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Review Paper

Nuclear Science and Technology as a Part of Ethiopia's Energy Mix and Sustainable Development Strategies: exploring opportunities and challenges

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Abstract

Ethiopia is rich in energy natural resources, but it has not sufficiently exploited this resource advantage for its economic growth. While the country is endowed with many untapped natural resources and opportunities for development, its socioeconomic development is not satisfactory. Its citizens are energy poor and don't have sufficient access to modern energy services. Access to modern energy service is a development imperative. The current Ethiopian government as a part of its multi layered activities in the Ten Years Perspective Plan (TYPP 2021-2030) has considered a nuclear power program (NPP) to use nuclear science and technology applications in its energy mix and sustainable development strategies and is planning and preparing on infrastructure requirements for its effective implementation. This review focused on the role of nuclear science and technology in energy production and sustainable development; and analyses the status, challenges and issues in the Ethiopian national nuclear program. The review sets out to discuss the main issues in a national nuclear program, nuclear energy management and nuclear knowledge management demands and strategies for its effective application in embarking countries. Knowledgeable commitment to the nuclear science and technology program in developing countries like Ethiopia can boost economic growth.

1. Introduction

Ethiopia is rich in energy natural resources, but it has not sufficiently exploited this resource advantage for its economic growth. While the country is endowed with many untapped natural resources and opportunities for development, its socioeconomic development is not satisfactory as such. Its citizens are energy poor and don't have sufficient access to modern energy services. Access to modern energy service is a development imperative.

International and regional development policies for the World and Africa (The 2030 agenda sustainable development goals, 2015; the African Union's agenda 2063, 2013), and national development policies such as the Ethiopia's home-grown reform agenda and the Ethiopia's Ten Years Perspective Plan (TYPP 2021-2030) (Ethiopia Vision 2030, 2021) have all require the use of science, technology and innovation (STI) and plan to develop energy infrastructures as enabling means

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to implement sustainable development and economic growth goals.

The new government of Ethiopia has made several reforms in different sectors and aimed to facilitate investment in major infrastructure projects in key sectors including the energy sector. The Ethiopia's national policies extended from the above visions such as the science, technology and innovation policy, the climate change resilient green economic policy (National Science Policy and Strategy and Ethiopia's Climate Resilient Green Economy, 2021), the national energy policy (Energy Proclamation No. 810/2013) and the Ethiopia's 25 years power system master plan (2022-2037) (Ethiopian Electric Power Corporation, 2022; Amsalu Yalew, 2022) are also all aligned to support the use of STI and plan to develop modern energy infrastructures in Ethiopia. The current government of Ethiopia have expressed interest in working in a nuclear science and technology (NST) program, revitalizing the revitalizing its intentions for embarking into the peaceful use of nuclear science and technology in Ethiopia for sustainable development.

In June 2019, the government of Ethiopia has launched a nuclear and science and technology program with international support from Russia's government and the International Atomic Energy (IAEA). The country has decided to include the use of nuclear science and technology in its economic sectors and is now preparing infrastructures to support sustain and develop a successful nuclear program.

The Ethiopian government is now in the process of establishing institutional components for nuclear the infrastructures. The first of its kind, a national nuclear science and technology centre, a research reactor and a nuclear power plant to benefit the use of NST in electric, non-electric and non-power applications to different sectors in the economy are envisioned in Ethiopia in the near future. The development of an effective and sustainable nuclear energy program requires the development of many critical infrastructural issues.

The objective of this paper is to critically assess nuclear science and technology as a technology and its applications; and explore the status, the opportunities, the gaps and the challenges in the use of nuclear science, technology and innovation program in Ethiopia. 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.

2. Ethiopia's Socio-Economic and political Situations

Ethiopia, a country with a population of 115 million, is the second largest country in Africa. Although the country is endowed with a substantial land mass and untapped natural resource potentials, its present socioeconomic condition is not satisfactory and it remains today one of the least developed countries in the world (World Bank Report, 2022). Although the country's economy has showed progress in the 1980s and 1990s relatively; 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 (FDRE, 2018 and MoWIE, 2019). Ethiopians, therefore, once again; under the new leadership have hopes and good reasons to enter the 2020s into accelerated growth with social justice.

