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EcoScan: Empowering Carbon-Optimised Design in the Digital Era

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Abstract: Poised for recognition at the ITA Awards for Digital and Information Technology, EcoScan is redefining sustainability in tunnel and underground infrastructure. With Scandinavian countries set to enforce strict carbon footprint limits on new-builds from 2025, the need for efficient, transparent, and adaptable carbon assessment tools has never been greater. This user-friendly web application answers the call—delivering rapid, precise, and visually engaging carbon calculations tailored for complex projects.

Seamless integration with the Autodesk ecosystem enables element-level optimisation using locally sourced materials, crucial for minimising embedded carbon in tunnel and metro station construction. Exportable 3D visualisations replace static regulatory tables, streamlining communication with stakeholders and authorities. Customisable material databases and real-time scenario comparisons empower teams to make environmentally responsible decisions at every phase.

Unlike conventional BIM tools, EcoScan's open-source approach fosters flexibility and user-driven innovation across the project lifecycle. Ongoing development—including construction site emissions analysis—positions this platform as a transformative solution for sustainable, high-impact infrastructure worldwide.

Engineered for the digital age, EcoScan doesn't just keep pace with the future of tunnelling—it helps shape it. Experience a new era of efficiency, transparency, and measurable impact in underground projects.

Keywords: Digital technology; Life Cycle Assessment; EcoScan; BIM, AI; Eco-design

1. Introduction

Digital and information technology are revolutionising the way we conceive and construct our cities. Nowhere is this transformation more profound—or more vital—than in the delivery of mega-projects such as the Grand Paris Express (GPE). Spanning over 200 kilometres of new metro lines and 68 stations, the GPE embodies the extraordinary scale, complexity, and ambition shaping contemporary infrastructure. These ventures are not merely engineering marvels; they are pivotal arenas for addressing some of the planet's most urgent environmental challenges. While their construction inevitably generates vast quantities of material and emissions, their enduring legacy lies in enabling a shift towards sustainable, high-capacity public transport—offering genuine and lasting environmental gains.

As the built environment sector is increasingly challenged to achieve more with fewer resources, digital innovation has become central to enabling smarter and more sustainable outcomes throughout the project lifecycle.

Against a backdrop of tightening global climate targets, the construction industry must now consider the entire lifespan of infrastructure—from material sourcing through to end-of-life disposal—instead of focusing solely on operational efficiency. Life Cycle Assessment (LCA) has therefore become indispensable, providing a holistic understanding of a project's environmental impact and revealing opportunities to meaningfully reduce carbon, energy consumption, and waste.

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As regulations evolve and carbon limits are tightened—especially in progressive regions such as Scandinavia—traditional methods of eco-design, often manual, slow, and reliant on rough estimates, are no longer fit for purpose. Enter innovative digital tools like EcoScan. Seamlessly integrated within established design platforms, the tool enables rapid, detailed LCA at the element level, harnessing local material data and delivering results in a fraction of the time required by conventional processes. Its open-source, visual interface turns compliance into a collaborative, transparent, and efficient endeavour, setting a new benchmark for environmental responsibility in construction.

2. Digital Transformation in Underground Structures: Integrating Sustainability with EcoScan

The construction and operation of underground structures, such as tunnels and underground railways, have long posed unique challenges for engineers and project managers. Traditionally reliant on manual calculations and fragmented data sources, infrastructure projects are increasingly adopting digital-first approaches. Building Information Modelling (BIM), artificial intelligence (AI), and data analytics are enabling engineers to design, simulate, and optimise projects before construction begins (Smith et al., 2021; ISO 19650, 2018).

At the same time, the demand for sustainable construction has intensified. Lifecycle Assessment (LCA) provides a framework for evaluating environmental impacts, as defined in ISO 14040/44 (ISO, 2006). Applying these methodologies within BIM environments allows project teams to integrate carbon and environmental performance directly into early-stage decision-making (Jones & Meyer, 2020).

At the forefront of this shift is EcoScan, an innovative tool developed by TRACTEBEL team to redefine sustainability management in underground infrastructure. EcoScan integrates seamlessly with Autodesk's API and viewer, empowering users to calculate carbon emissions and assess vital environmental parameters directly from Building Information Modelling (BIM) data. This integration enables project teams to evaluate environmental impacts at the earliest design stages and to continually monitor them throughout the project lifecycle. The objective is clear: to support sustainable decision-making throughout the lifecycle of a project.

Successfully integrating tunnel projects into this digital and sustainable process requires a strategic approach. It starts with a clear understanding of digital workflows and a willingness to embrace innovative technologies. Project teams must know how to manage data-rich BIM environments and coordinate effectively between engineering disciplines. The ability to adapt and incorporate EcoScan's insights into day-to-day decision-making is essential for achieving truly sustainable underground structures.

Rather than obscuring analysis within spreadsheets, EcoScan generates compelling 3D visualisations of environmental, energy, and waste impacts—outputs that are ready for direct regulatory submission. Its open-source nature sets it apart from the closed systems of traditional BIM providers, empowering users to customise and apply the tool across the entire infrastructure lifecycle: design, construction, operation, and maintenance.

