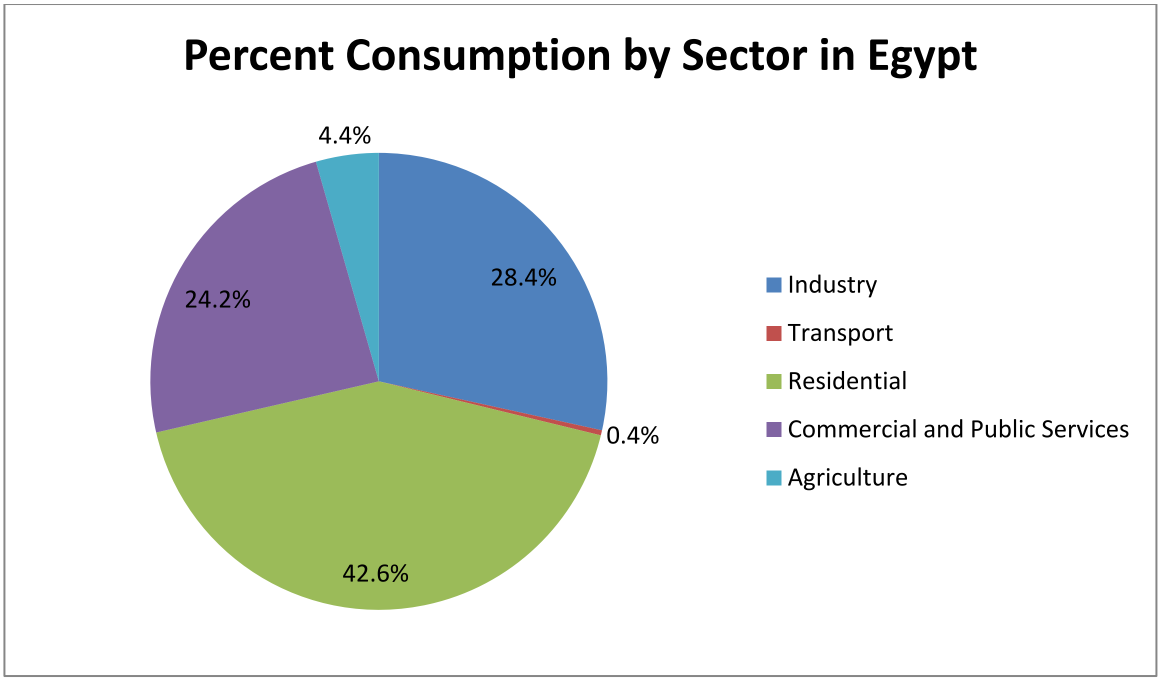

Figure 1: Electricity consumption by sector in Egypt

B. Iran

Iran had a generating capacity of 68 GW in mid-2013 and is expected to increase to reach 122 GW by 2022 (Nuclear Power in Iran, 2015).

In 2013, total electricity production was 270371 GWh of which 262788 GWh was used domestically. 66% of the total electricity produced comes from natural gas, 26.1% from oil, 5.6% from hydropower, 2% from nuclear, 0.2% from coal, and 0.1% from wind.

After accounting for losses and for energy industry own use, we are left with a final consumption of 212274 GWh distributed into the different sectors: 76797 GWh is consumed by the industry sector, 394 GWh transport, 65234 GWh residential, 32334 GWh commercial, 33650 GWh agriculture, and 3865 GWh other non-specified (Iran, Islamic Republic of: Electricity and Heat for 2013).

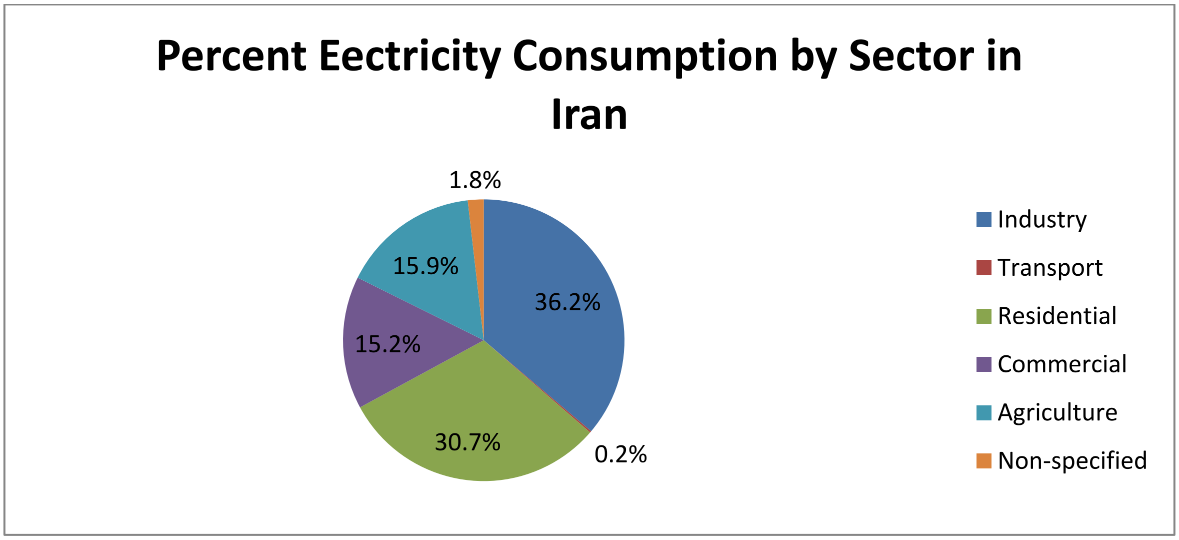

Figure 2: Electricity consumption by sector in Iran

C. Jordan

Jordan relies on more than 97% imports of its energy needs. In 2013, available generating capacity was 3.2 GW and is expected to need 5.3 GW in 2020 (NEPCO Annual Report 2013, 2013) and 8 GW of generating capacity by 2030 (Nuclear Power in Jordan, 2015).

Electricity production in Jordan was 17263 GWh in 2013, in which oil power plants were the dominant electricity producers with a 74.5% share, succeeded by natural gas at 25.1%, and then hydro and wind at 0.3% and 0.1% respectively.

After accounting for imports and exports, domestic supply is 17585 GWh which is higher than the amount produced. Removing losses and energy industry own use, final consumption becomes 14472 GWh of which 3425 GWh goes to the industry, 6265 GWh residential, 2706 GWh commercial, and 2076 GWh agriculture (Jordan: Electricity and Heat for 2013).

2007 projections showed that Jordan will be less reliable on fossil fuels by 2020 by increasing its energy mix to include 29% of primary energy from natural gas, 14% from oil shale, 10% from renewables, and 6% from nuclear (Nuclear Power in Jordan, 2015).

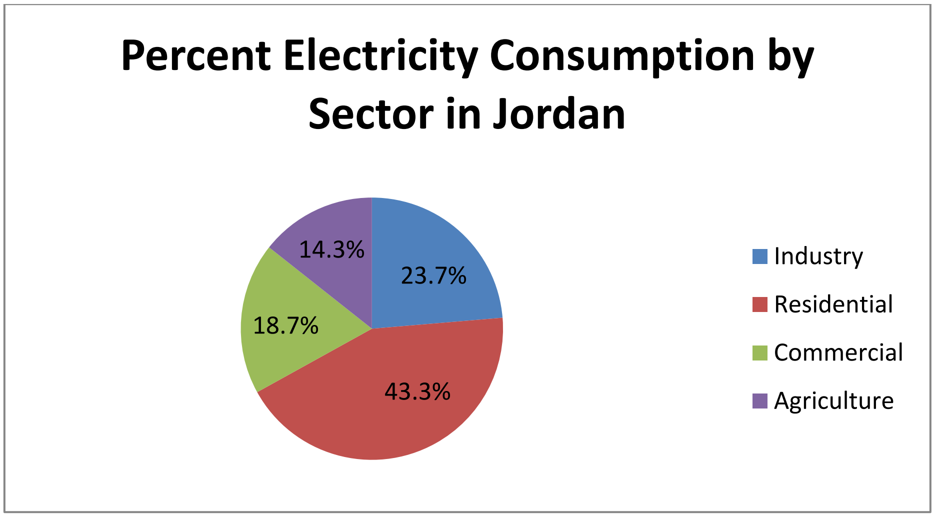

Figure 3: Electricity consumption by sector in Jordan

D. Saudi Arabia

In 2014 generating capacity in Saudi Arabia was 58 GW (Today in Energy, 2014) and demand is expected to be 70 GW by 2020 and 120 GW by 2032 (Nuclear Power in Saudi Arabia, 2015).

Electricity production in Saudi Arabia was 284017 GWh in 2013. All existing generating capacity is powered by either oil or natural gas. The share of oil is 47.2% and natural gas is 52.8%. Accounting for losses and energy industry own use, 248226 GWh remain for final consumption of which 41947 GWh is consumed by the industry, 125678 GWh by residential, 75639 GWh by commercial, 4290 GWh by agriculture, and 672 GWh by other non-specified (Saudi Arabia: Electricity and Heat for 2013).

Demand is growing 8%/year (Nuclear Power in Saudi Arabia, 2015). There are plans to reduce direct crude burn for electricity generation by switching to natural gas to increase their oil export capacity. By 2032 Saudi Arabia plans to add a combined capacity of 63 GW where solar energy will supply 41 GW, 18 GW from nuclear, and 4 GW from renewables (Grid: Powering Saudi Arabia).

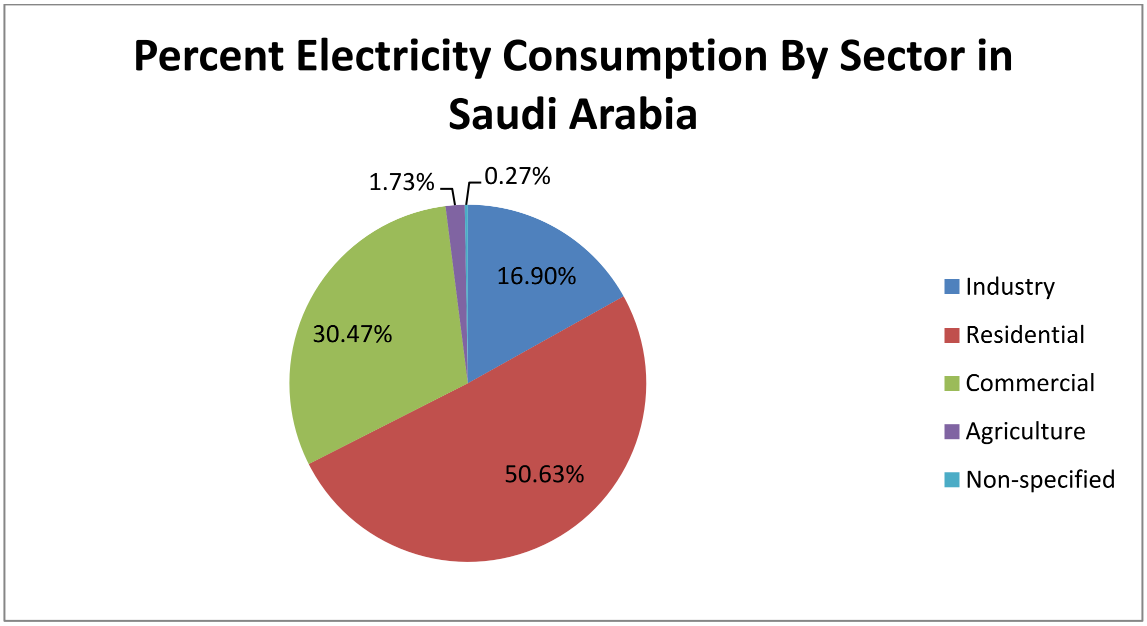

Figure 4: Electricity consumption by sector in Saudi Arabia

E. Turkey

Turkey had a generating capacity of 57 GWe in 2012 (Turkey: International Energy Data and Analysis, 2015).

In 2013 electricity production was 240154 GWh divided into the following: natural gas supplies 43.7%, 26.6% from coal, 24.7% from hydro, 3.1% from wind, 0.7% from oil, 0.6% geothermal, 0.4% from biofuels, 0.1% from waste, and 0.1% from other sources.

Turkey's electricity domestic supply was 246356 GWh in 2013, greater than its total production. This shows that Turkey is somewhat dependent on imports. Subtracting energy industry own use and losses, we are left with a final consumption of 196168 GWh. 91384 GWh out of the total domestic supply goes to the industry sector, 826 GWh to the transportation sector, 44972 GWh residential, 54072 GWh commercial, 4846 GWh agriculture, and 68 GWh fishing (Turkey: Electricity and Heat for 2013).

In Turkey, demand growth is about 8% per year. To cover this growing demand, projections for 2023 include plans to have 30 GW of coal-fired capacity and 4.8 GW of nuclear capacity. Also, there is a plan to boost the share of renewables by 30% by adding 34 GW of hydropower capacity, 20 GW wind, 5 GW solar, 1 GW geothermal, and 1 GW biomass (Nuclear Power in Turkey, 2015).

