Evaluation of the status of the Ethiopian nuclear infrastructure development

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ABSTRACT

Access to modern energy service is a development imperative. Ethiopia is rich in energy resources, but it has not sufficiently exploited them for its economic growth and as a result its socioeconomic development is not satisfactory. Its citizens are energy poor and don't have sufficient access to modern energy services. As part of its multi-layered activities in the Ten-Year Perspective Plan (TYPP 2021-2030), the current Ethiopian government, in addition to its renewable energy development plans has considered a nuclear power program (NPP) in its energy mix and desires to apply nuclear science and technology in its sustainable development strategies. The country is planning and preparing on infrastructure requirements for effective implementation of the national NPP. This review paper focuses on the role of nuclear science and technology in energy production and sustainable development, and evaluates the status of nuclear infrastructure development in the Ethiopian national nuclear program. The review discusses the main issues in a national nuclear program, nuclear energy management and nuclear knowledge management demands and strategies for its effective application. Knowledge-driven commitment to the nuclear science and technology program in developing countries like Ethiopia can boost economic growth.

Keywords: Nuclear Science and Technology; Nuclear Power Program; Nuclear Energy Management; Nuclear Infrastructure Development; Ethiopia
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INTRODUCTION

Ethiopia is a country known for its natural resources and strategic geographical location. However, its socioeconomic development is not satisfactory. Its citizens are energy poor and don't have sufficient access to modern energy services (World Bank, 2022). Despite having various energy sources, including hydropower, wind, solar, geothermal energy and opportunity to harness nuclear energy, the country still struggles to provide basic electricity services to its citizens. More than 50% of the Ethiopian population does not have access to electricity and only 3% of the population has access to clean cooking. Access to modern energy service is a development imperative. The current government of Ethiopia has made several reforms in different sectors and aimed to facilitate

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investment in major infrastructure projects in key sectors (MoWIE, 2019; FDRE, 2020; FDRE, 2021) including the energy sector. In June 2019, the government of Ethiopia has ratified a nuclear and science and technology program with international support from Russia's government and the International Atomic Energy Agency (IAEA) to build nuclear infrastructure. The first of its kinds in Ethiopia, a national nuclear science and technology center with a nuclear research reactor and a nuclear power plant to benefit the use of Nuclear Science and Technology (NST) in electric, non-electric and non-power applications to different sectors in the economy are envisioned in Ethiopia's future. Girma Kibatu *et al*. (2022) have presented a review on NST as a part of Ethiopia's Energy Mix and Sustaianable Development Strategies.

The development of an effective and sustainable nuclear energy program requires the development of many critical infrastructures. The objective of this paper is to evaluate the status of nuclear infrastructure development in the Ethiopian national nuclear program. The main issues in the national nuclear program such as the issues of nuclear energy management and nuclear education/nuclear knowledge management demands and strategies for the effective applications of a nuclear program in Ethiopia are evaluated and recommendations have been suggested for successful development and implementation.

ETHIOPIA'S SOCIO-ECONOMIC AND POLITICAL SITUATIONS

Ethiopia, a country with a population of 115 million, is the second populous country in Africa. The country has Africa's seventh largest economy by gross domestic products. Although Ethiopia is endowed with substantial land mass and natural resource potentials, its present socioeconomic condition is not satisfactory yet (World Bank, 2022). The country's economy has showed progress in the 1980s and 1990s relatively; however, economic development in Ethiopia has been beset with a continuing problem of balkanization and internal conflicts, lack of capacity in nation building, and political unrests due to lack of good governance. Thus, a new form of government has been formed in 2018. The current Ethiopian government has been learning from the development efforts in the 1980s and 1990s, and has redesigned a series of new policy measures to raise productivity in both private and public services including in the energy sector (MoWIE, 2019; FDRE, 2020). Ethiopians, therefore, once again, under the new leadership have hopes and good reasons to enter the 2020s into accelerated growth with social justice.

