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PS3/B3 - Opportunities for Sustainability and Circular Economy with Substations and HV equipment

Expedite Grid Sustainability using IIoT: Kickoff Models & Roadmap

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SUMMARY

The digital revolution is transforming the world, creating disruptive changes in science and culture and their impact on the future. The 4th industrial revolution became a key enabler of sustainable development, constituted by emerging technologies, including the Internet of Things (IoT), artificial. However, up to this moment, the Electrical Energy sector has been suffering from a low sustainable growth rate compared to what it should be as per the 2030 target.

The Industrial Internet of Things (IIoT) is an emerging technology widely applied in several domain areas, from smart homes to smart grids. IIoT is constantly rising as a critical differentiator in the energy sector, improving operational efficiency and productivity and adapting the 'True Zero' concept instead of 'net zero.'

This paper explores the grid sustainability challenges of reducing the carbon footprint and empowering the circular economy. Furthermore, it illustrates the ways of using IIoT in grid sustainability with two pioneer implementation models, which can help find a suitable implementation technique for the national grid level.

Finally, it will provide some recommendations and a roadmap to utilize the IIoT system on grid sustainability.

KEYWORDS

Substations, Green Infrastructure, IIoT, Smart Grid, Sustainable Grid, Circular Economy

1 Introduction

The Earth faces grave sustainability problems, part of an interconnected global dilemma affecting everyone. Many supranational political and economic unions urge united action to solve major ecological problems before solutions become impossible. They note that businesses can save and earn money through environmentally sound products and policies.
To help restore nature and boost biodiversity, all E.U. and some other countries' policies are promoting the use of Green Infrastructure, which is a strategically planned network of natural and seminatural areas with other environmental features designed and managed to deliver a wide range of ecosystem services such as stormwater management, increasing biodiversity, space for recreation and climate mitigation and adaptation [1].
Even though the Green Infrastructure (G.I.) terminology refers to "green" infrastructure, it is a network of green and blue spaces that can improve environmental conditions. An interconnected network of green/blue areas and other ecological assets that conserves the functions of the natural ecosystem and provides associated benefits to all species. As a strategic approach to land preservation, G.I. addresses the impacts of sprawl and the accelerated consumption and fragmentation of open land on ecological and social life.
The electrical grid, including the substations, is a vital infrastructure element that can vary from simple to complex. For example, a modest substation of about 50 square meters may comprise little more than a transformer and related switches. Other substations are large and may be several hectares in volume, with several transformers and tens of switches. Substations are constructed in all environments, within farms, rural areas, urban areas, or between residential developments.
Picking a substation location takes into consideration of several factors. A sufficient plot area is required for equipment erection with requisite electrical safety clearances and access to maintain significant substation elements, such as transformers. The substation should have space for growth due to load evolution or determined transmission additions. Possible environmental effects such as stormwater drainage, noise, and wildlife disturbance must also be considered. In the following section, we are going in brief through the significant environmental impacts of the substation construction and the standard methods to mitigate them.

2 Substations Ecological Impacts

There are many ways to classify the substations' ecological impacts based on if it's temporary (associated with their construction activities) or Permanent (during their operation). Also, it can be classified based on its impact on the environment or mitigation method. Common potential effects are discussed below: -

1. Uncovering Vegetation

   Associated impacts during the substation construction are Soil erosion and stormwater runoff, which occur when the existing vegetation is removed during foundation excavation, leading to expos the bare ground. Therefore, appropriate erosion control measures compassions, such as filter fences and straw wattles, must occur through construction and stay in place until the affected vegetation around the fenced-in site has recovered.

   The lay down-dense gravel coat in the substation area is an opaque layer, increasing runoff at rain events. In addition, constructing permanent stormwater ponds attached to the fenced area is a widespread practice, mainly for larger substations, to mitigate the severe effects of stormwater overflow on water nature in nearby streams and wetlands.

2. Heritage Sites

   Natural or archaeological heritage sites can be potentially impacted in several ways, like disturbing ground activities that could result in the loss of or damage to archaeological artifacts, unmarked burial sites, or physiographical formations.

