21, rue d'Artois, F-75008 PARIS
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Improving Grid Infrastructure Sustainability by BIM and Optioneering Design Approach

L. COVERT, P. SOMBOONYANON
Burns & McDonnell
USA

SUMMARY

In the past few years, the electric power industry has been increasingly scrutinized for its environmental impacts due to its contribution to global greenhouse gas (GHG) emissions. At the same time, electrical utilities are expected to continue to meet an increased demand and to improve system reliability in a changing landscape. On the generation side, renewable energy is being introduced onto the grid, meaning additional infrastructure is required to connect many new energy sources. On the power delivery side, aging infrastructure is requiring a considerable amount of maintenance and new construction to continue to serve the consumer. Together, this means utilities need to expand their reliable operations to keep up with demand increase, while still cutting their emissions. With an increased pressure on utilities to reduce their GHG emissions, they are seeking innovative technologies and design solutions that will help them meet emissions reduction targets.

Building Information Modeling (BIM) has been widely adopted by the AEC industry with proven success. BIM is a framework that promotes better team collaboration and more transparency throughout a project lifecycle with a common data source. Optioneering is a design approach where a designer can prioritize or filter results from a number of design options. Utilizing BIM for design gives the user access to data needed to apply optioneering efficiently during the tender stages of design. If emissions data is input into the BIM design, then the most optimized design option can be established that best fits utilities' sustainable goals.

In this paper, the background information of sustainable design parameters and their importance to the future of the electric power industry is described. Then, the use of BIM framework in conjunction with an optioneering design approach is described. In addition, an example of substation design use case utilizing this approach is presented. Using this new innovative solution, electrical utilities could better prepare and plan their infrastructure upgrades and new development with more sustainable design solutions.

KEYWORDS

Greenhouse gases, Emissions, Science-based targets, Embodied carbon, Environmental Product Declaration (EPD), Building Information Modeling (BIM), Optioneering

lcovert@burnsmcd.com

INTRODUCTION

Reducing greenhouse gas (GHG) emission has become an increasingly important target for all industry sectors in response to climate change concerns. Based on a report from the Environmental Protection Agency (EPA) [1], in 2019 the electrical utilities are responsible for nearly a quarter of the overall GHG emissions. This prompted commitments from several leading utilities to reduce their emissions and set targets in line with the 2015 United Nations Paris Climate Agreement [2]. The electric grid is also facing a dispersion of generation sources and widespread maintenance needs to keep up with increased demands. It is expected that to maintain reliable operations utilities will necessitate considerable investment in system upgrades or new developments. To support the changing electric grid infrastructure, all necessary upgrades and new construction will contribute a notable percentage of emissions to their operations, according to the United Nations Environment Programme [3]. Electrical utilities have accelerated a transition towards renewable or clean energy sources to reduce the amount of emissions associated with producing the energy. However, constructing and maintaining the power delivery infrastructure could still contribute a significant portion of GHG emissions. Therefore, more sustainable design and construction practices will be required to complement the shift toward more renewable energy generation.

Accurately reporting GHG emissions associated with overall utility's operations is not an easy task due to amount of information to be tracked. Using a conventional method for the task becomes time consuming, cumbersome, or even impractical.

In the past decade, Building Information Modeling (BIM) and its implementation has been widely adopted by the AEC industry with much success. BIM transforms the design procedure by minimizing redundant labor, optimizing coordination among disciplines, and providing greater transparency of a project to all parties. Not only does BIM improve existing processes throughout a project life cycle, but it also opens a new world of possibilities when it comes to assigning and tracking data.

Optioneering is a design approach where results from a set of design options can be prioritized or filtered to aid a designer in selecting the most optimized design option. With BIM capability in conjunction with optioneering design approach, it offers utilities more innovative design solutions and can help them with their GHG emission reduction goal.

CLIMATE CHANGE, GREENHOUSE GASES, AND SCIENCE-BASED TARGETS

It is known that GHG emissions have a direct impact on climate change. GHGs are a group of harmful gases emitted into the air by industrial and mechanical processes. GHGs get trapped in Earth's atmosphere and insulate the planet, contributing to negative climatological impacts. As the amount of trapped GHGs increases, the planet's average temperature rises, causing climate change. The change essentially results in a less habitable environment and more extreme and unpredictable climates. Climate change was recognized by a coalition of governments as a looming humanitarian crisis at the 2015 United Nations Climate Change Conference in Paris [2]. During this conference, the coalition sought to establish a unified approach to curbing GHG emissions and avoiding the existential threat of continued global average temperature rise. The 2015 Paris Climate Agreement asserted that if global warming were limited to 1.5°C, the most catastrophic impacts of climate change would be avoided.

