

POWER SYSTEM SUSTAINABILITY AND ENVIRONMENTAL PERFORMANCE

SPECIAL REPORT FOR SC C3

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Special Reporters

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The scope of Study Committee C3 covers the identification, assessment, and management of the interactions between the natural and social environments and the electricity system throughout the life of the infrastructure (cradle to grave), recognising the importance and influence of stakeholders and communities and seeking to anticipate changes in the energy system and the environment.

For the 2024 CIGRE session, three preferential subjects were defined, all of them well aligned with the Strategic Directions of the SC C3:

- PS1: Public acceptance and stakeholder engagement in power system generation, transmission & distribution infrastructures
- PS2: Climate change and impact on power system, a holistic approach
- PS3: Sustainability starting for the supply chain.

PS1: Public acceptance and stakeholder engagement in power system generation, transmission & distribution infrastructures

General

Public participation in energy sector projects is becoming increasingly important today due to heightened environmental awareness, regulatory requirements, and economic factors.

Social awareness and activity are increasing, and authorities and companies are becoming more responsive to public concerns and needs, leading to more comprehensive and just outcomes. The benefit is mutual: early and meaningful engagement can identify and address concerns, reducing the potential for conflicts and opposition. On the other hand, input from stakeholders can lead to more efficient use of resources and cost savings by identifying potential issues early on.

Many countries have legal frameworks that require public participation in the planning and implementation of energy projects. Nevertheless, authorities, investors, and scientists do not limit themselves to the minimum; instead, they try to propose increasingly broader solutions and methodologies to account for public participation.

Paper description and discussion

12 papers were accepted for PS1, which can be divided into 3 groups:

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1. Strategies, tools, indicators, and methods that allow for an effective stakeholders' engagement.

There are 4 papers in this group, C3-11069; C3-11001 & C3-11406 are focused on generation, RES development process in particular, and C3-10643 is applicable to transmission infrastructure development projects.

- a) Methods enabling the consideration of public opinions and conclusions from stakeholders in RES development process.

C3-11069 Investigation on Current Trend of Land Use of Installation Site for Photovoltaic Power Generation Systems. In this paper, the current status of PV installation sites in Fukushima, Nagano, and Aichi was investigated using the statistics of land use and visual identification of satellite images. According to the authors, such an analysis – based on “lessons learned” approach - may be helpful in forecasting the future areas of PV installation in other parts of Japan, considering the currently required information sessions with stakeholders and obtaining their approvals.

C3-11001 Dialogue as an important link for increasing the level of project feasibility. The paper introduces a holistic approach employed in facilitating the integration of RES into the electricity sector of Slovenia. One of the results of the project was the mapping of RES potential for electricity production in Slovenia and the analysis of optimal sites for deploying large RES for electricity production. The publication contains a detailed description of the method used in the project. As the method includes a dialogue conducted on three levels of public: state stakeholders, investors, and the local public, the authors demonstrate how knowledge exchange between stakeholders can improve the final results of the analysis, and ultimately, the entire investment process.

C3-11406 Assessing the Sustainability of Future Regional Energy Systems: Integrating Stakeholder Perspectives. The publication provides an analysis of how stakeholders weight different perspectives on the energy system. The presented discussion compares four scenarios of the future energy system of the District of Steinburg, Germany, for 2050. According to the authors, understanding how stakeholders prioritize different perspectives on the energy system is crucial for determining the final configuration of a future energy system and the framework for investment decisions.

- b) Methods enabling the consideration of public opinions and conclusions from stakeholders in transmission infrastructure development process.

C3-10643 A geodesign-based framework that implements BIM methodology with GIS tools and involve stakeholders in transmission infrastructures projects. The paper addresses a methodological approach based on BIM methodology and GIS tools providing support for managing the investment projects. The presented methodology, with a dedicated interface, allows for consideration of stakeholders' opinions in each individual phase of a project (environmental, engineering, permit obtainment, and construction), providing the “feedback-iteration-consensus” approach.

- **Question 1.1.** Is the voice of stakeholders essential in order to undertake those large-scale RES or scenarios development?

- **Question 1.2** Are there any indicators regarding public participation which support the sense of stakeholder's involvement?
- **Question 1.3** Is the lack of social acceptance a barrier to RES infrastructure development?
- **Question 1.4.** Paper C3-1043 presents a specific methodology used for transmission infrastructure projects. How the mentioned methodological approach helps to accelerate the investment process along with the strengthened of social acceptance?
- **Question 1.5** Is it possible to provide any examples or inputs collected during dialog sessions?

2. Experiences in dealing with public acceptance of new and existing infrastructures.

Papers C3-10938, C3-10942 & C3-10943 refer to experiences related to generation, hydropower and C3- 10669 is applicable to transmission infrastructure development projects.

- a) Public participation in the hydroelectric sector including experiences with the development and decommissioning phases of hydro power plants.

C3-10938 Periodic Stakeholder Perception Mapping combining Social Impact and Relationship Assessments: A strategy to evaluate and enhance levels of social legitimacy for enterprises. The paper focuses on the effectiveness of the Social License to Operate which must be continually negotiated between the investor and stakeholders. The authors present their conclusions based on a case study – a retrospective analysis of "stakeholders - investor" relationship management at Santo Antonio Hydroelectric Power Plant, which has been in operation since early 2012.