   A strict control measure must be taken in cooperation; a comprehensive national database of known cultural and natural resources must be consulted, and the direction of the state agencies must be followed if it appears that national resources might be affected by the substation running.

3. Applied Aesthetics

The overall aesthetic impact of a new substation, especially H.V. substations that interconnect transmission lines, can appear quite industrial. Residents of the substation's surrounding area may find that the physical appearance of the transformers, switches, and high fences of new substations detract from the neighborhood's character. Substation construction applications may include green infrastructure baselines so that the public can realize how the substation will provide an ecological balance to their community compared to relative land uses.

The noise generated by the substation operation can negatively impact to adjacent environment. A mixed barrier of green edges like mature trees and sustainable material like recycled poly material between the substation and outer zone can be magnificently helpful in reducing the noise impacts.

One of the success stories in that field is this project in which TEF improved one of PG&E substations in the Uptown Tenderloin Historic District by a design that meets the practical needs of the utility operator while enhancing the surrounding community [2].

The project features an ever-changing expression of the sun's energy throughout the day and pulsating LED light patterns after sundown. In addition, a high green wall provides biophilia relief to the urban neighborhood, progressive the utility operator's commitment to developing sustainability in the communities it serves **Error! Reference source not found.**. And the facility is empowered by solar energy, the first Net-Zero electrical switchgear building in the U.S. certified by the International Living Future Institute's (ILFI) Zero Energy Building (ZEB) Certification™ of the Living Building Challenge.

Figure 1: PG&E Larkin Substation outer view during day & night

4. Electric and Magnetic Fields (EMFs)

The electric and magnetic field (EMF) levels within a substation or from transmission lines have been entangled in adversely impacting multiple facets of human health, like increasing the risks of deadly diseases, and there are many discussions and argument works out whether exposure to EMFs affects the endocrine, cellular, reproductive, and immune systems of vertebrates. Many studies show that birds' EMF exposure changes but is not always consistent in their behavior, generative success, growth and evolution, and physiology [3].

The operator must have ideas for EMF's ecological impact. It is also necessary to conduct a detailed observation of the nature of the spread of radiation. As a result, the technological measures taken to mitigate the impact on which the H.V. equipment and transmission lines are located have minimal effect on the surrounding environment.

From the previous demonstration, we can observe that maintaining a green grid requires dedicated efforts with multi-collaborated stakeholders; that's why sustainability used to count as a cost. However, increasingly, heads of utility operators and governments alike rely on sustainability as a chance they can't tolerate missing. And the rapid-fire innovations of the Industrial Internet of Things (IIoT) and other 4th industrial revolution tools like Artificial Intelligent (A.I.) and Digital Twins are generating these opportunities in practically every utility sector, especially the electrical grid. So, in the remaining part of this paper, let's dive deep into how IIoT can be developed as a tool to help operators go towards a greener grid.

3 The Industrial Internet of Things (IIoT)

The term the Industrial Internet of Things is omnipresent in industrial and utilities applications as digital transformation has become a business target for various communities. It's also known as the industrial Internet bringing together critical assets, sophisticated predictive and prescriptive analytics, and modern industrial individuals; it comprises a network of a multitude of industrial assets connected by telecom technologies that result in systems that can monitor, collect, interchange analyze and deliver rich new insights like never these insights can then assist in driving comprehensive business decision-making for utilities and industrial companies.

Before diving into the concepts of IIoT, we must acquaint ourselves with the IoT reference model in Figure 2, which was approached at the IoT World Forum [4].

