Nuclear Safeguards with Digital Transformation for Sustainable International Development

Junho Kwon[1], Man-Sung Yim[1*]
[1]Korea Advanced Institute of Science and Technology (KAIST)
*Corresponding author: msyim@kaist.ac.kr

Abstract

The current international aid mechanism is unsustainable because the value flows unidirectionally. However, science, technology, and innovation (STI) can promote sustainability in international development cooperation. Particularly, the paper suggests a nuclear energy project and the nuclear safeguards system as sustainable international development programs in the context of digital transformation. The digital transformation of society requires a large, clean, and stable electricity supply, which nuclear energy can provide. Also, the technological innovations that can be achieved through the digitalization of a nuclear facility make the application of nuclear technology easier. Therefore, nuclear energy is expected to expand to meet the increasing demands of the future. However, the expansion of nuclear technology will increase the risk of nuclear proliferation. Therefore, an adjustment and enhancement of the nuclear safeguards system is required. By doing so, nuclear safeguards will be viable means of sustainable international development cooperation in the future. Based on the findings, the paper proposes a nuclear energy project and the safeguards as an international development cooperation program for North Korea's denuclearization.
Keywords: Nuclear safeguards, digital transformation, sustainable development, international cooperation

1. Introduction

A typical international development project is not sustainable because the international aid mechanism is unidirectional. Under the traditional structure of international aid, the aid and the influence flow only from a donor country to a recipient country [1]. This structure handicaps a recipient country's development capability by heightening its dependency on donor countries [2]. Therefore, a sustainable international development system is required.

In 2015, the United Nations (UN) member countries adopted the Sustainable Development Goals (SDGs). It is a universal action plan, to be implemented by 2030, to benefit all people and the planet by promoting prosperity, global peace, and freedom [3]. The SDGs which pursue a collaborative partnership among all countries and stakeholders should be the ultimate goal of a new international development system to resolve the unidirectionality of the traditional system.

STI (science, technology, and innovation) plays a significant role as a catalyst for the SDGs' implementation. STI is being discussed as an effective and efficient tool to promote sustainable development by increasing productivity, reducing costs, and thereby leading to the economic growth of a country while contributing to its environmental sustainability [4]. Also, STI policy roadmaps for the SDGs involve diverse stakeholders' participation in design and implementation [5]. This means that STI can ignite a reciprocal interaction between a donor country and a recipient country under a sustainable international development system.

As a part of STI, nuclear energy has several advantages that allow it to contribute to a sustainable international development system. Nuclear technology supports the implementation of all seventeen SDGs in various ways [6]. It is a well-qualified candidate for a large international development project because it is a high-level technology that requires long-term and nationwide efforts. For example, a typical well-planned nuclear power plant takes up to 11-12 years for construction and commissioning [7]. Therefore, a national government's engagement in determining, planning, and regulating is highly important in managing a nuclear power plant project [8]. Considering an international development project as a government-to-government interaction, a nuclear power plant project may be a suitable example.

In addition, contemporary digital transformation accelerates sustainable development. Generally speaking, digital transformation affects changes at all levels of societal life by applying newly emerging digital technologies, such as cloud computing, big data, the Internet of Things (IoT), and artificial intelligence (AI) [9]. It contributes to the achievement of the SDGs by improving the quality, relevance, efficiency, and impact of the UN Development Program (UNDP) through better data usage and sharing [9]. For example, the UNDP Guinea-Bissau Country Office has established a digital platform connecting local communities to share their innovative solutions to contemporary social challenges [9]. Through digital transformation, not only can progress in socioeconomic growth be achieved, but also environmental sustainability can be accomplished by decoupling carbon emissions from economic growth [10].

From this point of view, the present paper considers a sustainable international development system through nuclear energy cooperation amid the digital transformation era. Specifically, the research is focusing on the potential role of nuclear safeguards during the process of digital transformation. It discusses why and how nuclear energy and nuclear safeguards are useful to promote a sustainable international development system in the digital transformation era. Prior to this point, it considers the prospects of nuclear energy as a supporter and driver of digital transformation. On the other hand, change in the global nuclear industry and market due to digital transformation is also expected. Based on the findings, an adjustment and enhancement of the current nuclear safeguards system according to the potentially increasing demand for nuclear energy is discussed as a mean of sustainable international development cooperation in the future.