To counteract the GHG emission trends, the 2015 Paris Climate Agreement introduced the concept of science-based targets (SBT). SBTs are an effort to quantify the emissions reductions timeline that must be met by corporations and world governments to adhere to the 1.5°C global warming limit. Globally, emissions must halve by 2030 and reach net-zero by 2050 to meet science-based targets [4]. In Figure 1, historical data of global mean surface temperature is used to estimate the impact of human development since 1950 [5]. A trendline projected from that estimated human-induced warming is projected out and compared to the range of potential mitigative commitments and successful adherence to those by governmental bodies.

*** Source: [5]**

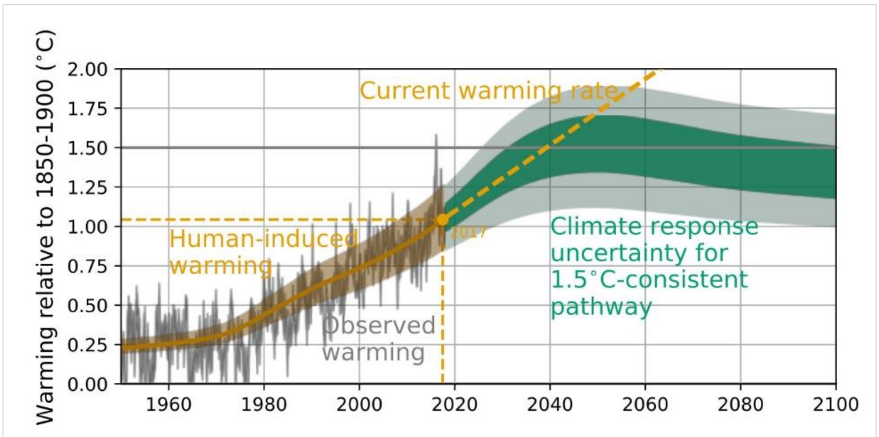

Figure 1*: IPCC Special Report on Global Warming of 1.5°C

GHG emissions are categorized into three different scopes: Scope 1, Scope 2, and Scope 3 emissions. Scope 1 emissions come directly from operation of assets owned by an organization, like the emissions produced by a company-owned vehicle. Scope 2 emissions are emitted during production of heating, cooling, and electricity the organization purchases from a third-party. Scope 3 emissions encompass all emissions not covered by Scope 1 and Scope 2 that an organization might indirectly impact in its value chain. For example, an electrical utility is required to count emissions produced by a supplier or contractor within their Scope 3 emissions. Currently, GHG Corporate Protocol does not require tracking and disclosing of Scope 3 emissions when reporting an organization's GHG emissions [6]. However, as electrical utilities near their emission reductions targets, reviewing their business partners' practices and electing to employ those with aggressive emission reduction practices will also reduce a utility's Scope 3 emissions.

GHG emissions attributed to a design are quantified through the design's embodied carbon. Embodied carbon is defined as the sum of GHG emissions released during chemical processes and the expended energy during the extraction, manufacture, transportation, assembly, replacement and demolition of materials and products. It is assessed based on carbon dioxide equivalent (CO_2e) given in kilograms (kg), which is also equivalent to one unit of Global Warming Potential (GWP) [7]. Examples of various chemical compounds with associated GWP values and their atmospheric life are presented in Table 1. For example, 1 kg of Sulfur Hexafluoride (SF_6), a commonly used gas in electrical substations, has a GWP of 23,500 (or 23,500 kgCO_2e) and causes 23,500 times more impact on global warming compared to 1 kg of carbon dioxide released.

Common Chemical Name (Chemical Formula)	Global Warming Potential (100 years)	Atmospheric Life (years)
Carbon dioxide (CO_2)	1	5-200
Methane, fossil (CH_4)	28	12.4
Methane, biogenic (CH_4)	30	12.4
Dinitrogen monoxide (N_2O)	265	121
Sulfur hexafluoride (SF_6)	23,500	3,200

Table 1: Greenhouse Gas GWP Comparison [7]

Per International Standards Organization's (ISO) Standard 14067 [8], embodied carbon can focus on different portions of a project life cycle and are differentiated by the terms cradle-to-gate, cradle-to-completed construction, cradle-to-grave, and cradle-to-cradle, as shown in Figure 2. While total embodied carbon considers the entire life cycle of a material or product, typical embodied carbon datasets are given as cradle-to-gate figures. Cradle-to-gate figures refer to the sum of GHG emissions released during chemical processes, expended energy during extraction, transport to manufacturer, and emissions released during manufacturing processes.

