AMERICAN UNIVERSITY OF ARMENIA

THE CLOSURE OF METSAMOR NUCLEAR POWER PLANT:

COSTS AND BENEFITS

A MASTER'S ESSAY SUBMITTED TO

THE FACULTY OF THE GRADUATE SCHOOL OF

POLITICAL SCIENCE AND INTERNATIONAL AFFAIRS

FOR PARTIAL FULFILLEMENT OF THE DEGREE OF MASTERS OF ARTS

BY

MANE ADAMYAN

YEREVAN, ARMENIA

MAY 2014

SIGNATURE PAGE

Faculty Advisor **Date**

Program Chair **Date**

American University of Armenia

May 2014

ACKNOWLEDGEMENT

I am very grateful to the American University of Armenia and, particularly, the School of Political Science and International Affairs, for the successful years of study in the field of Political Science and International Affairs, which gave me a lot of knowledge and skills of analytical and critical thinking as well as leadership qualities due to the high quality education and up-to-date teaching methodologies applied to

I would like to express my deep gratitude to my supervisor Dr. Aleksandr Grigoryan for the invaluable help, useful remarks and support. His guidance helped me during the whole process of my research. I am sure without his persistent help and supervision it would not be possible to write this master essay.

ABSTRACT

The Armenian Nuclear Power Plant (ANPP) is the only nuclear installation in Armenia as well as in the South Caucasus. It has become an inseparable part of the energy security of the country and the government tries to do its best in order to be able to make the operational life of the existing plant as long as possible until the construction of a new plant begins. However, both the European countries and neighboring states have expressed their concerns about its safety. Not only has the age of the plant become the reason for their worry, but also the fact that Metsamor NPP is the only plant in the world which restarted to operate after full shutdown.

The main purpose of this study is to analyze the two possible scenarios of either closing the ANPP or allowing it to operate as long as possible. Each of the alternatives has its own possible consequences and costs.

The main finding of this research is that a very low probability of raising financial resources for a new nuclear power plant is required in order to shift the choice from operating of Metsamor NPP to the construction of a new nuclear facility.

Table of contents

Abbreviations

RA	Republic of Armenia
NPP	Nuclear power plant
TPP	Thermal power plant
HPP	Hydro power plant
SHPP	Small hydro power plant
KW	kilo watt
MW	mega watt
Km	kilometer
GWh	giga watt hour

INTRODUCTION

In 1991-1995 Armenia experienced a deep energy crisis as a result of which the country tested the loss of its energy security with all consequences. It had an impact on social, economical and environmental areas of the state. These years displayed the vulnerability of Armenia towards its energy security.

As the main reason of the energy crisis was the interstate conflicts in the region as a result of which was the blockade of the transportation of energy, the re-commissioning of Metsamor nuclear power plant became the best solution to the problem of power supply for the Armenian population at that time. It allowed the state to maintain the proper level of energy security and independence. Moreover, the nuclear power plant has facilitated the decrease of Armenia's dependence on imported gas. But since the very first day of re-commissioning of the ANPP, both the European countries and neighboring states have expressed their concerns about its safety. Not only has the age of the plant become the reason for their worry, but also the fact that Metsamor NPP is the only plant in the world which restarted to operate after full shutdown.

Nevertheless, both the president and prime minister of Armenia claimed that the only option for shutting down the operating plant is building a new one. But as the construction of a new power plant has not even started and the development of renewable energy is in its initial stage, the life of the existing plant has been extended until 2026.

The aim of this thesis is to analyze the possible scenarios of either closing the ANPP or allowing it to operate as long as possible. Each of the alternatives has its own possible consequences and costs.

LITERATURE REVIEW

Energy security

Modern society has become more and more dependent on energy in almost all spheres of human activities. Different forms of energy are important, be it either in the industrial, residential or transportation sector. As a result, the increasing dependence on energy has heightened the importance of energy security. After the first oil shock in the 1970s energy security and security of supply have become the key tasks of most industrialized nations. Effective and strong public policies are necessary in this sphere as, being a public good energy security is not properly valued by the market; it is equally available to those who pay for it and to those who do not.

Usually energy security is defined as "reliable and adequate supply of energy at reasonable prices"[1]. Reliable and adequate supply refers to uninterrupted supply which completely meets the necessities of the global economy. The meaning of reasonable prices is a bit difficult to determine as it can change over time as well as energy producers and consumers may perceive it differently. However, prices are determined by the market which is based on supply and demand. In the case of price, security focuses on achieving a state which has less risk of being suffered from rapid and severe fluctuations of prices[2].

Besides, the energy security issues can entail both the short and the long –term. In the first case security refers to the risks of disruption to existing supplies because of technical problems, political failure or weather conditions. Unlike it, the long-term security covers the risks that new

---

[1] Janusz Bielecky, "Energy security: if the wolf at the door?" *The Quarterly Review of Economics and Finance 42 (2002).* http://www.liv.ac.uk/~jan/teaching/References/Bielecki%202002.pdf (accessed December 9, 2013).

[2] Gawdat Bahgat, "Europe's energy security: challenges and opportunities." *International Affairs 82 (2006).*

supplies may not respond to growing demand. It can happen because of economic, financial or political factors that hinder investments in transport and production capacity[3].

Serious financial, social and economic losses can be resulted from even brief interruptions of energy supply. The security of the energy supply, especially electricity, is crucial for cities and urban regions due to the widespread use of sensitive electronic equipments. For the protection the continuity and quality of supply most of the investment goes into reserve generating plants and redundant facilities. Loosing energy security could have a great impact on the state national security and foreign policy[4].

Enough level of investments in resource development, generation capacity and infrastructure are all necessary for the energy security. The availability of such investments is greatly linked to prices but, naturally, both private and foreign investments depend on a political stability of the country. Investments in redundant facilities can improve supply security. Usually in order to reserve generating capacity a third of the investments by electricity supply industry is necessary. Naturally, developing low-income countries are unable to make such investments which itself lead to supply insecurity. That is the reason why in majority low-income states electricity supplies are enhanced by standby plants on consumer premises[5].

Shortages of electricity and supply interruptions can bring a lot of damage particularly to developing countries. The reasons why shortages of electricity can occur are system inadequacy and supply insecurity. The first one refers to shortfalls of delivered electricity even in the case of the best conditions in the power system. These shortfalls are very common in developing

---

[3] Bielecky, "Energy security: if the wolf at the door?"
[4] Edward Morse & Amy Myers Jaffe, "Strategic Energy Policy Challenges for the 21st century". *Council on Foreign Relations 58 (2001).*
[5] Bahgat, "Europe's energy security: challenges and opportunities."

countries. The second reason is the unreliability of supply because of non-availability of plants and breakdowns in distribution system[6].

Energy security may be ensured by local sufficiency which means abundant forms of energy resources. If it is about local shortage, the state should be able to draw on foreign energy resources as well as through energy conservation and efficiency measures it can ensure energy security. For a state, adequate national strategies for confronting any interruption or shortages are necessary[7].

As it was shown, the absolute security of energy supply is very important. For promoting energy security and peace preservation, the establishment of international relations and economic cooperation is crucial.

Nuclear Power Plants

Since the mid-1950s the world has lived two major waves of grid connections. The first one occurred in 1974 when 26 reactors started to operate. The second wave refers to the years from 1984 to 1985 before Chernobyl accident reaching 33 grid connections every year. But in 1990, after Chernobyl accident of 1986 for the first time the number of reactor shutdowns outweighed the number of startups. After the Fukushima accident in 2011 public trust in nuclear power has decreased rapidly not only among the Japanese, but also people around the world who have started opposing the use of nuclear power[8]. A number of countries have turned away from nuclear power soon after the accident. Among such countries are Germany, Switzerland, Greece, Israel, Portugal, Venezuela and many others. The president of Venezuela, Hugo Chavez, in spite of signing a deal with Russia for two 1,200-megawatt reactors only five months before the

[6] Bielecky, "Energy security: if the wolf at the door?"
[7] Hisham Khatib, "Energy security". *World energy assessment (2002).*
[8] Mycle Schneider, Antony Froggatt and Steve Thomas, "Nuclear Power in a Post-Fukushima World 25 Years After the Chernobyl Accident." *Worldwatch Institute* (2011).

Fukushima accident, soon after it declared about the risks associated with nuclear power plants and about the changes of his plans. Even those countries which have large energy demands moved away from their "nuclear" plans. One of such countries was Brazil where soon after the accident in Japan the decision to construct four additional reactors was canceled with the argument of no need for them. However, there were a group of countries which even rushed to sign agreements with nuclear vendors or announced about their decision about construction within months after Fukushima accidents. Among these countries were China, India, Russia, Turkey, the United Kingdom and the United Arab Emirates. Some of them have already had some nuclear generating capacity, and some do not have any but have great interest. One of such interested countries is Turkey. As a justification for choosing nuclear power the fact of rapidly growing energy demands in the country has been brought. Determining to have nuclear power plants, Turkey wants to erect at least 23 nuclear units by 2023[9]. However, for the same argument of growing energy demand another choice has been done in Germany with its plan of expanding renewable energy production and constructing new coal- and gas-fired power plants. Thus, after the Fukushima crisis different countries has started to pursue different nuclear policies in a response to a common event.

Today only 30 countries in the world use nuclear energy, with the latest country of Lithuania to shut down its last reactor in 2009. Together these reactors supply about 14 percent of the world's electric generation while in 1993 nuclear power had its maximum share reaching 17 percent. Nowadays 13 countries are constructing their nuclear power plants which is twice less than in 2011.[10]

No nuclear plant, be it old or new, can survive any event more severe than the design basis accidents it was designed to resist. In case of experiencing an event beyond its design basis (what

[9] M.V. Ramana, "Nuclear power: economic, safety, health, and environmental issues of near-term technologies." *The annual review of environment and resources 34 (2009).*

[10] Mycle Schneider, Antony Froggatt and Steve Thomas, "Nuclear Power in a Post-Fukushima World 25 Years After the Chernobyl Accident." *Worldwatch Institute* (2011).

actually happened at the Fukushima Daiichi Nuclear Power Station) no plant can withstand. Each nuclear plant is vulnerable to some level to natural disasters such as floods, earthquakes, high winds or even terrorist attacks which means that there is always a possibility of an unexpected severe event to occur. However, it is hard to predict how vulnerable these power plants could be to natural disasters by not knowing the size of the safety margin. According to new information on seismic hazards, many plants may undergo much greater earthquake risks than they were designed to withstand[11]. Even though the engineering of safety features for nuclear power plants has improved, a possibility of an accident still exists. Thus, approximately 580 nuclear reactors in the whole world have been operating with at least 11 accidents with the result of a full or partial core melt. At this rate, if there were only one reactor in the world, the possibility of its major accident would be once every 1,300 years. In case of having 15,000 reactors, the world could have expected a major accident every month[12]. According to the calculations of Thomas Cochran, who is a physicist and consultant for the Natural Resources Defense Council, by crediting Fukushima with three partial core melts and Three Mile Island for the two, 1 percent of light-water reactors have had a partial core melt during the whole history of nuclear industry. Taking into an account the fact that safety trends in the nuclear power industry is measured in 'reactor years' (one reactor-year equals to the generated electricity by one nuclear reactor for one year), it means that one percent is much higher than one accident in every 10,000 reactor-years[13].