2.1. Energy Systems Scenario in Ethiopia

Ethiopia is rich in potential energy resources, but its citizens are still energy poor and access to modern energy services is limited (World Bank Report, 2019). Currently, the Ethiopia's per capita electricity consumption of 100kWh per year is the third-largest electricity access deficit in sub-Saharan Africa. The World Bank report in 2019 indicates access to electricity in Ethiopia stands at 44% and it is estimated that the demand would double in a decade. Much of the Electrification available is 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 outages.

2.2. Development options under considerations

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. Ethiopia's 25 years power system master plan (2022-2037) also aims to generate up to 37,000 MW of power by the year 2037. Energy is essential for development (IAEA, 2001). Ethiopia aims to achieve its vision through major scientific and technological projects in hydropower, solar, wind, and geothermal projects in the pipeline. The government of Ethiopia has also shown interest to commence a Nuclear Program for the peaceful applications of nuclear science and technology as one of the strategies to achieve its targets in both in its energy mix and sustainable development goals.

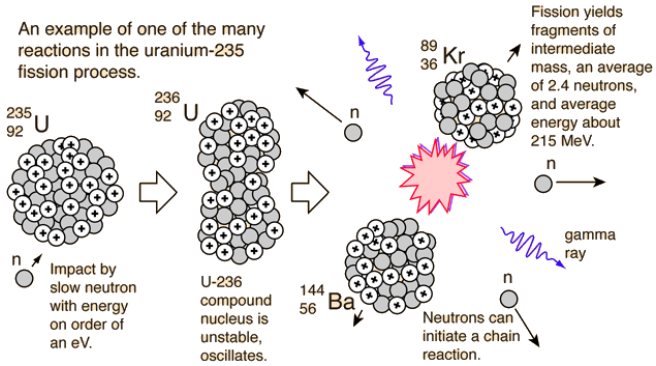
3. Nuclear Science and Technology

Nuclear science, technology and innovation are a multidisciplinary and highly specialized area of science and technology that involves nuclear reactions of atomic nuclei (Murogov, 2019). In nuclear physics and nuclear chemistry, a nuclear reaction is semantically considered the process in which fission or fusion reactions produce one or more nuclides that are different from the nuclide(s) that begin the process. A notable example of a fission reaction of Uranium-235 by accelerated neutron as shown below show results in a single nuclear reaction that can generate 200Mev energy.

In addition to the kinetic energy that is used for electrification, the heat from the reaction, the radioisotopes (radionuclides), the neutrons (sub atomic particles) and the photons of gamma radiation produced in nuclear reactions have been harnessed in various applications. Applications of nuclear science and technologies in energy, food and agriculture, health and medicine, manufacturing and industry, water resource management and in the sustainable environment management play significant roles in driving socioeconomic and sustainable growth of a society.

3.1. 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 was dedicated to the development of nuclear power plants for Electrification. Since 1956 the prime focus has been on technological evolution to reliable nuclear power plants and progress in non-electric and non-power application of nuclear science in other sectors other than electricity production.



Scheme 1: Schematic diagram for fission reaction resulting in excessive heat, transmutation (radioisotopes), subatomic particles (such as n neutrons) and gamma radiation.

3.2. Nuclear Fuel Cycle

The various activities associated with the production of electricity from nuclear reactions are referred to collectively as the nuclear fuel cycle. The nuclear fuel cycle is the series of industrial processes which involve the production of electricity from uranium in nuclear power reactors (IAEA, 2022). The nuclear Fuel cycle has the following processes and activities: Uranium Mining; Uranium Refining and Conversion; Uranium Enrichment; Fabrication of Nuclear Fuel; and Electric Generation at Nuclear Power Plant. Fuel removed from a reactor, after it has reached the end of its useful life, can be reprocessed to produce new fuel. The nuclear fuel cycle starts with the mining of uranium and ends with the disposal of nuclear waste.

3.3. Uranium Geology Exploration and Resources in Ethiopia

Ethiopia has prospective geology with mining potentials for certain minerals (Getaneh Assefa et. al. 1991). In a report from an old Newspaper on May 15 1954 – the Emperor Haile Selassie announced that some of the best uranium ore in the world had been discovered in Ethiopia (New York Times, May 15 1954). An outcome of a recent two-year survey on the prospect for mineral resources across Ethiopia, identified uranium among several other minerals in six weredas of the eastern region, including Harar, Kersa, Babile, Girawa, Midaga, and Faddis (Geological Survey of Ethiopia, Ministry of mines and energy, 2021). However, further research is needed providing technical assistance to help

survey Uranium mines in Ethiopia, to get a better idea of how much uranium ore in Ethiopia is economically feasible.

