21, rue d'Artois, F-75008 PARIS
http : //www.cigre.org

CIGRE US National Committee
2017 Grid of the Future Symposium

A Framework for Sustainable Design of Overhead Transmission Lines

S. WALKER, B. FIFE
POWER Engineers, Inc.
USA

SUMMARY

To make a lasting impact on the sustainability of the electric transmission system, we need a holistic approach to planning, designing, constructing, operating, maintaining and retiring facilities. The approach needs to address not only today's demands, but also consider the requirements of future generations. Such an approach considers impacts to individuals and their communities, incorporates knowledge of other projects and carefully considers the quantity and type of materials used. The approach also avoids or minimizes impacts to the natural environment and is resilient and flexible to accommodate changes in the future environment. The range of criteria and considerations can be extensive.

For the overhead line designer, this process cannot be tackled in a vacuum. It requires collaboration with a wide range of participants. This can include system planners, permitting specialists, right-of-way agents, material suppliers, constructors, system operators and external stakeholders, such as community leaders, landowners and other project planners or owners.

To help designers explore the impact of their decisions on the sustainability of transmission projects, the authors and other collaborators developed a tool called SustainEval. SustainEval is an online calculation tool that uses the Envision rating system as the basis of its calculation. A user interface allows transmission designers to enter common parameters into a worksheet and see the impact on a mock Envision score in real-time.

This paper provides an overview of the fundamental aspects of Sustainable Development, the Envision Rating System and the SustainEval tool. It also discusses the application of these principles to a sample project.

KEYWORDS

Overhead Transmission Line, Sustainability, Sustainable Design, Sustainable Development, Envision, SustainEval

buck.fife@powereng.com

Background

Transportation, water, communications, energy, manufacturing and other infrastructure systems have transformed dramatically since the start of the industrial revolution in the 1850s. Advancement in these areas has resulted in many efficiencies and improvements to quality of life. Measures of quality of life are subjective, but often include quantifiable metrics such as life expectancy, infant mortality rates, education level and per capita income. One commonly used method for measuring quality of life is the composite Human Development Index (HDI).[1] Trends in the HDI across nearly all countries indicate progressive improvement in human well-being since the index was established in 1990.

This improvement in quality of life has come with some costs to the natural world, though, such as pollution and depletion of natural resources. This can be demonstrated by weighing two competing measurements: ecological footprint and biocapacity. Both are measured in global hectares (gha) per person. Ecological footprint, the rate at which society consumes the earth's natural resources, has increased steadily along with HDI. By contrast, biocapacity, which measures the supply of resources available to a given society or geographical area, has not kept pace on a per capita basis as population has grown. Most developed nations are consuming more per capita than they can sustainably provide, i.e., their footprint is larger than their biocapacity. For example the United States has a biocapacity of 3.8 gha per person, whereas its ecological footprint is 8.6 gha per person. This means the United States is using approximately 2.3 times the amount of resources available. This is a trend that exists around the world, such that our average global footprint is larger than the earth's biocapacity (1.7 vs 2.9 gha/person). This trend of using exceedingly more resources to advance the quality of life seems consistent around the world, in all cultures and societies. This relationship between HDI, ecological footprint and biocapacity are shown in Figure 1.