2. Digital Transformation and Nuclear Energy

Nuclear energy is inevitably related to the implementation of digital transformation, while it is also being supported by digital transformation. The first part of the present section discusses the contribution of nuclear energy to digital transformation. The next subsection includes digital transformation happening throughout the nuclear energy sector.

2.1. Nuclear energy for digital transformation

First, the high energy density of nuclear power source is the most important feature. A single uranium fuel pellet (about ten grams) contains as much energy as one ton of coal, 149 gallons of oil, or 17,000 cubic feet of natural gas [11]. As mentioned above, new emerging technologies leading the digital transformation are all data-driven. Data processing and storage require large amounts of electricity. Total energy consumption by data centers around the world is estimated to be 200 terawatt-hours (TWh) each year, which, for example, is more than the total annual energy consumption in Iran [12]. Moreover, as the demand for information and communications technology (ICT) is increasing, it is predicted that by 2030 data centers will account for about 20 percent of total global energy consumption [12]. Thus, the skyrocketing energy demand due to digital transformation cannot be met without nuclear energy because nuclear has a significantly large energy density compared with other energy sources.

Second, nuclear energy is environmentally friendly to support a carbon-neutral digitalized society. Nuclear power produces very little amount of carbon emissions when generating electricity, and it can meet the surging energy demand of the digitalization of industries. This reduced CO_2 generation makes nuclear energy eco-friendly when compared with conventional fossil fuels. While coal-fired electricity generation emits 820 grams of carbon dioxide-equivalent (CO_2-equivalent) greenhouse gas (GHG) per kilowatt-hour (kWh) throughout its life cycle, nuclear power emits only 12 grams of CO_2-equivalent GHG per kWh [13]. Therefore, the environmental sustainability of digital transformation can be carried out by nuclear energy.

The third point is stability in the supply of nuclear energy. Digitalization and automation of industry enable a 24/7 business model, which requires a stable 24-hour electricity supply. Therefore, nuclear energy as a baseload electricity generator will be increasingly necessary as digital transformation continues to expand. In contrast, renewable energy such as wind and solar power can rapidly vary in electricity production due to the intermittency of wind and sunlight. California, which relies on renewable energy for thirty-three percent of its total electricity supply, experienced a huge blackout in 2020, as the electricity generation from renewable energy couldn't match regional electricity demand [14]. In addition, in a macroscopic and long-term view, nuclear energy maintains its economic stability. While fuel costs account for 78 percent and 87 percent of the operating costs for coal-fired plants and gas turbine plants, respectively, only 34 percent of the operating costs of nuclear power is fuel cost, and the remainder is operation and maintenance (O&M) costs [15]. Therefore, nuclear energy poses a smaller risk to supply chain security when compared with fossil fuels, considering a rapid change in the global energy source market. This is noteworthy amid the recent global energy security crisis because of the pandemic and wars. For example, the destruction of global natural gas supply chains due to the Ukraine war has led to difficulties in energy security in European countries [16].

Fourth, the flexibility of the next-generation nuclear reactors is also noteworthy. When considering an international development program for the region with poor social infrastructure such as electricity grid, digitalization of the community would require more flexible energy sources to minimize the impacts of drastic change due to the development. At this point, a small modular reactor (SMR) is highly accessible to the regions thanks to its small size [17]. The accessibility is highly characterized by portable microreactors, which can be mobilized by vehicles [18]. In addition, such small-sized nuclear reactors are easily dispatchable by adjusting their output according to the region's electricity demand so that they can be hybridized with intermittent renewable energy sources; this feature ultimately contributes to achieving the seventh SDG which aims for universal access to modern energy [19].

