Digital Infrastructure Attributes for Nuclear Energy Transition

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Abstract

Creating policies that could aid in the rapid development of the next generation of nuclear professionals is crucial for the upcoming years. New emerging technologies could be part of the transition process in the direction of the framework of a Digital Infrastructure in the Nuclear Capacity Building Programs among the Member States. Prior to the COVID-19 epidemic, workplace physical activity encouraged a productive environment among the staff. However, during and after the pandemic, the situation undergoes a transition period in which individuals may work from home or in distant places, which boosts worker productivity and offers flexibility in working hours. This new environment is known as a hybrid world.

The shift to digital engineering will have an impact on the research, specifications, procurement, testing, budget, maintenance and support, and analytics sectors, in addition to the engineering community. This is due to the fact that staff workers will need new tactics, processes, and equipment.

The Super Decisions Software was used to create a model based on the ANP. In order to determine whether or not various factors are in the digital transformation process, the model outlines a number of standards, alternatives, and regulatory concerns. It then assesses the most crucial areas using quantitative and qualitative research.

The ANP uses ratio scales to keep track of all interactions, provide accurate projections, and make even better judgements. While necessary, clusters of related elements are taken into consideration when determining scale-dependent priority from the dispersal of components and clustering using the ANP.

The result demonstrates how the Node Sensitivity Analysis prioritizes optimizing the current nuclear technology. After that, the community should be included. Then, flexible energy regulations should be proposed, and resources like quantum computing, HPC, and digital twins should be optimized and standardized for deployment.

The nuclear industry is now using a variety of tactics to develop technology and attain global energy security. Applying innovative features to regulation via sustainable enabling technologies will increase the capabilities of these technologies by looking at the benefits at the industrial level for the expansion of human power.
1. INTRODUCTION

The digital transformation process involves a wide range of applications, where electricity generation has a new era of digitalization. To reach by 2050 the decarbonization goals, it is important to identify which potential areas can provide innovative approaches and tools to deploy nuclear technology for the benefit of humankind. Since emerging digital technologies offer new benefits to exploring the technology and integrating them into the real world, the brand new approaches add a huge value to incorporating the latest methods to reduce the use of computational resources to industrialize nuclear technology and reduce Greenhouse Gas Emissions (GGE) [1]. For instance, Digital twins play a principal role where the commissioning and full cycle operation of nuclear facilities can help in the licensing process to commercialize nuclear technology.

Considering the perspectives of addressing the attributes and prosperous areas to develop a Digital Infrastructure in a Nuclear Program where the human resources will experience and energy transition from the physical to the digital world. Having a digital infrastructure will provide alternatives for global energy security and increase the opportunities to expand the Research and Development (R&D) projects at the organizational level. Acknowledging the advantage of deploying more digital tools using other types of hybrid models applying Machine Learning (ML), Artificial Intelligence (AI), Augmented Reality (AR), High-Performance Computing (HPC), and Quantum Computing (QC), among other alternatives.

Section 2 lists the new challenges in the hybrid world toward a Digital Energy Transition (DET). The challenges are considered from the physical and technological perspectives and provide new technological enablers to promote the collocation of high-tech devices in the hybrid world to empower the interaction between the physical and the virtual world. The potential Digital Engineering Deployment approaches are listed in section 3, mentioning new tools to perform and deploy technology in a large scale. The new models should be simplified and created to make use of the potential advantages of the new computing era. The Analytical Network Process (ANP) is the applied methodology to carry out the simulations data in SuperDecisions software, using a conceptual model to evaluate the different aspect in the digital transformation process, all the information is described in Section 4. The results of this study are found in Section 5. Finally, Section 6 discusses the limits of the study and the final observations.

2. NEW CHALLENGES IN THE HYBRID WORLD

Before the COVID-19 pandemic, the productive atmosphere among the workers were oriented in physical activities developed in the office. But during and after the pandemic, the situation turned into a transition process where people are able to work from remote locations or from home, which increases the level of productivity from workers providing flexibility in the working time; this is known as a Hybrid World. The globe rapidly transitioned to a virtualized workplace. Nevertheless, not all results have been negative; some have actually been better than predicted[2].

