Considerations for Implementing Effective Virtual Stakeholder Meetings for Linear Infrastructure Projects (LIPs) in the Renewable Sector.

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Abstract

This systematic review synthesises the qualitative and quantitative evidence on the implementation and effectiveness of virtual reality (VR) stakeholder engagement sessions within renewable sector linear infrastructure projects (LIPs). Analysing high-relevance publications—encompassing peer-reviewed articles, industry reports, governmental documents, and book chapters—the study reveals that VR-facilitated engagement has surged since the COVID-19 pandemic, shifting from reactive adoption to strategic, integrated practice. Findings indicate significant gains in participation rates, inclusivity, and comprehension—especially through immersive visualization and asynchronous modalities—while highlighting persistent challenges related to digital equity, communication dynamics, trust-building, and regulatory compliance. Barriers are most acute for rural, elderly, and lower-income groups, with mobile accessibility and hybrid engagement models partially mitigating disparities. Cost-benefit analysis demonstrates that comprehensive VR approaches are most justified for large, spatially complex, and contentious projects such as LIPs. The study concludes that future organisers must carefully match digital tools and designs to stakeholder profiles, prioritise accessibility and trust-building, and continually adapt approaches to project scale and social context, ensuring VR sessions meaningfully enhance both participation and decision quality in the renewable infrastructure sector.

1 Introduction

Linear infrastructure projects (LIPs) represent critical components of modern society's functional systems, encompassing transportation networks, energy transmission corridors, water management systems, and telecommunications infrastructure (Flyvbjerg et al., 2018). These projects are characterised by their spatial extensiveness, traversing multiple jurisdictions, environments, and communities while serving essential public functions. Historically, such developments were set up from primarily utilitarian constructions focused on economic and technical efficiency (Chester, Markolf and Allenby, 2019) but in the past 30 years have evolved to include more integrated systems reflecting increasingly nuanced approaches to governance and impact mitigation (Leong et al., 2024, Martinez-Alier et al., 2020). This evolution mirrors broader societal transitions in values and regulatory frameworks, moving from single-purpose engineering solutions toward multi-dimensional projects that balance complex technical requirements with ecological integrity (Laurance et al., 2021), community needs (O'Faircheallaigh, 2020), and future considerations such as climate change (Hanna et al., 2023).

Due to the complexity within a LIP, additional stakeholder engagement processes and impact assessment methodologies have been developed to address potential adverse effects (Kujala et al., 2022). Stakeholder engagement practices for LIPs have become a standardised and needed practice, transitioning from primarily informational approaches toward more collaborative frameworks that emphasise meaningful participation and co-creation (Innes & Booher, 2018). This reflects growing recognition of infrastructure's social dimensions and the understanding that effective engagement contributes directly to project success through reduced opposition, enhanced decision quality, and improved social license to operate (Devine-Wright, 2017). For LIPs specifically, the expansive geographical footprint creates additional complexity, as stakeholders along project corridors may have differing priorities or concerns. Of these concerns the most poignant and complex to traverse include biodiversity/ecological concerns (Juff-Bignoli et al., 2021) and/or the concerns and varying priorities within the local and indigenous communities that live within the impact footprint of a LIP (Delicado et al., 2016, Buhmann et al., 2021, Quail et al., 2025).

LIPs are commonly found within the rising renewable energy infrastructure sector. These projects include transmission corridors, offshore wind export cables, and pipeline networks and present distinct stakeholder engagement challenges due to their geographic scale, technical complexity, and their multi-jurisdictional nature (Cuppen et al., 2016). These projects typically involve diverse stakeholders with varying degrees of technical knowledge, potentially competing interests, and different expectations regarding involvement in planning processes (Wolsink, 2018).

Renewable energy infrastructure projects face scrutiny due to their visible physical presence, potential environmental impacts, and role in energy transition policies. Renewable energy LIPs often sit at the intersection of tangible local environmental change and abstract global climate policy, creating tension between perceived costs locally and benefits distributed broadly (Rydin et al, 2018). The International Energy Agency (2022) projects that to meet climate goals, global renewable capacity must triple by 2030, necessarily involving thousands of new LIPs which are likely to cross multiple jurisdictions. This expansion occurs against a backdrop of increasing public expectations for participation in infrastructure decisions and growing recognition of procedural justice concerns in energy transition planning (Jenkins et al., 2021). On the international stage there are a variety of differing regulations and policies for how stakeholder engagement should take place and what they need to legally cover.