Energy systems scenario in Ethiopia

Ethiopia has currently a final energy consumption of around 40,000 GWh, whereof 92% are consumed by domestic appliances, 4% by transport sector and 3% by industry. Most of the energy supply thereby is covered by bioenergy which in case of domestic use and imported oil and gas which is usually stemming from unsustainable sources (Yalew, 2022). Ethiopia is endowed with renewable and clean energy sources and has a potential to generate over 60,000 megawatts of electricity from hydroelectric, wind, solar, geothermal and nuclear power sources. However, the current total installed capacity of electric generation is approximately 4758.77 megawatts (2021) mainly generated by hydropower (90%) followed by wind energy (7.6%) and others (2.4%). Only 44% of the total population has access to electricity. More than 50% of the Ethiopian population does not have access to electricity and only 3% of the population has access to clean cooking. Currently, Ethiopia's per capita electricity consumption of 100 kWh per year is the third-largest electricity access deficit in sub-Saharan Africa. The World Bank report in 2019 also indicates that the demand for electricity would double in a decade.

The current government of Ethiopia aims to achieve universal 100% access to electricity by 2030 and achieve Goal 7 of the United Nations Sustainable Development Goals, ensuring access to clean reliable and affordable energy for all. In the Ethiopia's 25-year power system master plan (2022-2037), the aim is to generate up to 37,000 MW of power by the year 2037. Energy is essential for development and additional investment in the energy sector in addition to the Great Ethiopian Renaissance Dam project and other wind and geothermal projects on the pipeline is mandatory for growth. Much of the electrification available now is also highly dependent on a single energy source –the hydropower, which is unreliable and sensitive to climate change which, as a result, causes shift services and several outages (Mokonnen *et al*., 2002). Ethiopia therefore aims to achieve its vision through major scientific and technological projects in solar, wind, and geothermal and nuclear in addition to hydropower projects. As a part of this direction, Ethiopia has therefore shown interest to commence a nuclear program for the peaceful application of nuclear science and technology as one of the strategies to achieve its targets in both in its energy mix and sustainable development goals.

Nuclear science and technology

Nuclear science, technology and innovation are multidisciplinary and highly specialized areas of science and technology that involves nuclear reactions of the atomic nuclei (Murogov *et al*., 2009). In addition to the kinetic energy and

the heat from the reaction that is used for electrification, the radioisotopes (radionuclides), the neutrons (and or sub atomic particles) and the photons of gamma radiation produced in nuclear reactions have been harnessed in various applications. A notable example of a fission reaction of Uranium-235 by accelerated neutron as shown below shows results in a single nuclear reaction that can generate 200Mev energy.

Brief history of nuclear science and technology

The science of atomic radiation, nuclear change and nuclear fission was developed from 1895 to 1945, much of it in the last six of those years (World Nuclear Association, 2022). Over the years from 1895-1945 most development was focused on atomic bomb development. The years 1946-1956 were dedicated to the development of nuclear power plants for electrification. Today nuclear energy provides about 10.4% of the world's electricity from about more than 440 nuclear power reactors all over the world. South Africa remains the only African country to possess a nuclear power station. Many African countries including Ethiopia are preparing to be nuclear by 2030-2040. Since 1956 the prime focus of nuclear technology has been on technological evolution to smaller, safe and more flexible design and reliable nuclear power plants and recently much progress have also been made in non-electric and non-power application of nuclear science in other sectors other than electricity production which gave the technology a higher demand in the next decades.

Applications of nuclear science and technology

In the course of developing nuclear weapons, nuclear scientists and technologists had acquired a range of new power and non-power nuclear technology applications for peaceful purposes. Applications of nuclear science and technologies in nuclear energy for electric and non-electric applications, and in non-power applications in food and agriculture, health and medicine, manufacturing and industry, water resource management and sustainable environment management play significant role in driving socioeconomic and sustainable growth of a society (Walter, 2003). Application of nuclear energy in electrification is seen in below (Figure 1).