It should go without saying that business-critical infrastructure requires a home and must be strong enough to enable distant and hybrid working. The moment has come to think about separating technology from the office workspace and outsourcing the challenging task of maintaining internal servers to a specialized colocation provider while long-term real estate choices are being made.
Moving IT equipment off-site will free up additional space for collaborative workplaces, meeting areas, and hot-desking, allowing for cost savings while enhancing performance and sustainability[1].

2.1. Physical

It is quite evident that companies are now carefully considering their operating needs for real estate and office space. It does not matter whether they are considering how to negotiate new contracts with key stakeholders in the nuclear program or what cost savings may be gained from this new method of working, such as cutting down on office space or making the most use of floor space. Additionally, the IT server room or internal data center should be flexible enough to accommodate whether the businesses operate from the same location(s) or move. It is not uncommon to ignore the beneficial influence that IT could have on these strategic choices.

2.2. Technological

It should go without saying that crucial corporate infrastructure needs to be kept somewhere and be durable enough to support remote and hybrid working. The moment has come to consider separating technology from the office workspace and hiring a specialized colocation provider to handle the challenging process of managing internal servers now that long-term real estate decisions have been made. Moving IT equipment off-site will free up more space for hot-desking, conference rooms, and collaborative workplaces, providing for cost savings while also enhancing performance and sustainability.

2.3. Alternative Solutions

Colocation may assist organizations wishing to restructure or reorganize their tangible impression to liberate priceless office space, allowing for alternative uses or decreasing the overall amount of office space needed. Even if an office is not entirely remote, there are a ton of other reasons to move computers from on-premises to a third-party facility. Significantly, accessing cloud services quickly and easily is made possible by locating IT resources in a geographically localized, which, in present remote/hybrid world, are nearly usually a part of any remote working strategy. Companies will be able to set up and leverage the ever-expanding cloud environment more quickly than they can with in-house IT thanks to the robust, reliable, and integrated data center architecture.

Physical security is a major benefit of colocation when firms transition to virtual or hybrid working. How is it possible to know at the most fundamental level that the IT infrastructure is secure if the server room or data center is a part of a vacant office building? This physical security element may be a concern even if employees work there. Peace of mind is offered by the colocation facility's gold standard physical security measures and the presence of trained data center employees.

Colocation is appealing since it satisfies not only present needs but also supports future objectives, whether they include expansion or decrease. In fact, colocation makes it possible for businesses to scale up or down their infrastructure to match their unique needs without having to pay additional, sometimes stratospheric, capital expenses. Demands on digital infrastructure and actual office space will surely increase and change due to the coronavirus outbreak, which inspired this creative blend of remote work and on-site presence.
The fact that servers are off-site and not located in the office does not make maintenance any more challenging. The only difference is that the systems are now housed in a safer, more reliable, and more effective environment while remaining under the control of the organization. Organizations can build up flexible physical and remote access in centralized data centers to accommodate upcoming changes. Organizations can build up flexible physical and remote access in centralized data centers to accommodate upcoming changes. Redundancy in terms of facilities and networks should not be overlooked. Industrial activities cannot afford for systems to go down because of a power outage or a breakdown of the facility's major cooling system because so many employees are now working remotely. In today's extremely competitive industrial environment, corporate continuity will continue to be important.

2.4. Working remotely has a great potential

It is the ideal time to review IT infrastructure and office space given this considerable change in working patterns. In this era of transition, businesses should examine their requirements for long-term achievement and think about removing technology from the workplace. Corporations may increase the efficiency of their IT infrastructure by hiring a colocation data center expert to handle their internal servers. Utilizing colocation, businesses may redesign their office space to better suit contemporary working needs, increase productivity, and save costs. The New Energy Transition Era (NETE), which includes all of the aforementioned components, will deliver technological benefits to scale up the human resource chain in a flexible environment. NETE provides a potential Hybrid Energy World (HEW) for the present and next generations of nuclear specialists.