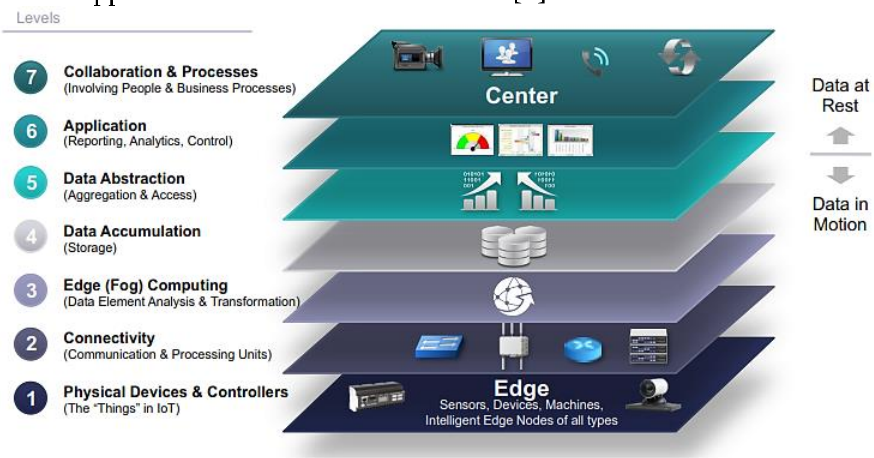

Figure 2. The 7 Levels of an Internet of Things reference model [5]

The Internet of Things (IoT) Reference Model is a determined first step toward standardizing the conceptions and terms encompassing the IoT. From physical sensors and actuators at Level 1 to the enterprise and processes at Level 7, the IoT Reference Model specifies the practicalities required and involvements that must be addressed before the industry can comprehend the value of the IoT. With the main aim of enabling IoT, this reference model affords a touchstone for understanding its obligations and possibilities.

Back to IIoT, which leverages many IoT technologies and applies them to the complex needs of the industrial environment. IIoT is a technology group that gathers and sends data within legacy isolated industrial devices found in Supervisory Control and Data Acquisition (SCADA) systems and other Industrial Control Systems (ICS) that monitor and control critical industrial infrastructure that includes factories, electrical utilities, marine facilities, water systems, and other industrial services. The global industrial Internet of Things (IIoT) market was over 263 billion U.S. dollars in 2021. The market growth is expected to reach some 1.11 trillion U.S. dollars by 2028.

The energy industry is facing one of the most transformative times in history. Change has become constant with changing customer roles and customer expectations, different regulatory and market conditions, new types of competitors, and a continual stream of new technologies. The business models identified in the utility sectors are changing. Industry players are at varying levels of maturity in the realities of their market environment and how they seek to respond to ongoing disruptions. The recognition of the need to transform as the energy value chain grows around them is shared across the market. Energy business leaders are challenged to consider how their businesses can be changed in the market environment in which they operate. This transformational need is prompting organizations in the energy sector to rethink their technology strategy, including incorporating innovative accelerators such as the Industrial Internet of Things (IIoT).

IIoT gives energy organizations access to more data than ever, speeding up a company's transformation efforts. IIoT is ubiquitous in utilities, with ongoing work on the top five strategic priorities:

- **Connected assets** — Using IoT and sensors to improve asset performance.
- **Next-gen safety** — Using IoT and sensors to continuously evolve workforce environment, safety, and health (EHS).
- **Digital refining/grid** — Using IoT and sensors to improve assets and operational performance

- **Digital upstream** — Using IoT and sensors to improve discovery and upstream retrieval.
- **Connected customers** — Using IoT and sensors to enhance customer experience.

The most significant opportunity for transformation comes from an asset standpoint. At the core of all energy companies are their assets. In utilities, investments lay the foundation for operations and, in most cases, rates and revenue. As grid operations are upgraded and expanded, more and more assets can communicate with control and each other. In oil and gas, companies spend significant money on maintaining and inspecting all their assets to ensure maximum uptime and performance. This priority lays the foundation for transformation within the energy and is where most organizations start.

By now, we have a better understanding of IIoT Structure and capabilities. Hence, let's illustrate how to use IIoT to expedite Grid Sustainability by using two different models in the following sections.