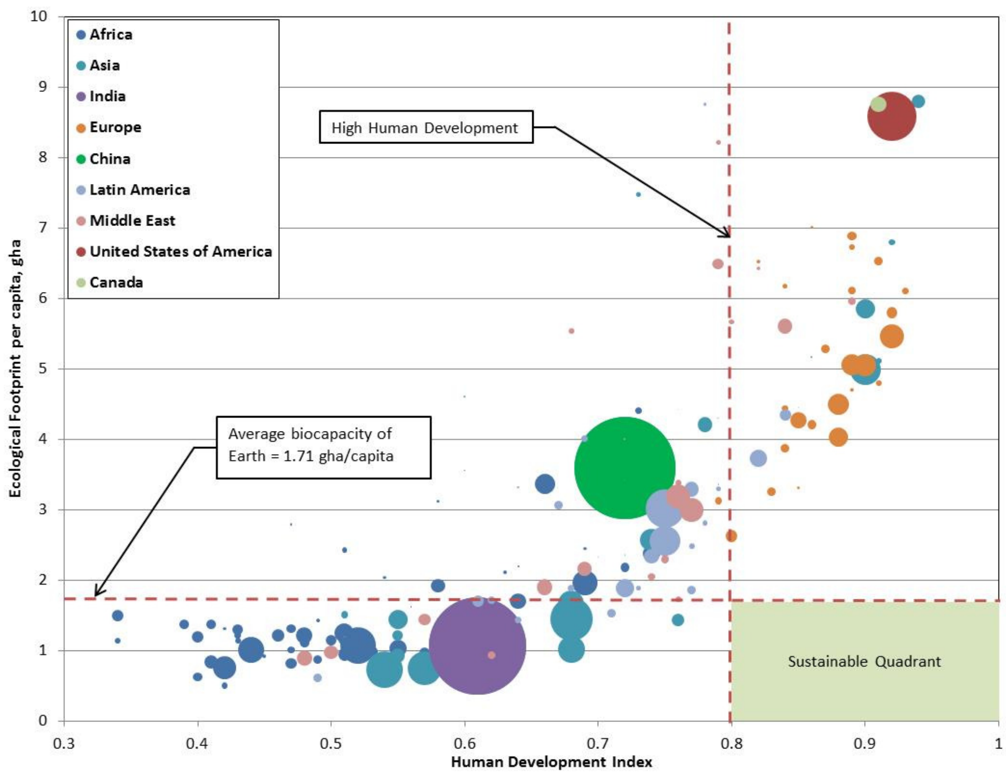


Figure 1 : Human Development Index vs. Ecological footprint.[2] (Relative Population indicated by circle diameter)

The challenge going forward is to achieve acceptable levels of HDI (in this example above 0.8) while managing our ecological footprint to fall below the biocapacity of the Earth. This is the challenge that the concept of Sustainable Development (SD) seeks to solve.

SD is defined as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs."[3]

As engineers and designers, we have the opportunity and the obligation to shape our built environment to conform to the principles of SD. There are a number of tools and systems available to help guide our efforts. Probably the most well-known is the Leadership in Energy and Environmental Design (LEED) system used primarily in the building industry. For those of us who practice in the energy industry, we also have guides from groups like CIGRE[4] and the American Society of Civil Engineer's (ASCE) Institute for Sustainable Infrastructure (ISI).[5]

These guides and publications are informative; however, they provide little specific guidance on how overhead high voltage transmission lines (OHTL) should be configured to support SD. Despite that challenge, OHTL designers have a significant role to play as our generation mix shifts to more sustainable sources such as wind and solar and as we confront the challenge of rebuilding much of the existing system as it reaches the end of its useful life.

OHTL have not evolved in the same way that other portions of the electric grid have. We still use materials and apply design and construction techniques that were in place decades ago. Some advances in materials have certainly occurred, such as high-temperature, low-sag conductor or composite structure materials. These materials are currently used sparingly and, by themselves, don't offer a more sustainable system, nor do they provide a solution for all needs. If we are to make a meaningful impact in the realm of SD, we need a larger, more encompassing approach to transmission line development.

Envision Rating System

To make a lasting impact on the sustainability of the electric transmission system, we need a holistic approach to planning, designing, constructing, operating, maintaining and retiring facilities. The approach needs to address not only today's demands, but also consider the requirements of future generations. Such an approach considers impacts to individuals and their communities, incorporates knowledge of other projects and carefully considers the quantity and type of materials used. The approach also avoids or minimizes impacts to the natural environment and is resilient and flexible to accommodate changes in the future environment. The range of criteria and considerations can be extensive.

For the overhead line designer this process also cannot be tackled in a vacuum. It requires collaboration with a wide range of participants. This can include system planners, permitting specialists, right-of-way agents, material suppliers, constructors, system operators and external stakeholders, such as community leaders, landowners and other project planners or owners.

Fortunately, we are not the first to venture down this path. Many have come before us and have developed useful tools. One of the most relevant is the Envision rating system developed as part of a joint effort between the Zofnass Program at Harvard University and the ISI.