C3-10942 Stakeholder engagement in the hydropower decommissioning process: a groundbreaking study in Latin America. The paper describes public participation aspects during the decommissioning phase of hydropower plant infrastructure and presents results from a study developed as part of the decommissioning plan of the Pandeiros Small Hydropower Plant Dam in Brazil. The described phase of decommissioning plan includes social studies that engage the stakeholders in the hydropower plant's decommissioning plan resulting in significant changes in the primary investor's assumptions.

C3-10943 Indicator Systems to Measure Efficacy and Effectiveness of Socio-Environmental Programmes of Hydroelectric Power Plants. This paper presents the research methodology for evaluating, monitoring, and controlling the effectiveness of environmental programmes and actions arising from the environmental licensing of hydroelectric generation projects. One of the main objectives was to develop a methodology for evaluating, monitoring, and controlling the performance of socio-environmental programs implemented by electric power generating companies in Brazil, and to present guidelines and actions to increase the efficacy and effectiveness of these programs.

- b) Experiences in dealing with public acceptance during the planning, modernization, and construction of substations and power lines.

C3-10669 Public acceptance of facilities in power transmission network in Montenegro. The publication focuses on the experience of Montenegrin Transmission System Operator with avoidance, mitigation, and compensation measures during the planning, modernization, and construction of substations, overhead and cable lines. Special attention is given to stakeholder engagement in project management and public acceptance.

- **Question 1.6** According to paper C3-10942 there is a legal gap regarding the decommissioning of hydropower dams and therefore every case must be individually evaluated by authorities and stakeholders. Could Social License to Operate mentioned in paper 10938 be applied instead?
- **Question 1.7** What is a difference between Social Licence to Operate and socio-environmental programmes for public participation stage?
- **Question 1.8** Is there any legal gap which should be fill referring to the public participation to help the TSO to conduct public consultations even more effectively?

3. Role of mitigation, compensation, and offsetting measures - whole life of infrastructures.

Papers in this group describe different technical solutions to reduce environmental impact that are relevant and can increase public acceptance. Among these solutions, measures regarding biodiversity conservation are especially relevant.

- a) Specific technical solutions reducing spatial scope of transmission lines impact which can increase public acceptance of the infrastructure.

C3-10894 Levels of Electromagnetic Field in the Vicinity of Transmission Overhead Power Lines with Special Conductors. The paper focuses on the application of special conductors on power lines designed to increase the capacity of existing lines while maintaining the same width of the corridor. In situations where finding new corridors is not possible and ensuring reliable and safe transmission of electricity is necessary, the use of special conductors can be a suitable solution in terms of environmental impact and public acceptance.

C3-11535 Design & Development of India's 1st Indigenous Pivoted Type Insulated Cross Arm for 400kV Transmission Line. Introducing pivoted type insulated crossarms as a solution, the paper highlights their efficacy in constructing lean transmission lines with minimal corridor demand. Replacing conventional steel crossarms, with described ones may result in a reduction in the need for land use, thereby potentially improving public acceptance while ensuring increased network efficiency.

- **Question 1.9** Can you describe whether the mentioned technical solutions help to accelerate the investment process along with the strengthened of social acceptance?
- **Question 1.10** What is the relevance of social acceptance in deciding on the application of these measures?

- b) Biodiversity and environment as a sensitive topic for stakeholders

C3- 10676 Multidisciplinary approach to managing wildlife risk in a DSO. The paper describes actions taken by the Distribution and Transmission System Operator in South Africa to mitigate the impact of electricity infrastructure, both constructed and planned, on biodiversity wildlife. According to the authors, these actions aim to enhance stakeholder engagement and public acceptance of energy infrastructure. The authors focus on the results of the work of a multidisciplinary group established by the operator in cooperation with one of the NGOs.

C3-11515 Harmonizing Nature's Symphony: biodiversity as a powerful tool for public acceptance. The paper focuses on the crucial role of commitment to biodiversity as a tool for public acceptance and a solid investment, leading to reduced process times and cost savings for Dutch Transmission System Operator. Examples presented in the publication involve mitigation and compensation measures that exemplify TSO's collaborative approach with local communities, nature organizations, and government agencies. These projects involve extensive ecological research, artificial badger setts, heath corridors, and fauna passages, showcasing how TSO simultaneously builds trust and positive relationships.

- **Question 1.11** What is the role and effectiveness of these actions? Does it increase social acceptance and therefore accelerate investment implementation?
- **Question 1.12** Are there any indicators regarding public participation which support the sense of their involvement?
- **Question 1.13.** To what extent are stakeholders involved in the definition, implementation and monitoring of mitigation/compensation/offsetting measures?

Finally, some general questions are proposed (applicable to all the groups):

- **Question 1.14** How would you define public participation and stakeholders' engagement in the subject described in your publication? What was the role of public participation – supportive, initiating, supervising, etc.? What was the assumed result of public participation? was the goal achieved?
- **Question 1.15** Was the stakeholders engagement cost by the legal bidding requirements or was it investors' choice to involved them?