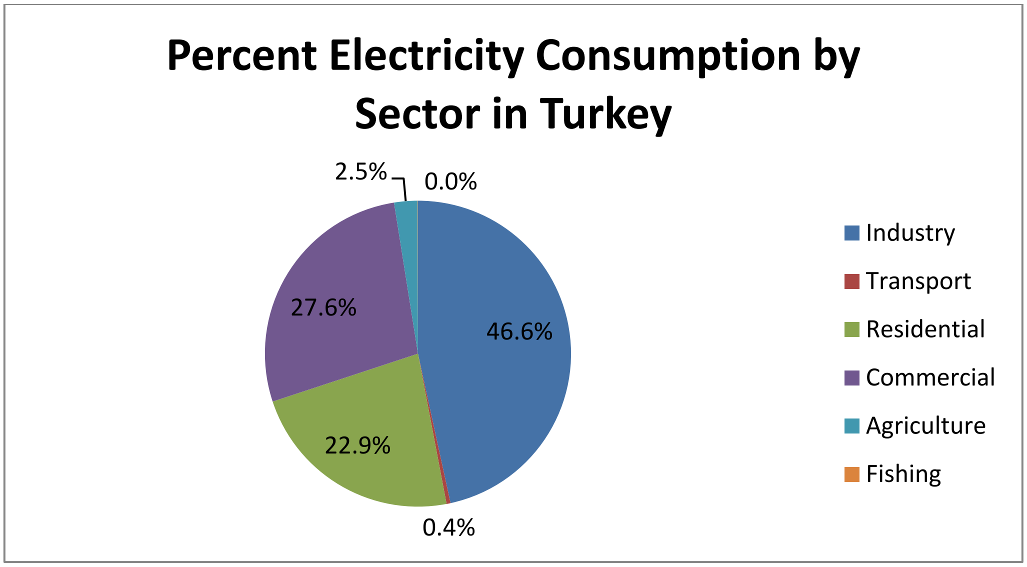

Figure 5: Electricity consumption by sector in Turkey

F. United Arab Emirates

The United Arab Emirates had a generating capacity of more than 27 GW in 2013 (United Arab Emirates: International Energy Data and Analysis, 2015) and expected required capacity in 2020 is 40 GW (Nuclear Power in the United Arab Emirates, 2015).

Electricity production in 2013 was 106222 GWh of which 98.7% of the production is from natural gas and 1.3% from oil. Adjusting for exports, domestic supply of electricity in 2013 was 106199 GWh. Subtracting losses and energy industry own use, final consumption reduces to 91499 GWh. 10237 GWh is supplied to the industry, 35207 GWh residential, 32923 GWh commercial, and 13132 GWh other non-specified (United Arab Emirates: Electricity and Heat for 2013).

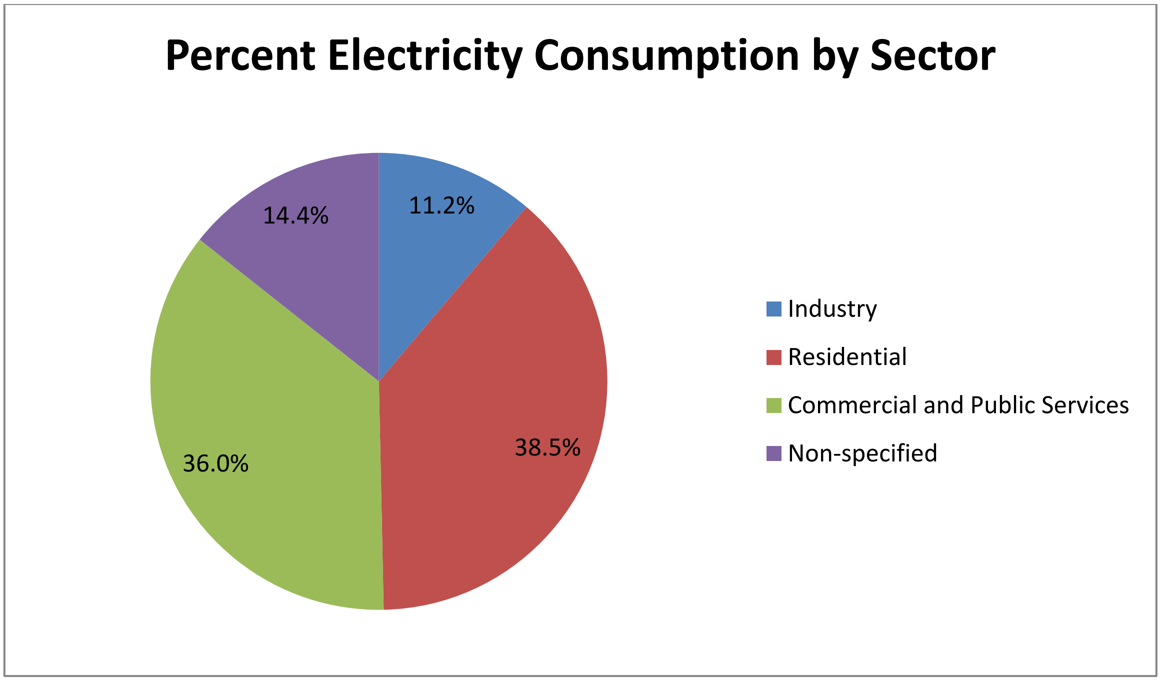

Figure 6: Electricity consumption by sector in the UAE

Electricity demand in the UAE is growing about 9%/year (Nuclear Power in the United Arab Emirates, 2015). By 2030, there is a plan to decrease reliability on natural gas and have a more diverse energy mix. Clean coal is expected to have a share of 12% of generating capacity, nuclear will have a share of 12%, solar energy will contribute 5% and the share of natural gas will decrease to 71% (United Arab Emirates: International Energy Data and Analysis, 2015).

	Egypt	Iran	Jordan	Saudi Arabia	Turkey	UAE
Coal	-	0.2	-	-	26.6	-
Oil	14.5	26.1	74.5	47.2	0.7	1.3
Natural Gas	76.8	66.0	25.1	52.8	43.7	98.7
Biofuel	-	-	-	-	0.4	-
Waste	-	-	-	-	0.1	-
Hydropower	7.7	5.6	0.3	-	24.7	-
Geothermal	-	-	-	-	0.6	-
Wind	0.8	0.1	0.1	-	3.1	-
Solar	0.2	-	-	-	-	-
Nuclear	-	2.0	-	-	-	-
Other	-	-	-	-	0.1	-

Table 1: Percent of energy source for total electricity production of the countries under study

CHAPTER III

SMALL MODULAR REACTOR DESIGNS

There is an increase in the number of reactor designs being proposed, some of them nearing the final stages before being marketed and others still in the preliminary design phase. Because of the considerable variety in SMRs technology, the simplest way to sort them is by putting them in the following categories: Light Water Reactors, Heavy Water Reactors, High-Temperature Gas-Cooled Reactors, Fast Neutron Reactors, and Molten Salt Reactors.

A. Light Water Reactors

Light water reactors more specifically pressurized water reactors are currently the dominating nuclear reactor technology. Some of these reactor designs are in their final stages and are almost ready to be released to the market. Many components and materials similar to the existing large reactors are being implemented in these small modular reactors. The fuel proposed for use is practically identical to the current light water reactors which is fuel enriched to less than 5% U-235. One important difference from the conventional pressurized-water reactors is the location of the steam generators. In SMRs, it is located in the same reactor vessel as the reactor core whereas in the current pressurized-water reactors, it is located outside the reactor vessel. Another difference would be fuel handling.

The entire core of the SMR will be removed and replaced during each refueling whereas in the conventional pressurized-water reactors, only one-third of the fuel assemblies are replaced when refueling and the other two-thirds are placed in other locations inside the core for the fuel to be used more efficiently. Currently, China, South Korea, USA, and Argentina have the most technologically mature designs (Glaser, Ramana, Ahmad, & Socolow, Small Modular Reactors: A Window on Nuclear Energy, 2015).

- KLT-40S (Russia): This reactor is a 35 MW pressurized water reactor from OKBM Afrikantov in Russia and is a floating nuclear power plant. It is capable of powering nuclear icebreakers. The reactor core is cooled by forced circulation. Fuel is up to 20% enriched uranium with a refueling period of 3 to 4 years (Rowinski, White, & Zhao, 2015).
- RITM-200 (Russia): It is a 50 MW pressurized water reactor from OKBM Afrikantov in Russia which uses enriched uranium up to 20% as a fuel and refueling period is around 7 years. It is designed to power icebreakers (Zverev, Pakhomov, Polunichev, Veshnyakov, & Kabin, 2013).
- CNP-300 (China): This is a reactor in China that has an electrical capacity of 325 MW. The fuel used is enriched uranium 2.4 to 3.0% and a refueling period of 1 year (Rowinski, White, & Zhao, 2015).
- NuScale (USA): The NuScale module is a pressurized water reactor that has an electrical capacity of 45 MW that is submerged in a pool of water. The fuel would be enriched uranium up to 4.95% with a refueling cycle of 24 months

(Glaser, Ramana, Ahmad, & Socolow, Small Modular Reactors: A Window on Nuclear Energy, 2015).

- mPower (USA): This reactor by Babcock & Wilcox is a 180 MW pressurized water reactor that would be built underground and would use enriched uranium up to 5% with a refueling period of 4 years (Makhijani, 2013).
- IRIS (International): IRIS is a 335 MW light water reactor that uses enriched uranium at 5% as its fuel and a fuel cycle of 4 years. An international group of organizations is working on this reactor concept (Vujic, Bergmann, Skoda, & Miletic, 2012).
- Westinghouse SMR (USA): This SMR has an electrical output of 225 MW. Many important features from the Westinghouse AP1000 reactor were used to design this SMR. The fuel is enriched uranium up to 5% with a 2 year fuel cycle (Liu & Fan, 2013).
- Alex-50 NPR (Egypt): The Alex-50 NPR is a pressurized water reactor that has an electrical capacity of 50 MW and that uses water as its coolant and moderator. The fuel used is low enriched uranium up to 5% U-235 and refueling periods are around 18 months. This reactor is based on the APR-1400 by KEPCO. A small prototype of 1 MW electrical capacity was manufactured with all real components except the Uranium fuel at the Nuclear Engineering Department of Alexandria University where a national factory helped in manufacturing this model. This project was designed and supervised by Dr. Yousry Abushady, former head of safeguards at the IAEA and former head of the Nuclear Engineering Department at

Alexandria University in Egypt. Currently one of the major universities in Egypt got interested in establishing a nuclear center for this project (Abushady, 2015).

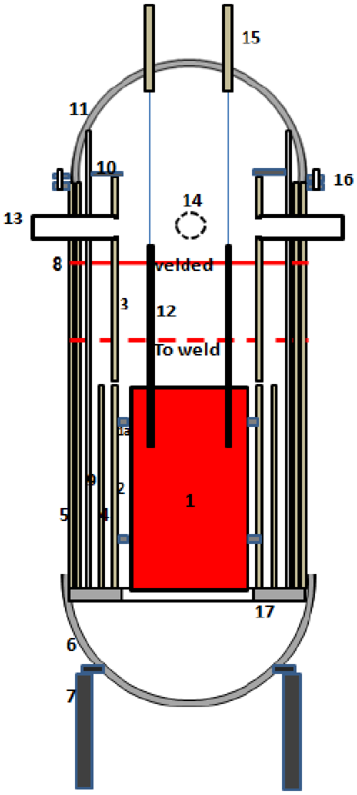

Figure 7: Alex-50 reactor section

– Holtec SMR-160 (USA): This SMR produces 160 MW of electricity which uses water as a coolant and moderator and uses low enriched uranium as its fuel (SMR-160).

– CAREM (Argentina): CAREM is a 25 MW pressurized water reactor that has a prototype design currently under construction. The final model will have an electrical output of 300 MW that will use 3.1% enriched uranium as its fuel with a refueling cycle of 14 months (Glaser, Ramana, Ahmad, & Socolow, Small Modular Reactors: A Window on Nuclear Energy, 2015).

- SMART, KAERI (South Korea): It is a pressurized water reactor with an electrical capacity of 100 MW. This model was proposed by the Korea Atomic Energy Research Institute (KAERI). It uses enriched uranium 4.8% as its fuel and has a refueling period of 36 months. It became the first modern small modular reactor to be licensed in 2012. As of 2015, a feasibility study of constructing SMART reactors in Saudi Arabia is being conducted (Glaser, Ramana, Ahmad, & Socolow, Small Modular Reactors: A Window on Nuclear Energy, 2015).
- ACP100 (China): It is a pressurized water reactor with an electrical output of 100 MW carried out by the China National Nuclear Corporation (CNNC). The fuel is 4.2% enriched uranium with a fuel cycle of 2 years (Glaser, Ramana, Ahmad, & Socolow, Small Modular Reactors: A Window on Nuclear Energy, 2015).
- Flexblue (France): The Flexblue has an original design where the reactor is submerged and placed on the sea bed and can be operated from land. It has 160 MW of electrical power and uses low enriched uranium as a fuel with a refueling period of 3 years (Rowinski, White, & Zhao, 2015).
- UNITHERM (Russia): This reactor is a pressurized water reactor that has a main objective to provide power to areas that are difficult to access. The fuel required to operate this reactor is CERMET UO_2-ZrO_2 enriched to 19.75% (Rowinski, White, & Zhao, 2015).

- FBNR (Brazil): The Fixed Bed Nuclear Reactor is a pressurized water reactor that generates 40 MW of electricity. This reactor is a one of a kind design since it uses tristructural-isotropic (TRISO) fuel to operate. This type of fuel is typically used in high temperature gas reactors. It uses 5% enriched uranium fuel with a refueling period ranging between 3 and 7 years (Rowinski, White, & Zhao, 2015).

B. Heavy Water Reactors

Heavy water reactors are the second most common type after light water reactors. They use heavy water as their moderator which is water that is modified to slow down neutrons by having almost all the hydrogen atoms in the form of Deuterium, the heavier hydrogen isotope. By using heavy water as a moderator, there would not be any need for enrichment technology, and natural uranium would be recommended as a fuel source. The moderator is typically stored inside a stainless steel tank called calandria at low pressure and temperature (Heavy Water Reactors: Status and Projected Development, 2002). As for the coolant, usually light or heavy water is used. Currently, Canada and India seem to be the countries that are most interested in this specific technology (Rowinski, White, & Zhao, 2015).

- EC6 (Canada): The Enhanced CANDU 6 reactor is considered to be a medium sized pressure tube reactor with an electrical capacity of 740 MW. The assembly of the EC6 includes the calandria vessel where the pressurized heavy water moderator is circulated and fuel channel assemblies where the heavy water coolant flows. Different fuel types can be used to power this model, from low enriched uranium up to 1.2% to thorium to MOX fuel (Status of Small and Medium Sized Reactor Designs, 2011).