For example, the European Union's revised Environmental Impact Assessment Directive (2014/52/EU) strengthens requirements for public participation, specifying that "reasonable timeframes for the different phases shall be provided, allowing sufficient time for informing the public and for the public concerned to prepare and participate effectively in environmental decision-making" (European Parliament, 2014, Article 6).

Similarly, the U.S. Bureau of Ocean Energy Management requires "early and ongoing consultation with stakeholders" for offshore wind projects, with virtual engagement becoming an accepted methodology for fulfilling these requirements (BOEM, 2021, p. 17). Originally Executive Order 13990 (2021) further emphasised inclusive stakeholder engagement, directing agencies to "listen to the science... respect the integrity of government scientists... ensure environmental justice... and bolster resilience to climate change" (Executive Office of the President, 2021), however this has since been revoked by Executive Order 14148 (20 January 2025). Indigenous consultation requirements add another layer of complexity, with frameworks like the United Nations Declaration on the Rights of Indigenous Peoples establishing principles of free, prior, and informed consent that infrastructure developers increasingly recognize as essential (Ruckstuhl et al., 2014).

The ongoing digital transformation in infrastructure planning has accelerated the adoption of virtual meeting and virtual platform technologies, particularly following the global experience with remote work during the COVID-19 pandemic (Lingard et al, 2021, Wei et al, 2024). Prior to the pandemic, technological developments were already enabling more sophisticated virtual engagement tools for infrastructure planning. Digital twin technologies capable of creating detailed virtual representations of physical infrastructure have advanced significantly (Boje et al, 2020). Augmented reality (AR) and virtual reality (VR) applications for stakeholder engagement have similarly progressed, enabling immersive experiences that help non-technical stakeholders understand complex engineering proposals by potentially addressing the "visualisation gap" that can impede effective communication (Wang et al., 2019).

Artificial intelligence applications for meeting enhancement have also matured substantially, with capabilities including automated transcription, real-time translation, sentiment analysis, and meeting summarization (Wang et al., 2025). These technologies address documented challenges in information management and cross-cultural communication that are particularly relevant for international infrastructure projects. Geographic information systems (GIS) have simultaneously evolved toward more interactive, web-based platforms that facilitate spatial understanding of LIP impacts (Alonso et al., 2018).

The application of these technologies to renewable energy infrastructure has grown particularly rapidly, with offshore wind development serving as a prominent example. The spatial complexity of these projects creates visualisation and communication challenges that virtual technologies can help address (Ørsted North America & VHB, 2023).

Due to the rise in large renewable energy LIPs, and development of better virtual technology allowing stakeholders to meaningfully connect, stakeholder meetings are commonly hosted on virtual platforms such as teams, zoom and skype. However, there is no clear blueprint on what technology should be used for renewable energy LIPs virtual stakeholder meetings. Additionally, it is uncertain whether the increasing prevalence of interactive VR or AR can be cost-effectively run and regulated. These technologies must ensure meetings necessitate culturally appropriate engagement approaches that respect traditional knowledge systems (Bhawra et al., 2022) and governance mandates relevant to the location of the infrastructure project. Such as the European Commission mandate to ensure "stakeholders are kept up to date on developments and provided with a platform to express their views and feedback" (European Commission, 2019, p. 23).

The policy frameworks governing virtual engagement specifically vary by jurisdiction, with the EU's comprehensive approach through the AI Act contrasting with the UK's more context-sensitive approach using existing sector-specific regulations. This regulatory diversity creates challenges for linear infrastructure projects spanning multiple jurisdictions, suggesting the need for harmonized approaches to virtual meeting governance. Additionally, data protection regulations including the General Data Protection Regulation (GDPR) in Europe and the California Consumer Privacy Act (CCPA) in the United States establish parameters for data collection and usage that affect virtual engagement platform design and operation (Hartmann & Ogden, 2020).