Considering the expense of such accident as the one at Fukushima, old reactors can be too risky financially to operate as the accident can lead to even bankruptcy. It has been found out that severe accidents can cost hundreds of billions of dollars. Even the Tokyo Electric Power

---

[11] Edwin Lyman, "Surviving the one-two nuclear punch: Assessing risk and policy in a post-Fukushima world." *Bulletin of the Atomic Scientists* 67 (2011), http://thebulletin.sagepub.com (accessed April 13, 2014).

[12] Derek Abbott, "Limits to growth: Can nuclear power supply the world's needs?." *Bulletin of the Atomic Scientists* (2012), http://thebulletin.sagepub.com (accessed April 13, 2014).

[13] Steve Featherstone, "Chernobyl now: Are nuclear disasters the new normal?"*Popular science 58 (2012).*

Company (TEPCO) which is the fourth largest in the world can hardly bear such a massive blow to its bottom live without aid[14].

Besides the great risk that the nuclear power plants carry, the investment cost for building a plant is another great barrier. Both the size and the complexities of nuclear reactors make the cost per megawatt much higher than for renewable alternatives. According to the World Bank calculations, if nuclear power were a large part of the energy mix “the high costs would require large increases in tariffs and could threaten the financial viability of the systems.” The main concern of a company which invests in new nuclear power plant is the ability to repay the costs associated with building the plant. Even though the operating costs are much smaller in comparison with the construction costs, but are still not insignificant. Moreover, the longer the construction takes the time, the higher the construction costs are. Those plants which are completed late can bring additional costs, including interest charges and market costs in case of buying the utility outside. The costs of decommissioning are not well known as there is little worldwide experience with full decommissioning of the power plants. Besides, building a new plant requires well-trained and experienced staff but taking into consideration its toxicity and longevity, human resource needs can be complicated[15].

Since the beginning of the nuclear century, the construction time of nuclear power plant has increased. But the reasons for these lengthening construction periods are not known. Growing system complexity can have one of possible impacts. During the period of 1992-2012 89 reactors started up with the average construction time of almost 9 years. After the Three Mile Island accident in 1979, construction time of a nuclear power plant in the United States has increased from six years to twelve[16].

---

[14] Mark Cooper, "Nuclear safety and affordable reactors: Can we have both?." *Bulletin of the Atomic Scientists* 68 (2012), http://thebulletin.sagepub.com (accessed April 13, 2014).

[15] Schneider, "Nuclear Power in a Post-Fukushima World 25 Years after the Chernobyl Accident."

[16] Mycle Schneider and Antony Froggatt, “2011-2012 world nuclear industry status report”. *Bulletin of the atomic scientists 68 (2012).*

Another problem is the finding of the exclusive zone for the plant. Each nuclear power plant needs an area approximately 20.5 square kilometers. It is necessary to build the plant near water sources unlike solar thermal plants or wind power plants which can be located in remote areas. The average age of operating nuclear power plants is about 26 years. Some plants can have reactor lifetime reach 40 and even 60 years[17].

Many financial institutions perceive nuclear power as a high risk investment, much higher than new renewable electricity-generating sources. After the Fukushima accident, the investment rate in the nuclear industry has decreased rapidly while at the same time global investment in clean energy has reached 260 billion USD in 2010, almost five times more than in 2004. However, not only the high risk, but also the construction time has made many investors prefer new renewable energy which can be built in a few months only. As a result, new renewable energy has greatly left behind nuclear energy during the recent years[18].

Nuclear power plants can also become a target for terrorists. For example, one of the plans for striking with airplanes on September 11 for al-Qaeda was American nuclear facilities[19].

However, one of the positive sides of nuclear power plants is the little need in fuel compared with those generating power through the use of fossil fuels. 40 million kilowatt-hours can be produced by only one ton of uranium which equals burning 16,000 tons of coal or 80,000 barrels of oil[20].

Nowadays the world possess 439 nuclear reactors with the nuclear capacity of 372 GW (gig watts). Some reactors have been shut down for an extended period, while more than 30 are under construction. All reactors including those under development, can be classified into water-cooled, gas-cooled, and fact reactors. The most widespread type is the light-water reactor (LWR)

[17] Abbott, "Limits to growth: Can nuclear power supply the world's needs?."
[18]Schneider and Froggatt, "2011-2012 world nuclear industry status report".
[19] Li Quan, Matthew Fuhrmann, Bryan Early and Arnold Vedlitz. "Preferences, Knowledge, and Citizen Probability Assessments of the Terrorism Risk of Nuclear Power." *The Policy Studies Organization*29 (2012)

[20] Dorothy Davis, "The Necessary Good that is Nuclear Power."*Nuclear ENergy* (2012): 7-9.

which is a water-cooled reactor moderated by water. LWR includes two categories: pressurized water reactors (PWR) and boiling water reactors (BWR)[21].

Nuclear power plants are designed according to the concept of defense in depth for preventing severe accidents. The defense-in-depth strategy refers to multiple layers of protection which is targeted at reducing risks to workers and the public. If accidents cannot be prevented, this strategy helps to mitigate their consequences[22]. However, it is obvious that the strategy is unable to eliminate the possibility of accidents and that in some cases accidents can be caused by human error. The Three Mile Island accident in 1979 helped to remove the weakness in defense in depth. The accident occurred a few years later in Chernobyl demonstrated the need for a safety culture which was insufficient in the Soviet nuclear power program. Even when nuclear power plants are designed according to the defense-in-depth principles they can suffer from greater forces than they were designed to withstand like it was the case with Fukushima[23].

Nuclear power plants can have both radiological and non-radiological impacts which could result from accidents or routine operations. The health of not only workers but also the public can be impacted from nuclear power-related operations. Even though all countries with nuclear facilities possess regulations governing the extent of radiation from these facilities, several epidemiological studies demonstrates increased risk of various diseases, mostly cancer among people living near power plants. Moreover, researches carried out in Canada, Germany, the United Kingdom, France, Spain and Japan covering 136 nuclear facilities, shows that the rate of leukemia among children who live near nuclear sites is very high[24]. A research in Germany

---

[21]Ramana, "Nuclear power: economic, safety, health, and environmental issues of near-term technologies"

[22] International atomic energy agency, "Defense in depth in nuclear safety," (1996) http://www-pub.iaea.org/MTCD/publications/PDF/Pub1013e_web.pdf (accessed January 9, 2013).

[23] Duyeon Kim and Jungmin Kang, "Where nuclear safety and security meet," *Bulletin of the atomic scientists, 68,* (2012): 86-93

[24] Ramana, "Nuclear power: economic, safety, health, and environmental issues of near-term technologies."

identifies an increased risk for childhood cancer less than five years among those children who live near nuclear power plants in Germany. In most cases it was leukemia[25].

Coming to the conclusion, it can be stated, that in spite of the risks associated with the use of nuclear energy, still many countries continue to use and some even construct nuclear power plants as a response to the growing energy demands. But one point is obvious too: the nuclear renaissance has come to its end after the Fukushima disaster leaving its role to new, alternative types of energy.

---

[25] Sven Schmiedel and Peter Kaatsch, "Case-control study on childhood cancer in the vicinity of nuclear power plants in Germany 1980-2003," *European Journal on Cancer 44* (2008) http://www.ejcancer.com/article/S0959-8049(07)00855-6/abstract (accessed January 5, 2014).

METHODOLOGY

This thesis is divided into two chapters. The first chapter gives a broad picture of the current energy system of Armenia, referring to all obstacles and risk factors on energy security of the state. Even though Armenia possesses a great potential of renewable energy, only a miserable part of it has been developed so far. The main factors blockading the further development and a real potential of the renewable energy will be discussed.

The paper's main focus will be directed on the scenarios which refer to the decision of either to close the operating nuclear power plant or allow it to operate. This will be discussed in the second chapter of the paper. Besides, the last part which refers to the discussion will give an analysis of both positive and negative sides of all scenarios, mostly referring to the issue of the closure of the Metsamor NPP.

The main goal of the thesis is to answer the following questions:

- What are the possible energy sectors which can serve as a replacement for Metsamor NPP?
- Does the replacement of Metsamor NPP by a new NPP feasible in the near future?
- Will the closure of the ANPP lead to the energy crisis?

The thesis has only one hypothesis which states that the closure of Metsamor NPP will foster the development of alternative energy sectors.

CHAPTER I

Background information

In 1991-1995 Armenia experienced a deep energy crisis as a result of which the country tested the loss of its energy security with all consequences. It affected social, economical and environmental areas of the state. This crisis had a great impact on the Armenian's psychology and preserving Armenia from another energy crisis has become a priority for the leaders of the country. These years displayed the vulnerability of Armenia towards its energy security. That is the reason why the development of energy sector and issues related to it are one the most important in the state policy nowadays[26].

After gaining independence post-soviet Armenia like many other former Soviet republics faced a lot of serious challenges. During the Soviet Union Armenia's electricity was not autonomous; it was part of Trans-Caucasus electrical grid. Armenia was greatly depended on imported fuel from neighboring countries. However, the start of the war over Nagorno Karabakh and as a result of it the economic blockade by Turkey and Azerbaijan deprived Armenia from its only source of gas and oil for its thermal plants. A few years prior to it, because of the massive earthquake, the only Armenian Nuclear Power Plant was closed for preserving safety in the region. The ANPP was a source of almost one-third of the country's generating capacity. In 1993 a new gas pipeline was built through neighboring Georgia; however gas supply was regularly interrupted. The only energy source was hydropower resources, mostly Lake Sevan. That is why between 1992 and 1996 Armenians were suffering the country's brutal winters with two hours of electricity per day[27].

---

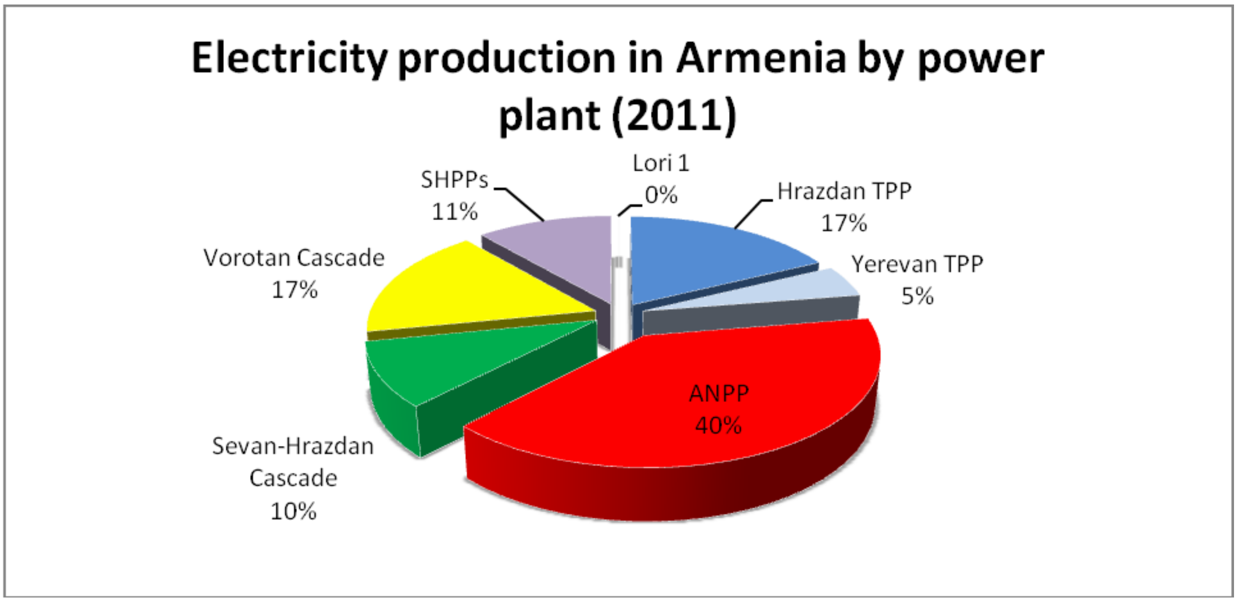
[26] International Center for Human Development, "Directions of Effective Integration of the Energy Systems of the South Caucasus Countries." (2004).