- PHWR-220 (India): This pressurized heavy water reactor from India is designed to have an electrical capacity of 220 MW and uses heavy water as both the moderator and the coolant. This reactor uses natural uranium as its fuel with refueling intervals of 2 years (Status of Small and Medium Sized Reactor Designs, 2011).

- AHWR300-LEU (India): The Advanced Heavy Water Reactor with Low Enriched Uranium and Thorium Mixed Oxide Fuel or AHWR300-LEU is an Indian reactor designed to make use of thorium as a fuel since thorium is abundant in India. The reactor consists of a calandria vessel that houses the core and filled with heavy water that is used as a moderator. The vessel has vertical cooling channels where boiling light water flows through them and acts as a coolant. The fuel used is (Th, ^{233}U)-MOX and (Th,Pu)-MOX. The fuel cycle is closed, however, ^{233}U and thorium can be recovered from the spent fuel and used as fresh fuel (Status of Small and Medium Sized Reactor Designs, 2011).

C. High-Temperature Gas-Cooled Reactors

These reactors use graphite as their moderator. As for the coolant, and as their name applies, they use gas such as helium, carbon dioxide, or nitrogen. Fuel for these reactors is not conventional: it is in the form of TRISO (tristructural-isotropic) particles which are very small particles that have a diameter of less than 1 millimeter. Each particle has a uranium core enriched up to 20% U-235 or less and coated with carbon and silicon carbide. These reactors are able to deliver high temperature helium, up to 1000°C, that can drive a direct Brayton cycle gas turbine or an indirect Rankine steam cycle gas turbine for electricity. Thermal efficiencies as high as 50% can be reached (Rowinski, White, & Zhao, 2015).

- HTR-PM (China): The HTR-PM is a high temperature gas cooled pebble bed reactor from China that is currently under construction and has an electrical output of 210 MW in which two pebble bed reactors each with 105 MW electrical capacity are connected to a single turbine (Glaser, Ramana, Ahmad, & Socolow, Small Modular Reactors: A Window on Nuclear Energy, 2015).
- PBMR (South Africa): The pebble bed modular reactor designed in South Africa that has an electrical capacity of 164 MW. It is a helium gas cooled reactor that uses graphite as its moderator. The fuel that it uses is TRISO with 9.6% enriched uranium (Rowinski, White, & Zhao, 2015).
- GT-MHR (USA): The Gas Turbine-Modular Helium Reactor or GT-MHR is an American design that can produce electricity at high efficiencies up to 50%. The fuel used is TRISO with enrichment of 15.5% uranium. Helium acts as the coolant and graphite plays the role of the moderator (Rowinski, White, & Zhao, 2015).

- EM^2 (USA): The Energy Multiplier Module or EM^2 is designed to have an electrical capacity of 240 MW. It operates by burning used nuclear fuel with a core that can operate up to 30 years without any refueling interval. It uses helium as both its moderator and its coolant (Glaser, Ramana, Ahmad, & Socolow, Small Modular Reactors: A Window on Nuclear Energy, 2015).

D. Fast Neutron Reactors

These reactors can generate energy while reducing the nuclear waste problem by "burning" the different isotopes found in the already spent fuel. The fission products and the elements with higher atomic numbers produced are highly radioactive and the latter have half-lives much larger than the typical fission products. Some developers of nuclear reactors are focusing on minimizing the nuclear waste that is being produced. Designs of nuclear reactors that fall into this category are based on "fast" neutrons rather than "thermal" neutrons. In pressurized-water reactors, neutrons that are produced during fission are slowed down due to collisions with nuclei in the water. This leads to a higher probability of fission to occur in uranium nuclei which facilitates the sustainment of a chain reaction. In fast neutron reactors, there is no moderator to slow down the neutrons which leads to a lower probability for fission to occur; however, this is compensated by using a higher proportion of fissile materials which actually leads to a better fuel utilization. Transuranic elements recovered from spent fuel are best used with fast neutrons because they increase the efficiency when it comes to fuel consumption. Bear in mind that this type of reactor will be very costly and the benefits of reducing spent fuel would be outweighed by the cost (Glaser, Ramana, Ahmad, & Socolow, Small Modular Reactors: A Window on Nuclear Energy, 2015).

1. Sodium Cooled Fast Reactors:

- PRISM (USA): The Power Reactor Innovative Small Module or PRISM is an American fast reactor with 311 MW of electrical capacity. Since it is a fast reactor, it does not need a moderator: the fast neutrons can sustain the chain reaction from fission. The coolant is Sodium and it uses plutonium as its fuel with a refueling period of 18 months (Glaser, Ramana, Ahmad, & Socolow, Small Modular Reactors: A Window on Nuclear Energy, 2015).
- CEFR (China): The Chinese Experimental Fast Reactor or CEFR was designed by the China Nuclear Energy Industry Corporation or CNEIC. It is a sodium cooled reactor that has an electrical capacity of 20 MW and uses (Pu, U)O_2-MOX fuel (Rowinski, White, & Zhao, 2015).
- 4S (Japan): The Super-Safe, Small, Simple or 4S is a Japanese fast reactor that uses sodium as its coolant and generates 10 MW of electricity. It uses a metallic alloy of zirconium and uranium as its fuel with the uranium enriched to 19.9%. The core has a 30 year life and does not have any refueling intervals. It is ideally designed to be used in remote locations and can be a source of water desalination (Glaser, Ramana, Ahmad, & Socolow, Small Modular Reactors: A Window on Nuclear Energy, 2015).

– TWR (USA): The Traveling Wave Reactor is an American design proposed by Terrapower LLC and strongly supported by Microsoft founder Bill Gates. It is a medium sized reactor with an electrical output of 600 MW, however, sizes might differ with a range from a few hundred MW to more than 1000 MW. This reactor uses sodium as its coolant and would run on current spent or depleted fuel (Glaser, Ramana, Ahmad, & Socolow, Small Modular Reactors: A Window on Nuclear Energy, 2015).

2. Lead and Lead-Bismuth Cooled Fast Reactors:

– BREST-300 (Russia): This is a Russian fast cooled reactor that uses lead as its coolant and fuelled with uranium-plutonium mono nitride (PuN-UN) that is of high density and high conductivity. It generates 300 MW of electricity (Rowinski, White, & Zhao, 2015).

– SVBR-100 (Russia): This is a Russian designed fast reactor that uses lead-bismuth as its coolant without the need for moderator. It has an electrical capacity of 101 MW. The fuel used is enriched uranium up to 16.3% and loaded as a single cartridge without the need for partial refueling. The spent fuel is then removed after a cycle of 7 to 8 years to be replaced by a fresh cartridge (Rowinski, White, & Zhao, 2015).

– HPM (USA): The Generation 4 Hyperion Power Module is a fast reactor that generates 25 MW of electricity. It uses lead-bismuth as a coolant and operates on 19.75% enriched uranium fuel. This design would not need refueling during the 10 year life of the core. The reactor is planned to power remote locations (Glaser, Ramana, Ahmad, & Socolow, Small Modular Reactors: A Window on Nuclear Energy, 2015).

E. Molten Salt Reactors

Molten-salt reactors were extensively assessed in the past. In this type of reactor, salt is used to describe a chemical compound that forms when two ions of different polarity bond. Usually fluorine is used as the negative ion and metals such as lithium or beryllium as the positive ion which bond together to form a chemical compound in which nuclear fuel is dissolved in this liquid-carrier salt. Boiling temperatures of this chemical compound or salt can be very high, more than 1600 degrees Celsius. In this reactor design, molten fuel is cycled continuously in and out of the reactor in order to remove the unwanted fission products and to add makeup fuel. Molten-salt reactors have some technical challenges such as handling the highly radioactive molten-salt stream and ensuring that the components that make up the reactor can handle such high temperatures and high irradiation levels, as well as corrosion from the salts. (Glaser, Ramana, Ahmad, & Socolow, Small Modular Reactors: A Window on Nuclear Energy, 2015)

- IMSR (Canada): The Integral Molten Salt Reactor is a model that has electrical outputs ranging from 25 MW to 300 MW. The moderator used is graphite and the fuel is low enriched uranium without the need for refueling. The core life is 7 years (Glaser, Ramana, Ahmad, & Socolow, Small Modular Reactors: A Window on Nuclear Energy, 2015).

– WAMSR (USA): The Waste Annihilating Molten Salt Reactor or WAMSR also named Transatomic Power reactor or TAP is a molten salt reactor that generates 520 MW of electricity. Zirconium hydride acts as its moderator and fuelled by low enriched uranium up to 2%. The fuel used in this reactor will be recovered from light water reactors spent fuel (Glaser, Ramana, Ahmad, & Socolow, Small Modular Reactors, 2015).

– Flibe LFTR (USA): The Flibe Liquid Fluoride Thorium Reactor is a US design that uses uranium-233 as a fuel and has a generating electrical capacity of 40 MW. It uses graphite as its moderator and lithium fluoride/beryllium fluoride salt as its coolant (Small Nuclear Power Reactors, 2015).

This table summarizes the reactor technologies and their respective designs.

Reactor Technology	Model	Fuel	Coolant	Moderator	Electrical Output (MW)	Refueling Period
Light Water Reactors	KLT-40S	Enriched uranium (<20%)	Light water	Light water	35	3-4 years
	RITM-200	Enriched uranium <20%	Light water	Light water	50	7 years
	CNP-300	Enriched uranium (2.4-3.0%)	Light water	Light water	325	1 year
	NuScale	Enriched uranium (4.95%)	Light water	Light water	45	2 years
	mPower	Enriched uranium (5%)	Light water	Light water	180	4 years
	IRIS	Enriched uranium (5%)	Light water	Light water	335	4 years

	Westinghouse SMR	Enriched uranium (<5%)	Light water	Light water	225	2 years
	Alex-50 NPR	Enriched uranium (<5%)	Light Water	Light water	50	18 months
	Holtec SMR-160	Low enriched uranium	Light water	Light water	160	N/A
	CAREM	Enriched uranium (3.1%)	Light water	Light water	25	14 months
	SMART, KAERI	Enriched uranium (4.8%)	Light water	Light water	100	38 months
	ACP100	Enriched uranium (4.2%)	Light water	Light water	100	2 years
	Flexblue	Enriched uranium (5%)	Light water	Light water	160	3 years
	UNITHERM	CERMET (19.75% enriched)	Light water	Light water	6.5	240 months
	FBNR	Enriched uranium (5%)	Light water	Light water	40	3 to 7 years
Heavy Water Reactors	EC6	Variety	Heavy water	Heavy water	740	Closed
	PHWR-220	Natural uranium	Heavy water	Heavy water	220	2 years
	AHWR300-LEU	(Th, ^{233}U)-MOX + (Th, Pu)-MOX	Light water	Heavy water	304	Closed
High-Temperature Gas-Cooled Reactors	HTR-PM	Enriched uranium (8.8%)	Helium	Graphite	210	Open (Continuous refueling)
	PBMR	Enriched uranium (9.6%)	Helium	Graphite	164	10 months
	GT-MHR	Enriched uranium (15.5%)	Helium	Graphite	150	18 months
	EM^2	Depleted	Helium	None	240	30 years

		uranium + plutonium				
Fast Neutron Reactors	PRISM	Plutonium (26%)	Sodium	None	311	18 months
	CEFR	(Pu-U)O_2-MOX	Sodium	None	20	N/A
	4S	U-Zr Alloy	Sodium	None	10	30 years
	TWR	Depleted uranium + enriched uranium	Sodium	None	600	40 years
	BREST-300	PuN-UN	Lead	None	300	10 months
	SVBR-100	Enriched uranium (16.4%)	Lead-Bismuth	None	101	7 to 8 years
	HPM	Enriched uranium (19.75%)	Lead Bismuth	None	25	10 years
Molten Salt Reactors	IMSR	Enriched uranium	Molten salts	Graphite	25 to 300	Continuous refueling
	WAMSR	Enriched uranium (2%)	Molten salts	Zirconium hydride	520	Continuous refueling
	Flibe LFTR	Uranium-233	Lithium fluoride/beryllium fluoride salt	Graphite	40	N/A

Table 2: Small modular reactors criteria

CHAPTER IV

BEST PROSPECTS MARKETS FOR SMALL MODULAR REACTORS

A. Criteria

1. GDP

The gross domestic product (GDP) represents the total monetary value of all the goods and services produced in a specific period of time. It is a major indication of the health of the economy in the country under study.

Since SMRs require less capital cost to build and operate than typical nuclear reactors, this allows more countries to consider establishing a nuclear program. For large nuclear plants, the level of investment required is not affordable to many countries since such an investment that would cost billions would represent a large percent of their GDP rendering the project unfeasible. The lower cost of SMRs would represent a smaller proportion of these countries' GDP thus making it an appealing option. Even countries with a high GDP could find the option of SMRs to be attractive due to the fact that the time required to build SMRs is much less compared to large plants. Also, an advantage of SMRs is that one module could start producing electricity while another module is still being built.

This module that is producing electricity will generate a positive cash flow that will enable the next module to be built.

Out of the 6 countries under study, Jordan has the lowest GDP which makes it an ideal country to host SMRs. The other countries have a high GDP, therefore if they were to install SMRs, the total cost would not represent a high percentage of their GDP but nonetheless might find SMR technology interesting.

2. Electricity Grid Size

SMRs are particularly attractive to countries that have relatively small and less robust electricity grid sizes since SMRs will not destabilize the country's electricity grid. SMRs might also fit well in countries where the electricity demand in the future is expected to increase incrementally since SMRs could be installed in series. Also, it is recommended for each country to diversify their sources of electricity generation by reducing their dependence on one technology for the supply of energy. In that case, nuclear energy, more specifically energy stemming from SMRs, would present itself as a viable option in order to decrease this dependency.