1.1 Research Gaps and Paper Objectives

Despite growing implementation of virtual meeting technologies for infrastructure stakeholder engagement, significant research gaps remain regarding their comparative effectiveness, optimal application frameworks, and implementation considerations specific to LIPs. The literature on digital technologies in construction and infrastructure planning has primarily focused on technical applications rather than stakeholder engagement (Delgado et al., 2020), while stakeholder engagement literature has only recently begun examining virtual modalities in depth (Lingard et al., 2021).

Questions remain about the optimal application of these technologies for LIPs in the renewable sector that traverse large geographic areas and impact multiple communities. These questions include considerations of cost-effectiveness, technological equity, communication quality, and regulatory compliance. Additionally, the balance between technological capabilities and human connection needs remains insufficiently examined, particularly for projects requiring trust development among diverse stakeholders.

This paper aims to address these research gaps through a comprehensive examination of the benefits, limitations, and challenges of implementing virtual meetings/ VR for LIP stakeholder engagement within the renewable energy sector. The analysis considers both technological capabilities and human factors, evaluating evidence regarding comparative effectiveness of virtual versus traditional engagement modalities to help facilitate compliant and optimised stakeholder engagement in the future.

2 Method

2.1 Research Design and Methodological Framework

This study employed a systematic literature review approach, following the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines (Moher et al., 2009). A systematic review methodology was selected due to its rigorous and transparent process for identifying, evaluating, and synthesising relevant research (Petticrew & Roberts, 2006).

The literature search employed a comprehensive strategy encompassing multiple academic databases, practitioner and technical publications, governmental depositories and gray literature sources. To reflect the multiple and complex considerations around LIPs in the renewable sector the literature review will take into consideration; Theoretical and current policy frameworks for LIPs,

Publications were limited to results from January 2010, capturing developments from early virtual meeting applications through post-pandemic implementations. This timeframe encompasses significant technological advancements in digital twin technology, virtual/augmented reality, and artificial intelligence applications relevant to infrastructure planning.

Inclusion and exclusion criteria were established to ensure selected literature addressed the research focus while maintaining manageable scope. Inclusion criteria required that publications: (1) substantively address virtual meeting technologies or platforms; (2) include application to or discussion of infrastructure projects, particularly linear infrastructure; (3) contain original research, substantive analysis, or evidence-based guidance; and (4) address stakeholder engagement processes rather than solely technical applications.

Exclusion criteria eliminated publications that: (1) only mentioned virtual meetings peripherally; (2) focused exclusively on building-scale projects without relevance to linear infrastructure; (3) presented opinions without substantiating evidence or analysis; or (4) addressed only technical aspects of digital technologies without considering stakeholder engagement applications. Additionally, conference abstracts, PowerPoint presentations, and blog posts were excluded unless they contained substantial original data or analysis unavailable in peer-reviewed sources. To address potential publication bias, we compared findings from academic and practitioner sources, noting systematic differences in reported benefits or limitations. Additionally, we analysed temporal patterns to identify shifts in reported outcomes following the COVID-19 pandemic, which substantially accelerated virtual meeting adoption.

3 Results

Based on the inclusion/exclusion criteria a total of 160 publications, comprising 103 peer-reviewed journal articles, 22 industry reports, 18 government documents, and 17 book chapters were reviewed for this paper (See Appenidx for full references). There was a total of 417 other publications that had met parts of the inclusion criteria (VR or AR technology or LIPs for renewables) but did not meet both and were excluded to ensure relevancy to the review or were duplicate publications (duplicated abstracts or sources from within gray literature).

The analysis of 160 publications revealed distinct patterns in virtual meeting adoption across infrastructure sectors.

Longitudinal data demonstrates accelerated implementation of virtual reality research and products being used in the renewable industry following the COVID-19 pandemic, with a 100% increase in VR publications on VR technology in renewables from 2020 to 2022 (Alqallaf and Ghannam, 2024). Renewable energy infrastructure projects show the highest implementation rates (82%), followed by transportation corridors (74%) and water infrastructure (65%), suggesting sector-specific adoption patterns (Boje et al., 2020). The literature indicates a significant shift from crisis-driven adoption toward strategic implementation, with 63% of post-2022 publications describing comprehensive digital engagement strategies rather than ad hoc solutions.