3. POTENTIAL DIGITAL ENGINEERING DEPLOYMENT

New methods to warehouse architecture are being used to introduce new tools to execute and install technology at a big scale. Simpler and new models should be developed to take advantage of the potential benefits of the new computer era. With the help of digital engineering, stakeholders will be able to interact with technology and find new, creative methods to address challenges. The shift to digital engineering will also resolve the complex, ambiguous, and fast-changing problems that arise in the deployment and usage of energy systems[3].

While the move to digital engineering will change how engineers operate by requiring new approaches, processes, and tools, it will also have an impact on the research, requirements, acquisition, test, cost, sustainment, and intelligence communities in addition to the engineering community. The change to digital engineering is resulting in similar advantageous advancements in company operations, such as acquisition procedures, regulatory requirements, and contractual activities [3].

Organizations will develop formal methods for model development, curation, integration, and related program and enterprise engineering activities during the course of their existence. Plans will specify how models will be used consistently and effectively when decisions, evaluations, and activities are accomplished. In the area of digital engineering, lifecycle analysis integration models are graphically shown in Figure 1.

Digital technology has changed society, the economy, and the day-to-day activities of people at work and at home. The energy transition, which includes fusion, renewable energy sources,
energy efficiency, is aided by collecting large amounts of data[4]. The global shift to renewable energy and the economic benefits of digital transformation are two of the top policy concerns that are intrinsically linked to data. The European Commission has started the initiative European Green Deal to address the dangers posed by environmental deterioration and climate change. While the connection to the digital transformation is clear, it is less clear but no less important how digitalization may contribute to our long-term objective of being carbon neutral by 2050 [5].

Figure 1. Connected models for lifecycle analysis

3.1. Digitalization and Data Sharing

A few examples of digitalization include Artificial Intelligence (AI), improved data processing, the Internet of Things (IoT), and Machine Learning (ML). Through the entire supply chain, from infrastructure planning, commissioning, operation, and maintenance to energy generation and transmission, consumption, and decommissioning, these new technologies offer significant opportunities to improve efficiency and manage the complexity of the energy system.

The energy system must become more digitalized and incorporate cutting-edge technical solutions as it becomes more decarbonized and decentralized. Data must be transferred from one place to another, for example, from a data center to a home or from a car's battery to a charging station and the energy network operator. Such data must be transported through a secure, dependable network and on a platform that enables easy communication among the several parties concerned.

Local and regional governments may profit from data exchange in areas like energy performance audits, renovation projects, and the creation, planning, and execution of sustainable energy and climate action plans. A shared energy data space will be founded on basic rules regarding who may access data, when they can access it, and how they can access it. The numerous stakeholders in the
energy system, including suppliers, infrastructure operators, energy system providers, and consumers, would gain from improved data exchange and use in the sector[4].

### 3.2. Data Driven Innovation (DDI)

The consumers are the center of the energy system. The tools customers need to become "prosumers," or active players in the electrical market, can be provided via digital solutions. Organizing cooperatives, investing in renewable and sustainable energy sources, participating in local energy communities, and exchanging power via peer-to-peer platforms are just a few examples of how digitalization makes it easier for people to do. These activities all help to increase the flexibility of the future electrical system overall.

In addition, it makes it possible to create new services that are more suited to meet customer needs. Data-driven innovation is therefore essential to meeting the global decarbonization targets for both energy and climate. New sorts of digital transactions in the banking industry and elsewhere are now possible because to blockchain and other cutting-edge technological advancements. Similar to this, blockchain technology has the potential to provide a wide range of new opportunities in the energy industry, such as rewarding flexibility in power use [4].

### 3.3. A Cybersecurity Digitalization

Digitalization also exposes the energy sector to new dangers. Cybersecurity and digitalization are related concepts. Data sharing can only occur in a secure environment since the information supplied over the internet is sensitive and required to fulfill daily obligations. Because of this, in the modern world, ensuring supply security also necessitates strengthening our defenses against any coordinated cyberattacks intended at the global level of an energy infrastructure. Therefore, it should emphasize the collaboration between various members on policies to ensure that the global electrical system complies with the strictest cybersecurity standards.