3. CO_2 Emissions

Given the growing climate change concerns, nuclear power is particularly appealing due to its ability to generate electricity with negligible emissions of greenhouse gases (GHG), especially carbon dioxide. SMRs therefore could be a viable solution to this concern.

Calculations are based on the percentage change of CO_2 emissions from 2008 to 2012:

$$\frac{CO_2\ emissions\ in\ 2012 - CO_2\ emissions\ in\ 2008}{CO_2\ emissions\ in\ 2008} \times 100$$

Note that the unit of carbon dioxide emissions from the consumption of energy is in Million Metric Tons.

4. Population Density

Population density represents the number of people living in a certain country per unit area i.e. people per square kilometer. A country with a lower population density presents a better indication that SMRs may be appropriately deployed.

5. Economic Growth

Economic growth is the increase in a country's capacity to produce goods and services compared from one year to the next. By obtaining the annual percentage growth rate of GDP of each country from 2011 to 2014, calculations were conducted by averaging the annual growth rate for these 4 years. Results are shown below in the table. Note that the values in the table are obtained using World Bank data.

Countries that show an increase in GDP growth might have a more promising future with SMRs in order to meet the increase in energy demand since GDP and energy demand are directly correlated.

Country	2011	2012	2013	2014	Average (%)
Egypt	1.8	2.2	2.1	2.2	2.08
Iran	3.7	-6.6	-1.9	4.3	-0.12
Jordan	2.6	2.7	2.8	3.1	2.8
Saudi Arabia	10.0	5.4	2.7	3.5	5.4
Turkey	8.8	2.1	4.2	2.9	4.5
United Arab Emirates	5.2	6.9	4.3	4.6	5.25

Table 3: Average of Annual Percentage Growth Rate of GDP in Select Countries (GDP Growth, 2015)

6. Nuclear Capacity

Nuclear capacity shows whether a country has an operating nuclear reactor or not. Countries without or with limited experience with nuclear energy may find the option of SMRs to be attractive whereas countries with an established nuclear program and an operating nuclear plant or a reactor that will have successful operation in the coming few years might want to stay with the current technology and not shift towards SMRs.

7. Uranium Resources

Uranium is a metal found in the crust of the Earth. This section tackles whether the countries in the study have any reserves of Uranium.

B. Analysis

1. Egypt

a. GDP

Egypt's GDP in 2014 was USD 286.5 billion ranking 39th worldwide (Gross Domestic Product 2014, 2015).

b. Electricity Grid Size

Egypt heavily relies on natural gas to fuel its generators. A good way to reduce this dependency is the implementation of SMRs in the country.

c. CO_2 Emissions

CO_2 emissions in 2008 and 2012 were 181 and 206 Million Metric Tons respectively (Total Carbon Dioxide Emissions from the Consumption of Energy 2014, 2015).

$$\frac{206 - 181}{181} \times 100 = 13.81\ \%$$

The results show an increase in CO_2 emissions of 13.81% from 2008 to 2012.

d. Population Density

Egypt's population density in 2014 was 90 ppl/km^2 (Population Density, 2015).

e. Economic Growth

Average annual GDP growth rate from 2011 to 2014 was 2.08% which shows a steady and healthy economy in Egypt.

f. Nuclear Capacity

Egypt has had a nuclear program since 1955 that is responsible for licensing and regulation. Many plans to install nuclear power in the country have been proposed but until now, the country doesn't have any reactor in operation (Emerging Nuclear Energy Countries, 2015).

g. Uranium Resources

Some studies suggest that Egypt has large amounts of Uranium ore (Khaled, 2013), but no extra details are given in that matter. As long as there aren't any extensive studies yet, we will consider that Egypt does not have any Uranium resources.

2. Iran

a. GDP

Iran's GDP was USD 415.3 billion in 2014 ranking 29th worldwide (Gross Domestic Product 2014, 2015).

b. Electricity Grid Size

Electricity demand in Iran is expected to increase dramatically in the coming years. Large nuclear reactors and SMRs installed in series along with other sources that produce electricity are required to fill this gap.

c. CO_2 Emissions

CO_2 emissions in 2008 and 2012 were 512 and 604 Million Metric Tons respectively (Total Carbon Dioxide Emissions from the Consumption of Energy 2014, 2015).

$$\frac{604-512}{512}\times 100 = 17.97\ \%$$

As a percent change, this results in an increase in CO_2 emissions of 17.97%.

d. Population Density

Iran's population density in 2014 was 48 ppl/km^2 (Population Density, 2015).

e. Economic Growth

The average annual GDP growth rate from 2011 to 2014 was -0.12% which shows signs of an unhealthy and fluctuating economy.

f. Nuclear Capacity

Iran's nuclear program had been established in 1957. In September 2013, Iran had a fully operational nuclear plant in Bushehr that was producing power to the grid (Nuclear Power in Iran, 2015).

g. Uranium Resources

The head of Iran's Atomic Energy Organization mentioned in September 2015 that Iran has discovered high reserves of Uranium. However, previous studies conducted by Western analysts stated that Iran had low Uranium resources (Iran Says Finds Unexpectedly High Uranium Reserve, 2015). As long as there are not any further details and analysis regarding the matter, then it is safe to assume for now that Iran has a low supply of Uranium.

3. Jordan

a. GDP

Jordan's GDP was 35.8 billion in 2014 ranking 94th worldwide (Gross Domestic Product 2014, 2015).

b. Electricity Grid Size

Jordan has a small electricity grid size which renders it a perfectly suitable market for SMRs.

c. CO_2 Emissions

CO_2 emissions in 2008 and 2012 were 19 and 17 Million Metric Tons respectively (Total Carbon Dioxide Emissions from the Consumption of Energy 2014, 2015).

Based on the equation for percent change of CO_2 emissions, we get the following result:

$$\frac{CO_2\ emissions\ in\ 2012 - CO_2\ emissions\ in\ 2008}{CO_2\ emissions\ in\ 2008} \times 100 = \frac{17 - 19}{19} \times 100$$

$$= -10.53\ \%$$

Notice that the percent change has a negative value which means that CO_2 emissions from 2008 to 2012 decreased by 10.53%.

d. Population Density

Jordan's population density in 2014 was 74 people per sq. km (Population Density, 2015).

e. Economic Growth

The average annual GDP growth rate from 2011 to 2014 was 2.8%. Jordan showed a sustainable and steady increase in annual GDP percentage. This is promising for the future of SMRs in the country.

f. Nuclear Capacity

Jordan set up its nuclear program in 2007 which has a main objective of transforming the country to a net electricity exporter instead of a net importer by exploiting the Uranium resources and building nuclear reactors. Until now, no nuclear reactor has been built (Nuclear Power in Jordan, 2015).

g. Uranium Resources

Studies show that Jordan has 140,000 tU in addition to 59,000 tU in phosphate deposits (Nuclear Power in Jordan, 2015).

4. Saudi Arabia

a. GDP

Saudi Arabia's GDP was USD 746.2 billion in 2014 ranking 19th worldwide (Gross Domestic Product 2014, 2015).

b. Electricity Grid Size

Saudi Arabia relies on only natural gas and oil to produce the electricity required in this country. To lessen this dependency, nuclear energy and other sources such as renewables are advised.

c. CO_2 Emissions

CO_2 emissions in 2008 and 2012 were 422 and 583 Million Metric Tons respectively (Total Carbon Dioxide Emissions from the Consumption of Energy 2014, 2015).

$$\frac{583 - 422}{422} \times 100 = 38.15\ \%$$

CO_2 emissions increased by 38.15% from 2008 to 2012.

d. Population Density

Saudi Arabia's population density in 2014 was 14 ppl/km^2 (Population Density, 2015).

e. Economic Growth

Average annual GDP growth rate from 2011 to 2014 was 5.4%. This is considered as a high growth rate, but it does not hide the fact that the rate from year to year was highly fluctuating and unstable. With all that being said, it is worthy to note that the GDP growth rate in these 4 years stayed above the ideal rate of 2 to 3%.

f. Nuclear Capacity

A nuclear power program in 2010 was established to meet the growing demand for energy and production of desalinated water by reducing the reliance on hydrocarbons and looking at a new alternative which is nuclear energy. Until now, Saudi Arabia does not have an operating nuclear plant (Nuclear Power in Saudi Arabia, 2015).

g. Uranium Resources

There aren't any studies that prove that Saudi Arabia has Uranium resources. For now, it can be safely assumed that Saudi Arabia does not have Uranium reserves.

5. Turkey

a. GDP

Turkey's GDP in 2014 was USD 799.5 billion ranking 18th worldwide (Gross Domestic Product 2014, 2015).

b. Electricity Grid Size

Electricity demand growth is about 8% per year. Adding nuclear capacity to the energy profile of Turkey would help in covering this growing demand.

c. CO_2 Emissions

CO_2 emissions in 2008 and 2012 were 273 and 297 Million Metric Tons respectively (Total Carbon Dioxide Emissions from the Consumption of Energy 2014, 2015).

$$\frac{297 - 273}{273} \times 100 = 8.79\ \%$$

CO_2 emissions increased by 8.79% from 2008 to 2012.

d. Population Density

Turkey's population density in 2014 was 99 ppl/km^2 (Population Density, 2015).

e. Economic Growth

Average annual GDP growth rate from 2011 to 2014 was 4.5%. Although this is considered as a high growth rate, however this rate was highly fluctuating from year to year which shows a somewhat unstable economy. Note that even in 2012 which had the lowest percent growth rate of these 4 years with a value of 2.1%, the economy could be considered as healthy since this rate is within the norm.

f. Nuclear Capacity

Many nuclear power projects have been proposed in Turkey since 1970, however the country has zero nuclear capacity (Nuclear Power in Turkey, 2015).

g. Uranium Resources

Turkey has modest resources of Uranium. A total of approximately 9,100 tU were found (Uranium and Thorium).

6. United Arab Emirates

a. GDP

in 2014 UAE had a GDP of USD 401.6 billion ranking 30th worldwide (Gross Domestic Product 2014, 2015).

b. Electricity Grid Size

Electricity demand in the UAE is increasing at a rate of 9% per year. Also UAE generates electricity mostly from power plants that run on natural gas. Nuclear alongside other sources of energy are required to diversify the power production as well as to meet the increasing demand.

c. CO_2 Emissions

CO_2 emissions in 2008 and 2012 were 194 and 234 Million Metric Tons respectively (Total Carbon Dioxide Emissions from the Consumption of Energy 2014, 2015).

$$\frac{234 - 194}{194} \times 100 = 20.62\ \%$$

The results show an increase in CO_2 emissions of 20.62% from 2008 to 2012.

d. Population Density

UAE's population density in 2014 was 109 ppl/km^2 (Population Density, 2015).

e. Economic Growth

Average annual GDP growth rate from 2011 to 2014 was 5.25%. GDP growth rate somewhat maintained the same high level in these 4 years. Looking only at the economic growth of the UAE without taking into account the other criteria, SMRs could be used to meet the growing energy demand.

f. Nuclear Capacity

The UAE founded their nuclear energy program in 2009 and since then have been rushing to build reactors in the country. Four nuclear reactors are planned to start successful operation between 2017 and 2020 (Nuclear Power in the United Arab Emirates, 2015).

g. Uranium Resources

UAE does not have any Uranium resources.

C. Summary of Results

The results obtained above for the six countries show whether that specific country is or isn't a potential market for SMRs. To summarize these results, a table was constructed which ranked the countries based on seven traits for potential SMR market. These characteristics are as follow: GDP, electricity grid size, CO_2 emissions, population density, economic growth, nuclear capacity, and Uranium resources. A ranking system was then established with a cumulative score of 22. The closer the country is to this score , the more ideal it is for an SMR market.

The first 5 characteristics are assigned a score of 1 to 4 - a score of 4 meaning the country is close to an ideal SMR market based on that specific characteristic. Note that out of these 5 traits, population density is the only category where given a score of 4 means that population density is low.

The latter two characteristics are assigned a score of 0 or 1. For nuclear capacity, a score of 0 means that the country has an operating reactor or is in the final stages of successfully building one such as the UAE, and a score of 1 means the country does not have an operating reactor. For Uranium resources, a value of 0 means the country does not have Uranium resources, and a value of 1 means the country has Uranium resources.

Country	GDP	Electricity Grid Size	CO_2 Emissions	Population Density	Economic Growth	Nuclear Capacity	Uranium Resources	Total	Rank
Egypt	3	3	3	2	3	1	0	15	**4**
Iran	2	3	4	4	1	0	0	14	**5**
Jordan	4	4	1	3	4	1	1	18	**1**
Saudi Arabia	2	4	4	4	3	1	0	18	**1**
Turkey	2	3	2	2	3	1	0	13	**6**
United Arab Emirates	3	4	4	2	4	0	0	17	**3**

Table 4: Potential Best Prospect Countries for installation of SMRs

CHAPTER V

ANALYSIS ON SMALL MODULAR REACTORS

This part will gather information regarding the 6 countries about their past and current interest in small modular reactors. This thorough research will include data extracted from the nuclear trade press, research papers, articles in newspapers and magazines, and official government statements.

A. SMRs and Egypt

Egypt entered the world of nuclear energy in 1955 when it set up the Atomic Energy Commission that later became the Atomic Energy Authority. In 1961, a 2 MW thermal Russian research reactor went into criticality for the first time at the Nuclear Research Center in Inshas (Emerging Nuclear Energy Countries, 2015). This research reactor is under safeguards and monitored by the IAEA (AP, 1997). A second research reactor was also set up at the Nuclear Research Center that first reached criticality in 1997. This time, the research reactor was supplied by Argentina with a 22 MW thermal capacity (Emerging Nuclear Energy Countries, 2015).