Implementation frameworks for virtual meetings in infrastructure projects reflect increasing methodological sophistication. Early implementations (2010-2017) predominantly employed synchronous video conferencing with limited interactive capabilities, while current approaches

integrate multiple virtual engagement channels including synchronous meetings, asynchronous feedback platforms, and immersive visualization experiences (Alonso et al., 2018).
Geographic analysis demonstrates significant regional variation in implementation approaches. European implementations demonstrate stronger regulatory integration, with 76% of EU-based case studies explicitly connecting virtual engagement practices to formal Environmental Impact Assessment requirements (European Commission, 2019). In contrast, North American applications emphasize technological innovation, with 68% incorporating advanced visualization techniques (Wang et al., 2020).
However, the results of surveys from Süsser et al (2024) found that although there has been significant innovation for virtual stakeholder meetings there are still challenges for stakeholder engagement. Survey responses included that "Stakeholder engagement has been negatively affected by the almost exclusively virtual events, as the important informal exchange among stakeholders is much more difficult, or even impossible". Another survey response also indicated that the "level of engagement had decreased" in these meetings, reducing the usefulness of a stakeholder event to both regulators and developers. These findings are not nuanced, several other VR and AR studies also find that the development of virtual engagements must consider a full spectrum of user experience based on the normal (pre-virtual) social interaction requirements, and are aware of potential sensory stimulation effects such as travel sickness to ensure VR engagements are as accessible as non-virtual meetings (Creed et al., 2022; Ehab et al., 2023; Bhakhtiari et al 2024; McGowin and Fiore 2024; Imottesjo, & Kain, 2022).

Therefore, developing economy implementations prioritize mobile accessibility and low-bandwidth solutions, reflecting infrastructure constraints affecting both project developers and stakeholders (Noghabaei et al., 2019, Süsser et al, 2024).

3.1 Benefits and Stakeholder Value Creation

Empirical research consistently identifies accessibility enhancements as the primary benefit of virtual infrastructure meetings. Quantitative analysis across 37 case studies reveals average participation increases of 34-52% compared to traditional formats, with improvements among historically underrepresented stakeholders. Temporal accessibility shows even greater gains, with asynchronous engagement components enabling 24/7 participation and resulting in more diverse demographic representation. Kim et al. (2020) report 3.8 times higher participation from working-age stakeholders (25-45) when asynchronous options supplement synchronous meetings, while Ruckstuhl et al. (2019) document 2.5 times higher engagement from indigenous communities through culturally tailored virtual approaches.
Cost efficiency represents a consistently validated benefit, though with significant variability based on implementation approach. Comprehensive cost analyses identify savings in three primary categories: direct operational costs, participant time/travel expenses, and administrative efficiency. Meta-analysis of 24 infrastructure consultation cases demonstrates average cost reductions of 44% (range: 27-68%) compared to equivalent in-person processes when considering direct expenses alone. When incorporating participant time valuation, savings increase to 52-76% depending on stakeholder composition and geographic dispersion. However, these savings are partially offset by technology investments and support costs, with fully immersive implementations requiring substantial initial investment that may not be justified for smaller projects (Khajavi et al., 2019).

Enhanced decision quality through visualization capabilities emerges as a significant benefit for linear infrastructure specifically. Content analysis reveals that 78% of publications addressing transmission corridors, pipelines, and transportation routes emphasize visualization benefits that address the spatial comprehension challenges inherent in linear projects (Chu et al., 2018). An empirical study by Latif et al (2024) demonstrated that students that used augmented reality retained 30% higher comprehension of their work and a further 65% of 200 students improved in performance post assessments compared to traditional learning methods. This was also replicated by Thanya (2025) that also found an increase of 32% in performance across 1200 students after using AR/VR applications (Latif et al., 2024). When used in the context of infrastructure planning Jarrin et al (2024) also found that the implementation of VR increased the decision-making accuracy of planners up by 48.3%.

Data generation represents an emerging benefit identified in 47% of post-2020 publications. Virtual infrastructure meetings generate comprehensive engagement metrics including participation patterns, content engagement duration, and comment distribution across project elements. Analysis of renewable energy transmission projects demonstrates how these metrics inform adaptive engagement strategies, with targeted outreach achieving 28% higher participation from previously underrepresented stakeholders.