3.4. Applications of Nuclear Science and Technology

In the course of developing nuclear weapons, nuclear scientists and technologists in the Soviet Union and the west had acquired a range of new nuclear technology applications.

3.4.1. Power Applications of Nuclear Technologies

Electric Applications:

Inside a nuclear power reactor the fissile nuclei of atoms split (fission) and, in the process, release energy.

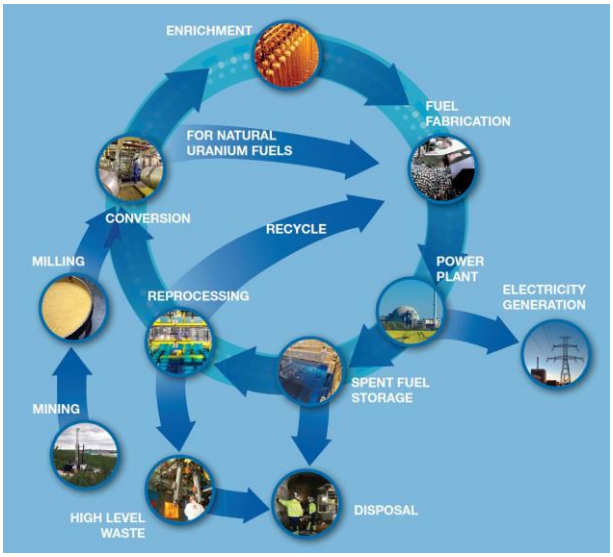


Figure 1: Overview of the Nuclear Fuel Cycle.

This energy is used to heat water and turn it into steam. The steam is used to drive a turbine connected to a generator which produces electricity (US DOE, www.energy.org/ne, 2022). As with as a coal-fired power station; about two thirds of the heat is dumped either to a large volume of water (from the sea or large river, heating it a few degrees) or to a relatively smaller volume of water in cooling towers, using evaporative cooling (latent heat of vaporisation).

The main reasons for a nuclear power option for electrification is that it is a reliable, high base load green energy source, carbon free/greenhouse gas (GHG) emission free electricity/ and by far resilient for climate change. Some concerns in this technology include high upfront cost, highly qualified human resources, and radioactive waste, safety and security issues.

Non-Electric Applications:

Commercial reactors are now offering various applications beyond providing electricity for homes and businesses (IAEA. 2022; Rosen, 2021). Nuclear technologies can now be used in water desalination, provide heat for metal refining, and can even be used to generate hydrogen as a clean burning alternative fuel for vehicles. Industries in hydrogen production; water desalination; process heating; district heating; nuclear powered-ship and rocket propulsion; and cooling and refrigeration machines could leverage nuclear processes heat and non-stationary power reactors to further help decarbonise human activities in our society.

3.4.2. Non-Power Applications of Nuclear Technologies

The applications of nuclear technology outside of civil electricity production in power plants and non-electric application from nuclear process heat and non-stationary nuclear reactors are less well-known (Fujjie, 1995). Radioisotopes and gamma radiations produced in the nuclear processes in nuclear reactors, accelerators and or generators have also essential uses across multiple sectors including in food and agriculture, medicine, industry and consumer products, water resources and the environment, in arts and society, and scientific research (Walter, 2003).

3.5. Nuclear Science and Technology in Ethiopia

3.5.1. The Ethiopian Nuclear and Radiation Protection Authority

The Ethiopian Nuclear and Radiation Protection Authority (ENRPA) is an established national regulatory control body to control the use of ionizing radiation sources in Ethiopia since 1993. The Ethiopian parliament has also ratified legal requirements that are meant to upgrade the scope of the Ethiopian regulatory body into the coming activities following a nuclear program in 2017. The new Nuclear and Radiation protection Proclamation (Proclamation No. 1025/2017) includes provisions on radioactive waste management. Continuous develop mental work, matching the progress of the program, is expected from the National Regulatory Body.