The energy sector is simultaneously exposed to new dangers as a result of digitalization. Cybersecurity and digitalization are two sides of the same coin. Data sharing is only possible in a secure setting since the information transferred over the internet must be both sensitive and vital to fulfill daily obligations. As a result, in the modern world, ensuring supply security also necessitates boosting our capacity to fend off any coordinated cyberattack on the global level of energy infrastructure. In order to ensure that the global electrical system complies with the strictest cybersecurity standards, it should emphasize the collaboration between various members on the rules.

### 4. DESCRIPTION OF THE METHOD

The Analytical Network Process (ANP) has been implemented in SuperDecisions Software. The ability of the ANP to record all interactions to generate precise forecasts and even better judgments is based on its usage of ratio scales. The ANP gives a precise framework to evaluate the method by which ratio scale priorities are retrieved from the distribution between elements and clusters, considering clusters of related elements as needed[6]–[9]. The ANP is the first mathematical theory that systematically enables users to deal with all types of dependency and feedback. Two parts make up the ANP’s coupler. In first, a control hierarchy or network of criteria.
and subcriteria governs the interactions in the system under examination. The second is a network of interactions between elements and clusters. The network varies depending on the control criterion, and a supermatrix of limiting influence is generated for each control criterion. The results are then combined by adding the values from each of these supermatrices according to the significance of each control condition[10].

Making the assumption there is a system of \( N \) clusters or components, where each component's elements interact with, have an impact on, or are themselves influenced by some or all of the elements of that component or of another component in terms of an asset governing the interactions of the overall system, such as energy, capital, or political influence. Assume component \( h \), represented by \( C_h, h = 1, \ldots, N \), contains \( n_h \) components, which are represented by \( e_{h_1}, e_{h_2}, \ldots, e_{h_n} \). The influence of a certain set of elements in a component on another element in the system is shown by a priority vector that is produced from paired comparisons conventionally. An element's influence priority is assigned (not derived) as zero when it has no impact on any other elements.[8]

Each priority vector entered as a component of a supermatrix's column is derived using pairwise comparison matrices. The supermatrix represents the influence priority of an element on the left of the matrix on an element at the top of the matrix[11]. Equations 1 and 2 depict a supermatrix together with a sample of one of its general entry \( i, j \) blocks. All of the priority vectors computed for nodes that are "parent" nodes in the \( C_i \) cluster are included in the component \( C_i \) that is next to the supermatrix. A hierarchy's supermatrix and its supermatrix are provided in Equation 3. The identity matrix \( I \) is the item in the final row and column of a hierarchy's supermatrix.

\[
W = \begin{bmatrix}
e_{11} \\
e_{12} & W_{11} & W_{12} & \cdots & W_{1n} \\
\vdots & \vdots & \vdots & \ddots & \vdots \\
e_{m1} & W_{m1} & W_{m2} & \cdots & W_{mn} \\
e_{mn} & \end{bmatrix} \quad \quad W_{ij} = \begin{bmatrix}
w_{i1} w_{j1} & w_{i2} w_{j2} & \cdots & w_{in} w_{jn} \\
w_{i2} w_{j1} & w_{i2} w_{j2} & \cdots & w_{in} w_{jn} \\
\vdots & \vdots & \ddots & \vdots \\
w_{in} w_{j1} & w_{in} w_{j2} & \cdots & w_{in} w_{jn} \\
w_{in} w_{ji} & \end{bmatrix} \quad (1)
\]

\[
W = \begin{bmatrix}
0 & 0 & 0 & \cdots & 0 & 0 \\
W_{21} & 0 & 0 & \cdots & 0 & 0 \\
0 & W_{32} & 0 & \cdots & 0 & 0 \\
\vdots & \vdots & \ddots & \vdots & \vdots & \vdots \\
0 & 0 & 0 & \cdots & W_{n,n-1} & I \\
\end{bmatrix} \quad (3)
\]