PS2: Climate change and impact on power system, a holistic approach

General

According to scientific research, it is evident that the global temperature has risen, and will continue to rise, thus resulting in an expected increase of impacts from climate change. Even with a successful limitation of the global warming temperature to 1.5° C, a scenario in which projected losses and damages could be reduced, impacts on the human systems and ecosystems cannot be completely eliminated. The energy industry, specifically the electrical systems, are expected to be affected by the following climate change effects: direct impact on infrastructures, generation, transmission, distribution, and demand. Therefore, it is both a necessity and obligation to address such climate risks, by identifying and assessing the risks to better define the anticipation, risk mitigation, and adaption measures.

Paper description and discussion

A total of 12 papers were accepted for Preferential Subject 2, ranging from climate change impact analysis on power systems and their assets, to risk strategies and methodologies as well as adaptation measures based on authors, stakeholders, and engineers experiences. The papers have been classified in three groups, although many of them are related to more than one group.

1. Expected variations in the climate variables according to different scenarios. Potential impacts on power infrastructure and on system operation.

These papers address critical concerns related to the impact of climate change on the operation of power systems and their infrastructures, spanning a diverse range of both geographical and technical scopes, ranging from photovoltaic outputs in China, to proactive investments in coastal substations.

C3-10381, Future projections of extreme conditions affecting the Italian Energy System with a multi-hazard approach, the reliability and demand of a power system depends on weather conditions, in particular, extreme weather events. Heavy rain, wet snow, strong winds, prolonged dry and hot periods can impact the energy infrastructure and industry. Terna and RSE have developed a risk-based methodology to compute the benefits at increasing resilience in the power system. This paper aims to improve the resilience of the Italian power system through climate change projections and providing useful information to stakeholders by determining the portfolio of investments for prevention, mitigation, restoration, and monitoring actions. Projections are focused on the 21st century, with the reference data spanning the period 1986-2019. By providing the datasets, methodology and results comparisons with other this paper offers adaptation strategies against climate hazards adopted by Terna. Euro-CORDEX models provided daily environmental outputs. Using climate models based on the Representative Concentration Pathway scenarios.

C3-10237 Climate Change Impacts on Low Power Output of Photovoltaic in China, due to frequent heatwaves and prolonged rainy weather, a reduction in the output of the PV in China is expected. This leads to an increase of risk of power supply shortages. By 2030 solar and wind capacity will surpass 1200 GW, with PV installations expecting to experience a 53% increase from 2022. This paper aims to project and understand the long-term impact of climate change on PV power output, the residual effects on the planning and development of China's power system, and to improve the reliability and stability of the power supply. This is realized by using data from as early as 1984 to project values up to the year 2060 where the reference dataset ranges from 1984-2014. Analyses across various scenarios and climate models done suggest an increase in severity of low output occurrences. Data is collected from 16 sets of the Coupled Model Intercomparison Project (CMIP). This paper used key factors such as the surface downwelling shortwave radiation, air temperature, windspeed, to assist in the projections, while also accounting for the PV potential index values. Authors also considered the potential errors of the CMIP models and determined which models provided the best results.

C3-10450, Quantifying the Financial Impact of Proactive Physical Infrastructure Improvements in Substations, because a high percentage of the global population live within 100km of the ocean and climate change in both the near and distant future will cause sea level rises, both substations and other asset investments near the coastline will inevitably be affected by such changes. Therefore, the focus of this paper lies on the topic of coastal substations and their concerning assets. This paper explores how a high-impact flood event can be measured and reduced through active investment in various forms of changes to the physical infrastructure of the electric grid. It also investigates the importance of true/lifetime costs versus initial investment costs. This paper tries to convince the FERC that they should incentivize utilities to increase the base investment to help improve the resilience of the system and total lifespan costs. Construction, lifetime operation, maintenance costs are determined, as well as the costs incurred by potential flood events. By comparing the cost analyses done in a scenario with proactive investment, the fiscal impacts of both types of scenarios are presented.

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C3-10750, Impact of Climate and Weather Variability on Energy Systems Planning, this paper seeks to enhance such capacity models by including the variability of the climate to help project future energy system demands and supply across specific European countries. By incorporating long-term planning strategies. This specific capacity expansion model utilizes multi-vector and multi-zonal techniques and implements data from the EURO-CORDEX and other climate models. This project was able to successfully integrate climate variables like air temperature, wind speed and solar radiation into the energy model. In the process of doing so, it revealed significant impacts on energy demand and generation efficiency.

- **Question 2.1** How might collaborating with both the policymakers and stakeholders influence the practical application of the findings from the research? How is collaboration with the public dealt with in such cases?
- **Question 2.2** Different studies implement various geographical scales to address the impacts of climate change on renewable generation and power transmission (some in Europe use a 4x4 km mesh), are there any suggestions to using specific scales to better analyse and address such impacts?
- **Question 2.3** Is there any specific experience to share regarding the scenario definition? Which are the main difficulties to identify/use climate projections?
- **Question 2.4** Are there any specific challenges in integrating either climate risk analyses, or new technologies into the planning, designing, and operation sections of a power network?