4 Model (1): Substation and Transmission Lines Sustainability Management System

This Model can be better explained with the following Figure 3:

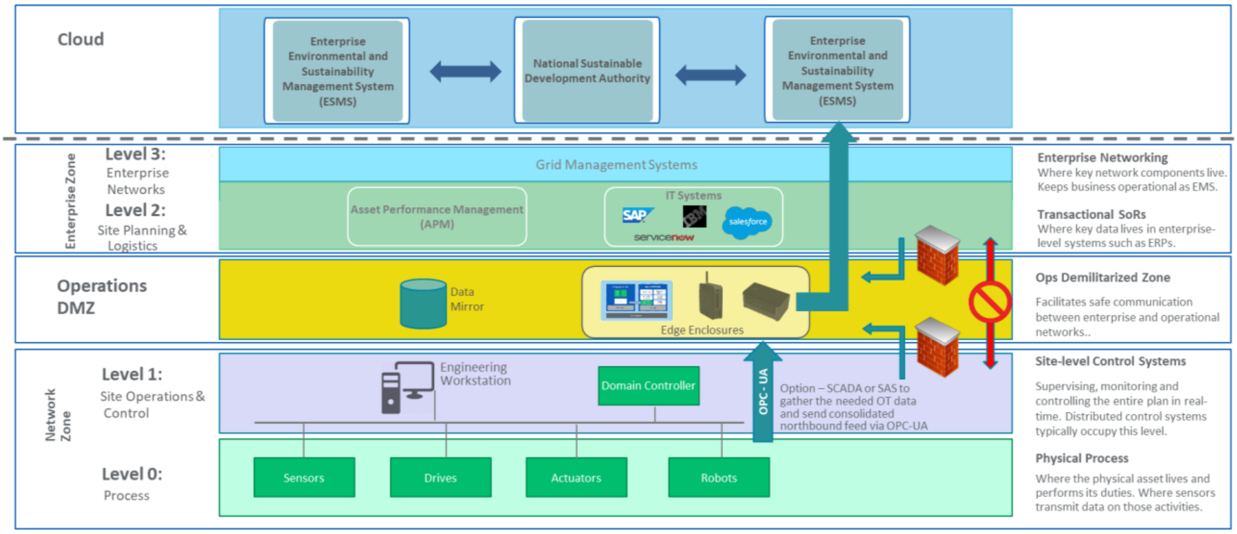

Figure 3 Substation and Transmission lines Sustainability Management System

The Model is based on a hybrid solution that integrates into the Purdue Model to maintain secure data exchange between the existing grid management systems and Environmental and Sustainable management system (ESMS), but also provides the flexibility needed to harvest the benefits of the IIoT and maximize collaboration with other sustainability stockholders. The goal of this Model is not only to evolve the substation and transmission lines' sustainability but to turn them into a sustainable development guardian tool for the surrounding society and environment. The Model consists of the following: -

4.1 Network zone

This zone can have a marvelous variety of objects connected to the Internet, changing our world completely and providing a solution for every challenge, as shown in Figure 3. As a demonstration, the challenges which have been illustrated earlier in section two can be easily mitigated with a set of IIoT schemes as follows:

- Using vegetation elements to monitor soil moisture and plant conditions, then provide selective irrigation in dry zones to reduce the water resources required in the green plus. Plus, it can study the weather conditions in the surrounding zone to forecast ice formation, rain, drought, snow, or wind changes. All this can be done with unmanned stems to decrease the overhead efforts & cost to the minimum.
- As for EMF impact, a set of EMF sensors can be installed in transmission line towers and wildlife monitoring suits to provide a comprehensive insight into the ESMS platform and obtain the right solution for any negative impact. Furthermore, these objects can be powered by the absorbed EMF from transmission lines to ensure minimum complication and maximum sustainability.

4.2 Operation DMZ

which contains the edge device that acts as the host for the algorithms and models–essentially mathematical representations of the asset. It measures the equipment's status based on sensor signals and calculates changes necessary to improve performance, sending commands to the actuators, as shown in Figure 4. It creates the environment for two essential and complementary functions:

A) Communicate with the operator operation systems, where the real-time systems on the core of the grid management process enjoy uninterruptible, or deterministic, connections across the machine to enable safe, secure, high-performance behavior of the substation and transmission lines.