Envision is a rating system involving the evaluation of 55 credits in five categories and addresses the range of parameters identified above. The five categories of credits include:

- Quality of Life
- Leadership
- Resource Allocation
- Natural World
- Climate and Risk

The Envision system provides the holistic approach that is needed to advance SD initiatives in OHTL. The Envision system is generic and can be applied to nearly any infrastructure project, whether it is a transmission line, generating plant, highway, wastewater treatment facility or pipeline.

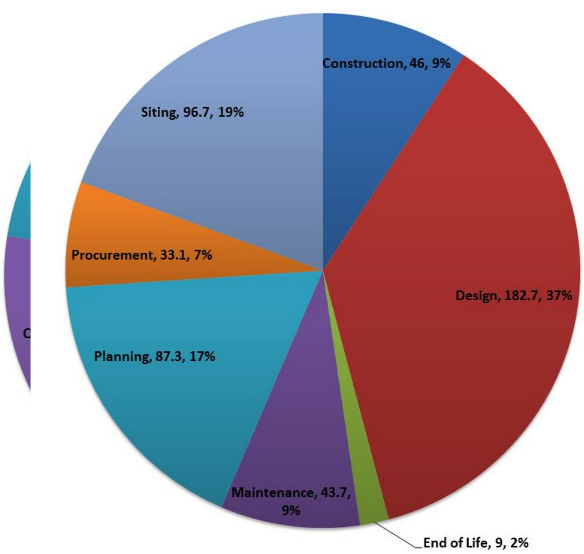
The application of Envision involves review and assessment of 55 credits and assigning a score to each. Each credit has a specified number of points available, and the points determine a level of achievement: Improved, Enhanced, Superior, Conserving or Restorative. The evaluation criteria and levels of achievement are outlined in the Envision guidance manual.[5]

Figure 2 shows the weighting and distribution of 809 points across the five categories of Envision credits. The figure demonstrates the holistic nature of the rating system, underscoring that no single parameter dominates the sustainability rating of a project.

<u>SustainEval – A Tool for the OHTL Designer</u>

With all of its strengths, the Envision system can be intimidating at first glance. For an industry that is just starting to embark on the SD path, this complexity can be a barrier to taking even small steps forward, including educating fellow industry members on what SD involves and how it can apply to OHTL design. With hopes of providing a tool that allows designers to explore the impact of their design decisions on the sustainability of a transmission project, the authors and other collaborators developed a tool called SustainEval. SustainEval is an online calculation tool that uses the Envision system as the basis of its calculation. A user interface allows a transmission designer to enter common OHTL parameters into a worksheet and see the impact on a mock Envision score in real-time.

SustainEval also includes extensive documentation summarizing how a specific transmission line parameter links to associated Envision credits, which is intended to be instructive to the transmission engineer eager to practice SD. For each project evaluated in SustainEval, a worksheet is created where the transmission parameters are grouped into seven categories: Planning, Siting, Design, Procurement, Construction, Maintenance and End of Life. Similar to the Envision system, SustainEval promotes a balance between the parameters evaluated. Figure 3 shows the relative weight of each of the parameters considered in the SustainEval tool.



Figu
contr

Figure 3 : SustainEval Credit Categories' relative contribution to total possible SustainEval score of 499.

As an example of how SustainEval links common transmission parameters to Envision credits, consider the common transmission design parameter of aluminium area in overhead conductors. In the SustainEval tool, this design parameter impacts several Envision credits, including:

- RA 1.1, Reduce net embodied energy
- RA 2.1, Reduce energy consumption

For this example parameter, the two Envision credits suggest opposing actions. When evaluating RA 1.1, increasing the area of aluminium lowers the score, as more aluminium requires more net embodied energy to extract, refine, manufacture, ship and install. At the same time, a larger aluminum area also reduces resistive losses inherent in the transmission line and, therefore, increases the score as measured by RA 2.1. These two credits must be balanced to optimize the aluminium area and achieve the most sustainable conductor size. This balance of competing priorities is common in SD and highlights the need for a holistic approach that considers the interdependence of parameters.