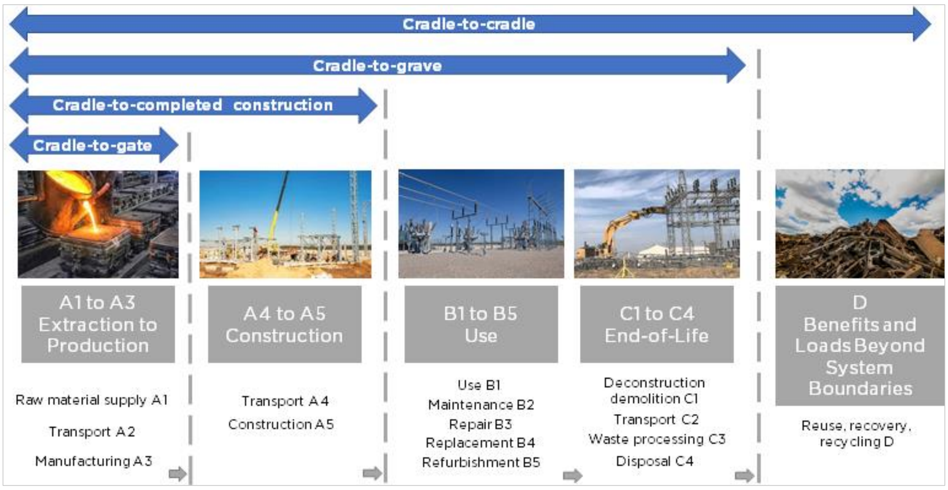

Figure 2: Embodied Carbon Lifecycles according to ISO 14067

ENVIRONMENTAL PRODUCT DECLARATION

As a growing number of organizations are expected to report their Scope 1 and Scope 2 emissions, they begin to track and store the data that can then be divided down to a per product basis and reported. This information can be publicized through Environmental Product Declaration (EPD), in compliance with ISO 14025 standard [9]. These EPDs establish a publicly accessible declaration of a product or material's embodied carbon. Organizations are compiling these EPDs into open-source datasets of varying degrees of detail. EPDs provide a reliable library of embodied carbon and other important environmental factors, including water use. An example of EPD for 4000 psi concrete with 50% supplementary cementitious material (SCM) is shown in Figure 3.

*** Source: [10]**

Summary of Environmental Product Declaration

Central Concrete
Mix 340PG9Q1
San Jose Service Area
EF V2 Gen Use P4000 3" Line 50% SCM

Performance Metrics

28-day compressive strength	4,000 psi
Slump	4.0 in

Environmental Impacts

Impact name	Unit	Impact per m3	Impact per cyd
Total primary energy consumption	MJ	2,491	1,906
Concrete water use (batch)	m3	6.66E-2	5.10E-2
Concrete water use (wash)	m3	8.56E-3	6.55E-3
Global warming potential	kg CO2-eq	271	207
Ozone depletion	kg CFC-11-eq	5.40E-6	4.14E-6
Acidification	kg SO2-eq	2.26	1.73
Eutrophication	kg N-eq	1.31E-1	1.00E-1
Photochemical ozone creation	kg O3-eq	46.6	35.7

Figure 3*: Example of Material Environmental Product Declaration according to ISO 14025

EPDs can be very useful to utilities to determine their GHG emissions based on current design and construction practices, as it essentially provides them with baseline information of the environmental impact data, like embodied carbon. When employed early in the design stage, the EPD data for each design option can be compared and allow a designer to make an informed decision that best fits utilities' overall GHG emission reduction goal.

COMBINING BIM WITH OPTIONEERING DESIGN APPROACH

The implementation of Building Information Modeling (BIM) framework has been widely adopted. BIM is not a software but rather a workflow that covers every aspect of a project lifecycle including conceptual design, estimation, project visualization, detailed engineering, procurement, fabrication, construction, and even operation and maintenance. BIM is favorable for its ability to handle large datasets shared in a common data source that provides a better collaboration among a multi-disciplinary project team. In the past, a 3D model design was primarily used for traditional 2D construction drawings. In BIM framework, 3D modeling and construction drawings are just by-products, and the primary focus is shifted to leverage data exchange from a common data source to support all aspects of a project lifecycle.