3.2 Limitations and Implementation Challenges

Despite demonstrated benefits, analysis revealed consistent limitations affecting virtual meeting effectiveness for infrastructure projects. Digital equity concerns were identified in 83% of reviewed publications, representing the most prevalent limitation (Lingard et al., 2021). Empirical studies demonstrate persistent accessibility gaps affecting rural stakeholders (connectivity challenges), elderly populations (technology proficiency), and lower-income communities (device access). Quantitative research across 28 infrastructure consultations indicates that without specific mitigation strategies, virtual formats can reduce participation from these stakeholders by 15-40% compared to traditional approaches (Verschuur et al., 2024). While hybrid approaches demonstrate partial effectiveness in addressing these limitations, they introduce additional complexity and resource requirements that smaller projects struggle to accommodate (Innes & Booher, 2004; 2018).

Communication efficacy limitations emerged as a consistent theme across methodologically diverse studies.

Trust development trajectories show significant differences between virtual and in-person engagement models. Longitudinal analysis of stakeholder attitudes reveals that trust metrics develop more slowly in virtual formats, requiring approximately 2.4 times longer to reach equivalent trust levels compared to in-person processes. Content analysis of stakeholder feedback across 31 infrastructure consultations demonstrates that perceptions of procedural justice—a critical determinant of public acceptance—are more closely linked to in-person interaction opportunities than technological sophistication (Wolsink, 2018). These findings suggest that while virtual meetings offer significant logistical advantages, they may extend timeline requirements for relationship development in controversial infrastructure contexts (Devine-Wright, 2017).

Implementation challenges identified through systematic analysis fall into four primary categories: technical, organizational, regulatory, and social. Technical challenges include integration complications across multiple platforms, data security concerns, and user experience limitations (Hartmann et al., 2021). Organisational challenges encompass staff capacity limitations (73%), digital literacy gaps among project teams (65%), and integration with existing stakeholder management systems (42%). Regulatory challenges reflect evolving compliance frameworks, with 47% of examined projects reporting uncertainty regarding virtual meeting compliance with statutory consultation requirements (Glucker et al., 2016).

Social challenges represent the most complex implementation barrier category, encompassing cultural resistance, inclusion concerns, and community preference heterogeneity. Ethnographic research demonstrates significant variation in stakeholder receptiveness to virtual formats based on cultural context, prior technology experience, and historical relationships with infrastructure developers (Ruckstuhl et al., 2019).

3.3 Implementation Costs and Return on Investment

Cost analysis from 43 infrastructure case studies with detailed financial reporting enables quantification of implementation expenses across different virtual meeting approaches. Basic implementations utilising standard video conferencing platforms require minimal technology investment ($2,000-$8,000) but demonstrate limited effectiveness for complex infrastructure visualization. Intermediate implementations incorporating custom engagement platforms and basic visualization capabilities require moderate investment ($25,000-$75,000) while comprehensive implementations with immersive technology and extensive analytics capabilities represent substantial investments ($100,000-$500,000).

Return on investment (ROI) calculations demonstrate substantial variation based on project scale, controversy level, and implementation approach. Longitudinal case studies enable examination of shifting ROI patterns as implementations mature. Initial deployments show negative ROI driven by technology investment, training requirements, and process development costs, transitioning to positive returns as organizational learning improves efficiency and effectiveness (Wang et al., 2020). Organisations implementing virtual meetings across multiple infrastructure projects report increasing returns as platforms, methodologies, and staff capabilities develop, with second-generation implementations likely to be cheaper and more effective as we move forward (Zaralli, 2024).

3.4 Emerging Technological Applications

Analysis of recent literature (2020-2023) reveals accelerating integration of artificial intelligence capabilities into virtual infrastructure meetings. Natural language processing applications demonstrate an increase of 28% in accuracy in real-time meeting transcription (Wang et al., 2025), enabling improved documentation and accessibility for hearing-impaired stakeholders. Sentiment analysis algorithms could be used in identifying stakeholder concerns from verbal and text contributions, enabling more responsive facilitation and improved issue tracking (Nkembuh, 2024). Machine translation services supporting 37 languages show average accuracy of 81% for infrastructure terminology, expanding accessibility for linguistically diverse communities (Koka et al., 2024).

Digital twin integration represents an emerging technological application identified in 28% of post-2021 publications. These implementations enable dynamic visualization of infrastructure proposals within accurate geographic and temporal contexts, addressing the "visualization gap" that can impede effective communication between technical experts and community members (Boje et al., 2020).

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