B) Provide access to the cloud. For example, insights from grid operator assets can be shared to provide field-level knowledge. In addition, applications on edge devices can perform analytics and only send critical insights into the cloud rather than more bandwidth-intensive raw data.

An essential need of the edge device here is that it is both Real Time (and, therefore, by necessity, local to the asset) and it is connected to field-level diagnostics capabilities in the cloud.

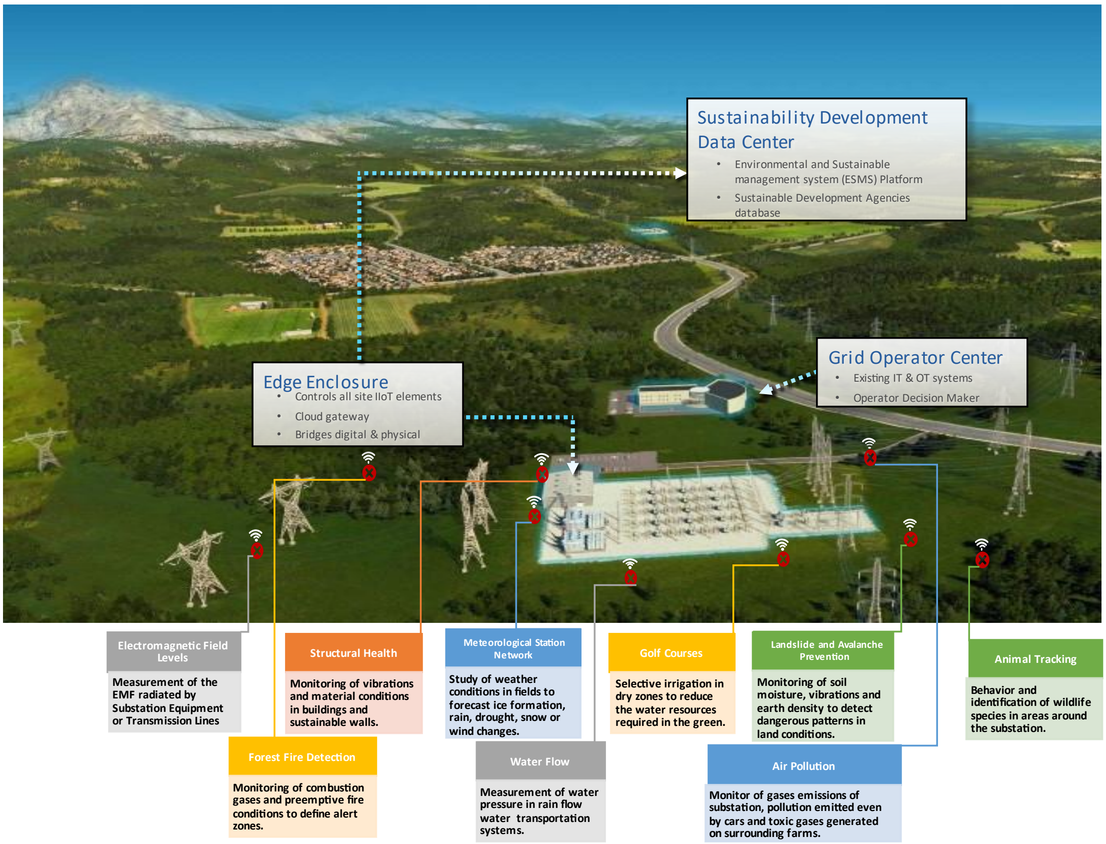

Figure 4 Sustainable Management System Interconnection

4.3 Cloud

Where there are various ways in which advances in A.I. could support the direct and indirect impact of grid components in sustainable cities and communities (SDG11), plus enable grid operators to transition to innovative infrastructure (SDG9) and speed up green transmission systems to help countries get affordable and clean energy (SDG7) among many benefits to the other SDGs too. For example, intelligent sensing systems powered by AI-infused data analytical capabilities will pull all the needed data from global and national sustainable development agencies to generate clear insights into how the operator or even A.I. can autonomously act on some actuators like wise guarding, as shown in Figure 5. In this way, a considerable overhead will be released from operator management to create and manage a dedicated structure for sustainability development, which means fewer investments and more