9 years after the Atomic Energy Commission was formed, Egypt expressed interest in small reactors by issuing a tender that aimed in building a small nuclear power

plant with 150 MW of electrical capacity. The project was shortly put to a halt in 1967 when the country went to war with Israel. Then in 1974, a new bid was issued targeting only US companies called for the development of a medium sized nuclear plant with 600 MW of electrical capacity at Sidi Kreir. The project was also cancelled in 1979 when the Three Mile Island accident happened in the USA (Kessides & Kuznetsov, 2012).

In 1988, the International Atomic Energy Agency decided to collaborate with Egypt in carrying out a case study that involved checking the feasibility of installing small and medium power reactors to supply the country's future electricity needs. The main focus of the study was the evaluation of the economical, financial, and technical features of these reactors (Case Study on the Feasibility of Small and Medium Nuclear Power Plants in Egypt, 1994).

In May 2001, the Egyptian Nuclear Power Plants Authority hosted a seminar on small and medium sized reactors in Egypt. This seminar provided information on the environmental, economical, technical, and social aspects of SMR deployment in the 21st century. The opening remarks were given by distinguished guests, including the Egyptian Minister of Electricity and Energy at that time (Small and Medium Sized Reactors: Status and Prospects, 2002).

In 2011, the International Trade Administration at the US Department of Commerce conducted a study on 27 countries, Egypt inclusive, to study the feasibility of introducing small modular reactors into the countries' energy mix. According to the different criteria used to assess each country, Egypt had a score of 9 over 18 thus putting it in the 18th place (The Commercial Outlook for U.S. Small Modular Nuclear Reactors, 2011). Another method to study the deployment potential of SMRs was published in July 2013 by a group of researchers. The study showed that Egypt has no interest in SMRs. The country's current focus is on large reactors (Locatelli, Mancini, & Belloni, 2013).

In 2014, researchers studied SMR deployment using the Analytic Hierarchy Process, a decision-making process that involves many criteria. 97 countries were selected for the study, and Egypt ranked 70th placing it in the third quartile (Black, Taylor Black, Solan, & Shropshire, 2014).

B. SMRs and Iran

Iran's nuclear program was established as early as 1957. It currently has a large nuclear reactor operating. It is worthy to note that there are currently four working small reactors at the Nuclear Technology Center of Isfahan solely for research purposes (Nuclear Power in Iran, 2015).

In 2013, researchers studied different countries and their potential deployment of small modular reactors. Their results showed that Iran had no interest in SMRs and that the country's main focus was on the expansion of large reactors (Locatelli, Mancini, & Belloni, 2013).

In August 2015, negotiations between the Atomic Energy Organization of Iran and China took place to construct the ACP100, a small modular reactor design. The main reason for these negotiations is to have a reliable plant for water desalination (FARS News Agency, 2015).

In February 2016, following the Joint Comprehensive Plan of Action (JCPOA) in 2015, Iran suggested to cooperate with Hungary on designing and building a small modular reactor that would make it appealing to poorer countries considering SMRs are more affordable than large reactors. This project was received well by Hungary and the two sides are hoping on starting this project soon (Dunai, 2016). Later in May 2016, Iran and South Korea were negotiating on terms to cooperate in the nuclear energy sector, South Korea being a reliable supplier of SMRs and of large reactors (Kim & Tabatabai, 2016).

On September 16, 2016 Ali Akbar Salehi, head of AEOI expressed in an interview that Iran's new nuclear strategy involves developing SMRs. The country plans on cooperating with other countries to design and develop SMRs (Mehr News Agency, 2016). The main reason for Iran's interest in small modular reactors is to supply electricity to areas where their electricity grid size is small (Tehran Times, 2016). The SMRs would fit perfectly with Iran's industrial infrastructure by building them close to the remote regions and saving on the transmission costs of electricity (Iran Ready to Share Nuclear Experience, 2016).

C. SMRs and Jordan

Small modular reactors are thought to be specifically attractive to developing countries. The reasons are many, such as their ease of implementation to smaller electricity grids and their lower capital costs just to name a few. Jordan is considered to be a developing country with a small generating capacity of 3.2 GW of electricity in 2013 (NEPCO Annual Report 2013, 2013) and a low GDP of 35.8 billion USD in 2014 (Gross Domestic Product 2014, 2015). Comparing it's GDP with recent estimates of the cost of Southern Co.'s Vogtle nuclear power plant which stands at greater than USD 17 billion (Henry, 2015), it would seem highly unreasonable to go with the option of building a conventional nuclear plant, but instead opt for small modular reactors that would fit perfectly with Jordan's small electricity grid size and where the investment would represent only a small percentage of the GDP.

Serious thoughts were put into considering the implementation of SMRs, and in 2007, after the Jordan Atomic Energy Commission was established, Khaled Toukan, Minister of Higher Education and later the chairman of JAEC, announced that by 2010 Jordan should determine if it were to settle with small and medium sized reactors by setting up a nuclear power infrastructure that is of limited scale or shift its attention and focus on generating power using large nuclear reactors, the latter largely decreasing Jordan's dependency on fossil fuels (Hibbs, 2007). At that same period, IAEA Director General at that time Mohamed El Baradei said during the World Nuclear Association's annual symposium that many countries, including Jordan, were looking for small reactors that had a generating capacity between 100 and 400 MW, and he was hoping that response from the vendors would be quick in order to fill this demand (NW, 2007).

In 2011, A study was conducted by the U.S. Department of Commerce on 27 countries to assess whether they are favorable prospect markets for SMRs or not. Based on the criteria used in the paper, Jordan obtained a score of 15 over 18 ranking it second best as a potential market for SMRs (The Commercial Outlook for U.S. Small Modular Nuclear Reactors, 2011).

In 2013, a group of researchers published a paper that aimed to study the countries where SMR deployment might be suitable. According to the study, Jordan showed no interest in SMR deployment for the time being, however, reevaluation at a later stage is possible and Jordan might reconsider the option of SMRs (Locatelli, Mancini, & Belloni, 2013).

Another study by a different group of researchers in 2014 focused on evaluating SMRs deployment in developing countries. This study used the AHP or Analytic Hierarchy Process which analyzes multiple criteria in the decision-making process for SMR deployment. Out of the 97 countries under study, Jordan ranked 36th (Black, Taylor Black, Solan, & Shropshire, 2014).

Also in 2014, the International Framework for Nuclear Energy Cooperation (IFNEC) in collaboration with JAEC organized a Small Modular Reactor Workshop in Jordan that aimed to better clarify how deployment of SMRs could be effected in different markets. Many stakeholders that are considered key for successful deployment of SMRs attended the workshop (Small Modular Reactor Workshop - June 2014, 2014). Furthermore, many Jordanian officials attended the workshop most notably The Minister of Energy and Mineral Resources Mohammed Hamed and the Chairman of the JAEC Khaled Toukan, where in the welcome and opening remarks of the workshop, they spoke about the interest of both the industry and customers of Jordan in the potential deployment of SMRs, stating that SMRs would be suitable due to their lower investment cost, their design simplicity, their enhanced safety, and Jordan's small electricity grid size (Ghazal, Electricity Demand Expected to Triple by 2030 - Minister, 2014).

Instead of deciding on SMRs, Jordan signed a USD 10 billion agreement with Russia to build a conventional nuclear power plant that comprises two reactors with a combined generating capacity of 2 GW (Al-Khalidi, 2015). With that in mind, JAEC chairman mentioned that SMRs would still be a feasible option since they are easier to finance and demonstrate less siting difficulties, however, he added that installing an additional 1000 MW reactor to the upcoming nuclear power plant is "not out of the question" (McAuley, 2015).

The first nuclear reactor in Jordan is expected to start up this year or the next. The Jordan Research and Training Reactor (JRTR) is a 5 MW thermal reactor currently being built at the Jordan University for Science and Technology. Its design is based on the 30 MW thermal reactor of the Korean Atomic Energy Research Institute's Hanaro design (Royal Recognition for Jordan's Nuclear Program, 2016), with a total cost of USD 130 million (Go-Ahead for Jordanian Research Reactor, 2013).

Top executives from several countries including Jordan attended the International SMR and Advanced Reactor Summit in Atlanta on April 14 and 15, 2016 (UPI Space Daily, 2016).

D. SMRs and Saudi Arabia

Saudi Arabia has been interested in diversifying its energy sources to meet the growing demand of the country. A large part of this plan is the introduction of nuclear energy into its energy portfolio, not just for electricity generation, but also for seawater desalination (Ahmad & Ramana, 2014). As early as 1994, a study conducted by a group of Saudi researchers tackled the problem of water desalination, indicating that it is essential for the country to introduce nuclear energy as a strong potential source. One of the suggestions in the paper is the introduction of small or medium sized reactors that can be used for desalination especially in remote locations where population density is small and infrastructure is weak (Kutbi & Al Sulaiman, 1994). Another study in 2003 was carried on to show that nuclear energy used for desalination proved to be competitive and economically feasible in Saudi Arabia. The study focused on small and medium reactors by using the DEEP computer code that economically evaluates desalination technologies. The results were promising and proved that these small and medium sized reactors were competitive options (Aljohani, 2004).

A publication in 2013 further studied the subject of nuclear desalination plants mentioning that currently all the plants are running on crude oil. It stated that Saudi Arabia was looking at diversifying its energy mix, with nuclear energy having a substantial role in desalination. Some small nuclear reactors were put under investigation for installation in the country such as System-integrated Modular Advanced Reactor (SMART) and Central Argentina de Elementos Modulares (CAREM), that are well suited for the desalination process (Saudi Arabia Eying Nuclear Power Despite Substantial Oil and Gas Reserves, 2013). The option of small reactors would increase crude oil export by decreasing the reliability on desalination plants that run on oil. To make possible the establishment of these desalination plants, Saudi Arabia signed a cooperation agreement with the International Atomic Energy Agency in 2007. In June 2011, Saudi Arabia signed a cooperation agreement with Argentina with an aim to install the CAREM reactors at a later stage, and in November 2011, the country signed another cooperation agreement with South Korea that would facilitate the installation of the SMART reactor for use in the desalination process (Progressive Digital Media, 2013).

Another assessment by a group of researchers in 2013 investigated a vast number of countries and the possibility of deployment of small modular reactors in them. Eight strategic scenarios were used to evaluate where the countries stand in regards to SMR deployment. Saudi Arabia was included in the study and proved to be a strong potential market where SMRs could be deployed (Locatelli, Mancini, & Belloni, 2013).

A paper published in 2014 focused on the economics of nuclear power for Saudi Arabia. The results obtained were not promising for nuclear compared to other electricity sources, such as natural gas and solar energy. As far as SMRs are concerned, detailed analysis showed that these reactors will probably cost per kW of capacity more than the reactors that are currently running. In addition, solar power will probably produce electricity at a cheaper rate than SMRs (Ahmad & Ramana, 2014). Another paper aimed at analyzing SMR deployment in select countries using multiple criteria. Out of the 97 countries considered, Saudi Arabia ranked 11th, placing it in the first quartile (Black, Taylor Black, Solan, & Shropshire, 2014).

In June 2014, Dr. Maher Alodan, Director at King Abdullah City for Nuclear and Renewable Energy (KACARE) gave a presentation on national market perspectives regarding SMRs at the International Framework for Nuclear Energy Cooperation that took place in Jordan (Report of the Small Modular Reactor Workshop: Practical Deployment Issues and Approaches, 2014).

A memorandum of understanding was signed on August 7, 2014 between China National Nuclear Corporation (CNNC) and KACARE to cooperate on the design and technology of small modular reactors (China Business News, 2014). On another note, NuScale Power, a United States privately owned company, made a few follow-up meetings with Saudi Arabia in 2014 concerning designing, licensing, and building of a small commercial scale nuclear unit; however, no agreement had been signed between them (Nuclear Plant Journal, 2014).

On Tuesday March 3, 2015 South Korean and Saudi Arabian leaders agreed to find options to build possibly more than two small and medium reactors that may cost more than USD 2 billion. These two countries want to find ways to cooperate in the energy sector, thus signing a memorandum of understanding with a goal on developing the South Korean SMR technology: the SMART reactors designed by the Korea Atomic Energy Research Institute. A three year preliminary study will be conducted to check the feasibility of integrating this SMR technology in Saudi Arabia. If this project sees the light of day, it will be a first-of-a-kind case where a small modular reactor is exported to a foreign country (GlobalData, 2015). Analysts predict that the South Korean company Daewoo E&C will probably benefit the most from this deal since it would handle on an exclusive basis the export of SMRs (Han-na, 2015). A few days later, Saudi Arabia formed a joint venture company with Argentina called Invania in order to aid Saudi Arabia in implementing its new nuclear program. One of the focuses of this venture will be on SMRs such as CAREM for use in desalination plants (Saudi Arabia and Argentina Form R&D Joint Venture, 2015).

On September 2, 2015 KAERI signed a new memorandum of understanding with KACARE to carry on the Pre-Project Engineering (PPE) program before erecting the SMART reactor. The PPE program will have a period of 39 months starting from December 2015, and based on the report, Saudi Arabia will decide whether it wants to build SMART reactors or not. A total joint investment of USD 100 million will be needed to conduct this program (Min-Hee, 2015).

Leaders from around the globe gathered in Atlanta for the International SMR and Advanced Reactor Summit on April 14 and 15, 2016. Top executives from Saudi Arabia were present at the summit (UPI Space Daily, 2016).

E. SMRs and Turkey

Many nuclear projects since the 1970s have been proposed in Turkey, most of them regarding conventional nuclear plants. Some of the first initiatives of Turkey to enter the nuclear market were based on small reactors: a feasibility study on installing a 300 MW plant was proposed in 1970, and later in 1973 a demonstration plant with an electrical capacity of 80 MW was going to be built but the plans were stopped (Nuclear Power in

Turkey, 2015). The main focus of Turkey was then directed towards nuclear power plants with high generating capacity, but then in 2006 a 100 MW demonstration plant at Sinop on the Black Sea Coast was in the process of being built before actually hosting a nuclear plant at that location. It is worthy to note that Turkey has a very small 250 kW thermal research reactor at Istanbul Technical University that went into criticality in 1979 (Istanbul Technical University Research Reactor, 2011).