THE ETHIOPIAN NUCLEAR POWER PROGRAM

Nuclear science and technology in Ethiopia

The application of nuclear techniques in Ethiopia started in the early sixties in the medical field and has gradually expanded to other areas such as agriculture, animal health and research, hydrology, mining and industry. Applications of nuclear energy are not known in Ethiopia. Ethiopia has only one public nuclear

medicine center and one radiotherapy center at Black Lion Specialized Hospital in Addis Ababa for the whole country (Demena, 2002).

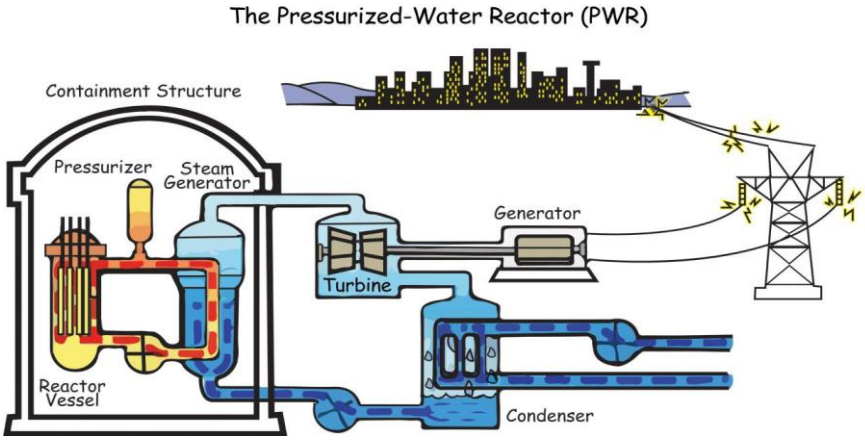

Figure 1. Typical nuclear power plant

The government has plans to expand these services in regional hospitals. The tsetse fly eradication project using radiation technology in the Rift Valley, and plant breeding project using radiological methods to improve teff varieties in Debere Ziet are other main endeavors in the Ethiopian national agricultural research centers (Alemu *et al*., 2007). Nuclear measuring and detecting devices have also been used for gauging in different beverage, construction, transport industries and customs services.

Uranium geology exploration and resources in Ethiopia

Ethiopia has prospective geology with mining potentials for certain minerals (Assefa *et al*., 1991; Oluma, 2009). In a report from an old Newspaper *New York Times* on May 15, 1954 it was mentioned that Emperor Haile Selassie I has announced that some of the best uranium ore in the world had been discovered in Ethiopia (New York Times, May 15, 1954). This was even before the formation of the IAEA where the world also knew little about the nuclear technology. An outcome of a recent two-year survey in 2019/20 on the prospect for mineral resources across Ethiopia, identified uranium among several other minerals in six weredas/districts of the eastern region, including Harar, Kersa, Babile, Girawa, Midaga, and Faddis (Geological Survey of Ethiopia, Ministry of mines and energy, 2021). However, results of this work have not been published or verified and therefore further research is needed by providing technical assistance to help the survey of Uranium mines in Ethiopia, to get a better idea of how much uranium ore in Ethiopia is economically feasible.

Nuclear knowledge management in Ethiopia

The Ethiopian education and training system and research activities provides little or no base for NST. There are only a few nuclear education and training programs in the education system in Ethiopia (Belete, 2004). Physical components like facilities and training and research institutions are at their primary level. Less emphasis is given for nuclear education at high school and undergraduate studies in sciences or engineering. Only some universities in Ethiopia are running MSc programs in nuclear and radiation physics. Addis Ababa University has a PhD program in nuclear physics and specialty degrees in radiology and nuclear medicine. Addis Ababa Science and Technology University has recently established a center for Nuclear Reactor Technology, an MSc program in Nuclear Science and Engineering and is planning to build capacity in the field. There are otherwise no typical universities running nuclear and radiological sciences, nuclear engineering or technology and radiopharmaceutical programs in the country.