2. Risk assessment methodologies & experiences.

Using analytical models, simulations, and experience, these papers address studies to improve the resilience regarding impacts due to climate change and risk mitigation strategies.

C3-11488, Risk Management of Fluvio-Torrential Events on Electric Transmission Infrastructure in the Face of Climate Change: Lessons Learned from the Mocoa Disaster, this paper was written to develop a comprehensive risk management strategy for the transmission infrastructure affected by fluvio-torrential events. It uses the 2017 Mocoa disaster as a case study to better the infrastructure resilience and safety in the future. By identifying and addressing potential risk scenarios linked to such events, the decision-making for site selection and design in flood-prone areas can be improved. The project utilized advanced methodologies like the AS/NZS 4360:1999 standard for risk management and hydrological models from the Inter-American Development Bank. Techniques included detailed geological and geotechnical studies, hydraulic simulations using FLO-2D and Riverflow 2D, and the development of risk scenarios. The results of this paper show the conducted studies. Such studies include: topographical surveys, geological characterizations, and hydraulic simulations. With the data from the studies, a location deemed safer was determined for a new electric substation by identifying the hazards, vulnerability, and risk maps.

C3-11716, Faults and damages in the distribution network due to impact of climate change, the focus of this paper is to analyse the impact of climate change on Croatia's distribution grid through studying the effects of natural disasters that have been intensified by global warming, then to evaluate the resilience of the grid itself. By studying the effects of various storms and utilizing analytical models such as the Analytic Hierarchy Process (AHP) and Root Cause

Analysis (RCA), vulnerabilities in the network can be determined, and strategies for mitigation can be formulated. The result of this study indicates significant damage from such weather events, and possibly even the destruction of infrastructure. This paper's results also highlight the need for an update on the design standards and infrastructure to help deal with the severe weather projected.

- **Question 2.5** How can the results of the research influence the regulatory and planning processes, and what might be some challenges in integrating such methodologies into already existing company strategies?
- **Question 2.6** Using the findings of the papers, how might response protocols be updated, created, or designed to handle future weather events?
- **Question 2.7** Is there any experience (generation, TSOs or DSOs) regarding the global identification and assessment/prioritization of risks from climate change? Which risks has been assessed as relevant risks for the activity?.

3. Adaptation measures: lessons learned & criteria to be considered for the future and existing infrastructures.

With these papers (C3-10120, C3-11484, C3-11166) the authors offer innovative solutions and adaptations to pressing challenges in the power industry with topics ranging from changes in the network planning approach or tackling the water scarcity, to changing in maintenance approach and standardizing live line work methodologies in developed countries.

Some of the authors propose mitigation measures (measures to reduce CO₂ emissions) as a necessary action for climate change adaptation (C3-11166, C3-11531, C3-11794; C3-10974)

a) Adaptation measures to cope with climate change effects.

C3-10120, Installation of Near to Zero Liquid Discharge (NZLD) Units at New Capital Combined Cycle Power Plant (NCCCPP), describes the difficulties that the Egypt's share of the Nile River remains at a constant 55.5 billion m³ per year, almost ensuring a shortage of water share in the near future. By 2050, a forecasted deficit of nearly 46 billion m³ per day has been determined. Engineers in Egypt need to find a way to either reduce, reuse, or recycle the industrial wastewater of the power generation facility using modern technologies. To approach problems regarding the topics of environmental regulation, water scarcity, economics of water usage, and social responsibility. The engineers achieved a near to zero liquid discharge (NLZD) system while maintaining reasonable capital and operational costs. System's main functions are oil removal, removal of suspended solids, and dissolved salt reduction. Powerplant water consumption is nearly 10x less when implementing NLZD system. Highlights both the engineering and business aspects by addressing concerns on cost, construction time, payback period, type of filtering methods possible. This paper also focuses on the types of filtering possible with such a system. Reverse osmosis unit can provide up to 2150 m³per day of fresh water.

C3-11484, Methodology for the use of live line works as an effective solution during environmental phenomena and regulatory changes in developing countries, this study seeks to establish a standardized methodology for implementing live line works (LLW) in the electrical grid, specifically during times when environment phenomena and regulatory changes create limitations on grid operations. With such a standardization the authors goal is to enhance both

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the reliability and quality of the energy supply in developing countries. Using live line works to maintain and upgrade the electrical infrastructure on the grid without disrupting the supply is essential to reach such a goal. The methodology encompasses the entire Planning, Doing, Checking, and Acting (PDCA) cycle for live line works, incorporating stages such as identification of necessities, preliminary feasibility, innovation opportunities, risk assessment, and detailed planning and execution of live line works. The results show that the methodology has enabled critical maintenance and renovation to be carried out, without the need to compromise the grids operation, thus maintaining system reliability and reducing the downtime during such activities.