As mentioned previously, embodied carbon can be useful in aiding utilities to make informed decisions toward more sustainable solutions. However, as one can imagine, tracking embodied carbon for every material required to construct a substation, let alone all substations across utility network, can be challenging. With BIM's strength in handling large datasets, it can go beyond traditional parameters of interest, like material type, quantity take-off, and cost, to track other parameters for sustainability purposes.

In a common data environment, not only can changes be quickly adopted and better communicated with all project team members, but the impacts of said change to a project can also be better captured because of a data driven design approach within BIM framework. Although BIM framework allows changes in any stage of a project lifecycle, it is within the design phase that changes are most impactful and cost-effective. As a project progresses, there is an accepted inverse relationship between design flexibility and project cost associated to changes, as shown in Figure 4. Acknowledging this inverse relationship, investigating more sustainable design practices is the most advantageous earlier in the development phase, rather than later.

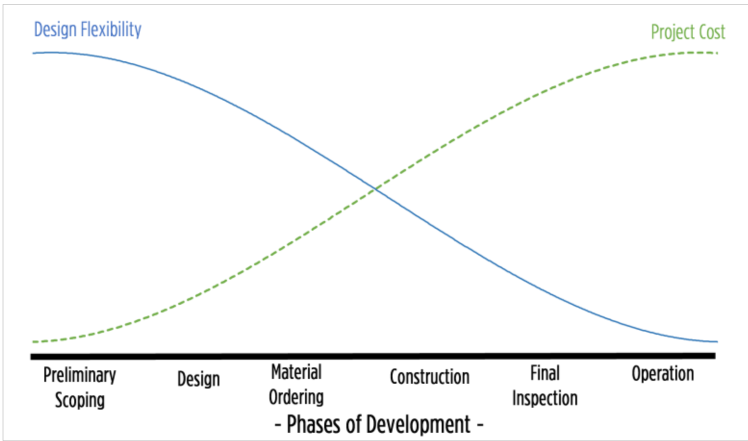

Figure 4: Design Flexibility versus Project Cost Throughout Project Lifecycle

Even with all benefits from BIM framework and the awareness of design flexibility in the early stage, utilities are still left with one challenge, limited project resources for exploring options. Humans are excellent at establishing design rules and creating design workflow, but we cannot compete with a computer when it comes down to performing repetitive tasks. This is where an optioneering design approach comes in to fill the gap of this shortcoming.

Optioneering is based in human decision making, but when dealing with multi-disciplinary designs with many decision-making criteria tied to them, some degree of automated design is necessary to produce a comprehensive list of alternatives efficiently. BIM technology is already being leveraged in broader AEC industries to assist in optioneering because of its efficiency and collaborative design capabilities, but has yet to take hold in utility industry [11]. Optioneering is a process of generating design options through design automations based on established constraints. The constraints can be anything including traditional variables such as cost or schedule, or even embodied carbon for sustainability purposes. Results of all design options that fit established constraints can then be prioritized and allow a designer to select and document the most optimized design options. Optioneering essentially puts the human's and the computer's strengths together with a computer running repetitive tasks based on a human's established workflows. Together, BIM in conjunction with optioneering design approach serves as a powerful and innovative tool to document sustainable decision-making for utilities and to help them meet their emission reduction targets.

SUBSTATION DESIGN USE CASE

Utilizing BIM framework and design approach previously outlined, this section provides an example of how these concepts can be implemented with substation foundation designs.

For a steel column supporting substation rigid bus as shown in Figure 5, two foundation categories may be considered including reinforced concrete foundation or helical pile foundation. For a reinforced concrete foundation, different configurations are available, such as spread footing or drilled shaft. Traditionally, for design and construction purposes a design option could be selected based on material and construction cost, material availability, or project schedule.