Following the need assessment and lack of human resources in the field of nuclear science and technology, developments of educational programs and curriculum development activities in Bahir Dar University to integrate nuclear education in its education base has been started. A joint new MSc in Nuclear Science and Engineering program based on best practices on nuclear knowledge management and education has been proposed and approved by the university where faculty (Figure 2) from the college of Science and the Institute of Technology join to manage the program in Bahir Dar. Despite the recent few developments in the national education system and education base for nuclear science and technology in the country, specific policy and regulation for standardization and modularization does not exist.

The status and development of nuclear program in Ethiopia

Ethiopia's National Nuclear Program has two parts. The first phase of the country's nuclear program aims to set up a National Center for Nuclear Science and Technology with Nuclear Research Reactor and other facilities for comprehensive services in non-electric applications and training and research needs by 2024.

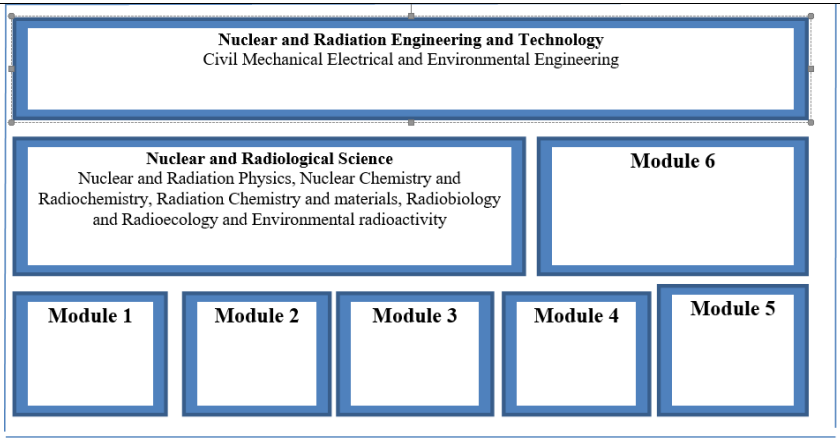

Figure 2. A schematic program structure for proposed curriculum for an MSc in Nuclear Science and Engineering; Module 1 Nuclear and Radiation Physics; Module 2 Nuclear Chemistry and Materials; Module 3 Nuclear Power Technology; Module 4 Nuclear Technology in Non-Power applications; Module 5 Nuclear Safety Security and safeguard'; Module 6 Mathematics Computer science and Social sciences/Humanities and arts (Kibatu *et al*., 2022).

The second part of the country's nuclear program is a Nuclear Energy Program to introduce nuclear energy into Ethiopia's energy mix. The country is currently considering both large and small modular reactors for its nuclear energy. The country is currently considering implementing large research reactor program in a national center for nuclear science and technology in the near future and has set a target of 2035-2040 to have its first nuclear power plant up and running.

The IAEA milestones approach

The International Atomic Energy Agency (IAEA) has developed an internationally accepted method to implement sustainable nuclear power programs for newcomer countries considering launching a nuclear power program in their development (IAEA, 2015) (Figure 3).

Nuclear energy management

Three key organizations are involved in building a nuclear power program (IAEA, 2006). The government should create these three organization structures as a mechanism to coordinate, regulate and operate. For example, a Nuclear Energy Program Implementing Organization (NEPIO) devoted to coordinate the work of all organizations involved, a competent, independent regulatory body must be developed to ensure it that it combines with all nuclear safety standards. The Owner/Operator may be state owned or private and must be competent to safely operate the nuclear power plant and meet regulatory requirements.