In 1990, Argentina and Turkey signed a formal agreement to develop the CAREM-25 SMR, but the Turkish Atomic Energy Agency seemed reluctant to continue with this project due to nuclear proliferation concerns and doubts over the reactor's capability in supplying electricity. The agreement was abandoned shortly after (Construction Start of Small Modular Reactor in Argentina, 2014).

A few papers assessing the feasibility of introducing small modular reactors in Turkey were published. In 2011, the U.S. Department of Commerce's International Trade Administration evaluated 27 countries based on several criteria. Turkey was ranked second best as a potential market for SMRs, scoring 15 over 18 and tying with Jordan (The Commercial Outlook for U.S. Small Modular Nuclear Reactors, 2011). A group of researchers published a paper in 2013 that also studied the likelihood of SMR deployment. The results show that Turkey is not interested in SMRs, but instead the focus of the country is on large reactors (Locatelli, Mancini, & Belloni, 2013). Another research paper used different methods to examine the suitability of SMR deployment. Turkey was ranked 43rd out of the 97 countries under study (Black, Taylor Black, Solan, & Shropshire, 2014). In a newspaper article issued on November 3, 2014, Haluk Utku, who is head of Institute of

Nuclear Science at Hacettepe University in Ankara said that Turkey should first build small reactors of 30 to 50 MW before thinking of building larger ones. He stated that the experience gained from these small reactors would lay the first stone for larger reactors if they were to be built at a later stage (Erkul & Ergodan, 2014).

Turkey hasn't shown much interest in SMRs until recently, on January 21, 2016, when it signed a cooperation agreement with Canada to investigate the possibilities of co-developing heavy water reactors, pressurized water reactors, and SMRs (Independent Turkey, 2016). It is yet to be known whether Turkey will show further interest in SMRs or not, all in due time.

F. SMRs and United Arab Emirates

The United Arab Emirates is a country with a fast increasing electricity demand. To meet its future energy needs, construction of four nuclear reactors began in 2012 and are expected to gradually begin operation between 2017 and 2020. So far, UAE hasn't shown any interest in SMRs, however, a few researchers were curious in studying the feasibility of installing SMRs in the UAE.

In 2011, 27 countries were evaluated by the U.S. Department of Commerce's International Trade Administration including the United Arab Emirates, which ranked fifth most potential market for SMRs, receiving the same score as India, Armenia, China, Morocco, and Estonia (The Commercial Outlook for U.S. Small Modular Nuclear Reactors, 2011).

In 2013, a paper on the suitability of deploying SMRs was published. The result for UAE showed that it is not interested in SMRs mainly due to the fact that the country is only interested in nuclear expansion through large reactors (Locatelli, Mancini, & Belloni, 2013). Another team of researchers used an alternative method to study SMR suitability in 97 different countries. UAE came seventh as a suitable country for SMR deployment (Black, Taylor Black, Solan, & Shropshire, 2014).

Also in 2013, a team of scientists at the Masdar Institute in Abu Dhabi designed a 100 MW small modular reactor and proposed to develop nuclear reactors locally instead of relying on international companies to build the reactors in the future (Yee, 2013).

CHAPTER VI

DEPLOYMENT CHALLENGES OF SMALL MODULAR REACTORS

A. Economic Competitiveness

Since the emergence of nuclear power, the levelized cost of electricity (LCOE) has been the single most important measure in evaluating the economic competitiveness of nuclear power plants. LCOE is roughly the cost of electricity to sell to end-user for the investor to break-even over the lifetime of the power plant and is generally expressed as dollars per megawatt-hour. The LCOE takes into account many factors such as capital costs, operating and maintenance costs, decommissioning costs, duration of construction of plant, lifetime of plant, the capacity factor, and the financing costs which makes it a comprehensive and accurate measure to assess the economic viability of a power plant (Ingersoll, 2016).

In order to check whether small modular reactors are economically competitive when compared to large nuclear power plants and other power sources, four scenarios were created by a team at Carnegie Mellon University. The first scenario presents a typical Gen III PWR with a generating capacity of 1000 MW. The second scenario presents 1 light water small modular reactor with a generating capacity of 45 MW. The third scenario presents 5 light water SMRs, each generating 45 MW, adding up to a total of 225 MW. The fourth scenario presents one light water SMR with a total capacity of 225 MW. In this study, 16 experts were asked to assess the LCOE of these four scenarios. The results of these experts are as follow: for scenario 1, the minimum estimated LCOE was 82 $/MWh whereas the maximum estimate was 99 $/MWh. The minimum and maximum LCOE estimates for the second scenario were 123 and 160 $/MWh respectively. The third scenario's results were 109 and 143 $/MWh for both the minimum and maximum estimates, and finally for scenario 4, the minimum LCOE estimate was 85 $/MWh and maximum was 106 $/MWh (Abdulla, 2014). As we notice from the results that the small modular reactor scenarios have a higher LCOE than the large reactor which make the large power plant more economically viable.

The next step will be to compare the levelized costs of electricity of different power sources to these four scenarios. A reliable source is the LCOE analysis conducted by the Energy Information Administration in its Annual Energy Outlook 2016. The previous scenarios will be compared to coal, natural gas, hydropower, and solar PV plants. For coal with carbon capture and storage (CCS), the minimum and maximum LCOE estimates were 129.9 and 162.3 $/MWh respectively. Conventional coal plants cannot be built without CCS technology that removes approximately 30% of the CO_2 emissions of the plant due to new regulations. For the natural gas-fired power plant with a conventional combined cycle, the minimum and maximum LCOE estimates are 53.4 and 67.4 $/MWh respectively. For the hydroelectric plant, the minimum LCOE estimate is 59.6 $/MWh whereas the maximum estimate is 78.1 $/MWh. Finally, for a solar PV plant, the minimum LCOE estimate is 65.6 $/MWh and the maximum estimate is 126.2 $/MWh (Energy Information Administration, 2016). Figure 8 summarizes the results.

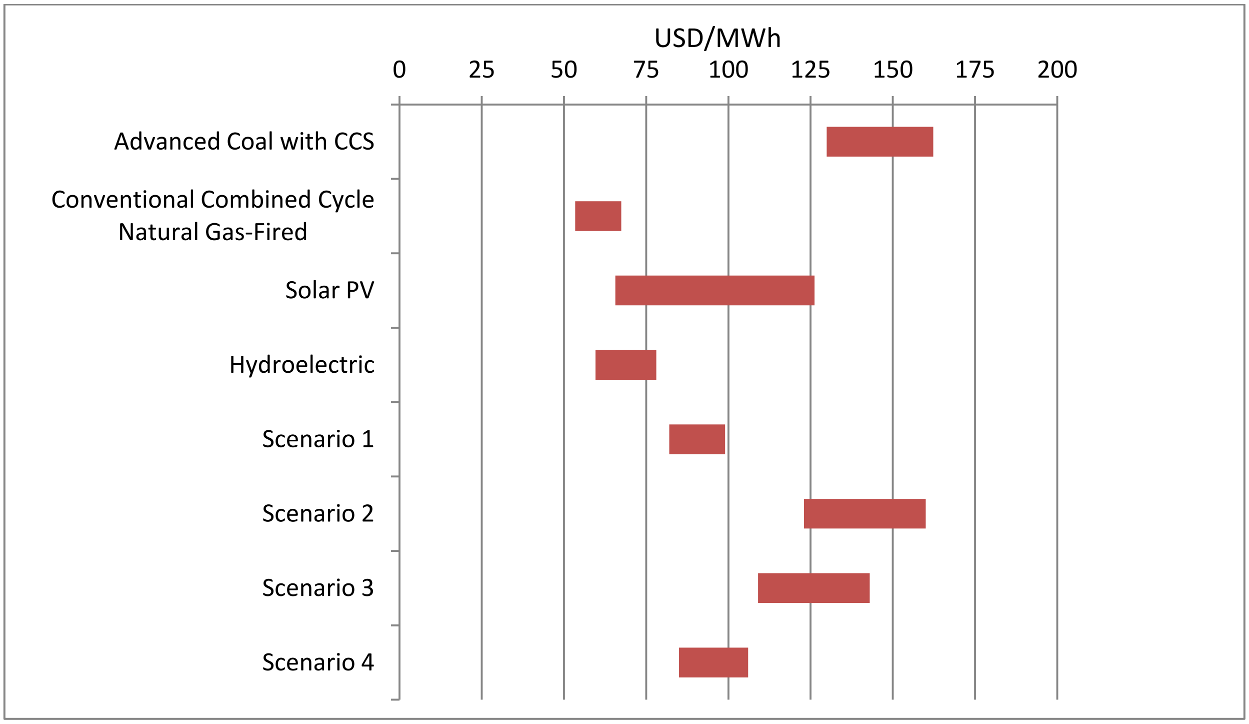

Figure 8: LCOE for SMRs and alternative sources

B. Proliferation

Countries with an established nuclear program might be tempted to produce weapon grade materials from either enrichment facilities or reprocessing of spent nuclear fuel.

If a country has the capability to produce highly enriched uranium, i.e. more than 20% U-235, then it can easily produce weapon grade uranium with enrichment of 90% U-

235 or more. Even countries that can produce low enriched uranium, i.e. up to 20% U-235, will have no difficulties in enriching uranium to a weapon grade material (Asculai, 2012)

Reprocessing spent nuclear fuel makes plutonium easier to access which is another way to produce nuclear weapons. Plutonium is created in the reactors during the irradiation process. Weapon grade plutonium can be obtained by reprocessing and separating it from the other spent fuel.

Countries that do not wish to produce nuclear weapons can buy low enriched uranium from other countries with such capabilities instead of building their own enrichment facility. Also, spent fuel could not be reprocessed, but instead disposed of properly (Glaser, Ramana, Ahmad, & Socolow, Small Modular Reactors: A Window on Nuclear Energy, 2015).

C. Safety

Stringent requirements are placed on the safety and reliability of small modular reactors due to the devastating nuclear accidents that happened over the years. SMRs are advertized to be safer than the reactor designs currently in the market, but some issues are still worrisome and need to be further studied.

Some of the small modular reactors designs use passive cooling systems that remove decay heat without needing any electrical power source. The larger surface-to-volume ratios of the SMRs makes it possible to passively cool the reactors by convection, not requiring an electricity source to operate the fans or pumps to circulate the coolant (Kessides I. N., 2012). This passive cooling system is not flawless and the SMR design must include backup sources to cool the reactor should this passive system fail.

SMRs are believed to be less dangerous than the larger reactors. This statement is misleading. SMRs require less fuel to operate since they generate less power thus making them less dangerous. Multiple SMRs placed in series are required to generate the same amount of electricity as the larger reactors which imposes a greater risk than one operating large reactor. If an accident occurred at one of the units, it would be very difficult to stop an accident from occurring at the other SMRs in series.

Typical nuclear reactors have an emergency planning zone with a radius of about 10 miles. SMR vendors have been pushing to reduce the size of the emergency planning zone. This will make it possible to install SMRs in more convenient locations and closer to populated zones (Glaser, Ramana, Ahmad, & Socolow, Small Modular Reactors: A Window on Nuclear Energy, 2015). If the Nuclear Regulatory Commission allowed this zone to be shrunk, the people living in proximity will be subjected to serious radioactive substances if any accident occurs in that plant.

D. Not Test Subjects

One of the main reasons some of the countries in this paper are not interested in small modular reactors is because the latter are a relatively young technology. There are currently no operating small modular reactors in any country which makes this technology unattractive. In a brief meeting at the American University of Beirut in January 2016 with Rakan Ayoub, the financial analyst at Jordan Atomic Energy Commission, he mentioned that although Jordan is an ideal case for small modular reactors to be deployed, JAEC does not want to invest in SMRs for the time being since it believes that new technology is prone to errors, and Jordan does not wish to be a test subject for this new technology. However, if SMRs proved to be reliable in the future, then JAEC would consider SMRs as a serious option.

E. Public Opinion

This section focuses on the six countries in the study whether they are with or against nuclear power. In a study in 2011, Egypt was one of the polled countries that does not yet have a running nuclear reactor. The results of the poll showed that support from Egyptian citizens to build nuclear plants in Egypt was high at 31%, while 36% of them were against the use of nuclear energy (Opposition to Nuclear Energy Grows: Global Poll, 2011). Around three decades ago, public support was very low that the government had to postpone its plans to build a nuclear plant (Aboul-Enein, et al., 2016).

Following the Egyptian revolution in 2011, and a new government replacing the old one, residents of the El Dabaa town have taken over the location where the first nuclear plant is set to be constructed. This problem was thought to have already been solved where the people of that town had an agreement with the government to get a compensation since the new nuclear plant was set to be built on their properties. Due to this, the government might have to look for a new site (Khlopkov), (El-Akkad, 2012).

In March 2015, an IAEA workshop that discussed the public awareness of nuclear power was held in Egypt. It was mentioned that there has been an increase in power cuts in Egypt especially during the months of summer mainly due to the continued increase in electricity demand. This problem made nuclear power more appealing to the public (Barfield, 2015).

Shifting to the public opinion in Iran, a survey conducted by the Iranian Students Polling Agency in 2006 showed that 85.4% of the population support nuclear power in the country. However, this percentage goes down to 64% if economic sanctions were to be effected and down to 55.6% if there was to be foreign military interference (Herzog, 2006). In 2010, another survey was conducted that showed that 87% of the population was pro the development of nuclear power (Elson & Nader, 2011). Then in 2012, a different poll showed that the number of people who supported nuclear power decreased to 57% (Esfendiary, 2012).