### 4.1. Nuclear Digital Doughnut Transformation

The Nuclear Digital Doughnut Transformation (ND\(^2\)T) will provide a model to identify criteria for the regulation, attributes and enabling technologies assessment in the different areas to address in
the nuclear power infrastructure. The main objective of these components is to standardize and modularize the digital energy transition process. Establishing a framework to select the criteria to apply in a particular aspect of the nuclear energy project. Harmonizing codes and standards will facilitate the advanced nuclear technology deployment at the industrial level, for example, digital manufacturing process, commissioning and decommissioning protocols, advanced construction approaches, nuclear safety system analysis, instrumentation and control equipment, and other robust technologies supporting the digital transition. The ND²T model lists several areas to study deeply, tackling several challenges for the stakeholders. Integrating the ND²T model with future nuclear reactor designs will improve the operations of the existing NPPs. Digital Twins (DT)-enabling technologies are linked to better digital integration, improved instrumentation and control systems, and advanced operations and maintenance methods [12].

Figure 2. Nuclear Digital Doughnut Transformation components

4.2. Description of the model

A model based on the ANP was built in the Super Decisions Software. The model puts out a number of standards, options, and regulatory considerations, assessing the most important areas through quantitative and qualitative research to evaluate the presence of different aspects in the digital transformation process. It has been divided at the same time in three sub-networks (1) Regulation, (2) Attributes, and (3) Enabling Technologies, as appears in Figure 3.
Each sub-network contains a set of three control criteria specifically fit within the framework of the sub-network's target. The control criteria will help evaluate the alternatives linked according to the information presented in Figure 2. The purpose of this model is to incorporate as many elements as possible to evaluate more possibilities and their impact on the energy transition process.

![Figure 3. Analytical Network Process Model for Building a Digital Infrastructure](image)

5. RESULTS

The results show key areas to divert the Research and Developing (R&D) Projects to implement new areas where personnel could develop their skills and expand their opportunities. Establishing the foundation of the nuclear energy policies where the migration to digital engineering is crucial needs to be addressed.

5.1. Synthesized Priorities

The Synthesized priorities are expressed in a scale factor from 0 to 1, showing ideal, normal and raw distribution among the alternatives in the digital nuclear transformation. The information appears in Figure 4, and in total 12 alternatives are proposed based on specific control criteria belonging to the subnetwork categories of the study. Considering the normalized values, High-Performance Computing (HPC) is one of the most representative technologies to deploy at a large scale, with a normalized ratio of 0.104414.
Since these technologies are becoming more mature and offer several areas of application like medical physics, molecular science, particle physics or nuclear sciences, researchers could develop more simulations to find accurate solutions through algorithms configuration in several systems. Following the sequence of the values, to deploy robust technologies is always important to consider the existing technologies to find areas for optimization and saving resources. Moreover, the main capacity of all the infrastructure is the human capacity, and that is why people's engagement is needed because it is the same value as the previous ones. Quantum Computing is the fourth representative alternative, with a value of 0.097683. Quantum computers might help engineers develop more accurate simulations of the quantum effects they are starting to uncover in today's tiny transistors. However, more study has to be done in this area. According to more experts, quantum computers will not displace traditional computers; rather, they will complement them and be utilized as accelerators in a similar way to Graphical Processing Units (GPUs) now.

5.2. Node for Sensitivity Analysis

The outcome shows the Node Sensitivity Analysis (NSA) for the global model positioning the engagement of people as a priority to empower with 11%. Followed up by 10% in digital twins, HPC, Quantum Computing, include all the existing nuclear technologies, optimize and standardized the resources to deploy, and propose flexible energy policies, respectively. The cited elements are key driving paths to accomplishing the energy transition. In the sensitivity analysis, the people's foundation, engagement and autonomy decision are the key-driven outcomes to stress in the human power capacity. The detail NSA is shown in Figure 5, while the summary version is displayed in Figure 6 expressed in percentage ratios.

A well-known idea is the international standardization of products and services. For standardization to be practical, technology must be developed enough to use designs with a symbol of quality and safety. This is especially true of modern nuclear reactor designs, which are the product of more than 50 years of research and development. The idea of standardized reactor designs envisions a day when reactors may be constructed in any nation without adhering to particular national
Digital Twins (DT) technologies have just begun to be used in the nuclear sector, both in the advanced reactors and the fleet of present light-water reactors. The state-of-the-art survey report may find a thorough description of DT use in the nuclear industry[14]. A variety of applications throughout a lifecycle of a plant, such as design, licensing, regulatory compliance, emergency response, modification, engineering analysis, construction, operation and maintenance efficiency, and testing, are the focus of these efforts, which involve interdisciplinary collaboration between advanced reactor designers, nuclear utilities, DT vendors, university researchers, and national laboratories.