[27] Ani Balabanyan, Arthur Kochnakyan, Gevorg Sargsyan, Denzel Hankinson, and Lauren Pierce, "Charged decisions: Difficult choices in Armenia's energy sector." *The World Bank, (2011).*

After the energy crisis in the 1990s the energy sector of the state has acquired a stability which is the feature of the developed countries rather than emerging markets. These results have been achieved due to a great amount of institutional, regulatory and legal reforms. However, the country has still some serious challenges and new challenges are appearing because of the country's old Soviet-era infrastructure which has almost reached its useful life. As it was found out during the evaluation of main power plants 38 % of the installed production capacity is used more than forty years, the use of thermal power plants has exceed the limit of 200 thousand hours while their technical and environmental indicators do not meet international requirements. The same situation is with hydroelectric power plants (Sevan-Hrazdan cascade, Vorotan HPP system), where 70% of the installed equipments are used more than forty years, and 50% even more than fifty[28].

Today the three main types of power generation in Armenia are thermal, nuclear and hydro. Nuclear power is mostly for covering the baseload consumption, while thermal power is for seasonal peaks, primarily during the autumn and winter, and hydro power covers daily load variation, reducing its capacity during winter months[29]. The total installed capacity of all plants is 3,147 MW. But because of the poor operating conditions this installed capacity does not reflect the availability of the plants.

[28] "Հայաստանի Հանրապետության նախագահի կ ա ր գ ա դ ր ու թ յ ու ն ը Հայաստանի հանրապետության էներգետիկ անվտանգության ապահովման հայեցակարգը հաստատելու մասին," (2013). http://www.minenergy.am/en/en/2013-12-18-11-49-40 (accessed December 13, 2013).
[29] Balabanyan, et al., "Charged decisions: Difficult choices in Armenia's energy sector."



The necessity of new generating capacity relies on assumption about the growth of electricity demand during the next 5-6 years. Approximately 300-400 MW of new generating capacity will be needed to Armenia by 2017; it is only under modest demand growth assumptions. But in case of higher GDP growth, like between 2003 and 2008, minimum 800-1000 MW of new operable capacity will be required, even if the operating nuclear power plant continues to operate[30].

Thermal power

There are two thermal power plants in Armenia-Hrazdan TPP and Yerevan TPP which together have 1,756 MW of installed capacity. They are mainly used to produce electricity during winter and to substitute the nuclear power plant when it is shut down for maintenance.

As it was mentioned above, both TPPs have been operating more than 40 years. In the nearest future Units 1-4 at Hrazdan Thermal Power Plant (800 MW operable capacity) and Units 1-2 at Yerevan Thermal Power Plant (50 MW operable capacity) will be discontinued because of their age and inefficiency. On December 2 2013 the exploitation of the 5th block of Hrazdan TPP with the installed capacity of 480 MW has started. The technology used for the block is the

[30] Balabanyan, et al., "Charged decisions: Difficult choices in Armenia's energy sector."

combination of steam and gas turbines making the structure unique not only in the region but also in the whole world. By using 278 grams of conventional fuel it is possible to produce 1 kW/h of electricity, thus reducing the cost of produced electricity. However, the electricity produced on the plant will be delivered to Iran as a payment for imported gas from Iran to Armenia[31]. A new combined-cycle gas turbine with the installed capacity of 240 MW at Yerevan thermal power plan was commissioned in 2010. But again most of the electricity produced will be supplied to Iran as an exchange for the imported gas[32].

Metsamor Nuclear Power Plant

The Armenian Nuclear Power Plant (ANPP) is the only nuclear installation in Armenia as well as in the South Caucasus. Built in the 1960s and 70s ANPP consists of two WWER-440 type units which is based on the first generation of V-230 reactor with the design life of 30 years[33]. Being the example of the earliest pressurized-water nuclear plant design, it is one of the remaining nuclear reactors that were built without primary containment structures. Classified by the EU as the "oldest and least reliable", the light water-cooled reactors VVER-440 Model V230 having "a limited functional capability of the emergency core cooling cannot cope with large primary circuit breaks"[34]. Although this type of reactors is similar to Western PWRs, it lacks a number of safety features, including the protection systems, emergency core cooling systems and strong containment structure[35].

---

[31] The 5th block of Hrazdan TPP has started to be exploited. http://www.7or.am/ru/news/view/60201/ (accessed March 28,2014).
[32] Balabanyan, et al., "Charged decisions: Difficult choices in Armenia's energy sector."
[33] Gera Sevikyan, "Armenian NPP experience in assuring of vital equipment's integrity," *IAEA* (2004).
[34] "Soviet-designed nuclear power plants in Russia, Ukraine, Lithuania, Armenia, the Czech Republic, The Slovak Republic, Hungary and Bulgaria", *Nuclear energy institute (1997).*

[35] International Atomic Energy Agency, "Final report of the program on the safety of WWER and RMBK nuclear power plants" (1999).http://www-ns.iaea.org/downloads/ni/wwer-rbmk/wwer_15.pdf (accessed March 15, 2014).

The NPP is situated approximately 28 kilometers away from Yerevan, capital of Armenia, and only 16 kilometers away from the Turkish border. After the earthquake in 1988 on December 7, in spite of the absence of any real damage, Metsamor NPP was closed.

The decision of the RA Government to restart the Armenian NPP Unit 2 in 1993 was based on the necessity to overcome the energy crisis. The decision was made in spite of the concern of many European countries about the safety of the plant as it is the only plant on the world which was restarted after the full conservation. In two years the Unit 2, after staying without monitoring for a few years, was restored. Before being restored, the Unit had gone through several hundred safety upgrades. In 1996 it was already producing 46 per cent of energy output of the country. The opening of Unit 1 didn't occur as it is a first generation WWER which requires a lot of safety upgrades[36].

Originally the seismic design for the Metsamor Nuclear Power Plant was based on studies which were carried out in 1966 and 1972. According to these studies the maximum earthquake intensity for this area could reach I=7 by the MSK-63 scale. After some recommendations, the seismic input was increased redefining the site seismicity as 8 balls[37]. However, the equipment and pipelines seismic resistance at Metsamor NPP was checked-up in 1988 shortly before the earthquake. The maximum possible earthquake was equal 8 degrees. But it was found out 14 equipments and 4 pipelines were not seismically resistant[38].

With the adoption of the declaration in 2004 on safety policy and quality, the Armenian NPP management has periodically performed self-assessments of the safety culture. Thus, in 2007 the final seismic test was performed during which 1193 items were seismically qualified according to the accepted methodology. 44 components were found out to be easily eliminated while 29

[36] Tamara Robinson, "Nonproliferation approaches in the Caucasus."*The nonproliferation review (1998).*

[37] Armenian nuclear Regulatory authority, "National report on the Republic of Armenia: convention on nuclear safety," (2010).

[38] S. Kaznovsky and I. Ostrestov, "Development of requirements for seismic upgrading of equipment of existing VVER-440 and VVER-1000type NPP's," *IAEA,* (2008).

equipments need significant modifications and strengthening[39]. Besides, during the past years a lot of safety upgrades were implemented at the Armenian NPP involving all aspects of the plant safe operation. The results of these improvements were estimated by an international team of nuclear installation safety experts under the guidance of the International Atomic Energy Agency (IAEA) in 2011. As it was found out, in spite of a lot of important safety system updates, still the plant maintenance work practices should be enhanced in order to meet the necessary quality and ensure the safe functioning of equipment[40]. In order to meet these required quality every year additional investments of about two million USD is necessary for ensuring the safety on the plant. And in case of the extension of the operation of the plant until 2018, the government will have to spend more than 300 million USD, the calculations of which are based on international practice[41].

Russia is the supplier of the whole fuel which incurred $40 million of foreign debt. As a result, since 2003 the nuclear plant has been operated by a subsidiary of RAO UES and Rosenergoatom as part of an arrangement for helping pay off the debts[42].

The neighboring countries Turkey and Azerbaijan continuously express their demands to close the plant. Especially, the neighboring Turkish province to Armenia Iğdır, often complaining of the possible danger, even collected 2500 signatures from the residents during a campaign launched by the mayor of the province[43]. The same negative position has Azerbaijan, which for many times has referred to international organizations. However, not only their requests to

---

[39] Armenian nuclear Regulatory authority, "National report on the Republic of Armenia: convention on nuclear safety," (2010).

[40] International Atomic Energy Agency, "IAEA leads operational safety mission to Armenian nuclear power plant" *IAEA,* August 2011, http://www.iaea.org/newscenter/pressreleases/2011/prn201108.html (accessed January 7 2014).

[41] "Հայաստանի Հանրապետության նախագահի կ ա ր գ ա դ ր ու թ յ ու ն ը Հայաստանի հանրապետության էներգետիկ անվտանգության ապահովման հայեցակարգը հաստատելու մասին," (2013)

[42] World Nuclear Association, "Nuclear power in Armenia," last modified November 2013, http://www.world-nuclear.org/info/Country-Profiles/Countries-A-F/Armenia/ (accessed January 4, 2014).

[43] Igdir mayor urges Metsamor closure. http://www.neurope.eu/article/igdir-mayor-urges-metsamor-closure (accessed April 14, 2014).

permit their specialists for examining the nuclear plant were declined, but also the reports from Agency review missions have been restricted and unavailable to the neighboring states.

The decision of the National Assembly of Armenia in 2009 to build a new nuclear power plant with the installed capacity of 1000 MW has created a new wave of complains. The new power plant's design life will be 60 years and it will be based on Russian constructed VVER-1000 reactor design. Taking into consideration the fact that the price on constructing the nuclear power plants is gradually increasing, the initial price of 5 billion USD for building a new plant in Armenia may change.

The customer and owner of new reactors and the generated electricity will be Metzamorenergoatom while Atomstroyexport will be the principal contractor. Armenia for enabling investors' return on capital will buy all electricity produced at commercial rates during the 20 years. In 2012 Russia agreed to finance 50 percent of the construction even though later in 2013 it was reported that the share would be 35 percent. The rest will be funded by Metzamorenergoatom. It is necessary to mention that Metzamorenergoatom is a 50-50 Russian-Armenian joint stock, the establishment of which was approved by the government in 2009[44].