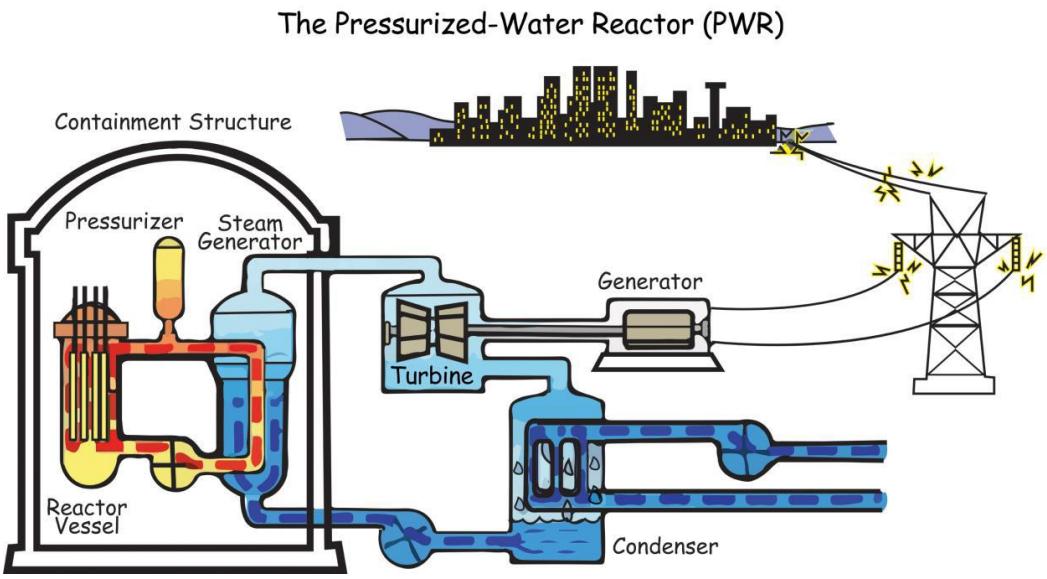


Figure 2: Typical Nuclear Power Plant.

3.5.2. Medical agricultural and industrial applications of Nuclear 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. Ethiopia has only one public radiotherapy centre at Black Lion Specialized Hospital in Addis Ababa for the whole country (Demena, 1993; 2002). 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 the main endeavors in the Ethiopian national agricultural research centres (Alemu et. al. 2007). Nuclear measuring and detecting devices have been used for gauging in different beverage, construction, and transport industries and customs services.

3.5.3. Education Research and Educational networks in Nuclear Science and Technology in Ethiopia

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. Some universities in Ethiopia are running MSc program in Nuclear and Radiation Physics. The Addis Ababa University has a PhD program in Nuclear Physics. The Addis Ababa Science and Technology University has established a centre for Nuclear Reactor Technology. Apart from training in traditional Sciences, Engineering and Medicine students there are no universities running nuclear and radiological sciences, nuclear engineering and technology, or Nuclear Medicine and Radiopharmaceutical programs in the country.

4. The Ethiopian Nuclear Power Program

4.1 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 (Noh and Kim, 2016). A nuclear power program is a major undertaking requiring careful planning, preparation and investment in time institutions finances and human resources. The IAEA milestones approach enables a sound development process for a nuclear power program. The Milestones approach helps the country understand its commitments and obligations to ensure its NPP is safe secure and sustainable. The Milestones approach is documented in the IAEA Nuclear Energy Series Publication.

4. 2. Nuclear Energy Management

Three key organizations are involved in building a nuclear power program (Danesi, P.R., 2011). The government should create a mechanism for example a Nuclear Energy Programme Implementing Organization (NEPIO) to coordinate the work all organizations involved, a competent, independent regulatory 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.

4.3. The Status and Development of Nuclear Program in Ethiopia

Ethiopia's nuclear journey started with vision and inspiration of previous governments to develop and promote the peaceful use of nuclear science and technology in the fields of energy, medicine, water and agriculture. Ethiopia's current government commitment to pursue nuclear energy is also a part of efforts to reduce dependence on fossil fuels, diversify its energy sources and adapt to climate change (Amanuel, 2020). Although Ethiopia has not drafted an independent national nuclear policy, the policies such as the TYPP, National Energy Policy, the National Strategy of Climate Resilient Green Economy, SIT policy, and the National Energy Master Plan all provide an overall framework and guide to the need to the implementation of a nuclear program. It can also be taken as a policy base to strengthen the legal, institutional, and operational framework of nuclear science and technology in the country.