C3-11166, Impacts on T&D products by climate change and vice versa, the research paper attempts to both develop and deploy infrastructure solutions that enhance resilience, so that the infrastructure can withstand the impacts of climate change. A resilient infrastructure ensures reliable and sustainable electricity supply while also reducing environmental impacts. This paper focuses on tech such as mobile plug & play transformers, Gas Insulated Switchgears, and net-zero manufacturing processes. By demonstrating such solutions, the authors hope to enhance the transmission and distributions grids to better cope with the increased electrification needs expected in the near and distant future. Various mitigation measures and sustainable assets like SF6-free switchgear and ester fluid transformers were successfully developed. This paper explains that these developments should prove to enhance the performance and safety of the T&D infrastructure during extreme weather events.

b) Reducing CO₂ emissions as part of adaptation to climate change

C3-11531, Climate Change Adaptation in Distribution Network Planning: A Resilient Approach for Sustainable Power Systems, the intent of this paper is to help advance India's commitment to achieving Net Zero by 2070 through the implementation of energy efficient measures across the power system. As a result, enhancement of the systems resilience to climate change was desired. The authors wanted to help in the reduction of emissions and the increase of efficiency through transformer swapping, optimization of switching, and net metering. By utilizing smart meters, dashboards for real-time monitoring, and box plots for peak load estimates, the impacts on the operational efficiency and sustainability of the system can be determined. This research paper aided in significant advancements in smart grid tech, better integration of renewable energy sources, and the optimization of network configurations. It has also helped demonstrate reduction in losses and operational costs demonstrating both environmental and economic benefits.

C3-11794, Development of Trinity Renewable Energy for the Future of East Nusa Tenggara Electricity, by developing renewable energy sources in East Nusa Tenggara, Indonesia, the authors hope to reduce the dependence on non-renewable sources, consequently supporting the region's sustainable and low-carbon development. By 2025, the region aims to meet 23% of its energy needs and achieve net zero by 2060. This short-term and long-term goal may be realized by utilizing the regions renewable sources like geothermal, biomass, and solar power. The authors of this paper have done a comprehensive literature review to assess the energy potential and included case studies showcasing stakeholders involvement. Preliminary results include identifying renewable source potentials on each major island, developing hybrid plants, and the promotion of collaboration between local government, universities, and other stakeholders to utilize biomass in power production.

C3-10974. Highlighting forgotten emissions: Calculate and mitigate carbon loss from infrastructure construction on peatland. The paper outlines the relevance of considering the

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conservation of soil carbon as a significant action to limit global warming and presents a tool to help to select the location of projects limiting emissions from soil carbon (peatlands).

- **Question 2.8** What are the significant adaptations to be made for DSO's and TSO's to better react and handle the increased frequency of severe weather events?
- **Question 2.9** Regarding adaptation measures or new technologies to face climate change: is the availability of such technologies or assets in large numbers, while also maintaining the usual delivery times to enable the expansion of networks. Has there been any look into this topic?
- **Question 2.10** How does the both the adaptation measures or new technologies compare to existing systems or strategies in terms of operational costs, environmental impacts, and overall efficiency?
- **Question 2.11** Concerning long-term sustainability, what measures are already in place, will be in place, or should be in place to address various forms of maintenance challenges regarding adaptation to climate change?
- **Question 2.12** How scalable and adaptable are the methods and technologies if applied in different geographical locations and various environmental conditions?

NGN paper:

C3-11879, The impact of climate change on the Dutch transmission grid: Leading risks and adaptation strategies, through the investigation of the impacts of climate change on the Dutch onshore HV grid, this paper aims to identify risks associated with climate effects and evaluate the preparedness and adaptation strategies of the Dutch Transmission System Operator (TSO), TenneT, in facing these challenges. The authors goal is to aid in ensuring the resilience and reliability of the Dutch onshore grid against climate risks like flooding, downbursts, and other extreme weather scenarios. The authors implemented qualitative analysis based on literature reviews, stakeholder interviews, and meteorological data. The results from this analysis include the identification of vulnerable substation to flooding, possible increases in frequency and severity of downbursts, and recognizing other weather-related impacts. It also assesses TenneT's existing and planned adaptation measures.

PS 3 Sustainability starting for the supply chain.

General

A truly sustainable power transmission and distribution system must take a holistic view of the impact on environment and society from cradle to grave (or cradle to cradle), maximizing usage of eco-design and circularity solutions. For monitoring real-life progress, generating and sharing sustainability data across the value chain is key. While each actor is able to collect data and optimize practices within their own range of activities, gaps remain in how information is transferred up and down the supply chain and how to reconcile differing interpretations concerning the right balance between conflicting sustainability targets. Accounting principles must be transparent, and information must be verifiable.