Thus, as it has become evident nuclear energy is an inseparable part of the energy security of the country and the government tries to do its best in order to be able to make the operational life of the existing plant longer unless the construction of a new plant begins as early as possible. As President of Armenia Serj Sargsyan mentioned, "Armenia reiterates her intention to develop nuclear energy which has a special place in the country's energy development program. Only nuclear power can allow us to maintain the proper level of the country's energy security and independence."[45]

[44] Nuclear power in Armenia. http://www.world-nuclear.org/info/country-profiles/countries-a-f/armenia/ (accessed February 18, 2014)
[45] Ibid

Renewable source of energy in Armenia

Developing the renewable energy acquires great importance in the case when the country like Armenia is not only in the political and economic blockade but also does not have its own energy resources. Even though in 2004 the Armenian government adopted the law on energy efficiency and renewable energy which was targeting at "strengthening the economic and energy independence as well as creation of new industries and organization of services to promote development of the energy efficiency and renewable energy"[46] not all possible potential of the country has been used. The development of renewable energy sources can be crucial to the security and quality of the country's electricity supply taking into consideration its great potential. The possession of a rich potential of renewable energy can also increase a country's independence from external supplies of primary fuels and enhance diversity of energy supplies.

The potential of the renewable energy in Armenia can be classified in the following way:

- wind power
- hydro power
- solar energy
- geothermal energy
- biomass energy

I. Wind Power

The development of wind energy of the Republic of Armenia is still on its initial stage. In spite of having a great potential in wind energy, most programs related to the construction of wind power plants has not accomplished yet. The assessment of wind energy potential in the country is based on information of meteorological stations and results got from implemented monitoring.

[46] Էներգախնայողության և վերականգնվող էներգետիկայի մասին Հայաստանի Հանրապետությոն օրենք. http://www.minenergy.am/en/en/laws (accessed February 25, 2014).

According to these results, theoretical wind energy potential is assessed at 11,000 MW, of which approximately 5,000 are areas with good to excellent wind energy potential. However, only a few sites with about 450 MW are economically feasible[47].

The first and the only wind power in Armenia and in the whole region with total capacity of 2,6 MW was installed at Pushkin Pass in 2005. It was funded by the Islamic Republic of Iran with the total project cost of 3.2 million USD. A few more sites have been identified as economically justified with total possible capacity of about 180 MW[48]. But as Armenia is located on remote mountainous passes with limited and hard access site transportation and installation costs of wind turbines will be higher than average. Moreover, cold climate at most of the sites where the temperature reaches minus 20 degree Celsius, can lead to the necessity of the installation of heated equipment which will be extra costs[49].

The development of wind energy mostly depends on investments and considering the fact that wind energy is capital intensive, it is natural that large wind farm projects will be financed with foreign capital. The assessment in 2006-2007 by several local developers and international vendors showed that the cost of installation of 1 MW will be in the range of € 1.3-1.6 million. For reaching 100 MW until 2020 approximately 100-130 million USD will be required[50]. But at current lower wind tariffs it is less likely to develop this sector which with the foreign capital will be depended on foreign investors' expectations for their return on capital.

---

[47] Ministry of Energy and Natural Resources of RA, "Wind energy". http://www.minenergy.am/en/en/investment-projects/wind-energy/124-2010-09-29-21-19-24 (accessed March 1, 2014).

[48] The United States Agency for International Development, "Wind energy in Armenia: overview of potential and development perspectives", *PA Consulting Group (2010).*

[49] EU TACIS program "Assistance to Energy Policy of Armenia", "34 MW Semenovka wind power project Gegharkunik marz of the Republic of Armenia", (2007).

[50] Ibid

II. Hydro power

Hydropower has always constituted a large part of Armenia's electrical energy resources. Development of hydropower potential envisages the construction and operation of small and medium hydropower plants, and recently this process has gained a momentum. It is mainly due to the existing favorable conditions in Armenia for the construction of small hydropower projects (SHPP), particularly preferential tariffs for electricity produced by SHPP and 15-year-old warranty on it purchase[51].

There are two large cascades (Sevan-Hrazdan HPPs Cascade and Vorotan HPPs Cascade) that provide peaking energy from over 1,000 MW of installed capacity. There are also small hydropower projects in the country. These projects are defined as those below 10 MW and even smaller than 5 MW. Some of these projects have remained since the Soviet years, and many have been constructed since the Armenian independence.

During the previous decade there has been a great interest towards Small Hydropower Power Projects (SHPP) in Armenia as a domestic and renewable energy supply for the country's system. By the end of 2013, there were 136 operating projects with more than 221 MW of installed capacity and with average annual energy of more than 665 GWh. They supply approximately 10 % of annual electrical energy and have great potential to produce even more. In addition to the existed projects, there are also licensed but still not operating projects. Some of them are still not constructed or waiting changes in tariff[52].

Based on the R2E2 study estimation, potential of the additionally installed capacity which can be possible by 2020 is 216.5 MW, that is 114,5 MW additional capacity with over 264 million GWh

---

[51] Vahe Odabshyan, and Susanna Khachatryan, "Renewable energy in the Republic of Armenia", 2*1st century 2, (2007).*

[52] The United States Agency for International Development, "Small hydro power (SHPP) sector framework, status, development barriers and future development", *PA Consulting Group (2010).*

per annum[53]. Moreover, the construction of the Lori-Berd HPP and the Shnogh HPP can bring extra 141 MW of installed capacity.

Thus, if those SHPPs which are still under the construction will operate, adding more than 200 MW of installed capacity, it means that they will be able to produce the half of energy produced by the Armenian NPP constituting approximately 12 % of the whole energy consumed in the state. The development of hydro power in Armenia is one of the most perspective choices as it is promoted by a well-developed infrastructure with experience as well as knowledge in that sphere. Besides, the development of the hydro power is not connected with the imported fuel, either nuclear or carbohydrate what is another but very important advantage.

III.Solar energy

Sun is the most widely used source of pure and endless energy. During the recent years the companies involved in the development of solar energy have become very profitable competing with companies working with traditional energy both by economic profitability and by the aspect of security. Solar energy is used for deriving thermal energy as well as electricity through photoelectric converters[54]. The amount of solar power reaching the surface of planet is 5,000 times more than the current global power consumption, or approximately 80 pet watts.
The climate conditions of Armenia are favorable for the development of solar energy. The average annual amount of solar energy flow per square meter of horizontal surface is approximately 1720 kWh with 2500 sunny hours per year while the average of solar energy in Europe is 1000 kWh[55].

[53] Armenia renewable resources and energy efficiency fund, "Potential by technology/ Hydro", http://r2e2.am/en/2011/06/hydro/ (accessed April 14, 2014).
[54] Odabshyan,"Renewable energy in the Republic of Armenia"
[55] Artashes Sargsyan, "Renewable energy use in the world and in Armenia: innovations towards clean technologies", *Lusabac (2009).*

The main barrier for using solar power is economic: the consequence of the current state of economy is the absence of investments. The current cost of solar photovoltaic plant per 1 kW is about 2520 USD. It still remains one of the reasons that except some small projects, there is almost no large project with solar energy.

However, due to the technology improvements and economies of scale, costs are decreasing. Taking into an account the reduction in cost every 10 years due to the development of technology, it is possible to represent the growth of consumption of solar energy in the following way: up to 2015-25MW,2020-65 MW, 2025-100 MW[56].

The utilizing the solar PV technology will allow the contribution an overall energy mix reaching to 3 % in the nearest 10 years. In case of building a 100 MW- solar power photoelectrical station in Armenia it will be possible to get annually 270 million kW/h, at the same time reducing the annual carbon emissions[57]. Moreover, the development of solar energy will eventually follow by the creation of new jobs which is a necessity in the current high unemployment rate of the country.

IV. Geothermal energy

Armenia is considered one of the most perspective regions in terms of development of the geothermal energy. As a result of explorations and investigation of the geothermal sources, it has been found out that Armenia has 75 MW of potential. It mostly refers to the Syuniq volcanic plateau, particularly near Jermaghbyur[58]. The estimated cost of for the 25 MW installed capacity

[56] The United States Agency for International Development, The United States Agency for International Development," National Program on Energy saving and renewable energy of Republic of Armenia", *(2007).*
[57] Ibid
[58] Ministry of Energy and Natural Resources of RA, "Geothermal energy", http://www.minenergy.am/en/en/investment-projects/eothermal-energy/126-2010-09-29-21-43-35, (accessed March 28, 2014).

Jermaghbyur GPP would be approximately USD 39 million[59]. Even though the capacity is not so much great, geothermal energy has a few advantages over other types of renewable energy. Unlike wind or solar power, the thermal energy is constant. Moreover, its costs are not very high. In more than 30 countries geothermal resources provide used heat capacity of 12,000 MW[60].

V. Biomass energy

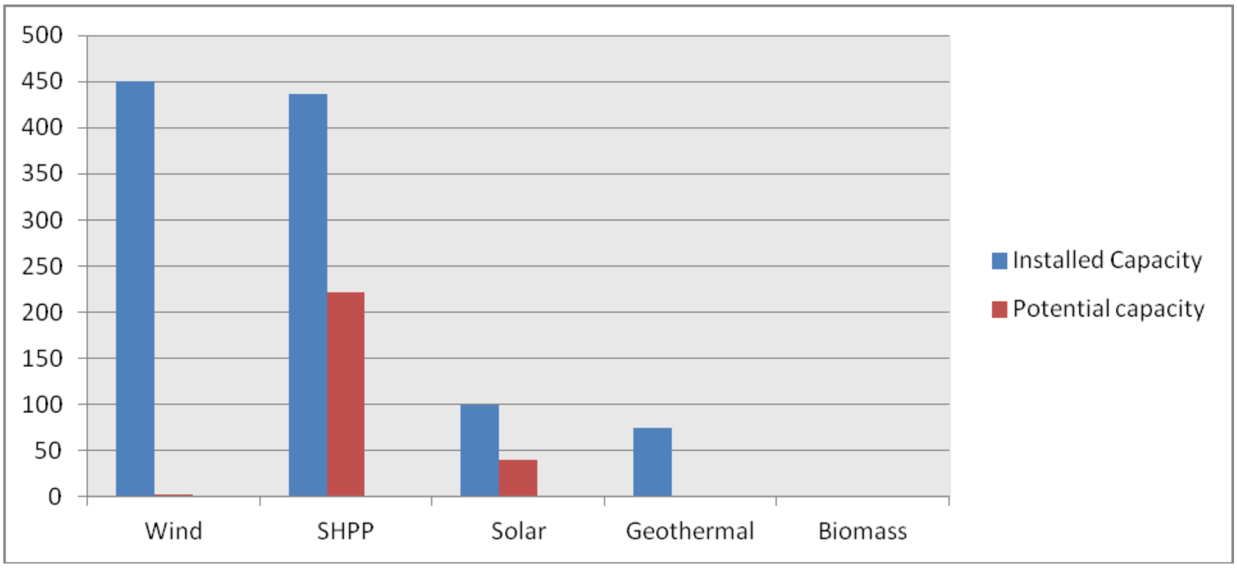
In Armenia the process of obtaining energy from biogas is still on its initial stage even though during the last few years it has become more active. Some foreign companies are interested in these technologies as the interest in biogas is due to the relatively short payback period-7-8 years. Stocks of manure derived from farms breeding pigs and cattle and poultry farms have great potential in getting biogas.