Lastly, thanks to the aforementioned advantages of nuclear energy, it can be applied to diverse fields of industry beyond electricity generation. The heat produced by nuclear energy is used for the desalination of seawater, hydrogen production, refining and synthesis of gas products, and industrial process heating [20]. Therefore, nuclear energy is expected to show its synergetic potential to support newly emerging industries according to digital transformation while meeting carbon neutrality. Considering the flexibility of an SMR and microreactors, the effect can be expanded to the regions beyond rural areas, which are still under development.

2.2. Digital transformation for nuclear energy

On the other hand, digital transformation is also happening throughout the nuclear energy industry. Digital technology is enhancing the cost-effectiveness of the whole lifecycle of a nuclear power plant, including design, construction, operation, and dismantlement, by replacing human labor with automatic systems [21]. For example, a nuclear power plant's digitalized instrumentation and control (I&C) system facilitates the automatic optimization of equipment according to performance targets and safety requirements, with a high level of confidence in its accuracy [22]. Since O&M accounts for most of the total operating cost of nuclear energy as noted above, the digital transformation of the I&C system can reduce the socio-economic burden of nuclear energy to potential newcomer countries. For example, the high social cost of nuclear energy is due to the public's perception of its risk [23]. This perception can be moderated by enhancing nuclear safety through digital transformation. Simultaneously, the economic O&M cost of nuclear energy will also decrease [24]. Therefore, digital transformation can lower the social and economic barrier against nuclear energy for countries with less experience in nuclear power.

2.3. Increasing global demand for nuclear energy and the proliferation risk

Since nuclear energy has a large capacity to support digital transformation and vice versa, it is expected that the global demand for nuclear energy will increase in the future. The International Atomic Energy Agency (IAEA) projects that world nuclear energy generation capacity will double from 393 gigawatts of net electricity (GWe) in 2020 to 792 GWe by 2050 [25]. In fact, about 55 new nuclear reactors are already under construction as of 2022, which is equivalent to about fifteen percent of the existing capacity of the total nuclear power plants worldwide [26]. Approximately thirty more countries are considering, planning, or starting their first nuclear power programs, and additional twenty countries have expressed their interest in nuclear energy [27].

However, global nuclear proliferation risk is also expected to increase at the same time. Even though a commercial nuclear power plant is prevented from being converted into a nuclear weapons-related facility by various technical devices and political institutions, the expansion of nuclear energy inevitably causes wider dissemination of nuclear materials throughout the world. This raises the potential nuclear proliferation risk [28]. Furthermore, some advanced nuclear reactor types that are currently under development can newly heighten the proliferation risk. For example, an SMR can raise concerns about its proliferation risk, since several designs require a more highly enriched uranium fuel than typical large nuclear reactors [29]. Also, the characteristic mobility of a microreactor can make monitoring and tracking nuclear materials more difficult [18]. More importantly, since most of the potential newcomers to nuclear energy are developing countries, the lack of their ability to establish a reliable nuclear safety and non-proliferation culture is considered a major concern and challenge for the nuclear industry and the international community [30]. Thus, it is required to globally discuss to sustain nuclear non-proliferation against the upcoming change in the global nuclear reactors market which is expected to grow and be diversified by the influence of digital transformation.

3. The Role of Nuclear Safeguards in International Development Cooperation

At this point, nuclear safeguards can play a significant role in international development cooperation for its sustainability. International nuclear safeguards are expected to promote the multi-directionality of international development programs if nuclear energy cooperation is used as a program.

Nuclear safeguards are a set of measures used to verify a state's legal obligation not to divert nuclear facilities and materials for non-peaceful purposes [31]. Under the international nuclear non-proliferation regime centered in the Nuclear Non-proliferation Treaty (NPT), all states using nuclear technology for peaceful purposes are required to join multilateral or bilateral agreements [32]. For example, as a multilateral agreement, all non-nuclear-weapon states (NNWS) of the NPT members shall consent to the Comprehensive Safeguards Agreement (CSA) accepting the IAEA's independent monitoring and verification [33]. Also, a nuclear technology supplier country is required to make a bilateral agreement with the importer country. An example is the nuclear cooperation agreement between South Korea (a nuclear exporter) and the United Arab Emirates (a nuclear importer) to ensure the peaceful use of nuclear power [34].