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 Nuclear and Radiation Protection Authority as a regulatory body are now guiding and work on regulating services pertaining to the national nuclear program Ethiopia. The Ethiopian Nuclear Program also enjoys bipartisan support from technology providers.

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. 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 centre 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 evaluation of the status of the Ethiopian Nuclear energy Program using the IAEA's milestone approach; the timeline shows that Ethiopia is now in phase I. The country has already taken some decision measures to include nuclear in its future Energy mix. The country currently is undergoing feasibility study and is also in parallel planning for the development of other infrastructures needed for an effective program and may hit the milestone I at in this year 2022.

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 the guidance from the national agencies and an intergovernmental cooperation, the government of Ethiopia has taken both the cabinet and the parliament to decisions to introduce a national nuclear program in 2021. 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; the IAEA Integrated Nuclear Infrastructure Review (INIR) mission). These documents and missions are either under consideration or yet to be produced for a strong policy justification and commitment from all stakeholders involved in the project.

4.4. 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 projects in the energy sector. Some of the important issues, concerns and challenges raised in the 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 treats;

Radioactive waste and limited fuel supply; and Public opinion and awareness (Adams and Odonkor, 2021 and Karim et al., 2018). The evaluation of status of these challenges 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 in these areas (Endalew, 2021). The success of the program is highly dependent on how these challenges and issues are addressed properly on time,

4.5. Nuclear Capacity Building and Education in Ethiopia

For countries looking to implement nuclear energy and leverage all other potential applications of nuclear science and technology; capacity building in knowledge management, education and training are important part in the development of the nuclear science and technology programs.

4.5.1. Nuclear Knowledge Management

Knowledge management is an integrated, systematic approach for identifying, acquiring, transforming, developing, disseminating, using, sharing and preserving knowledge relevant to achieving specific objectives (IAEA TECDC-1510. 2022). Countries with existing nuclear programs need to secure the capacities and human resources necessary to sustain the safe operation of existing installations, including their decommissioning and related programs for spent fuel and waste.

4.5. 2. STEM education coupled with humanity and arts

In an ever-changing, increasingly complex world, it's more important than ever that the young generations are prepared to bring knowledge and skills to solve problems, make sense of information, and know how to gather and evaluate evidence to make decisions. These are the kinds of skills that students develop in science, technology, engineering, and math, including computer science, humanity and arts—disciplines collectively known as STEM (The US national academies of science engineering medicine, 2018)

4.5. 3. Systematic Approach for Training

Training is a planned process that directs learning towards achieving specific outcomes, leading to achieving performance objectives. The Systematic Approach to Training infers that training is done in a planned, systematic way and that it is directed towards improving job performance (Al-Moayad, 2019; IAEA's Systematic Approach to Training for Nuclear Facility Personnel: Processes, Methodology and Practices. 2022). For any training program in nuclear education and training to be successful it is very essential to follow a certain process. Training can be viewed as a process comprised of five related stages or activities: assessment, motivation, design, delivery, and evaluation.