According to the study by USAID 2007, the potential of biogas in Armenia in 2006-2007 was estimated in the following way: by investing 34,17 million USD it is possible to get 38,34 million m3 of biogas annually which will reduce the greenhouse gas emissions equivalent to 544,6 thousand tones of CO2 per year[61]. The only gas collection wells are installed at the Nubarashen landfill which is for collecting natural gas released from solid waste breakdown. It is also necessary to pay attention at biomass and the fuel derived from it. Biomass refers to mass which is obtained from specially grown corps or residue after the harvest which is later processed for getting fuel. The example of it can be ethanol and biodiesel derived from biomass which in some countries is used as a fuel additive for internal combustion engine[62]. However, it

---

[59] Armenia renewable resources and energy efficiency fund, "Potential by technology/ Geothermal", http://r2e2.am/en/2011/06/geothermal/ (accessed March 27, 2014).
[60] Ministry of Energy and Natural Resources of RA, "Geothermal energy", http://www.minenergy.am/en/en/investment-projects/eothermal-energy/126-2010-09-29-21-43-35
[61] The United States Agency for International Development, The United States Agency for International Development," National Program on Energy saving and renewable energy of Republic of Armenia".
[62] Odabshyan,"Renewable energy in the Republic of Armenia"

is not widely used as a power in Armenia. Annual potential of the country for receiving biogas is approximately 135 million m3[63].



Although the development of the renewable energy has become one of the main targets of many countries, Armenia, having a great potential in almost all kind of renewable energy, has not used the whole possibilities yet. Nowadays the renewable energy plays a very small role in the energy supply of the country. In spite of the interest of the state and many international investors, the results cannot be called inspiring. Moreover, most projects related to wind, geothermal and biomass energy is still on paper. Only the construction of SHPPs has gained a great progress during the recent years. But as is shown on the table above, more than 200 MW is possible to develop.

[63] Ministry of Energy and Natural Resources, "Biomass energy", http://www.minenergy.am/en/en/investment-projects/biomass-energy/127-2010-09-29-22-53-34, (accessed March 26, 2014).

CHAPTER II

Possible scenarios

In the discussions about the nuclear energy of the Republic of Armenia the issue of the Armenian Nuclear Power Plant has gained a great attention not only inside the country but also in the whole world. In spite of the numerous demands of the neighboring countries as well as the European Union to close the plant, it still continues to operate and will probably operate during the upcoming 10 years. Various studies on Armenian energy system have offered their own possible solutions for meeting the growing electricity consumption in the country. However, an important question of whether to allow the Metsamor Nuclear Power Plant operate as long as it is possible with all safety upgrades or to find alternative solutions along with the decommissioning of the plant is still unanswered. In order to show all possible variants with their own costs and positive and negative sides the following scenarios will be discussed:

1. **In case of closing the Metsamor NPP:** building a new nuclear power plant with the installed capacity 1000 MW at the site of the Metsamor plant.
2. **In case of closing the Metsamor NPP:** developing the renewable energy and building a new Thermal Power Plant with the installed capacity of 480, similar to the 5^{th} block of Hrazdan TPP.
3. **In case of the operation of Metsamor NPP:** Armenian Nuclear Power Plant successfully continues to operate as long as possible along with the development of the renewable energy
4. **In case of the operation of Metsamor NPP:** considering the fact that it is impossible to give 100 percent of guarantee for the successful operation, there can be a possibility of an accident

1. Building a New Nuclear Power Plant

In October 2009 the National Assembly of the Republic of Armenia has adopted a law about building a new nuclear power plant in Armenia. According to the law, the new nuclear power plant will be based on the Russian designed VVER-1000 whose design life reaches 60 years. Based on the initial calculations the total cost of the construction of the plant equals 5 billion USD. Even though the international experience has shown, the initial calculations rarely coincide with the real expenses and since 2002 there has been significant escalation in worldwide materials costs[64], this study takes the initial price for the new NPP.

2. Alternative to the nuclear energy

As it has been already shown, Armenia is very rich in the renewable energy. But in spite of having a great potential, only a miserable portion of it has been developed and used. Thus, the renewable energy can be a good substitute to the nuclear power plant.

First of all, in spite of constructing many small hydro power plants, there is still a possibility to build additional 70 SHPPs with the total installed capacity 158 MW. The required investment for this is approximately 200 million USD. With the construction of Lori-Berd and Shnogh hydro power plants Armenia can get additional 141MW by investing about 225 million USD. It means that only by its hydro energy Armenia has the opportunity to gain more than 290 MW with annual generation of 10,389 million kW/h.

Although the studies have showed that a few sites with about 450 MW of wind power is economically feasible, considering the high cost of the technology and all difficulties with the transportation of the turbines as well as the lack of investors, this study considers the

64 Balabanyan, et al., "Charged decisions: Difficult choices in Armenia's energy sector."

development only 100 MW of wind power. The total required investments for this are about 130 million USD.

For getting 100 MW/y of solar energy investors have to spend more than 270 million USD but taking into consideration the technological progress and the decrease in costs, the price will be probably much less. However, all the required costs will be calculated by their maximum price. And finally, geothermal energy which is almost undeveloped in Armenia can bring an additional 25 MW in case of building Jermaghbyur GPP which will require 39 million USD.

But along with the development of the renewable energy, a new Thermal Power Plant will be considered as an alternative. The TPP will have the total installed capacity of 480 MW, similar to the recently exploited 5th block of Hrazdan TPP. The cost for this new TPP will be also similar to that of the 5th block-approximately 300 million USD.

Thus, by investing less than 1,2 billion USD Armenia can have more than 1000 MW of installed capacity which is already similar to that of the planned new nuclear power plant.

3. ANPP continues to operate

The third scenario covers the possibility of a successful operation of the Armenian Nuclear Power Plant until the government finds solutions to meet the growing electricity demand. In order to make the plant continue operating as safely as possible the government will have to invest up to 300 million USD for implementing all kind of safety upgrades[65]. Based on the results of the experts under the guidance of the International Atomic Energy Agency (IAEA) during the previous years some important safety systems have already been updated. It is

---

65 “Հայաստանի Հանրապետության նախագահի կ ա ր գ ա դ ր ու թ յ ու ն ը Հայաստանի հանրապետության էներգետիկ անվտանգության ապահովման հայեցակարգը հաստատելու մասին,” (2013). http://www.minenergy.am/en/en/2013-12-18-11-49-40 (accessed December 13, 2013).

supposed that the plant will be successfully operating until being decommissioned. Besides, it is supposed that the government will also develop the renewable energy potential for which total cost will be approximately 850 million USD.

4. Possibility of an accident

No nuclear plant can withstand an event more severe than the design basis accidents it was designed to resist. Based on new information on seismic hazards, many plants may undergo much greater earthquake risks than they were designed to withstand.[66]Armenian nuclear power plant is not the exception. In order to find the probability of an accident it is necessary to refer to the probabilistic safety analysis for Metsamor NPP. The optimistic approach to the probabilistic safety analysis shows 1/3.46 E-0.5= 28900 years, while the conservative approach is decreased by 54% which equals 1/5.42 E-0.5=18800 years[67]. So ANPP fills the requirement as according to the European and International Atomic Energy Agency any nuclear power plant must fulfill the 1 E-0.5= 10000 years. The probability of an accident for ANPP is 1 accident per 28900 reactor years which equals 0.0000346.

For calculating approximate costs in case of any accident, the total costs for Ukraine during the Chernobyl accident have been used in the study. The choice of using the Chernobyl case and not Fukushima has been made based on some similarities between the designs of reactors. During the Chernobyl accident the total costs were calculated as 235 billion USD[68]. But here it is necessary to take into consideration that the reactor in Chernobyl NPP is RBMK-1000 which

---

[66] Edwin Lyman, "Surviving the one-two nuclear punch: Assessing risk and policy in a post-Fukushima world." *Bulletin of the Atomic Scientists* 67 (2011), http://thebulletin.sagepub.com (accessed April 13, 2014).
[67] Poghosyan, Sh. and Malkhasyan, A. "Component selection for ageing PSA of Armenian NPP Unit 2." *American nuclear society, (2008).*

[68] Belarus Foreign Ministry, "Chernobyl disaster, Why are the consequences still observed? Why is the international assistance still critical?" http://chernobyl.undp.org/russian/docs/belarus_23_anniversary.pdf (accessed April 15, 2014).

produces 1000 MW, while in case of ANPP it is V270 with 400 MW produced, that is 40 percent of material existed in core of the Chernobyl plant. Thus, 40 percent of the total costs from the accident in Chernobyl plant will be taken as an assumption which equals 94 billion USD.

Decision tree

The Government of Armenia stands in front of an important decision: to close the ANPP or to allow the plant to work as long as possible. Each choice has its own outcomes with payoffs and probabilities. The task of the government is to choose the decision alternative with the lowest expected value.

For finding payoff for allowing the ANPP to operate, first of all we should find the probabilities for 'failure' and 'success' after which we multiply each by its own cost.

$P\ (F/O) = 0.0000346$

$P\ (S/O) = 1 - P\ (F/O) = 1 - 0.0000346 = 0.9999654$

$C\ (O) = P\ (S/O) \cdot C\ (S/O) + P\ (F/O) \cdot C\ (F/O) = (0.9999654 \cdot 1.1) + (0.0000346 \cdot 94) \approx 1.1$

So, 1.1 is the estimated value for choosing the strategy of 'operate'. The lowest possible estimated value of 'closure' in case of choosing the strategy 'operate' is 1.3. By knowing this, the probabilities for 'new NPP' and 'alternative' can be calculated:

$C\ (C) = P\ (A/C) \cdot C\ (A/C) + P\ (N/C) \cdot C\ (N/C)$

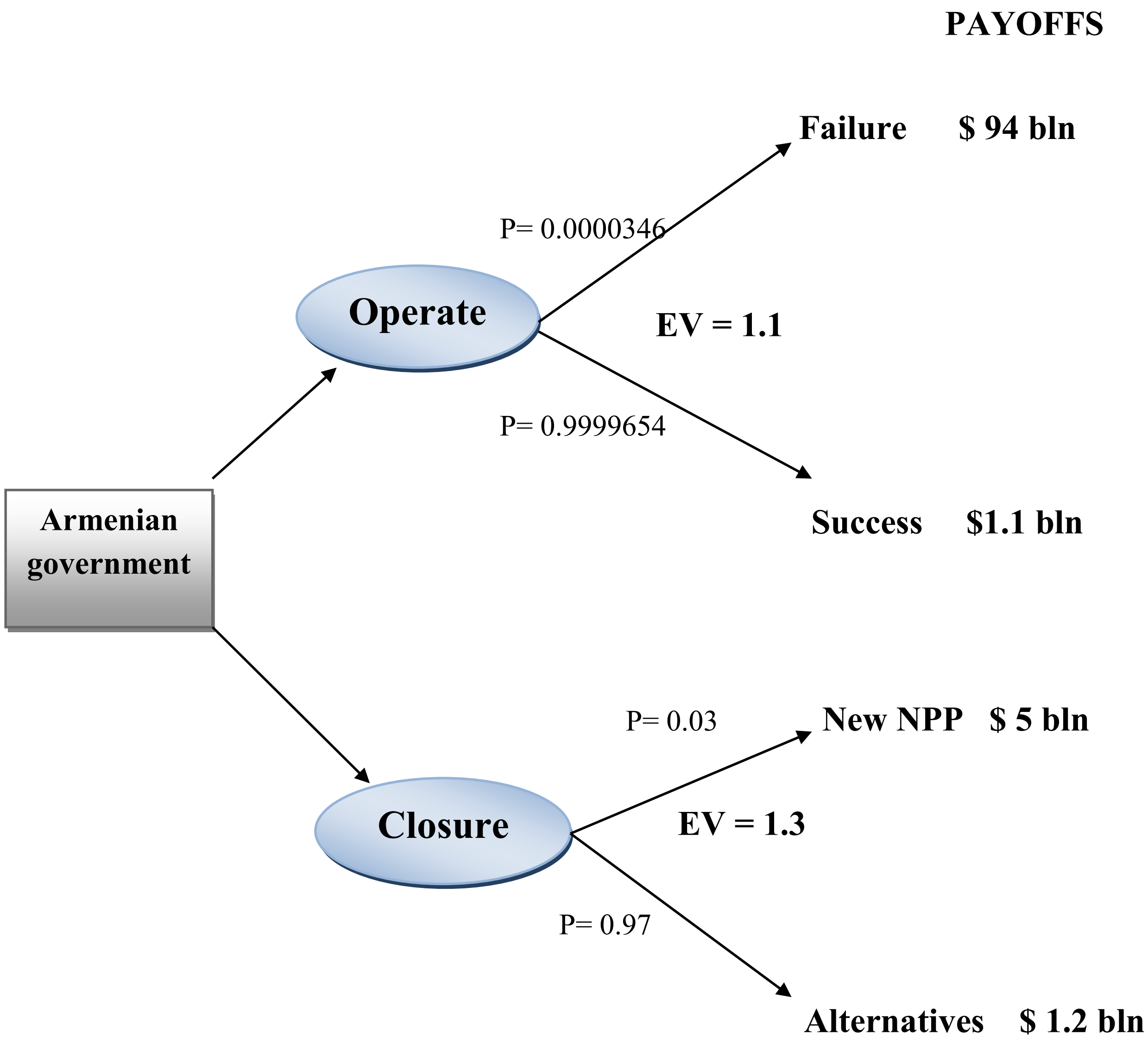
$1.3 = P\ (A/C) \cdot 1.2 + (1 - P\ (A/C)) \cdot 5$

$1.3 = 1.2\ P + 5 - 5\ P$

$-3.7 = -3.8\ P$

$P\ (A/C) = 0.97$

P (N/C) = 1 – P (A/C) = 0.03



Thus, given the probability of the successful operating of ANPP, the lowest probability for constructing new nuclear power plant is 0.03.

Now, let's change the probability of the new NPP and see how the P (S/O) will respond to these changes. By taking a few probabilities of new NPP, the following changes in P (S/O) will take place:

C (C) = (0.975 · 1.2) + (0.025 · 5) = 1.17 + 0.125 = 1.295

Using proportions P (S/O) will be changed into 0.9996.

C (C) = (0.98 · 1.2) + (0.02 · 5) = 1.176 + 0.1 = 0.98 ⟹ P(S/O) = 0.98

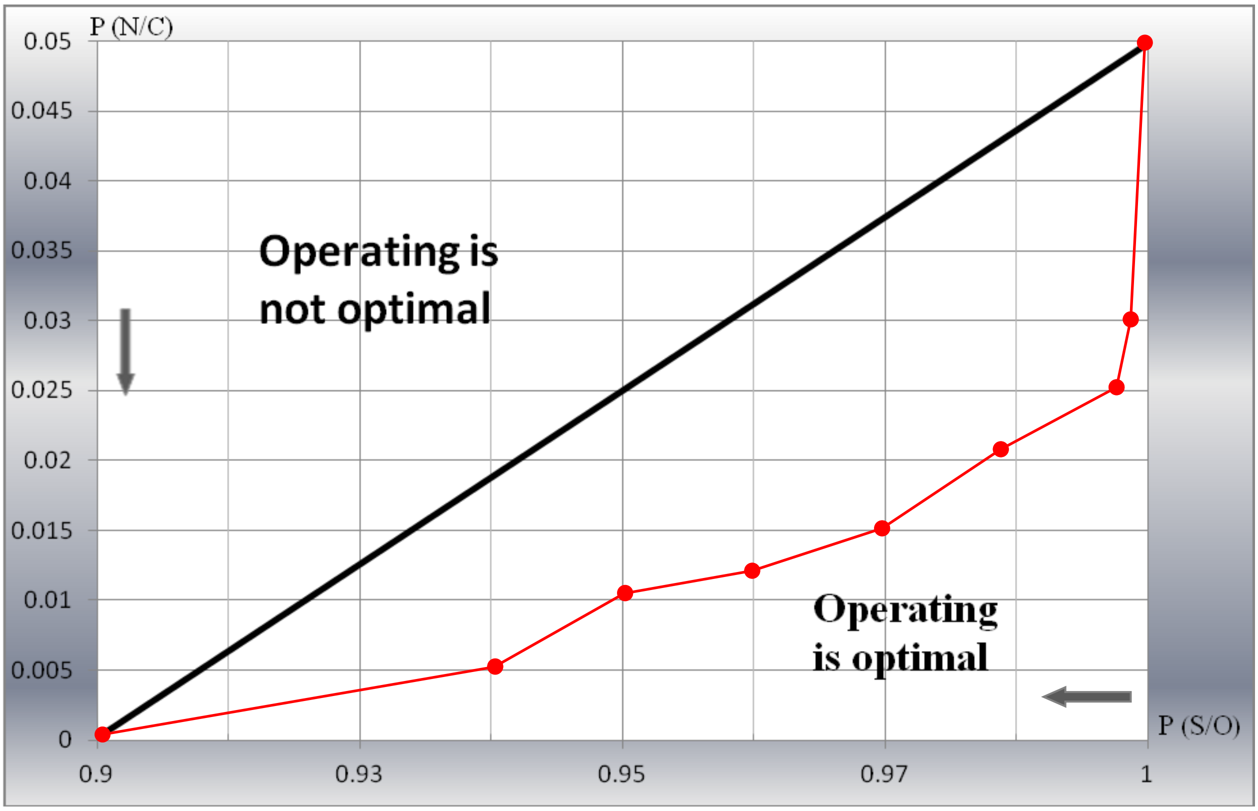
C (C) = (0.985 · 1.2) + (0.015 · 5) = 1.182 + 0.075 = 1.257 ⟹ P(S/O) = 0.97

C (C) = (0.987 · 1.2) + (0.013 · 5) = 1.1844 + 0.065 = 1.2494 ⟹ P(S/O) = 0.96

C (C) = (0.99 · 1.2) + (0.01 · 5) = 1.188 + 0.05 = 1.238 ⟹ P(S/O) = 0.95

C (C) = (0.995 · 1.2) + (0.005 · 5) = 1.194 + 0.025 = 1.219 ⟹ P(S/O) = 0.94

Here we get the graph where horizontal axis represents P(S/O) while the vertical one P (N/C). By connecting the points got from the above calculation, we draw the following curve painted in red.



The section below the red curve represents the area where to continue the operation of the Metsamor NPP is optimal, while the area above shows the non-optimality of the operation. However, an interesting point in this graph is the required extremely low probability of raising financial resources for a new NPP in case of which the choice can be shifted from the operating Metsamor NPP to a new nuclear facility. It is decreasing even more in case of changing the probability of ‘failure’ from 0.0000346 to 0.003. In that case P(S/O) will be equal to 0.997while the estimated value of “Operate” will increase rapidly:

$$EV (O) = (0.997 \cdot 1.1) + (0.003 \cdot 94) = 1.3787$$

But at the same time this slight change in P (F/O) will lead to a downfall in P (N/C). The estimated value for ‘Closure” will decrease as well:

$$EV (C) = (0.025 \cdot 5) + (0.975 \cdot 1.2) = 1.295$$

As it has been already stated, the lowest estimated value can be the best choice for the government to make. In the case of the initial probability for an accident in ANPP, it was evident that to choose the strategy “Operate” is the most preferable. However, a slight change in the probabilistic safety analysis for Metsamor leads to a totally another choice. By this little change in the probability of failure the estimated value for ’operate’ has increased so much that nothing is left but to choose the other option.

DISCUSSION

The high level of energy security can be considered as one of the main factors of sustainable development of Armenia. Like state security, energy security is a live process which evolves under the influence of different factors. One of the main factors in Armenian case is geopolitical. The interstate conflicts in the region were the main reason of energy crisis in Armenia as the consequences of them was the blockade of the transportation of energy. Even though these conflicts are frozen, the possibility of their re-emergence cannot be excluded. That is why for such a landlocked country as Armenia the developing of energy sources which do not require transportation can be considered a necessity.

One of the solutions for finding transport-free energy source was the re-commissioning of Metsamor nuclear power plant. It not only solved the problem of power supply for the population in the early 1990s, but has also allowed the state to maintain the proper level of energy security and independence. By ensuring a long-term supply of energy in the large quantities the nuclear power plant has contributed to the decrease of the country's dependence from imported gas. However, starting from the very first day of re-commissioning of the plant, many European countries as well as the neighboring countries have expressed concerns about its safety. The reason for their worry is not only the age of the plant; but Metsamor NPP is the only plant in the world which restarted to operate after full shutdown[69]. In spite of the high risk associated with not only the old ANPP but also nuclear power in general, the Armenian government is not going to shut it down until an alternative is found. On the one hand the growing electricity demand inside the country would not be able to be met in case of losing the existing 400 MW power plant which supplies 40 percent of the population; so the choice of the

[69] Nuclear Power in Armenia. http://www.world-nuclear.org/info/country-profiles/countries-a-f/armenia/ (accessed April 18, 2014).

government can be justified. But on the other hand, even if the ANPP continues to operate as long as possible, new energy producing facilities will be required in any case.

However, one should never forget about the risks of nuclear accidents. It is actually the main issue against using nuclear power in Armenia. In spite of having a relatively low probability of an accident (one accident per 28900 reactor years), it is really impossible to state that the country is 100 percent safe with the operating ANPP. Moreover, being situated in the very high seismic zone Armenia is very vulnerable to earthquakes. Even though Dr. Richard Wilson claims that the ANPP can also become attractive for a terrorist or a saboteur from an unfriendly neighboring country and that unlike western plants Metsamor does not have a containment vessel becoming more vulnerable to attacks[70], such scenario seems to be a bit unlikely nowadays. Besides, according to the study and trajectory analysis carried out in Istanbul Technical University, in case of an accident in Metsamor NPP, already in 5 days the radioactive cloud would reach Izmir, western part of Turkey[71]. So the probability of an attack from a neighbor country is very low, while the probability of a direct hit by a falling aircraft can be as high as the probability of any other accident taking into consideration the fact that the reactor is near an airport. Nevertheless, these are all possibilities, the occurrence of which may or may not happen.

This means that the development of alternative source of energy should become a priority for Armenia. As it has been mentioned above, the energy system of Armenia provides opportunity to diversify energy producing plants introducing wind, solar and geothermal power. Almost all of them are still on their initial stage of development in spite of the great potential they have. The small and medium hydro plants and wind farms can cover a significant amount of electricity which is required for households and industry. To construct small and medium size hydro plants

[70] Armenian Nuclear Plant Report. http://asf.prime-task.com/cgi/ASFdbs.pl?&pass=&action=Linkview&link_res_doc=armnp1.897065114.html (accessed April 18, 2014).