A preeminent sustainability goal remains decarbonisation. The Greenhouse Gas (GHG) Protocol categorizes emissions according to Scope 1 (direct emissions from sources owned by the company), 2 (indirect emissions from the generation of purchased electricity) and 3 (other indirect emissions). For transmission and distribution networks, Scope 1 mainly relates to SF₆ leaks and can now be significantly reduced through introduction of equipment using SF₆ alternatives for insulation and interruption. Scope 2 mainly relates to power losses and is where increasing the share of renewable generation is the main lever to reducing these emissions. As electricity grids continue to decarbonize, Scope 3 emissions from manufacturing, installation and decommissioning of grid equipment are growing in relative importance for three main reasons: (1) the material intensity of the electricity grid is growing and main materials for T&D equipment are also much needed for producing lower carbon and renewable power generation solutions to address the growing need for electricity. (2) as grids continue to decarbonize, the share of Scope 3 to total life cycle emissions of T&D equipment is also increasing, and (3) the boundary of a net zero targets for the electricity system also includes Scope 3 emissions. It is time to formulate strategies to reduce such emissions through appropriate specifications and incentives in tendering processes with accurate and credible evaluations. One challenge is that the grid assets are often expected to be installed for several decades, making the prediction of future use, maintenance, and end of life scenarios in a changing world an integral part of cradle to grave life cycle assessment. Another challenge is that sustainability involves a multitude of considerations beyond decarbonisation. Other urging environmental challenges (as defined by the concept of the planetary boundaries) such as fresh water and land use, nutrient overload, or ozone depleting chemicals are also relevant for the life cycle impacts of T&D equipment that must be also considered for advancing sustainability where a need for a balanced approach between the different environmental impact categories in tendering practices is required.

Paper description and discussion

A total of 11 papers were accepted for Preferential Subject, covering different aspects of the topic. They have been divided into three groups according to their content, although most papers touch on multiple aspects.

1. Inclusion of eco-design and circularity criteria: solutions to reduce impact along the whole life of the assets.

Articles C3-10286, C3-10287; C3-11395; C3-11078, address different concepts related to circular economy, eco-design, LCA and other approaches to measure the environmental impact of different equipment or components of the power system. Results of studies carried out for some equipment, proposals, and more environmentally friendly solutions, paying special attention to the reduction of GHG emissions, are included.

Document C3-10885 shows how other environmental aspects (noise) can be better mitigated by applying an eco-design approach.

Finally, articles C3-10944 & C3-11067 address other approaches of eco-design and LCA applicability.

C3-10286 Ecodesign aspects to enhance circularity and boost sustainable solutions through procurement provides an overview of Life Cycle Assessment including environmental footprint methodology with multiple environmental impact categories and modelling of recycling. Examples are given for an offshore substation, high voltage AC submarine cable, as well as a comparison between overhead lines and underground cables.

C3-10287, Circularity for HV equipment defines product circularity targets including recyclability, extension of the useful life, and reduction of the environmental impact linked to materials, with Gas Insulated Switchgear and Power Transformers as examples of high voltage power devices benefiting from the approach. Use of recycled materials, low waste manufacturing processes, selection of insulation gases with reduced global warming potential, more compact design, extending lifetime by monitoring.

C3-11395, CO₂-reduced steel in transformers & challenges with impact evaluation discusses the environmental impact of Grain Oriented Electric Steel where the CO₂ emissions during manufacturing have been reduced by replacing some part of iron ore by scrap. Life Cycle Assessment is the performed cradle to gate for a power transformer with a steel core considering impact categories of global warming potential, acidification, eutrophication, abiotic depletion, ozone depletion, and photochemical ozone formation.

C3-11078 Identifying key factors to mitigate life cycle carbon emissions of stationary battery energy storage systems evaluates CO₂ emissions from raw material extraction, refinement, production, transportation and operation of lithium-ion batteries for battery energy storage systems, comparing the results to scenarios where the energy mix has lower carbon intensity and where material is sourced from repurposing and where the lifetime is extended.

C3-10885 Audible noise reduction of high-voltage overhead lines by applying an eco-design approach while considering impact on the environment selects noise reduction as an eco-design target and provides a methodology for rating overhead lines based on their importance to the power system, the technical feasibility of noise reduction measures, present acceptability of noise levels, and assessed future acceptability of noise levels, and provides a recommendation for noise reduction activities based on this ranking.

C3-10944 A step forward on sustainability in the electricity sector: putting LCA on the table describes Life Cycle Assessment of electricity generation in Brazil considering both water and CO₂ footprint, performing evaluation of hydropower, wind power, and natural gas thermal power from cradle to grave.

C3-11067 Development of EV Charging Demand Estimation Model based on Road Traffic Census Data for Impact Assessment of High Penetration EV defines different scenarios of Electric Vehicle charging behaviour and evaluates the required charging infrastructure and the possibility to utilize surplus renewable energy thereby reducing CO₂ emissions.

- **Question 3.1** One way of achieving circularity is through repurposing, e.g., reusing lithium-ion batteries from mobile applications for energy storage (C3-11078), or recycling for reusability of a recycled content in new material production for T&D equipment such as mixing scrap metal in grain-oriented steel (C3-11395), or recycled aluminium for gas-insulated switchgear (C3-10287). What are the most promising applications for repurposing of parts and components in grid technologies? What boundary conditions (standards, policies...) could support a higher circularity (reusability, repurposing...) at end-of-life of this equipment?
- **Question 3.2** Life-time extension of existing assets is presented as a method of reducing environmental impact of the other stages in the life cycle assessment (C3-10286, C3-11078), for example through digital solutions and improved maintenance? What are the most appropriate methods to quantify the sustainability benefits of life-time extensions? Considering that a large share of environmental impact occurs during the use stage (as the

source of electricity energizing the units and its associated life cycle environmental impacts dominates the life cycle environmental impacts of the T&D equipment on most of the environmental impact categories).