These bilateral and multilateral nuclear agreements can provide an institutional basis for bidirectional and multidirectional interactions between nuclear suppliers and importers, thus replacing the unidirectionality of the current international development programs. As it is expected that the demand for nuclear energy will surge, more cases of nuclear technology export and relevant negotiations are foreseen. To prevent such technology transfer from being diverted to undesirable military actions, a reformation of the nuclear technology export regime by building consensus on the technology supply conditions and enhancing constraints on the rule-breaking through several consortium and joint deals was suggested [35]. Based on this idea, nuclear safeguards can be used to build trust among nuclear suppliers and recipients and they can make a virtuous cycle to foster international cooperation through nuclear technology export. In other words, the nuclear exporter should keep monitoring and supporting the nuclear importer's non-proliferation, while the importer should continuously implement nuclear safeguards. Also, since a nuclear power plant project is conducted at the governmental level in a long term, such a relationship between the countries mediated by nuclear safeguards may last at least a few decades, so that temporal sustainability is guaranteed. Furthermore, based on the sustainable relationship among the parties, additional programs may be derived from nuclear safeguard activities, such as research and education cooperation in nuclear safeguards policy and technology.

3.1. The role of digital transformation in nuclear safeguards

Particularly, digital transformation can enhance the contributing role of nuclear safeguards by promoting efficiency. Introducing digital technologies to nuclear safeguards enables the implementation to be easier, overcoming the limitations of conventional monitoring and verification system.

First, digitalized remote monitoring and information transmission facilitate unattended nuclear safeguards which solve the limited capacity of manpower to reach out to rapidly increasing and widely spreading nuclear facilities. The improved efficiency of digitalized nuclear safeguards helped the IAEA to overcome hindered onsite reachability due to COVID-19 and aided the inspectors to draw soundly-based nuclear safeguards more quickly [36]. A demonstration test showed that a digitalized multi-agencies remote monitoring system is reliable without compromising data confidentiality [37].

Beyond information transmission, digital technology plays a key role in data analytics by reducing input human resources. A machine-learned AI easily detects outliers from large datasets of satellite imagery and environmental sampling [38]. For example, an AI-based technique was developed for nuclear forensics of a mixed nuclear material sample, which makes the forensics harder to track the production and burnup history [39]. Such digitalized analytics would shorten the time required for increasing size of nuclear safeguards.

The AI technology can also be supported by another digital technology: digital twin. A virtual environment depicting diverse types of nuclear facilities can be demonstrated through digital twins and they could provide a large amount of data that can be used for a training of a machine-learning model, through a number of simulations [40]. The technology would also reduce the cost of nuclear facility workers education, which could be a part of a cooperation between a nuclear exporter and importer as mentioned earlier.

In addition, digital information security technology such as blockchain is helpful to enhance nuclear material information management by preventing it from being contemplated [41]. A nuclear material accounting and control (NMAC) system whose data is saved in the form of blockchain promotes transparency of information such as nuclear material movement history between facilities and countries, so that reduces costs and delays in the regulator's processes [42].

On the other hand, the digitalization of nuclear safeguards is projected to inherently bring openness and interconnection of information that has been classified conventionally. Therefore, global discourses on the norms in digitalized nuclear safeguards are needed simultaneously. It can also promote active and multidirectional engagement of both nuclear newcomers and their technology exporters by building trust through such rulemaking.

3.2. Case study: North Korea

A more concrete future direction of nuclear safeguards can be derived from the history of nuclear safeguards in the Democratic People's Republic of Korea (DPRK, North Korea). North Korea became a member state of the NPT in 1985, and inspections by IAEA under the Safeguards Agreement began in 1992. However, IAEA could not completely and correctly verify North Korea's nuclear activities due to its noncooperation [43]. After a series of nuclear crises in North Korea, it finally withdrew from the NPT in 2003 and then conducted a nuclear test in 2006 [43]. As a de facto nuclear state [44], North Korea has been developing its nuclear weapons capability counter to the global nuclear non-proliferation regime. The case of North Korea is now seen as a limitation of current nuclear safeguards or a challenge to it [32].