In a more recent survey conducted in 2015 by the University of Tehran following the Joint Comprehensive Plan of Action, the findings showed that 57% of the public support the negotiations to which Iran would gradually decrease its number of centrifuges, and would limit its Uranium enrichment to a maximum of 5% (Mohseni, Misreading Public Opinion on P5+1 Nuclear Negotiations with Iran, 2016). Only 15% opposed to this deal and 28% were unsure (Poll, 2015). However, the majority of the citizens of Iran support this plan of Action only if the United States of America would remove all of its previously held sanction on the country (Mohseni, Gallagher, & Ramsay, Iranian Public Opinion on the Nuclear Negotiations, 2015).

Jordan's public opinion varies significantly from that of Iran's. In a 2005 survey conducted by Globescan for the IAEA, Jordan greatly opposes nuclear power and 41% of the citizens prefer for all existing nuclear plants to shut down since they believe nuclear power to be dangerous. In addition, 64% of Jordanians are against nuclear power for use in meeting the growing demand of energy (Global Public Opinion on Nuclear Issues and the IAEA, 2005). A more recent survey by the International Republican Institute in December 2013 showed that 54% of Jordanians support the country's nuclear program, a substantial change from the results obtained in 2005. However, 67% of the people surveyed said they knew very little about nuclear power (Seeley, 2014). The most recent poll conducted in August 2016 by the Center for Strategic Studies proved that public opinion can vary considerably with time. Analysis from 2005 showed that the majority of the public were against nuclear power. A decade later, 77% Jordanian's are in favor of the nuclear program (Ghazal, Most Jordanians Support Nuclear Energy Programme - Poll, 2016).

In the case of Saudi Arabia, results from 2005's survey conducted by Globescan showed that Saudi Arabia shared the same opinion as Jordan where the majority preferred the shutdown of existing nuclear plants where 36% of the population think of nuclear power as dangerous (Global Public Opinion on Nuclear Issues and the IAEA, 2005). A 2011 poll showed that the public opinion hasn't changed since 2005 with 58% of the population in Saudi Arabia oppose to nuclear power (Kessides I. N., 2012).

Turkey, on the other hand, resulted in 41% of the population against the use of nuclear energy, according to a survey conducted in 2011 (Opposition to Nuclear Energy Grows: Global Poll, 2011). Also, around two-thirds of the population are against constructing nuclear reactors in Turkey (Benmayor, 2011).

Finally, the public opinion in the United Arab Emirates has continuously been in great favor of nuclear power. Polls conducted in 2011 showed that 85% of the population support peaceful use of nuclear energy in their country (UAE Poll Shows Continued Support for Peaceful Nuclear Energy Program, 2011). 72% believe that nuclear power will be essential for the growing energy need of the country (UAE Nuclear Program Gaining Popular Support, 2011).

CHAPTER VII

POLICY RECOMMENDATIONS AND CONCLUSION

All of the countries in the study are highly dependent on oil and natural gas as energy sources for their electricity production. For example, the United Arab Emirates and Saudi Arabia are 100% dependent on fossil fuels, followed closely by Jordan at 99.6% dependency. Both Iran and Egypt's dependency is 92.1% and 91.3% respectively. Finally, Turkey is 44.4% dependent on oil and natural gas and 26.6% dependent on coal. The aim of these countries should be to decrease their reliability on these energy sources, and instead focus on having a more diverse energy mix such as adding nuclear and solar to their portfolio of electricity producing sources.

Although small modular reactors are a relatively new concept in the nuclear world since they're not miniature versions of the larger nuclear reactors, they could be a strong candidate for electricity generation for these countries, this is why we conducted a study on the most suitable countries for the development of SMRs. We based this study on seven different characteristics that are the GDP, electricity grid size, CO_2 emissions, population density, economic growth, nuclear capacity, and Uranium resources. We then assigned a grading system with a maximum cumulative score of 22. The countries closest to the maximum score were Jordan and Saudi Arabia, both receiving 18 points out of 22. The United Arab Emirates came in third place with 17 points, followed by Egypt with 15 points, Iran with 14 points, and Turkey receiving a total score of 13 over 22. Nuclear power might be an appealing solution for some of these countries that are looking to meet the future energy needs without increasing CO_2 emissions. SMRs come in play when these countries looking for cleaner forms of energy also have electricity demands that are expected to increase incrementally, and possess smaller electricity grid sizes. Also, countries with a lower population density or where the population is dispersed in remote areas are better indications that SMRs may be appropriately deployed. In addition, developing countries with a lower GDP such as Jordan would be more suitable to install SMRs.

For the countries in this study that might be interested in deploying SMRs, the best option would be to install light water reactors since they are currently the dominating technology and some reactor designs are in their final stages and almost ready to be released in the market. The next best option would be to opt for Heavy Water Reactors. These types of reactors would be attractive for countries that want to stay away from enriched Uranium and use instead Uranium in its natural form.

After analyzing the best prospects markets for SMRs, extensive research was conducted on the 6 countries to show their past and current interest in small modular reactors. Egypt showed no interest in deploying SMRs. Iran on the other hand showed interest in SMRs mainly for desalination purposes when negotiations took place with China to construct an SMR in Iran. Iran also expressed that its new nuclear strategy involves designing and developing SMRs. Jordan put some serious thought into considering SMRs, but later opted for larger reactors when it signed an agreement with Russia to build a conventional nuclear power plant thus dismissing the option of SMR deployment for the time being. As for Saudi Arabia, it has been interested in diversifying its energy sources, including the introduction of nuclear energy for both electricity production and desalination. Saudi Arabia later signed agreements with Argentina and South Korea to install SMRs. For the case of Turkey, the country showed interest in SMRs when it signed an agreement with Argentina to develop an SMR, but quickly abandoning this agreement due to proliferation and reliability concerns. When it comes to the UAE, SMRs aren't currently an option and the country's focus is on large reactors.

Investigating some of the deployment challenges facing SMRs such as proliferation, safety, and public opinion, the most serious challenge would be the economic competitiveness of SMRs against other energy sources. The levelized cost of electricity of SMRs is higher than the LCOE of natural gas and hydroelectric deployment options, but appears to be competitive with solar PV. However, delving into the cost trend of solar PV over the years, we notice a strong downward trend in the cost, hence it can be argued that solar could not just be a more viable option than SMRs, but can even compete with natural gas in the near future (Cooper, 2014). Whether these countries will choose to have SMRs as part of their portfolio of future energy technologies, one thing is certain is that sooner or later these countries will have to build new power plants to settle the increasing need of electricity, and with the increasing greenhouse gas emissions, the best options would be renewables and nuclear. This is where small modular reactors could prove to be invaluable to the energy mix.

REFERENCES

Abdulla, A. Y. (2014). Exploring the Deployment Potential of Small Modular Reactors. *ProQuest Dissertations and Theses* , 214.

Aboul-Enein, S., Al-Khunaizi, T., Chekina, V., Erdurmaz, S., Khalil, A., Khlopkov, A., et al. (2016). *Prospects for Nuclear Power in the Middle East: Russia's Interests.* Moscow: Valdai Discussion Club.

Abushady, Y. (2015, December). Dr. (R. R. Fattouh, Interviewer)

Ahmad, A., & Ramana, M. V. (2014). Too Costly to Matter: Economics of Nuclear Power for Saudi Arabia. *Elsevier* , 682-694.

Aljohani, M. S. (2004). Nuclear Desalination Competitiveness in the Western Region of the Kingdom of Saudi Arabia. *Elsevier* , 213-223.

Al-Khalidi, S. (2015, March 24). *Jordan Signs $10 Billion Nuclear Power Plant Deal with Russia*. Retrieved from Reuters: http://www.reuters.com/article/us-jordan-nuclear-russia-idUSKBN0MK2QD20150324

AP. (1997, May 18). *Work on Egyptian Nuclear Reactor Ahead of Schedule*. Retrieved from LexisNexis: http://www.lexisnexis.com.ezproxy.aub.edu.lb/lnacui2api/results/docview/docview.do?docLinkInd=true&risb=21_T25621941414&format=GNBFI&sort=RELEVANCE&startDocNo=1&resultsUrlKey=29_T25621941419&cisb=22_T25621941418&treeMax=true&treeWidth=0&csi=11810&docNo=2

Asculai, E. (2012). Nuclear Power in the Middle East. *The Nonproliferation Review* , 391-400.

Barfield, K. (2015, March 03). *IAEA Workshop Discusses Egyptian Public Awareness in Nuclear Power*. Retrieved from International Atomic Energy Agency: https://www.iaea.org/NuclearPower/News/2015/2015-03-03-nenp.html

Benmayor, G. (2011, April 29). *Turkish Public Reluctant About Going Nuclear, Says Opinion Poll*. Retrieved from Hurriyet Daily News: http://www.hurriyetdailynews.com/turkish-public-reluctant-about-going-nuclear-says-opinion-poll.aspx?pageID=438&n=turkish-public-reluctant-about-going-nuclear-says-opinion-poll-2011-04-29

Black, G., Taylor Black, M. A., Solan, D., & Shropshire, D. (2014). Carbon Free Energy Development and the Role of Small Modular Reactors: A Review and Decision Framework for Deployment in Developing Countries. *Elsevier* , 83-94.

(1994). *Case Study on the Feasibility of Small and Medium Nuclear Power Plants in Egypt.* Austria: International Atomic Energy Agency.

China Business News. (2014, August 21). *Saudi Arabia to Cooperate with China on Nuclear*. Retrieved from ProQuest: http://search.proquest.com.ezproxy.aub.edu.lb/central/docview/1554974661/citation/1CBE2DF3336046AAPQ/1?accountid=8555

Construction Start of Small Modular Reactor in Argentina. (2014, February 12). Retrieved from World Nuclear Industry Status Report: http://www.worldnuclearreport.org/Construction-Start-of-Small.html

Cooper, M. (2014). Small Modular Reactors and the Future of Nuclear Power in the United States. *Elsevier* , 161-177.

Dunai, M. (2016, February 18). *Iran Proposes Nuclear Power Cooperation with Hungary*. Retrieved from Reuters: http://www.reuters.com/article/us-iran-nuclear-hungary-idUSKCN0VR2IN

Earp, J. E. (2013). Briefing: Small Modular Reactors. *Proceedings of the Institution of Civil Engineers , 166* (2), 53-57.

Egypt: Electricity and Heat for 2013. (n.d.). Retrieved from International Energy Agency: https://www.iea.org/statistics/statisticssearch/report/?country=EGYPT&product=electricityandheat&year=2013

Egypt: International energy data and analysis. (2015, June 2). Retrieved from U.S. Energy Information Administration: http://www.eia.gov/beta/international/analysis.cfm?iso=EGY

El-Akkad, D. (2012, December 20). *Challenges Outnumber Resources*. Retrieved from Bulletin of the Atomic Scientists: http://thebulletin.org/nuclear-journalism-developing-world/challenges-outnumber-resources

Elson, S. B., & Nader, A. (2011). *What Do Iranians Think? A survey of Attitudes on the United States, the Nuclear Program, and the Economy.* Santa Monica: National Defense Research Institute.

Emerging Nuclear Energy Countries. (2015, November). Retrieved from World Nuclear Association: http://www.world-nuclear.org/info/Country-Profiles/Others/Emerging-Nuclear-Energy-Countries/

Energy Information Administration. (2016). *Levelized Cost and Levelized Avoided Cost of New Generation Resources in the Annual Energy Outlook 2016.* U.S. Energy Information Administration.

Erkul, N., & Ergodan, H. (2014, November 03). *Nuclear Technology, Priority for Turkey's Third Plant*. Retrieved from LexisNexis: http://www.lexisnexis.com.ezproxy.aub.edu.lb/hottopics/lnacademic/?

Esfendiary, D. (2012, March 16). *Why Iranian Public Opinion is Turning Against the Nuclear Program*. Retrieved from The Atlantic: https://www.theatlantic.com/international/archive/2012/03/why-iranian-public-opinion-is-turning-against-the-nuclear-program/254627/

FARS News Agency. (2015, August 25). *Spokesman: Iran Negotiating with China on Construction of Small Reactors*. Retrieved from ProQuest: http://search.proquest.com.ezproxy.aub.edu.lb/central/docview/1707691144/5DA3CA0E25604DCDPQ/17?accountid=8555

GDP Growth. (2015). Retrieved from The World Bank: http://data.worldbank.org/indicator/NY.GDP.MKTP.KD.ZG

Ghazal, M. (2014, June 11). *Electricity Demand Expected to Triple by 2030 - Minister*. Retrieved from The Jordan Times: http://www.jordantimes.com/news/local/electricity-demand-expected-triple-2030-%E2%80%94-minister

Ghazal, M. (2016, August 31). *Most Jordanians Support Nuclear Energy Programme - Poll*. Retrieved from The Jordan Times: http://www.jordantimes.com/news/local/most-jordanians-support-nuclear-energy-programme-%E2%80%94-poll

Glaser, A., Ramana, M., Ahmad, A., & Socolow, R. (2015). Small Modular Reactors. *Andlinger Center for Energy + the Environment* .

Glaser, A., Ramana, M., Ahmad, A., & Socolow, R. (2015). Small Modular Reactors: A Window on Nuclear Energy. *Andlinger Center for Energy + the Environment* .

(2005). *Global Public Opinion on Nuclear Issues and the IAEA.* Globescan.

GlobalData. (2015, September 03). *KAERI and K.A.CARE Signed SMART PPE Agreement*. Retrieved from LexisNexis: http://www.lexisnexis.com.ezproxy.aub.edu.lb/lnacui2api/results/docview/docview.do?docLinkInd=true&risb=21_T25622716547&format=GNBFI&sort=RELEVANCE&startDocNo=1&resultsUrlKey=29_T25622716551&cisb=22_T25622716550&treeMax=true&treeWidth=0&csi=333601&docNo=3

Go-Ahead for Jordanian Research Reactor. (2013, August 20). Retrieved from World Nuclear News: http://www.world-nuclear-news.org/NN_Go_ahead_for_Jordanian_research_reactor_2008131.html

Grid: Powering Saudi Arabia. (n.d.). Retrieved from Saudi Power: http://www.saudi-power.com/en/Media/Press-Releases/SE-Press-Releases/GRID-Powering-Saudi-Arabia/

Gross Domestic Product 2014. (2015, September 18). Retrieved from World Bank: http://databank.worldbank.org/data/download/GDP.pdf

Han-na, P. (2015, March 06). *Daewoo E&C to Benefit from Saudi Reactor Deal*. Retrieved from LexisNexis: http://www.lexisnexis.com.ezproxy.aub.edu.lb/hottopics/lnacademic/?