Case Study – Base Case

To demonstrate the application of SustainEval, consider the following case study involving a double circuit, 230 kV transmission line recently constructed in the desert of the southwest United States. This project applied existing utility standards for criteria, conductor type and configuration, lattice structure family, insulator assemblies, and foundations. The project required a focus on environmental considerations with significant stakeholder involvement. There was substantial consideration, avoidance and mitigation of environmental and cultural impacts. This project represents a typical transmission project, designed and constructed using utility standards and permitted in accordance with local, state and federal requirements.

Evaluation of this project within SustainEval highlights some of the parameters of interest for SD considerations. Below are specific parameters evaluated in the SustainEval tool along with corresponding Envision credits. For the purposes of this case study, only nine parameters of interest were considered. A comprehensive evaluation within the SustainEval tool will consider 50 parameters to evaluate a project holistically.

Planning, Generation, Renewable Energy

The SustainEval rating tool considers the generation source of the energy transmitted, with higher ratings associated with more renewable energy transmitted. SustainEval asks for a percentage of renewable energy transferred on the line, understanding that this percentage changes based on system conditions daily and over time as the generation mix changes. An approximate percentage is estimated by the user based on the location of the line in the system and the current system generation mix. This corresponds to the following Envision credits:

- QL1.2, Stimulate sustainable growth and development
- RA2.2, Use renewable energy
- CR1.1, Reduce greenhouse gas emissions
- CR1.2, Reduce air pollutant emissions

The project considered in the case study resulted in a direct link for renewable energy connection to the system, and therefore scored well in this category.

Siting, Alignment and Spotting, Existing ROW

Where transmission lines are sited has a significant impact on surrounding communities and environmental resources. Creating new greenfield right of way generally has a larger impact than use of existing corridors. Collocating with existing facilities is generally preferred. The project considered in the case study involved the rebuild of an existing transmission circuit on existing right of way and therefore scored well for this parameter in SustainEval. This corresponds to the following Envision credit: NW1.7, Preserve greenfields.

Siting, Alignment and Spotting, Cultural Resources

The project considered in the case study included both cultural resource surveys as well as stakeholder outreach to reduce negative impacts to features such as public access. This is common practice in the US and supports a strong score for this parameter in SustainEval. This corresponds to the following Envision credit: QL3.1, Preserve historic and cultural resources.

Design, Criteria and Layout, Storm Water and Fresh Water Protection

Impacts to fresh water and increases in storm water runoff related to project development can negatively impact drinking water quality, degrade wildlife habitat and create soil erosion. The project considered in the case study developed and applied a Storm Water Pollution Prevention Plan, resulting in a favorable score in SustainEval. This corresponds to the following Envision credits:

- RA3.1, Protect fresh water availability
- RA3.2, Reduce potable water consumption
- NW2.1, Manage storm water
- NW3.3, Restore disturbed soils
- NW3.4, Maintain wetland and surface water functions

<u>Case Study – Optimized Case</u>

Overall, the project performed well when compared to other projects evaluated in SustainEval. However, the holistic approach applied during the evaluation revealed possible areas of improvement in SD performance. For example, consider the following parameters where the project did not perform well and the suggested approaches for improvement.

<u>Design, Criteria and Layout, Return Period</u>

Increasing the return period beyond the standard 50 years used in the US results in longer expected life and risk reduction. If a moderate increase beyond 50 years is selected, then loads are not significantly larger and the advantages thus outweigh the financial costs. The benefits of a longer return period from a sustainability point of view are many, but most notable are the reduced chance of failure and planned obsolescence, as well as the reduced overall demand for resources by the project over its life. This corresponds to the following Envision credits:

- QL2.1, Enhance public health and safety
- LD3.3, Extend useful life
- CR2.1, Assess climate threat
- CR2.4, Prepare for short-term hazards

Increasing the return period from the typical 50 year period to 100 would have improved the sustainability rating of the case study project and had little impact on the total project cost, as the loads increase by only approximately 15% with this doubling of return period.

<u>Design, Life Expectancy of Conductors, Insulators and Structures</u>

Extending the useful life of major materials, such as conductors, insulators and structures, is attractive from a sustainability perspective. Reducing the need for future maintenance or replacements reduces the resources (labor and materials) needed to maintain the project over its lifetime, which reduces environmental impact. These parameters in SustainEval correspond to the Envision credit LD3.3, Extend useful life.