4.5.4. Competence based Practice Oriented Program

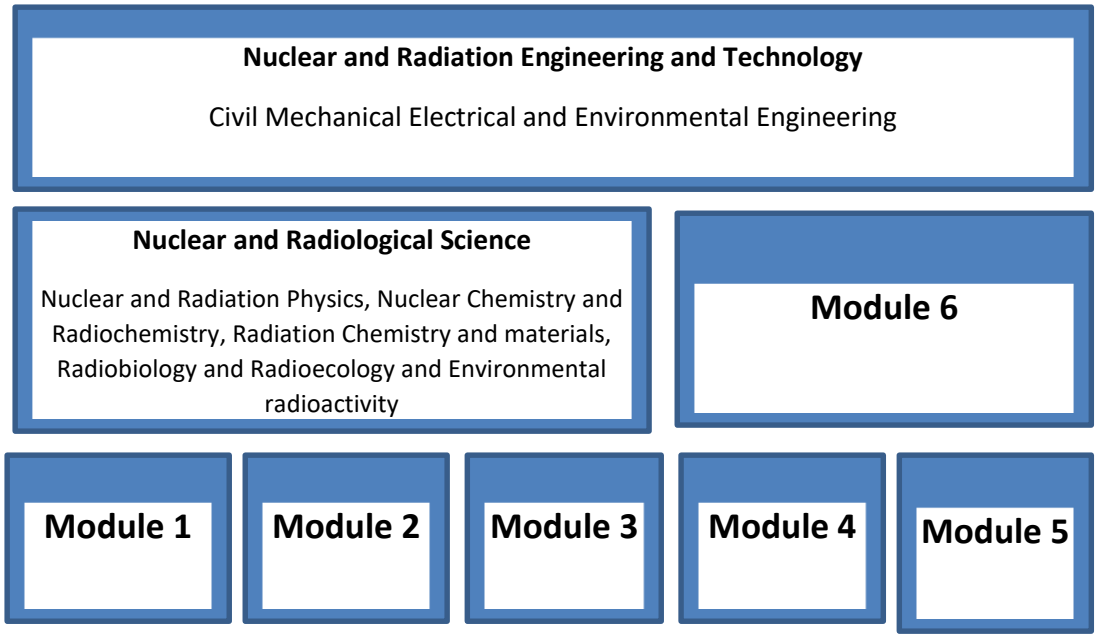
Competency-based training refers to a learning model where students must demonstrate the required level of knowledge and skill (competency) on a task prior to advancing to the next task (IAEA. 2014). The competency-based education (CBE) approach allows students to advance based on their ability to master a skill or competency at their own pace regardless of environment. This method is tailored to meet different learning abilities and can lead to more efficient student outcomes.

4.5.5. Curriculum development Proposal for Nuclear Science and Engineering

Developments of educational programs and curriculum development activities by some universities in Ethiopia have shown some developments in integrating nuclear education in their education base. The Addis Ababa Technology University has established a research sector in Nuclear Power Technology and have initiated a research reactor acquisition project for the development of the centre. A project by Bahir Dar University to integrate nuclear education in its education base has developed and proposed a new MSc joint curriculum (Murogov et al., 2009) in Nuclear Science and Engineering between the college of Science and Bahir Institute of Technology.

4.5.6. International Regional and National Educational Networks for Nuclear Knowledge

The International Atomic Energy Agency is the world's central intergovernmental forum for scientific and technical co-operation in the nuclear field. Cooperation with International, regional and national nuclear education networks provide solutions, best practices and lessons (Murogov et al., 2009). The national educational network in Ethiopia has not been properly organized so far. In Ethiopia there are many balkanized educational societies that are related to nuclear



Scheme 2. A Program Structure 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.

science and technology of which each of them fail into an overlapped mission and single goal. It may be better to bring stakeholders in the field into one national society 'The Ethiopian Nuclear Society' and establish a National Nuclear Network for Education in Science and Technology; 'The Ethiopian Nuclear-NEST' bringing stakeholders in nuclear industry in one bigger society as umbrella society with divisions and sub divisions depending on the needs.

5. Conclusions and Recommendations

This review set out to discuss why the peaceful use of nuclear science and technology makes sense in an Ethiopian context. Economic and environmental considerations point to the use of nuclear power generation as a viable option to include in the energy mix of Ethiopia and to accelerate sustainable development. The peaceful use of the nuclear fission process not only play a role in nuclear power generation but also in non-electric and non-power applications in medical agricultural and industrial sectors that can boost socioeconomic development. The IAEA has introduced stricter oversight and regulatory instruments to assist countries. Ethiopia, therefore, needs to be an active participant in the nuclear field, and not just an observer. Alternative sources of electrical power generation are currently attracting more attention, primarily due to the need for reliable energy source to support the economic growth, global demands for sustainability and environmental considerations. Ethiopia should strive to have as robust an energy mix as possible, taking advantage of its renewable and non-renewable clean resource endowment. A cooperative approach between Ethiopia and the international, regional and local organizations and industry and educational networks could assist in gathering critical mass for developing nuclear as a viable source of energy. As nuclear technology is highly regulated, Ethiopia also needs to develop robust infrastructures for the national nuclear program. .

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