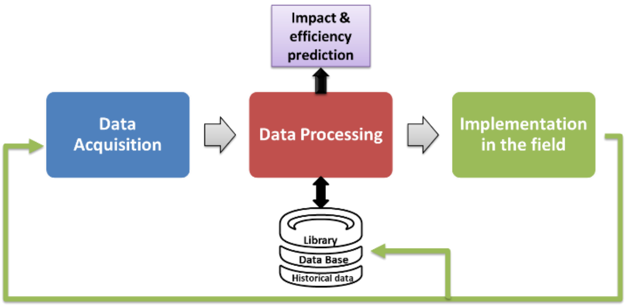

Figure 5 AI-driven closed-loop automation system

efficiency.

5 Model (2): Renewable Energy Integration with H.V. Systems

Integrating massive amounts of renewable energy into the grid not only influences the low voltage distribution network but also influences transmission, sub-transmission, and high voltage (H.V.) distribution network in terms of power quality issues such as voltage fluctuations, overloading of transformers, and injection of harmonics.

One of the famous techniques of power exchange between the current large-scale generation–including, for example, offshore wind power–and the numerous distributed resources is the Camel scenario.

The Camel scenario is based on large power plants interconnected to one another via a high-voltage (H.V.) transmission network, while a low-voltage (LV) distribution network interconnects the microgrids that are (nearly) self-supported. Finally, power is exchanged between the H.V. and LV layers over a relatively lightweight medium-voltage (MV) network.

That means that in the LV network, substantial investments would be mostly made at the customer site to balance domestic supply and demand properly, preserve voltage levels within limits, and manage the power quality and precision at the connection hubs.

IIoT, as a comprehensive solution, will provide a single solution targeting remote communities or organizations with energy generation capabilities that reduce energy losses and give clear insight and simplified ways to manage individuals and utility management, as shown in Figure 6.

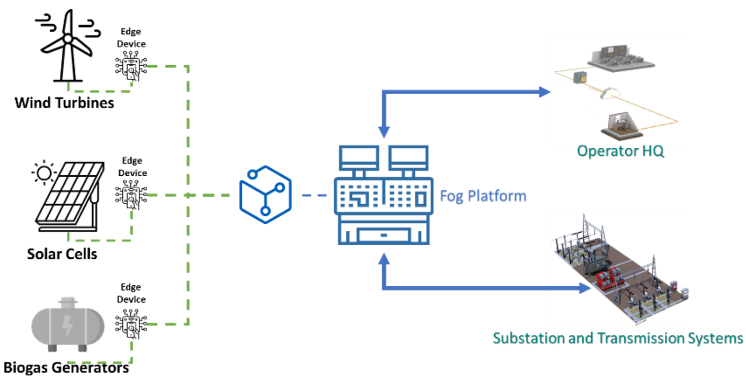

Figure 6 Renewable Energy Integration with HV Systems

The first part of this Model is an edge computing device for Renewable Energy nodes connected to their generation assists like wind turbines, solar cells, or biogas generators. A user-friendly interface will be provided along with the device for smooth management from the end-users side.
All end-user devices will be connected to the fog layer, which the cloud layer will manage. An A.I. system that works energy flow along with energy trading to enrich the electricity market with individual generation and saving contributions.