Actions to increase life expectancy of conductor include additional zinc coating on the steel core or use of Alumoweld core wires. Careful selection of insulator type, considering factors such as local contamination levels and rainfall amounts, can maximize the lifespan of insulation. Choosing an insulation type with a proven history in the region is important to extending useful life. Corrosion protection on steel structures with additional zinc thickness on galvanizing coating is another cost effective way to increase lifespan. If these factors had been considered on the case study, the SustainEval scoring would increase with only minor, if any, increases in total project cost.

<u>Design, Structure, Weight</u>

Optimizing structure weight while also satisfying project design constraints has a significant impact on the total required materials for transmission projects. This optimization is often not performed, especially for projects where lattice towers are used, given the time and design effort required to develop and test a new tower family. However, this practice can significantly hinder SD efforts. For the project considered in the case study, an existing tower family was used because of project time constraints. Developing a new structure family was an opportunity for additional SD benefits. The structure weight parameter in SustainEval corresponds to the Envision credit: RA1.1, Reduce net embodied energy.

<u>Design, Sustainability, Design Actions</u>

Coordinating the wide variety of participants and project activities required for a holistic SD effort requires sustainability-focused leadership. Hosting a workshop and pursuit of a formal Envision certification are examples of activities that promote SD on projects and can add significant value. For the project considered in the case study, an SD leadership effort would have contributed positively to its SustainEval score but was not undertaken. These efforts correlate with the following Envision credits:

- LD1.1, Provide effective leadership and commitment
- LD1.2, Establish a sustainability management system
- LD1.3, Foster collaboration and teamwork

Construction, Approach, Waste Recycling

Managing waste on large construction projects presents a significant opportunity for improved sustainability. Recycling rather than disposing of construction consumables, material packaging and existing material removed during construction can significantly reduce project-generated waste that fills landfills. Development of a waste management program for the case study project would have improved the overall project rating. The ideal program would seek opportunities for project waste to be reused by other projects and seek to recycle other materials that cannot be reused. The waste recycling parameter in SustainEval correlates to the following Envision credits:

- LD2.1, Pursue by-product synergy opportunities
- RA1.5, Divert waste from landfills

The following table shows how the case study project scored in each category in SustainEval both in the Base Case and the Optimized Case.

		Case Study Score	
Parameter Category	Total SustainEval Points Available	Base Case	Optimized Case
Construction	46	6	38
Design	183	22	97
End of Life	9	8	8
Maintenance	44	13	39
Planning	87	34	44
Procurement	33	2	13
Siting	97	64	68
Total	499	148	306

Conclusions and Recommendations for Further Study

There are many opportunities within the transmission line industry to address the needs of Sustainable Development. Improving understanding of the concepts of SD within our industry and promoting collaboration between project stakeholders from initial planning through detailed design, procurement, construction, maintenance, operation and ultimately retirement will result in projects with greater value to the communities they serve, increased synergies with complimentary projects and less impact to our natural world. This holistic approach must look at all aspects of a project, and designers and planners must look at the bigger picture if our industry is to meaningfully contribute to SD.

Our industry is just beginning to participate in the large SD conversation taking place in many other industries. To catch up, we need to collectively take action. Education is the most easily identified first step. Engaging with tools such as Envision and SustainEval is an ideal mechanism for increasing awareness and competency with this subject matter in our industry. The Envision Sustainability Professional certification is an excellent step for individuals to take. For more details, see www.sustainableinfrastructure.org. For utilities or developers, pursuit of an Envision certification for a future project would be an excellent step forward for our industry.

BIBLIOGRAPHY

[1] United Nations Development Program, Human Development Reports, http://hdr.undp.org/en/content/human-development-index-hdi
[2] Global Footprint Network 2017. National Footprint Accounts, 2017 Edition
[3] Brundtland Commission Report, UN World Commission on Environment and Development report 1987
[4] Working Group C3.03, CIGRE, Technical Brochure 340, “Utilities Practices Toward Sustainable Development”, February 2008
[5] Envision Guidance Manual, “A Rating System for Sustainable Infrastructure”, Institute for Sustainable Infrastructure, 2012