[71] Kindap, et al., "Potential threats from a likely nuclear power plant accident: a climatological trajectory analysis and tracer study." *Istanbul Technical University, (2008).*

can be more beneficial as large hydro plants, often not being considered a renewable energy source, can bring some harm to the environment and require too much investment.

On the other hand geothermal power plants and solar energy, particularly solar hot water systems which are already spread in Europe, can provide heat necessary for space heating in households. The biomass variant which is still not being taken seriously in Armenia could not only produce energy but also bring a lot of advantages to the environment such as reforestation. By developing all these domestic sources of energy Armenia will be able to meet at least 35 percent of its growing demand and at the same time to decrease its dependence on foreign source of energy. The only barrier to the development of the renewable energy sources is high cost of installation. However, it mostly refers to wind and solar energy, price of the technology of which is decreasing rapidly. So, if most of the potential of the renewable is developed, it would almost be able to cover the absence of Metsamor NPP.

A lot of studies have been carried out offering thermal power plants as a substitute to the ANPP. Having much less price than a new NPP, thermal power plants are more accepted by the EU and donor countries. Moreover, the construction time is relatively short and in case of low demand a small TPP might be sufficient[72]. The possession of large resources of gas in the neighboring countries Iran and Russia can also positively affect on the decision to build new TPPs. And the most important determinant for choosing the scenario with TPPs is lower tariffs. Based on the study carried out by World Bank, TPPs can be the best choice for Armenia for meeting the growing electricity demand unless the price for gas does not exceed 500 USD / tcm[73]. But along with so many advantages, TPPs would lead to an increase of dependence from other countries. The dependence on imported gas could increase up to 90 percent in case of elaborating the energy system on thermal power. This fact could have a negative effect in case of re-emergence of any conflict in the region which could jeopardize the energy security of the state.

[72] Balabanyan, et al., "Charged decisions: Difficult choices in Armenia's energy sector."
[73] Ibid

The last variant which is left as a solution to meet the consumption demand in case of the closure of the ANPP is building a new nuclear power plant which would be with more installed capacity. The position of the government on developing nuclear energy in the country is very stable; nuclear power has become inseparable part of the energy system of Armenia and it should be even more developed. The construction of a new NPP could allow Armenia not only satisfy all electricity needs inside the country but also keep its energy security as the dependence on imported fuel would automatically decrease. Nevertheless, the most problematic side of this issue is financing the project. After Fukushima crisis the interest in nuclear power plants has decreased in the world; most investors prefer more safe energy producing facilities. Besides, the investors would take into consideration the geopolitical aspect; Armenia is a landlocked country with closed borders. In case of building a 1000 MW nuclear power plant the country will have the energy surplus while the closed Armenian-Turkish border could prevent exporting electricity to Turkey. The only countries that were interested in a new nuclear power plant in Armenia were the USA and France. However, their interest has almost disappeared as fast as it had appeared. The explanation of France for giving up the idea to invest was the inability to build a nuclear power plant for a reactor which will be made in Russia. Unfortunately, till nowadays, no other country has shown her interest for making investments in nuclear power in Armenia.

And the last point is the tariffs. According to the study carried out by World Bank, in case of building a new NPP tariffs would be much higher than in case of a new TPP[74] and much higher than in case of the operating ANPP. It can be explained by the fact that the return on investments is not an issue in case of the Metsamor NPP as it was built during the Soviet times and the Republic of Armenia did not invest anything in the construction and does not seek return on investments from the ANPP. While in case of a new NPP the investor would like to have the return of investments and profits as soon as possible by making the tariffs on produced electricity much higher. But the population would unlikely be able to pay more for the electricity. Thus, to

[74] Balabanyan, et al., "Charged decisions: Difficult choices in Armenia's energy sector."

find an investor and ensure compensation of the investments in the relatively near future seems to be very difficult, at least during the upcoming years.

Returning to the issue of the closure of the operating nuclear power plant, as it has been shown Armenia has enough potential in alternative sources of energy for compensating the loss of the Metsamor. The exploited 5th block of Hrazdan TPP has the same capacity as the ANPP. Even though its electricity is delivered to Iran, it could be possible to use the additional capacity of the block for domestic use instead of exploiting it entirely for the export.

Moreover, the development of SHPPs has gained a great speed in the last decade and in case of realizing most of the potential hydro power has, it would be possible to produce almost the same amount of the electricity delivered by the ANPP. And the last option could be building small gas plants (200-300 MW) the construction time of which is very short and they would be more flexible in responding to changes in demand.

So, Armenia has many options to meet the electricity demand, be it ether renewable energy sources which has become spread all over Europe, or using electricity produced by existing TPPs. In all these cases the risk of losing its energy security is not high, while the risk of keeping the old nuclear power plant which is the source of concern in the eyes of the most of the world in spite of its numerous safety upgrades is much more risky. A supporting point for this can be a quotation from the Trade and Environment Database: “The energy crisis led Armenia to a sense of urgency to accept the risks that go along with running their dilapidated reactor. The nuclear reactor will be a threat to its environment as long as it is in service… as long as there is a threat of earthquakes like the one that killed 30,000 Armenians in 1988, the reactor can never be deemed totally safe”.[75]

---

[75] TED case studies, Armenia and nuclear. http://www1.american.edu/TED/armenia.htm (accessed April 18, 2014).

CONCLUSION

The thesis has discussed the possible scenarios both in case of closing the Metsamor NPP and in case of its operation. All the alternatives had their own positive and negative sides with the possible assumed costs. One of the variants in case of closing the operating nuclear power plant supposed the construction of a new nuclear power plant with more installed capacity and design life reaching 60 years. As it was shown, a very low probability of raising financial resources for a new nuclear power plant is required in order to shift the choice from operating of Metsamor NPP to the construction of a new nuclear facility.

In case of the continuation of the operation of the ANPP the possibility of an accident is relatively low referring to the probabilistic safety analysis of the plant. The analysis was done in 2008 and it took into consideration the equipment ageing effects. However, since that time 6 years has passed and the aging of the equipment may somehow change the initial probability of an accident.

The last possible variant after the closure of the Metsamor NPP has been the development of alternative energy sectors. The whole potential of the renewable energy could be enough to replace the old nuclear power plant at the same time not allowing the state to depend much on the imported fuels.

In any case the Armenian government has already made its decision and the life of the ANPP has been extended until 2026. It is the most optimal choice if considering the required relatively small amount of investments. However, the choice of the operation can also have another variant the cost of which would be almost impossible to cover only by money.

REFERENCES

Abbott, Derek. "Limits to growth: Can nuclear power supply the world's needs?." *Bulletin of the Atomic Scientists* (2012), http://thebulletin.sagepub.com (accessed April 13, 2014).

Armenian Nuclear Plant Report. http://asf.primetask.com/cgi/ASFdbs.pl?&pass=&action=Linkview&link_res_doc=armnp1.897065114.html (accessed April 18, 2014).

Armenian nuclear Regulatory authority, "National report on the Republic of Armenia: convention on nuclear safety," (2010).

Armenia renewable resources and energy efficiency fund, "Potential by technology/ Hydro", http://r2e2.am/en/2011/06/hydro/ (accessed April 14, 2014).

Armenia renewable resources and energy efficiency fund, "Potential by technology/ Geothermal", http://r2e2.am/en/2011/06/geothermal/ (accessed March 27, 2014).

Bahgat, Gawdat. "Europe's energy security: challenges and opportunities." *International Affairs* 82 (2006): 960-974.

Balabanyan, Ani, Arthur Kochnakyan, Gevorg Sargsyan, Denzel Hankinson, and Lauren Pierce, "Charged decisions: Difficult choices in Armenia's energy sector." *The World Bank, (2011).*

Belarus Foreign Ministry, "Chernobyl disaster, Why are the consequences still observed? Why is the international assistance still critical?" http://chernobyl.undp.org/russian/docs/belarus_23_anniversary.pdf (accessed April 15, 2014).

Bielecki, Janusz. "Energy security: Is the wolf at the door?"*The Quarterly Review of Economics and Finance*42 (2002): 234-240, http://www.liv.ac.uk/~jan/teaching/References/Bielecki%202002.pdf (accessed December 9, 2013).

Cooper, Mark. "Nuclear safety and affordable reactors: Can we have both?." *Bulletin of the Atomic Scientists* 68 (2012), http://thebulletin.sagepub.com (accessed April 13, 2014).

Davis, Dorothy. "The Necessary Good that is Nuclear Power."*Nuclear ENergy* (2012): 7-9.

EU TACIS program “Assistance to Energy Policy of Armenia”, “34 MW Semenovka wind power project Gegharkunik marz of the Republic of Armenia”, (2007).

Featherstone, S. “Chernobyl now: Are nuclear disasters the new normal?”*Popular science 58 (2012).*

Igdir mayor urges Metsamor closure. http://www.neurope.eu/article/igdir-mayor-urges-metsamor-closure (accessed April 14, 2014).

International atomic energy agency, “Defense in depth in nuclear safety,” (1996) http://www-pub.iaea.org/MTCD/publications/PDF/Pub1013e_web.pdf (accessed January 9, 2013).

International Atomic Energy Agency, “Final report of the program on the safety of WWER and RMBK nuclear power plants” (1999).http://www-ns.iaea.org/downloads/ni/wwer-rbmk/wwer_15.pdf (accessed March 15, 2014).

International Atomic Energy Agency, “IAEA leads operational safety mission to Armenian nuclear power plant” *IAEA,* August 2011, http://www.iaea.org/newscenter/pressreleases/2011/prn201108.html (accessed January 7 2014).

International Center for Human Development, "Directions of Effective Integration of the Energy Systems of the South Caucasus Countries." (2004): 217-254, (accessed April 7, 2014).

Kaznovsky, S and Ostrestov, I., “Development of requirements for seismic upgrading of equipment of existing VVER-440 and VVER-1000type NPP’s,” *IAEA,* (2008).

Khatib, Hisham. "Energy security." *World energy assessment* (2000): 112-142.

Kim, Duyeon and Kang, Jungmin, “Where nuclear safety and security meet,” *Bulletin of the atomic scientists, 68,* (2012): 86-93.

Kindap, Tayfun, Turuncoglu, Ufuk Utku, Chen, Shu-Hua, Unal, Alper, and Karaca, Mehmet, “Potential threats from a likely nuclear power plant accident: a climatological trajectory analysis and tracer study.” *Istanbul Technical University, (2008).*

Lyman, Edwin. "Surviving the one-two nuclear punch: Assessing risk and policy in a post-Fukushima world." *Bulletin of the Atomic Scientists* 67 (2011), http://thebulletin.sagepub.com (accessed April 13, 2014).

Ministry of Energy and Natural Resources of RA, “Wind energy”. http://www.minenergy.am/en/en/investment-projects/wind-energy/124-2010-09-29-21-19-24 (accessed March 1, 2014).

Ministry of Energy and Natural Resources, “Biomass energy”, http://www.minenergy.am/en/en/investment-projects/biomass-energy/127-2010-09-29-22-53-34, (accessed March 26, 2014).

Ministry of Energy and Natural Resources of RA, “Geothermal energy”, http://www.minenergy.am/en/en/investment-projects/eothermal-energy/126-2010-09-29-21-43-35, (accessed March 28, 2014).