6 Technology Adoption

As illustrated previously, plenty of digital tools now allow operators to generate better, harvest, integrate, and analyze data–to better see, plan for, manage, and understand the enormous complexities of substations and transmission lines' sustainable development. Figure 7 shows the general guidelines for IIOT system adoption: -

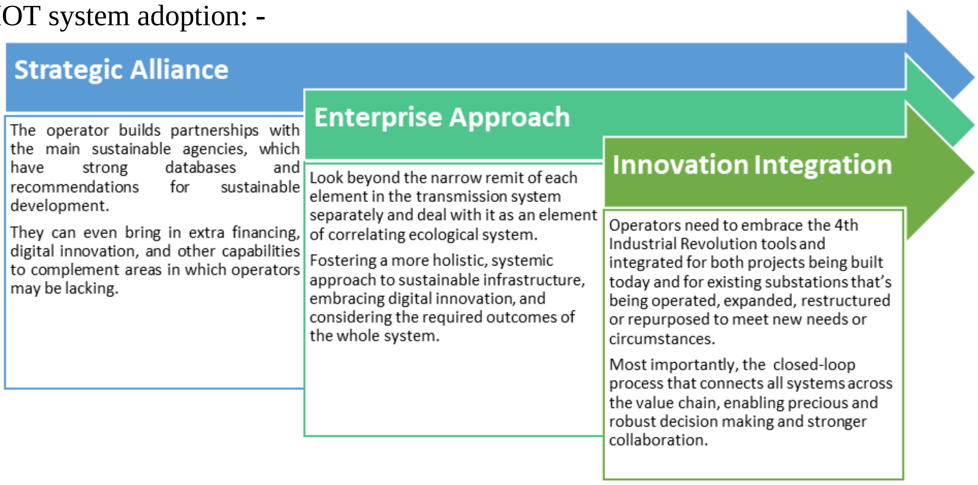

Figure 7 Technology Adoption Path

6.1 Strategic Alliance

While many grid operators have plans to develop green infrastructure, there is a need for increased coordination to enable operators to share lessons they have learned globally.
Plus, to avoid reinventing the wheel and unnecessarily overhead, greater collaboration with other organizations in sharing experiences of pilot programs, databases, insights, and predictions is required. It also stresses the necessity to develop common standards, policies, and frameworks between grid operators and other stakeholders that will help optimize and speed up the development and deployment of necessary technology, which must consider the sensitivity of grid utilities.

6.2 Enterprise Approach

To make IIoT a valuable tool that helps utilities meet external and internal challenges during substations and other associated assets' sustainable development journey, a different mindset is to create the required execution plan and framework for the new system.
Frame infrastructure development as a platform to improve economic, environmental, and social outcomes, plus focus on the interconnectedness of natural, built, and human systems, and treat infrastructure as a system of systems
Design infrastructure procurement models to be more collaborative and optimize risk allocation (allocating it to the correct party) while promoting full-life-cycle value. Reframe the cost-benefit analysis for infrastructure development to include new financial and non-financial considerations.

6.3 Innovation Integration

Empowering engineers, designers, and other front-line infrastructure workers to innovate and scale up good ideas will always be the foundation for any technology adoption.

Establish a system based on a Closed-Loop Engineering approach that focuses on data-driven sustainable development planning by ensuring data consistency and traceability between process planning and development if securing substation operation by combining aspects and functions from Assets Performance Management (APM) systems, IIOT, and other systems and databases. During this stage, segregation between critical substation operation systems and environmentally sustainable Management Systems is highly recommended for safe operation.

7 Conclusions

As António Guterres – Secretary General of - the United Nations, states, "We must rise higher to rescue the Sustainable Development Goals – and stay true to our promise of a world of peace, dignity, and prosperity on a healthy planet.". Eight years have passed since world leaders met in New York and agreed on 17 Sustainable Development Goals (SDGs). However, as per The SDGs Report 2022 [6], continuous and interconnected crises are putting the 2030 SDGs at severe risk; along with humanity's existence, achieving global energy and climate objectives will require a significant push in the deployment of renewables, with massive financial investments. Hence, the comprehensive solutions of the 4th industrial revolution, like IIOT, A.I., and Digital twins, represent a priceless chance not only for posting sustainable grid development and decreasing its negative impact on the surrounding ecological system but also to convert it into a valuable tool in social sustainability. Plus, it will decrease the required cost and overhead efforts to achieve all previously mentioned goals, but this will require out-of-the-box thinking plus high-level collaboration with all sustainable development stockholders.

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