Nuclear infrastructure development

The International Atomic Energy Agency (IAEA, 2008) provides member states embarking into a nuclear program an opportunity and a methodology to evaluate the status of their national ***nuclear*** infrastructure on the basis of the Milestones Approach and associated 19 infrastructure issues (Figure 4). The evaluation methodology used is documented in the IAEA publication *Evaluation of the Status of National Nuclear Infrastructure Development, IAEA Nuclear Energy Series No.NG-T-3.2 (Rev. 1), IAEA, Vienna, (2016)*. The methodology provides a comprehensive assessment of all facets of a nuclear power program to ensure that the infrastructure required for the safe, secure and sustainable use of nuclear power is developed and implemented in a responsible and orderly manner. Recommendations and suggestions to the Member State can be obtained from this assessment to support the development of a national action plan to identify the gaps and address the gaps identified.

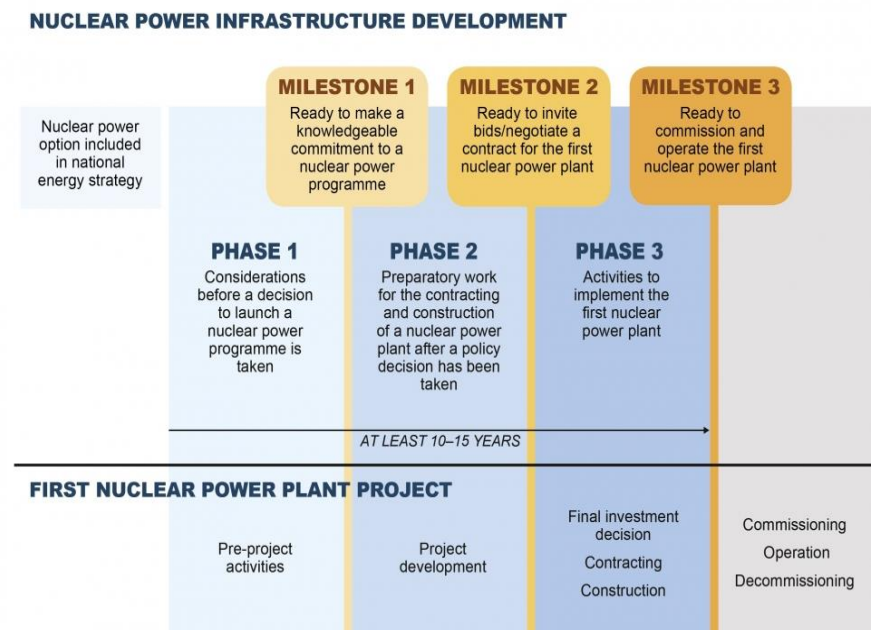

Figure 3. Phases of infrastructure development for nuclear power

Figure 4. Infrastructure issues

Evaluation of status and development of nuclear program in Ethiopia

Two agencies; a Nuclear Energy programme Implementation unit (NEPIO/National Nuclear Science and Technology Task Force) in the ministry of innovation and technology as a promoter, planner and organizer to the national nuclear program and an Ethiopian Technology Authority as a regulatory body are now guiding and working on regulating services pertaining to the national nuclear program of Ethiopia. The new Nuclear and Radiation protection (Technology Authority) Proclamation (Proclamation No. 1025/2017) includes provisions on regulating nuclear infrastructures and radioactive waste management. The Ministry of Water, Irrigation and Energy directs the energy situation in the country. State-owned companies own and operate energy infrastructures in the country. However, plans on who owns or operates future nuclear power plants to be established are not yet decided. The Ethiopian Nuclear Program also enjoys bipartisan support from technology providers.