Morse, Edward L and Amy Myers Jaffe. "Strategic Energy Policy Challenges for the 21ST Century." *Council on Foreign Relations* 58 (2001): 436-510.

Nuclear power in Armenia. http://www.world-nuclear.org/info/country-profiles/countries-a-f/armenia/ (accessed February 18, 2014).

Nuclear Power in Armenia. http://www.world-nuclear.org/info/country-profiles/countries-a-f/armenia/ (accessed April 18, 2014).

Odabshyan, Vahe, and Susanna Khachatryan, “Renewable energy in the Republic of Armenia”, *21st century 2, (2007).*

Poghosyan, Sh. and Malkhasyan, A. “Component selection for ageing PSA of Armenian NPP Unit 2.” *American nuclear society, (2008).*

Quan, Li, Matthew Fuhrmann, Bryan Early and Arnold Vedlitz. "Preferences, Knowledge, and Citizen Probability Assessments of the Terrorism Risk of Nuclear Power." *The Policy Studies Organization*29 (2012).

Ramana, M.V., “Nuclear power: economic, safety, health, and environmental issues of near-term technologies,” *The annual review of environment and resources 34,* (2009): 128-130.

Robinson, Tamara. "Nonproliferation approaches in the Caucasus." *The Nonproliferation Review* (1998): 108-120.

Sargsyan, Artashes, “Renewable energy use in the world and in Armenia: innovations towards clean technologies”, *Lusabac (2009).*

Sevikyan, Gera, “Armenian NPP experience in assuring of vital equipment’s integrity,” *IAEA* (2004).

Schmiedel, Sven and Kaatsch, Peter, “Case-control study on childhood cancer in the vicinity of nuclear power plants in Germany 1980-2003,” *European Journal on Cancer 44* (2008) http://www.ejcancer.com/article/S0959-8049(07)00855-6/abstract (accessed January 5, 2014).

Schneider, Mycle, Antony Froggatt and Steve Thomas. "Nuclear Power in a Post-Fukushima World 25 Years After the Chernobyl Accident." *Worldwatch Institute* (2011).

Schneider, M. and Froggatt, A. “2011-2012 world nuclear industry status report”. *Bulletin of the atomic scientists 68 (2012).* 8-22.

“Soviet-designed nuclear power plants in Russia, Ukraine, Lithuania, Armenia, the Czech Republic, The Slovak Republic, Hungary and Bulgaria”, *Nuclear energy institute (1997).*

TED case studies, Armenia and nuclear. http://www1.american.edu/TED/armenia.htm (accessed April 18, 2014).

The United States Agency for International Development, “Wind energy in Armenia: overview of potential and development perspectives”, *PA Consulting Group (2010).*

The United States Agency for International Development, “Small hydro power (SHPP) sector framework, status, development barriers and future development”, *PA Consulting Group (2010).*

The United States Agency for International Development, The United States Agency for International Development,” National Program on Energy saving and renewable energy of Republic of Armenia”, *(2007).*

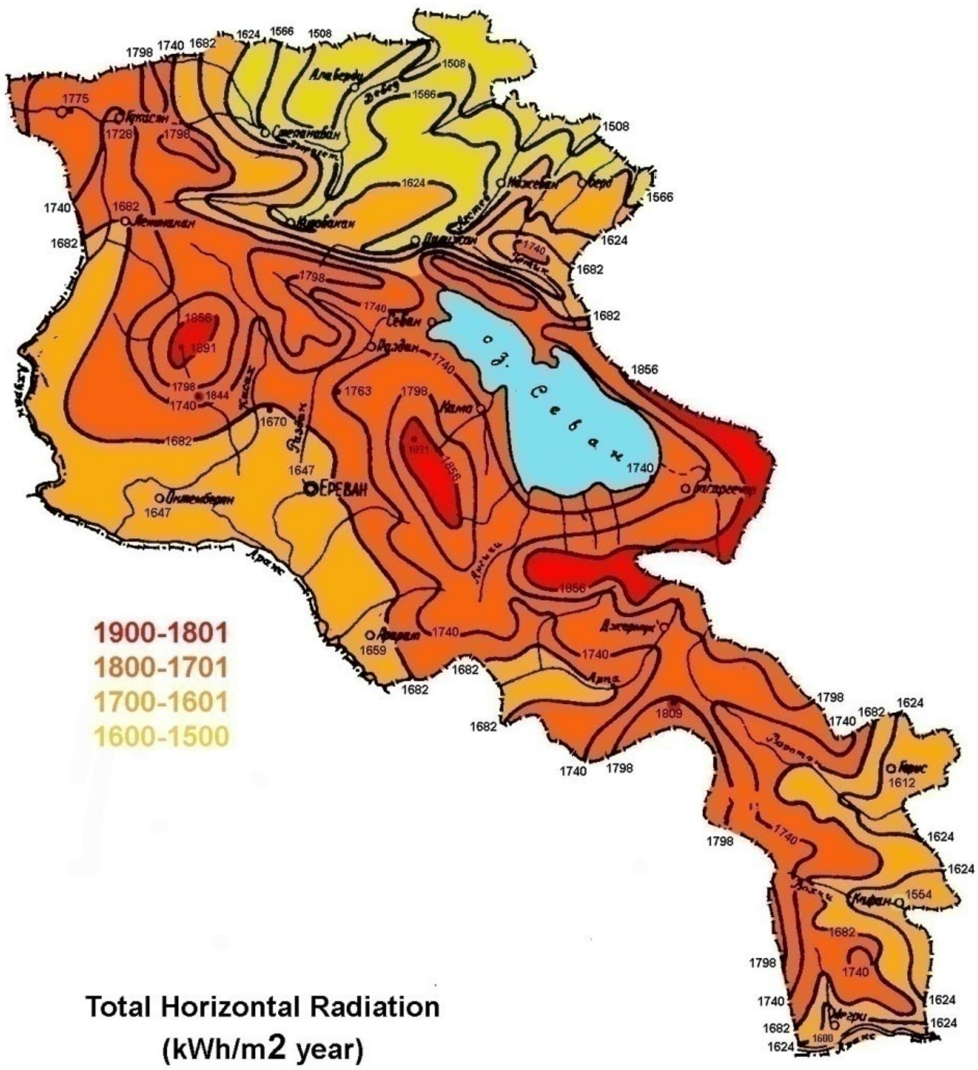
World Nuclear Association, “Nuclear power in Armenia,” last modified November 2013, http://www.world-nuclear.org/info/Country-Profiles/Countries-A-F/Armenia/ (accessed January 4, 2014).

Էներգախնայողության և վերականգնվող էներգետիկայի մասին Հայաստանի Հանրապետության օրենք. http://www.minenergy.am/en/en/laws (accessed February 25, 2014).

“Հայաստանի Հանրապետության նախագահի կարգադրությունը Հայաստանի հանրապետության էներգետիկ անվտանգության ապահովման հայեցակարգը հաստատելու մասին,” (2013). http://www.minenergy.am/en/en/2013-12-18-11-49-40 (accessed December 13, 2013).

APPENDIX A

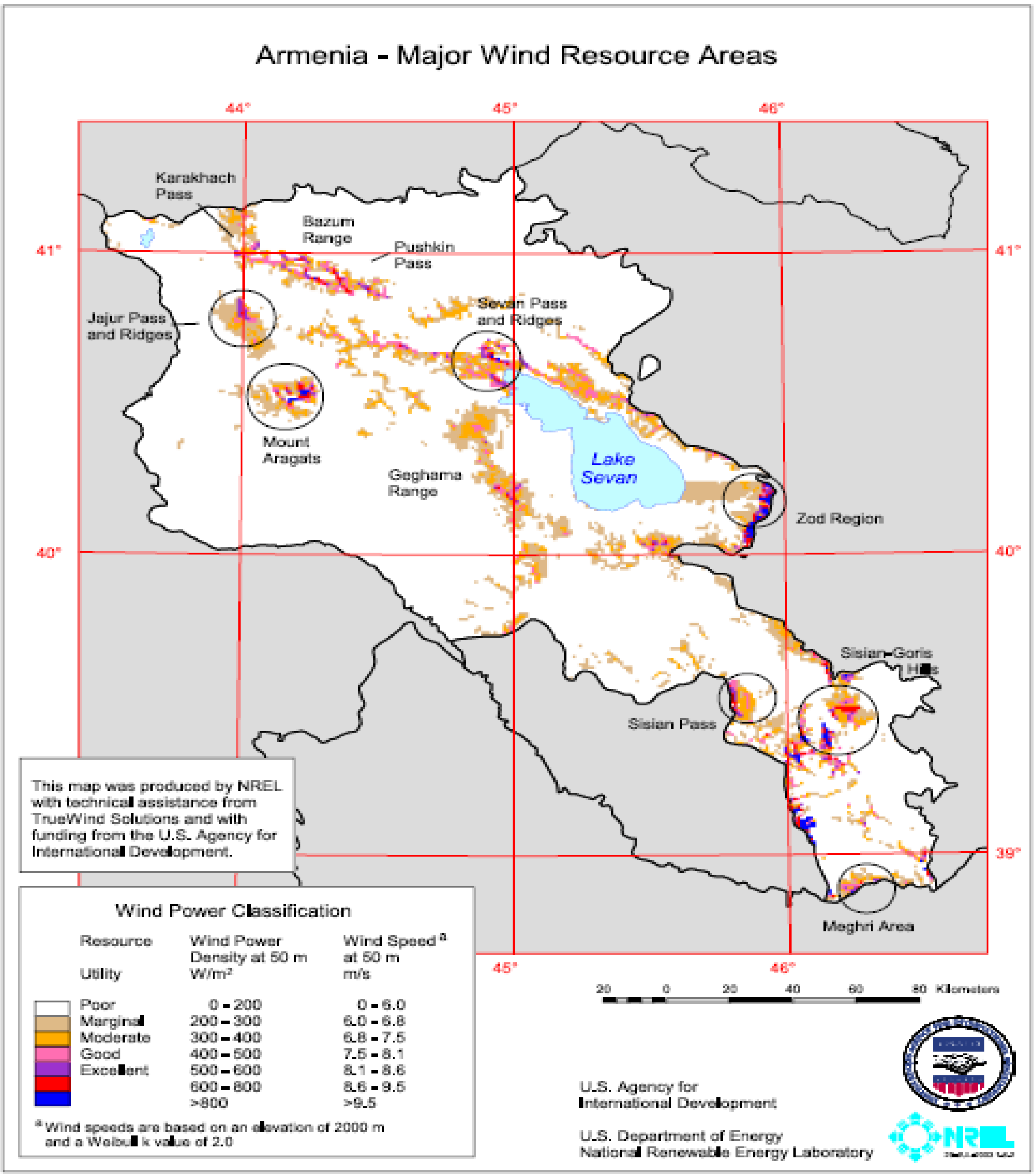
Solar resources in Armenia



Source: "Support to the Energy Policy of Armenia", TACIS PROJECT, EUROPAID/120653/C/SV/Am, 2007, http://www.renewableenergyarmenia.am/images/Re_sources/3_1_.2.a._solar_potential_fig_1.jpg

APPENDIX B

Wind potential in Armenia



Source: The United States Agency for International Development "Wind energy in Armenia: overview of potential and development perspectives", (2010).