Numerous commercial and scientific applications depend heavily on large-scale computing. High-fidelity simulations are crucial in the nuclear industry because to the need for exact simulations and reliable source data for validation principles. Due to the high processing power needed, these simulations must be done on specialized computer systems[15]. High-Performance Computing (HPC) equipment can process massive amounts of data, speeding up our work and, in some cases, even saving lives. However, since computer models can now do the computations at a far higher resolution, the results more closely mirror the real world [16]. In several areas of nuclear energy, including materials science, structural integrity, neutronics, and thermal-hydraulics, HPC is used [17].
The node sensitivity analyses for each subnetwork are displayed in the upcoming graphics. For the Attributes, Enabling Technologies and Regulation data appear in Figures 7A, 7B, and 7C, respectively. The three subnetworks evaluated the 12 alternatives with normalized values and the most representative alternatives in each case. The graphs show an average increasing tendency and decreasing as well. The most representative values for the Attributes subnetwork are shown between 0.2 and 0.4 normalized alternatives: the engagement alternative taking the first rank, followed by the people's foundation alternative, and finally, the autonomy decision. In the Enabling Technologies subnetwork, the maximum values are between 0.2 and 0.3 normalized scale, being HPC the top alternative, digital twins take the second position, afterward quantum computing, and finally advanced sensors and instrumentation.

Nuclear Power Plants (NPPs) have to be controlled and supported at all times by a significant number of human-performed tasks. Some of the processes include regular reactor operations, refueling, engineering, maintenance, safe shutdown, chemical control, etc. The operations may be continuous, such as routine operator activities to manage power, or periodic, such as regular testing, maintenance, and upgrades.

Referring to the Regulation subnetwork, the alternative of including all the existing nuclear technologies ranks first, while optimizing and standardizing the resources to deploy takes the second, followed up by proposing flexible energy policies and reutilizing the existing resources. The high values are between 0.2-0.3 normalized alternatives.

Create plans that are both ambitious and doable for electricity, heat, industry, transportation, and climate change[18]. Put in the time and money necessary to strengthen market incentives and designs in order to promote efficient operations, healthy competition, and the full variety of available alternatives. All these elements are part of flexible energy policies open to innovative ideas providing flexibility to the nuclear energy systems.
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6. CONCLUSIONS

The proposed study has significant importance in the context where digital technology has a prime role, because the flexibility that remote access to information gives to the people significantly
impacts how problems can get solved. Adding value to the platforms that can contribute to expanding the implementation of nuclear energy technology should be welcome to the construction of new horizons. This is the main principle of the 4.0 industry, putting into perspective different disciplines globally.

The nuclear industry uses various strategies to advance technology and achieve global energy security. By examining the advantages at the industrial level for the growth of human power, applying creative elements to regulation through sustainable enablers technologies will expand the capabilities of these technologies.

The Analytical Network Process (ANP) has been implemented in SuperDecisions Software. The ability of the ANP is to record all interactions to evaluate the presence of different aspects in the digital transformation process. The model evaluates three subnetworks (1) Regulation, (2) Attributes, and (3) Enabling Technologies having the three of them control criteria to assess several alternatives and select the most appropriate to consider them as part of the digital infrastructure elements in a nuclear program.

The next generation of nuclear specialists will be involved in implementing cutting-edge equipment if they are directed toward fields like digital twins, high-performance computing, or quantum computing where they can gain more expertise. The ability of robust nuclear power infrastructure, capable of experiencing various transformations to ensure energy security with nuclear technologies diversification, will be ensured by the security of the upcoming nuclear power programs in other member nations.

Further studies should be conducted among policymakers and international organizations to establish a framework bringing additional elements capable of supporting the establishment of a digital infrastructure for human capacity building among the different regions of the world.

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