The national policies such as the TYPP, the National Energy Policy, the National Strategy of Climate Resilient Green Economy, SIT policy, and the National Energy Master Plan for Ethiopia (EFDRE, 2020-2021) all provide an overall framework and base to justify the need for the implementation of a nuclear program. These policies have been taken as a policy base to strengthen the legal, institutional, and operational framework of nuclear science and

technology in the country. Key government decisions have been made based on policies and recommendations from the NEPIO, the national regulatory body, the technology vendor and the international atomic energy agency. With this guidance the government of Ethiopia has taken both the cabinet and the parliament to decisions to introduce a national nuclear program in 2021. However, Ethiopia has not yet drafted an independent national nuclear policy. Ethiopia's decision to embark into the nuclear program, however, has not been supported by strong policy justification strategic documents and missions (a National Nuclear Policy, Pre-feasibility study for a national nuclear program, a national Nuclear power roadmap, a nuclear programme implementation plan, request for information issued to seek both technical, financial and contractual information from the vendor countries regarding the technology they intend to deploy to Ethiopia and other issues remains to be completed before stronger decision to go on). These endeavors are either under consideration or yet to be produced for a strong policy justification and commitment from all stakeholders involved in the project.

The evaluation of the status of the Ethiopian Nuclear Program using the IAEA's milestone approach, and considerations to the timeline shows that Ethiopia is now in pre-project activities in phase I. The country has already made some preparations to include nuclear power in its future energy mix. The Ethiopian national power program is still at the end of its phase I stage and is prior to achieving the 1st milestone. Accordingly meta-activities including 1) Developing pre-feasibility studies, policies and strategies; 2) Developing legal and regulatory framework; 3) Conducting site related activities and 4) Developing and maintaining organizational structures are activities that have to be completed before the *Integrated Nuclear Infrastructure Review* (INIR) Phase I mission for Ethiopia to reach into its 1st milestone in the development of the nuclear Program. The country currently is undergoing working on strategic plan, feasibility study, and potential site selection and is also in parallel planning for the development of other infrastructures needed for an effective nuclear program and may hit the 1st milestone probably at the end of 2023.

Concerns/challenges on the national idea on nuclear power program

Newcomer countries like Ethiopia embarking into a new nuclear energy power programs with little experience in the science and technology usually face some concerns to implement an effective, affordable, and large sustainable development project in the energy sector. Some of the important issues, concerns and challenges raised in building national nuclear program are included in the following list: National position and capacity building; Finances and funding schemes; Human resource development; Nuclear energy management; Legislative and regulatory framework; National electrical grid;

Accidents and security threats; Radioactive waste and limited fuel supply; and Public opinion and awareness (Adams and Odonkor, 2021). The evaluation of the status of these challenges, techno economic analysis for the construction and operation of nuclear power plants and concerns in the Ethiopian Nuclear Program, based on the international practice and guidelines for the development of a nuclear program for embarking countries, show gloomy situations (Ayalew, 2021; Wondimagegn, 2022). As nuclear technology is highly regulated, Ethiopia also needs to develop robust infrastructures *(such as Atomic Energy Commission; Nuclear Power Authority; Nuclear and Radiation Protection Authority; Nuclear and Radio waste Management Agency and organization for Nuclear Security*) in the national nuclear program. The success of the program is highly dependent on how these challenges and issues are addressed properly on time.

CONCLUSIONS AND RECOMMENDATIONS

This review shows why the peaceful use of nuclear science and technology makes sense in an Ethiopian context. Socio-economic and environmental considerations show that the use of nuclear and radiation technologies in the energy-mix and to accelerate sustainable development in Ethiopia are essential. The Ethiopian national power program is in pre **project** activities, at the end of its phase I stage prior to achieving the 1st milestone. The mix of energy supply in Ethiopia is as important as energy supply in low-income countries striving for sustainable development. Renewable energy sources such as hydropower, solar, wind and geothermal energy developments coupled with nuclear based energy development provide a future gateway for sustainable economic transformation through industrialization, urbanization as well as through the provision of access to modern and clean energy to all sectors in society. In addition to the provision of modern and clean energy, non-electric and non-power peaceful applications of the nuclear science and technology in many sectors such as health, agriculture and industry help Ethiopia to achieve its sustainable development goals.

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