(2002). *Heavy Water Reactors: Status and Projected Development.* Vienna: International Atomic Energy Agency.

Henry, R. (2015, February 13). *Southern Co.'s Vogtle Costs Could Top $8 Billion, State Analysis Says*. Retrieved from The Augusta Chronicle: http://chronicle.augusta.com/news/metro/2015-02-13/southern-cos-vogtle-costs-could-top-8-billion-state-analysis-says

Herzog, M. (2006). *Iranian Public Opinion on the Nuclear Program.* Washington, D.C.: The Washington Institute for Near East Policy.

Hibbs, M. (2007, September 27). *Jordan Reactor Siting Study to be Done in 2009, JAEC Says*. Retrieved from LexisNexis: http://www.lexisnexis.com.ezproxy.aub.edu.lb/hottopics/lnacademic/?shr=t&csi=8032&sr=HLEAD(%22Jordan%20reactor%20siting%20study%20to%20be%20done%20in%202009,%20JAEC%20says%22)%20and%20date%20is%202007

Independent Turkey. (2016, January 23). *Turkey and Canada Sign Nuclear Agreement*. Retrieved from Research Turkey: http://researchturkey.org/turkey-and-canada-sign-nuclear-agreement/

Ingersoll, D. T. (2016). *Small Modular Reactors: Nuclear Power Fad or Future?* Woodhead Publishing.

Iran Ready to Share Nuclear Experience. (2016, September 16). Retrieved from World Nuclear News: http://world-nuclear-news.org/NP-Iran-ready-to-share-nuclear-experience-1609167.html

Iran Says Finds Unexpectedly High Uranium Reserve. (2015, September 12). Retrieved from Reuters: http://www.reuters.com/article/us-iran-nuclear-uranium-idUSKCN0RC0A020150912

Iran, Islamic Republic of: Electricity and Heat for 2013. (n.d.). Retrieved from International Energy Agency: http://www.iea.org/statistics/statisticssearch/report/?country=IRAN&product=electricityandheat&year=2013

Istanbul Technical University Research Reactor. (2011, March 01). Retrieved from Nuclear Threat Initiative: http://www.nti.org/learn/facilities/494/

Jordan: Electricity and Heat for 2013. (n.d.). Retrieved from International Energy Agency: http://www.iea.org/statistics/statisticssearch/report/?country=JORDAN&product=electricityandheat&year=2013

Kessides, I. N. (2012). The Future of the Nuclear Industry Reconsidered: Risks, Uncertainties, and Continued Promise. *Elsevier* , 185-208.

Kessides, I. N., & Kuznetsov, V. (2012). Small Modular Reactors for Meeting the Electricity Needs in Developing Countries. *The World Bank* , 97.

Khaled, R. (2013, January 18). *Egypt Discovers Large Amounts of Uranium*. Retrieved from Egypt Independent: http://www.egyptindependent.com/news/egypt-discovers-large-amounts-uranium

Khlopkov, A. *Prospects for Nuclear Power in the Middle East After Fukushima and the Arab Spring.* Moscow: United Nations Institute for Disarmament Research.

Kim, D., & Tabatabai, A. (2016, May 31). *Should South Korea be Iran's Next Nuclear Energy Partner?* Retrieved from Bulletin of the Atomic Scientists: http://thebulletin.org/should-south-korea-be-irans-next-nuclear-energy-partner9495

Kutbi, I. I., & Al Sulaiman, K. M. (1994). Features of Nuclear Desalination Systems for Saudi Arabia. *Elsevier* , 327-337.

Liu, Z., & Fan, J. (2013). Technology Readiness Assessment of Small Modular Reactor Designs. *Elsevier* , 20-28.

Locatelli, G., Mancini, M., & Belloni, P. (2013). *Method to Select the Countries and Scenarios More Appropriate for the Development of SMR.* ASME.

Makhijani, A. (2013). *Light Water Designs of Small Modular Reactors: Facts and Analysis.* Institute for Energy and Environmental Research.

McAuley, A. (2015, October 31). *Jordan Closes in on Deal with Russia to Build Two Nuclear Reactors*. Retrieved from The National: http://www.thenational.ae/business/energy/jordan-closes-in-on-deal-with-russia-to-build-two-nuclear-reactors

Mehr News Agency. (2016, September 16). *Iran Focused on Small Reactors: Salehi*. Retrieved from LexisNexis: http://www.lexisnexis.com.ezproxy.aub.edu.lb/lnacui2api/results/docview/docview.do?docLinkInd=true&risb=21_T25621979480&format=GNBFI&sort=RELEVANCE&startDocNo=1&resultsUrlKey=29_T25621979484&cisb=22_T25621979483&treeMax=true&treeWidth=0&csi=363072&docNo=3

Min-Hee, J. (2015, September 03). *South Korea-Designed SMART Reactors to be Built in Saudi Arabia for First Time*. Retrieved from Business Korea: http://www.businesskorea.co.kr/english/news/industry/11917-smart-choice-south-korean-designed-smart-reactors-be-built-saudi-arabia-first

Mohseni, E. (2016). *Misreading Public Opinion on P5+1 Nuclear Negotiations with Iran*. Retrieved from Huffington Post: http://www.huffingtonpost.com/ebrahim-mohseni-phd/misreading-public-opinion_b_7730488.html

Mohseni, E., Gallagher, N., & Ramsay, C. (2015). *Iranian Public Opinion on the Nuclear Negotiations.* Center for International & Security Studies at Maryland.

(2013). *NEPCO Annual Report 2013.* Amman: National Electric Power Company.

Nuclear Plant Journal. (2014, Sep/ Oct). *SMR Update*. Retrieved from ProQuest: http://search.proquest.com.ezproxy.aub.edu.lb/central/docview/1681111628/7419045B2EA741E0PQ/5

Nuclear Power in Iran. (2015, October 20). Retrieved from World Nuclear Association: http://www.world-nuclear.org/info/Country-Profiles/Countries-G-N/Iran/

Nuclear Power in Jordan. (2015, October). Retrieved from World Nuclear Association: http://www.world-nuclear.org/info/Country-Profiles/Countries-G-N/Jordan/

Nuclear Power in Saudi Arabia. (2015, September 15). Retrieved from World Nuclear Association: http://www.world-nuclear.org/info/Country-Profiles/Countries-O-S/Saudi-Arabia/

Nuclear Power in the United Arab Emirates. (2015, September). Retrieved from World Nuclear Association: http://www.world-nuclear.org/info/Country-Profiles/Countries-T-Z/United-Arab-Emirates/

Nuclear Power in Turkey. (2015, October). Retrieved from World Nuclear Association: http://www.world-nuclear.org/info/Country-Profiles/Countries-T-Z/Turkey/

NW. (2007). *Kazatomprom Poised to Close Westinghouse Deal*. Retrieved from ScienceDirect.

Opposition to Nuclear Energy Grows: Global Poll. (2011, November 25). Retrieved from Globescan: http://www.globescan.com/news-and-analysis/press-releases/press-releases-2011/94-press-releases-2011/127-opposition-to-nuclear-energy-grows-global-poll.html

Poll, E. (2015, June 30). *New Poll Finds Strong Iranian Support for a Nuclear Deal*. Retrieved from National Iranian American Council: https://www.niacouncil.org/new-poll-finds-strong-iranian-support-for-a-nuclear-deal/

Population Density. (2015). Retrieved from The World Bank: http://data.worldbank.org/indicator/EN.POP.DNST

Progressive Digital Media. (2013, September 26). *Saudi Arabia's Nuclear Ambitions*. Retrieved from ProQuest:

http://search.proquest.com.ezproxy.aub.edu.lb/central/docview/1545869798/abstract/11908D18618F4ECDPQ/1?accountid=8555

(2014). *Report of the Small Modular Reactor Workshop: Practical Deployment Issues and Approaches.* Amman: International Framework for Nuclear Energy Cooperation.

Rowinski, M. K., White, T. J., & Zhao, Z. (2015). Small and Medium sized Reactors (SMR): A review of technology. *Elsevier* , 643-656.

Royal Recognition for Jordan's Nuclear Program. (2016, February 02). Retrieved from World Nuclear News: http://www.world-nuclear-news.org/NP-Royal-recognition-for-Jordan-nuclear-program-0202167.html

Saudi Arabia and Argentina Form R&D Joint Venture. (2015, March 09). Retrieved from World Nuclear News: http://world-nuclear-news.org/NP-Saudi-Arabia-and-Argentina-form-joint-venture-0903158.html

(2013). *Saudi Arabia Eying Nuclear Power Despite Substantial Oil and Gas Reserves.* GlobalData.

Saudi Arabia: Electricity and Heat for 2013. (n.d.). Retrieved from International Energy Agency: http://www.iea.org/statistics/statisticssearch/report/?country=SAUDIARABI&product=electricityandheat&year=2013

Seeley, N. (2014). *The Battle Over Nuclear Jordan*. Retrieved from Middle East Research and Information Project: http://www.merip.org/mer/mer271/battle-over-nuclear-jordan

(2002). *Small and Medium Sized Reactors: Status and Prospects.* Austria: International Atomic Energy Agency.

Small Modular Reactor Workshop - June 2014. (2014, June 11). Retrieved from The International Framework for Nuclear Energy Cooperation: http://ifnec.org/Meetings/Workshops/SMRWorkshop2014.aspx

Small Nuclear Power Reactors. (2015, November). Retrieved from World Nuclear Association: http://www.world-nuclear.org/info/Nuclear-Fuel-Cycle/Power-Reactors/Small-Nuclear-Power-Reactors/

SMR-160. (n.d.). Retrieved from Holtec International: https://holtecinternational.com/productsandservices/smr/smr-technology/

(2011). *Status of Small and Medium Sized Reactor Designs.* International Atomic Energy Agency.

Tehran Times. (2016, September 16). *Iran Luring Foreign Partners to Small Nuclear Reactors*. Retrieved from LexisNexis:

http://www.lexisnexis.com.ezproxy.aub.edu.lb/lnacui2api/results/docview/docview.do?docLinkInd=true&risb=21_T25622015756&format=GNBFI&sort=RELEVANCE&startDocNo=1&resultsUrlKey=29_T25622015760&cisb=22_T25622015759&treeMax=true&treeWidth=0&csi=407851&docNo=3

(2011). *The Commercial Outlook for U.S. Small Modular Nuclear Reactors.* Washington, D.C.: U.S. Department of Commerce International Trade Administration.

Today in Energy. (2014, September 24). Retrieved from U.S. Energy Information Administration: http://www.eia.gov/todayinenergy/detail.cfm?id=18111

Total Carbon Dioxide Emissions from the Consumption of Energy 2014. (2015). Retrieved from International Energy Statistics: https://www.eia.gov/cfapps/ipdbproject/IEDIndex3.cfm?tid=90&pid=44&aid=8

Turkey: Electricity and Heat for 2013. (n.d.). Retrieved from International Energy Agency: http://www.iea.org/statistics/statisticssearch/report/?country=TURKEY&product=electricityandheat&year=2013

Turkey: International Energy Data and Analysis. (2015, August 6). Retrieved from U.S. Energy Information Association: http://www.eia.gov/beta/international/analysis.cfm?iso=TUR

UAE Nuclear Program Gaining Popular Support. (2011, June 20). Retrieved from World Nuclear News: http://www.world-nuclear-news.org/NP-UAEnuclear_program_gaining_popular_support-2006117.html

UAE Poll Shows Continued Support for Peaceful Nuclear Energy Program. (2011, June 17). Retrieved from Emirates Nuclear Energy Corporation: https://www.enec.gov.ae/news-and-events/news/uae-poll-shows-continued-support-for-peaceful-nuclear-energy-program/

United Arab Emirates: Electricity and Heat for 2013. (n.d.). Retrieved from International Energy Agency: http://www.iea.org/statistics/statisticssearch/report/?country=UAE&product=electricityandheat&year=2013

United Arab Emirates: International Energy Data and Analysis. (2015, May 18). Retrieved from U.S. Energy Information Administration: http://www.eia.gov/beta/international/analysis.cfm?iso=ARE

UPI Space Daily. (2016, March 14). *Global Leaders in Nuclear Innovation Gather at SMR and Advanced Reactor Summit in Atlanta*. Retrieved from ProQuest: http://search.proquest.com.ezproxy.aub.edu.lb/pqcentral/docview/1772655116/7419045B2EA741E0PQ/18?accountid=8555

Uranium and Thorium. (n.d.). Retrieved from Republic of Turkey Ministry of Energy and Natural Resources: http://www.enerji.gov.tr/en-US/Pages/Uranium-and-Thorium

Vujic, J., Bergmann, R. M., Skoda, R., & Miletic, M. (2012). Small Modular Reactors: Simpler, Safer, Cheaper? *Elsevier* , 288-295.

Yee, A. (2013, September 29). *Abu Dhabi Looks at Bigger Role in Nuclear*. Retrieved from LexisNexis: http://www.lexisnexis.com.ezproxy.aub.edu.lb/lnacui2api/results/docview/docview.do?docLinkInd=true&risb=21_T25621867606&format=GNBFI&sort=null&startDocNo=1&resultsUrlKey=29_T25621867610&cisb=22_T25621867609&treeMax=true&treeWidth=0&csi=381176&docNo=1

Zverev, D. L., Pakhomov, A. N., Polunichev, V. I., Veshnyakov, K. B., & Kabin, S. V. (2013, April). RITM-200: New-generation reactor for a new nuclear icebreaker. *Atomic Energy* , 404-409.