This history implies that the framework of nuclear safeguards as a unidirectionally restrictive regulation should be transformed. The reason for North Korea's 1993 refusal to submit to a special inspection requirement by IAEA was that it considered the requirement an infringement on its sovereignty [45]. The advancement of North Korea's nuclear weapons program these days is seen as a failure of the nuclear safeguards based on the "crime-and-punishment" strategy [45]. Without resolving this problem, it would be difficult to strengthen the current nuclear safeguards system by increasing participant countries or bringing back countries that withdrew from the system.

A potential solution to this challenge is to integrate nuclear safeguards with international development cooperation. An international development cooperation project could include the construction of a nuclear power plant, and nuclear safeguards would be a part of the project as a step in a long-term process. Compliance with nuclear safeguards would be a voluntary activity of the recipient country (nuclear importer) to achieve its socio-economic development. Accordingly, nuclear safeguards would not be a mandatory measure imposed as a conditional requirement for receiving nuclear technology. Such a framework would reduce controversies about sovereignty since it would involve a cooperative global effort for achieving sustainable development.

This approach could be applied to North Korea which has recently experienced a huge economic crisis. With a plunge in overseas trade due to the pandemic, coupled with the international economic sanctions against North Korea, it has been reported that the supreme leader Kim Jong-Un anomalously admitted to the failure of its economic development policy in almost all sectors recently [46]. If North Korea needs and wants a large amount of electricity to reconstruct its economy, international cooperation to build a commercial nuclear power plant as a sustainable international development project can be considered. An international consortium can be structured to plan and implement the project which also contains continuous implementation of nuclear safeguards under the cooperation among the parties. Since it automatically brings North Korea under the international nuclear non-proliferation regime through various bilateral and multilateral agreements, it can be an innovative way to make a breakthrough toward the denuclearization of North Korea. Such an approach is analogous to a "techno-diplomatic approach to engaging North Korea" [47]. A civilian nuclear power plant project as an international development effort could lead North Korea and other participating countries to actively play a role in diverting the nuclear weapons program into a peaceful nuclear energy program.

4. Conclusion

Nuclear energy technology can significantly contribute to building a sustainable international development model in the digital transformation era. As a part of STI, nuclear energy can support and enhance the socioeconomic capacity for sustainable development, which is being accelerated by digital transformation. Other than its technical advantages for implementing the SDGs, a nuclear energy project also has the potential to improve the unidirectional flow and structure of the conventional international development mechanism through nuclear safeguards. A recipient country that is a nuclear newcomer and importer promotes its sustainable development through nuclear energy with its continuous implementation of nuclear safeguards. On the other hand, a donor country that exports nuclear technology maintains its long-term and reciprocally influential relationship with its counterpart through continuous monitoring and technical support for nuclear safeguards. The two sides can have leverage with each other through nuclear safeguards, which can foster continued efforts in global nuclear non-proliferation. Moreover, the technical benefits of digital transformation are expected to contribute to nuclear safeguards for nuclear energy cooperation as a sustainable international development project.

From the present study as a starting point, more discussion is needed to promote the integration of nuclear energy and international development cooperation. A detailed structure along with the mechanism of nuclear cooperation will make the integration more feasible. Also, beyond the projects for nuclear power plants, nuclear cooperation can be expanded to include various nuclear technologies, such as radiation biology and medicine. By doing so, nuclear technology will no longer hinder global peace and prosperity but instead contribute to sustainable global peace and prosperity. This new approach to nuclear energy as a medium of international development cooperation is expected to be a role model of science diplomacy in a cooperative manner rather than from a competition-based perspective. Also, the role of nuclear energy in international development cooperation is expected to improve the social perception of the technology and enhance public acceptance in the future.

Acknowledgment

This work was supported by the National Research Foundation of Korea (NRF) grant funded by the Korean government (Ministry of Science and ICT) (No. NRF-2022M2C7A1A02063817).

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