Under what circumstances does it make sense to replace a functional equipment by an eco-design version with lower environmental impact versus extending the lifetime of an existing asset? Under what circumstances does it make sense to introduce a recycled/reused component with shorter lifetime than a component from virgin materials?

- **Question 3.3** While decarbonisation targets play a preeminent role in eco-design (as it's the case in the existing EU-Tier 2 eco-design directive for new transformers in Europe or in other environmental directives in other regions typically regulating operational energy efficiency), it may be pertinent to focus specifically on other environmental impact such as noise pollution (C3-10885) or water footprint (C3-10944) depending on local conditions or on circularity aspects such as upgradability, or materials recoverability at end of life . What sustainability goals that are not receiving sufficient attention in grid technologies and require more considerations in eco-design policies and methodologies for T&D equipment?
- **Question 3.4** Life Cycle Assessment tend to show the main environmental impacts during use stage (determined by the electricity-mix energizing the equipment), followed by the material manufacturing stage (C3-10286, C3-10287). Considering that power losses can be reduced by increasing conductor diameters, e.g., increased use of materials during manufacturing, what is the right balance between losses (energy efficiency) and material impact (material efficiency)? What are other important trade-offs that require attention?
- **Question 3.5** The mass balance approach (MBA) is widely accepted as methodology for estimating recycled content in new material production but it's a controversial approach if it's used for allocating carbon emission reduction (thanks to higher share of scrap metal) totally to a certain amount of the production process output. So, what is the way forward on the MBA (C3-11395) to balance the need for environmental integrity while supporting the decarbonization efforts (and associated investments) in the supply chain (particularly the steel industry in short- to mid-term)?
- **Question 3.6** The energy mix has a large impact on the evaluated environmental impact. However, grid equipment is designed for use over several decades, during which the energy mix and power flows (C3-11067) can be expected to change. Other sustainability aspects such as the impact of noise pollution could also be expected to change due to urban development (C3-10885). How should uncertainty in future predictions be handled and what time horizon should be used? Are there also any required implications of these future uncertainties on the design process of new equipment today?
- **Question 3.7** The information flow is typically assumed to be from the supplier to the operator, but information from monitoring and operation performance will also be useful for the supplier to improve eco-design solutions and reduce (real-life) environmental impact (C3-11078). What methods and processes are envisioned to help the suppliers better understand the environmental impacts of their products under real service- and end-of-life conditions?

2. Consideration of circularity criteria in the decision making. Green procurement.

In order to achieve a more sustainable electricity system, it is not enough to know the impacts and identify the different solutions. It is necessary to activate mechanisms to ensure that circularity criteria are considered in decision-making, whether these decisions affect the definition of a project, the choice of certain technologies or materials, or purchasing decisions in which solutions or even suppliers whose performance is more in line with sustainability criteria can be chosen.

Paper C3-10451 presents a methodology to facilitate decision-making and papers C3-11694 & C3-10286 (also included in the previous group), include proposals for the consideration of sustainability criteria in tendering processes.

C3-11694 Transforming Sustainable Procurement in the Power Transmission Sector: Evolving Qualification Requirements and Evaluation Criteria describes sustainable procurement with a Lifecycle Cost approach, including Total Cost of Ownership, and assigning monetary values to external sustainability related risks and opportunities through shadow pricing. Sustainability requirements with a evaluation methodology are also proposed.

C3-10451 A Framework for Sustainability-centric Decision Making in the Selection of Construction Materials for Power System Projects presents a methodology with a graphical representation of sustainability versus feasibility as a visual aid for decision-making and to facilitate communication to stakeholders. Use cases for low embodied carbon concrete and SF₆ alternative circuit breakers are provided.

- **Question 3.8** Certification programs (C3-10287) and digital product passports targeting higher transparency and traceability (C3-10286) are put forward as important tools to align impact quantification methodologies across different industries in the supply chain (steel producers, copper producers, insulating fluids produces serving different economic sectors beyond the T&D equipment manufacturing) and to verify the sustainability data from the supply chain. What is the potential of the blockchain technology on supporting circularity and Scope 3 emission management and reduction? (C3-11789) What other traceability methods and technologies could play a role here as well?
- **Question 3.9** Transparent sustainable procurement practices may involve shadow-pricing (C3-11694) and only opening bidding to suppliers fulfilling predefined qualification criteria (C3-10286) What are the available solutions to transparently evaluate sustainability- and economic performance when awarding contracts?
- **Question 3.10** The result of Life Cycle Assessments depends on the input data quality and the underlying assessment methodologies. A standardised approach with harmonised rules would support robust and consistent quantitative environmental data (C3-10286) but might not always be representative of specific countries (C3-10944), suppliers (C3-11395), or changing practices (C3-10451) and might sometimes lead to less sustainable decisions (C3-11303) unless the methodology is sufficiently nuanced and data quality is sufficiently high. What is the way forward to resolve these challenges?
- **Question 3.11** Some examples of qualitative tools to support communication and decision making are provided for mapping sustainability versus feasibility (C3-10451) and prioritization of design and sourcing choices (C3-10885). When is qualitative analysis sufficient and when should the step be taken to quantitative methods?