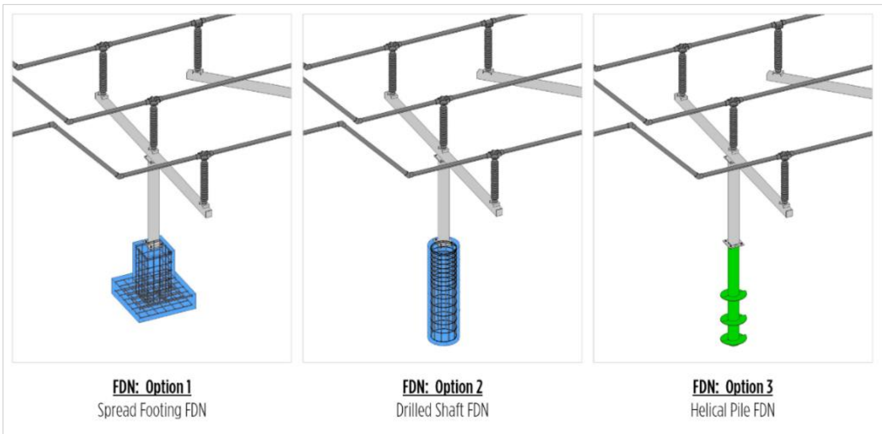

Figure 5: Foundation Design Alternatives in BIM Substation Model

To add sustainability considerations into this same design, different construction materials are considered, which would further expand the design to several more options. An example of these options is shown in Figure 6.

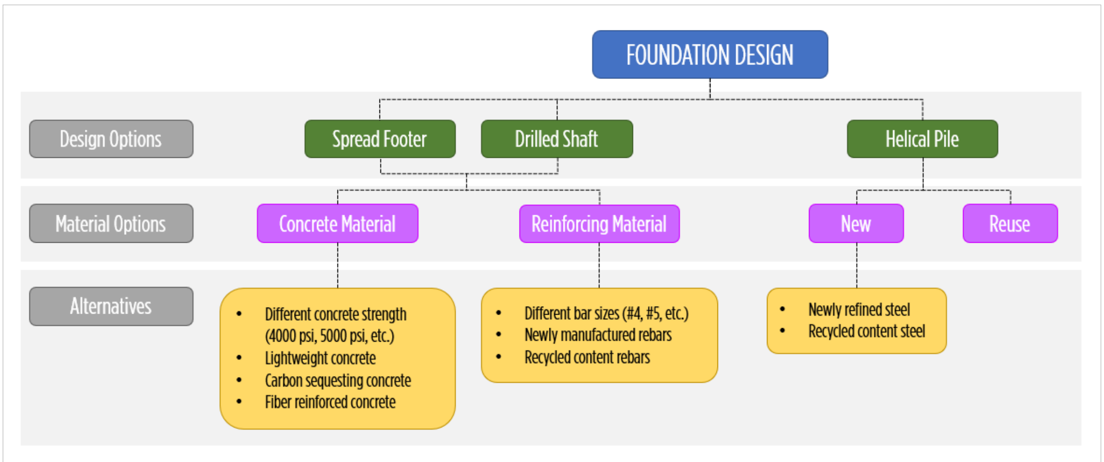

Figure 6: Decision Matrix of Foundation Design and Material Alternatives

Each alternative of foundation components, concrete, reinforcing steel, or steel pile, will have an associated EPD containing the embodied carbon information. Then, a total embodied carbon for each design option can be calculated. For example, Design Option 1 can be a spread footing foundation with 4000 psi concrete with newly manufactured #5 rebars. Design Option 2 can be a drilled shaft foundation with 5000 psi lightweight concrete with recycled content #4 rebars. Design Option 3 can be a newly refined steel helical pile, and so on. Other design constraints can be established for each design option such as material cost, associated labors for construction, impact to construction schedule, etc. Then, these established constraints can be prioritized to aid a designer to select the most optimized design option. The most optimized design option is not necessarily limited to cheapest cost option. It can be the lowest material cost, the lowest total embodied carbon, the combination of the two, or any constraint that best fits a designer's or utility's goals.

From options shown in Figure 6, nearly 20 design options can be generated, just for one foundation design. The complexity as well as the number of options of this decision matrix can quickly grow when considering all designs components, such as equipment selections, steel supporting structures and foundations, for an entire substation.

CONCLUSION

There is a growing concern regarding climate change and the disastrous impacts it could have on humanity's access to clean water, reliable energy, and livable climatological regions. With their contribution to the overall global emission, more electrical utilities have committed to the net-zero emission goals. However, this is a considerable undertaking, so utilities are seeking a new innovative solution that would allow them to provide customers with more reliable and sustainable energy. BIM has been widely adopted by the AEC industry with proven success with its strength in handling large sets of data. This capability of BIM to manage large sets of data is typically utilized to cover traditional project parameters like quantity take-off, cost, and a few others typical priorities. In addition, it can be used to track other parameters for sustainability purposes such embodied carbon. The optioneering design approach can provide a designer with insight and information to obtain the optimal design based on their priorities. Combining the two technologies, it is through a quantifiable understanding of key sustainable parameters alongside traditional decision-making parameters that utilities can economically maintain and update their infrastructure to provide reliable services while minimizing their environmental impact.

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