3. Decarbonisation: accounting scope 3 emission and reduction strategies.

Climate change is a central issue for the electricity sector, which in addition to its role as a central player in the decarbonisation of the economy must work to reduce the carbon footprint associated with the development of the electricity system. This involves working on the emissions associated with the materials, equipment and works that come from the supply chain (so-called Scope 3 emissions).

As mentioned above, many of the methodologies for measuring impacts and proposed solutions focus primarily on reducing GHG emissions, but it is necessary for companies to establish a systematic approach to accounting for these emissions as one of the essential steps to understanding and measuring progress. Paper C3-11303 provides an example of an accounting methodology for grid investments by collecting information from the supply chain.

Reduction strategies would relate to the incorporation of emission reduction criteria into the decision-making process and the selection of the best available alternatives (both issues addressed in sections 1 and 2 above).

C3-11303 Tackling Scope 3 GHG Emissions of Grid Investments: Creation of Accounting Platform and CO₂ Models for Tracking Emissions of Purchased Goods and Works describes a methodology and the creation of an inhouse software to report greenhouse gas emissions linked to new assets and construction, defining layers of data based on their accuracy, with external emission factors the least credible, and certified cradle to grave LCA from suppliers the most credible, where examples for cables, overhead lines and substations are used to demonstrate the importance of high accuracy data.

C3-11789 RENOVA: Traceability System for the Trading of Renewable Energies in the Chilean Electric Market based on Blockchain Technology describes a digital platform for tracing the origin and destination of renewable energy intended for large consumers who need certifications of their energy usage. Blockchain technology was chosen for security and the ability to verify transactions.

- **Question 3.12** What are the main difficulties in measuring emissions associated with purchased goods and services?
- **Question 3.13** Is the measurement of scope 3 emissions useful or can it facilitate sustainable purchasing decisions?
- **Question 3.14** Several contributions deal with the complexity of assessing environmental impact of equipment and services for the power system, e.g., C3-10287 focuses on power transformer and substations, C3-11303 on scope 3 emissions of investments in general. Are there some clear “low-hanging fruit” procurement decisions or technology choices available today, which can significantly reduce carbon footprint or other impact categories of capital expenditure for operators?

General information about Contributions and SC C3 activities during the 2024 Paris Session

C3 Group Discussion Meeting

The C3 Group Discussion Meeting (GDM) will be held on **Tuesday 27th August**, at the **Room Havane** from 08:45 to 18:00.

All contributors shall follow the following procedure:

1. Each duly registered delegate or author of a session paper wishing to present a contribution to the questions raised by the Special Reporters in this Special Report has an opportunity to post a contribution on through the registration portal, link : <https://registrations.cigre.org/>. The portal will be open for uploads from end of May until 10th August 2024. **No new contributions will be accepted after August 10th, 2024.** Contributions can only be made by contributors that will be present in Paris.
2. Contributors must prepare **two** versions of their contributions: a **visual** version for the GDM – 2 or 3 slides maximum (including text and visuals such as graphs or photos) and a **written** version (text only). It is important that each contribution is easily identifiable. Each file must be named as follows: **SC_PS*_Question Number_CONTRIBUTOR'S NAME (in capital letters)_Country (official short name)**, for example B2_PS3_Q3.5_WANG_CN. The contributions shall be prepared in the dedicated template. A guide for contributors, as well as templates and sample pages will be available on the CIGRE > CIGRE Session 2024 website.
3. A confirmation email will be automatically sent to the delegate once the contribution has been posted. Kindly note that only registered delegates can access the contributions section.
4. Contributions will be made available to Study Committee Chair and Special Reporters for review and comments.
5. Contributors will be informed about the outcome of the review through the registration portal as soon as the review is completed but **no later than August 15th, 2024**. All contributors with accepted contributions will receive instructions on how to finalise the presentation should adjustments and revision be needed. Contributors can contact/ask questions to the Special Reporters to prepare the contribution.
6. All contributors with accepted and finalised contributions shall meet the SC Chairman, Secretary and Special Reporters as part of the preparatory work for the Group Discussion Meeting on Monday 26th August (preliminary time 12:30-16:30 Paris Time, exact time slot will be confirmed to the contributors)- Hall Ternes Level 1 Poster Session Area (Palais de Congrès).

Important note:

- All contributions will be uploaded prior to the Conference in Paris.
 - Last minute changes to the contributions will not be granted.
7. In case the number of contributions for each Preferential Subject needs to be limited, the selection will be based on relevance, quality, and time of submission of the contribution. Opportunity will be given for spontaneous verbal (no slides) contributions during the session.

Poster Session

It is expected that authors of C3 Session Papers present their papers at the C3 Poster Session which is on **Monday 26th August from 08:30 to 12:30**. The work will be on video screens (no paper print out necessary).

Before **July the 31st** authors shall send their posters to the C3 Special Reporters, C3 Secretary and Poster Convener (to be confirmed) who will review the draft posters.

After confirmation, they will upload the files in advance for the Palais des Congrès. Authors will not have the possibility to upload their own files. If the author(s) cannot attend the Poster Session he/she or the relevant National Committee is requested to send a substitute.

Details will be issued soon on the CIGRE homepage.

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