In essence, EcoScan reimagines LCA as a swift, visual, and collaborative process, empowering infrastructure projects not merely to meet, but to define, the next frontier of environmental performance.

3. Building Information Modelling (BIM)

At the heart of this transformation is Building Information Modelling (BIM). Far surpassing simple 3D geometry, BIM acts as the digital DNA of a project, capturing every tunnel element—from concrete linings and reinforcement steel to ventilation shafts, cabling, and drainage systems. However, a static model alone is not sufficient; it must be interactive, intelligent, and communicative. To achieve this, we extended Autodesk's API and viewer, developing bespoke Java and HTML functions that convert passive models into dynamic, navigable, and measurable environments. As a result, the tunnel evolves from a basic drawing into a fully realised digital twin.

Expanding upon this foundation, the proposed Life Cycle Assessment (LCA) tool—presented at the ITA Awards & SETC-2025—takes integration further by embedding LCA methodologies directly within BIM-enabled design workflows. Engineers can upload BIM models into the Autodesk Viewer, assign materials from a standardised database, and instantly calculate life cycle indicators and carbon footprint metrics. The tool supports the comparison of alternative material scenarios, with results visualised within the model using a green-to-red colour scale for immediate spatial feedback on environmental performance.

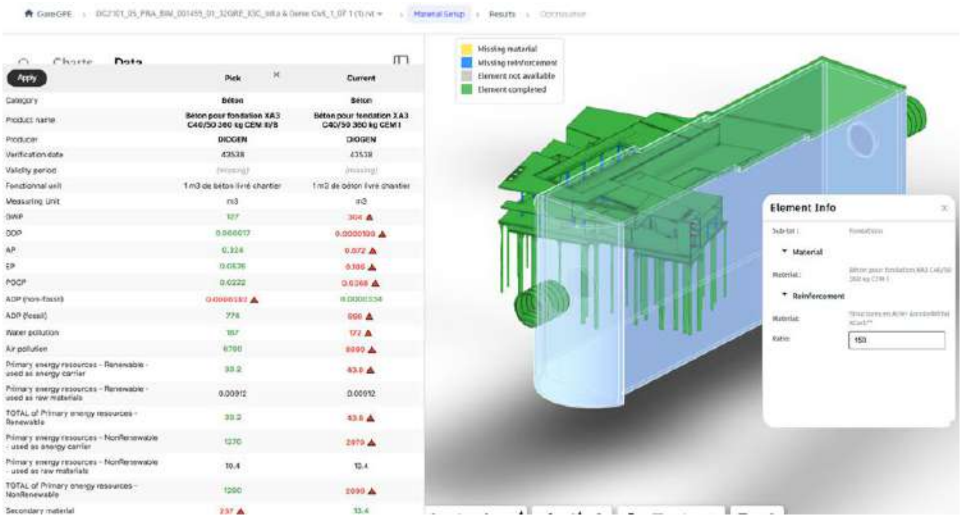

Fig. 1. Iterative Testing—Measuring Incremental Improvement at Each Stage.

Simultaneously, structured data on elements, materials, and impacts is exported via EcoScan-generated Excel files. A Python-based interoperability layer then feeds optimised material choices back into authoring tools such as Revit or Tekla, ensuring that assessment outcomes remain embedded within the BIM environment. This workflow yields three key research contributions: (i) it enhances the accuracy and usability of LCA in the early design stages; (ii) it ensures seamless interoperability across platforms and data formats; and (iii) it eliminates rework by directly linking assessment results to the BIM model. Ultimately, the convergence of BIM, LCA, and digital twin principles demonstrates how performance-driven material optimisation can be operationalised, empowering more sustainable and data-driven decision-making in underground infrastructure design.

4. Lifecycle Assessment (LCA)

The construction and operation of underground structures, such as tunnels and underground railways, have long posed unique challenges for engineers and project managers. Traditionally reliant on manual calculations and fragmented data sources, infrastructure projects are increasingly adopting digital-first approaches. Building Information Modelling (BIM), artificial intelligence (AI), and data analytics are enabling engineers to design, simulate, and optimise projects before construction begins (Smith et al., 2021; ISO 19650, 2018).

Infrastructure projects have traditionally carried substantial environmental footprints. Lifecycle Assessment (LCA) provides a rigorous, systematic method for measuring and reducing these impacts throughout every stage of a project.

EcoScan elevates Building Information Modeling (BIM) by automatically calculating carbon emissions and other environmental indicators directly from model data. This seamless integration offers:

- Clear visual outputs, enabling teams to identify precisely where environmental impacts occur within the tunnel design.
- Comprehensive, Excel-based reports that deliver detailed numerical results for in-depth analysis and optimisation.

Tasks that once required weeks of manual data extraction and computation can now be completed in minutes. More crucially, EcoScan empowers project teams to consider sustainability at the earliest design stages, when interventions are most effective and cost-efficient.

EcoScan incorporates a wide set of environmental parameters, ensuring that the assessment extends beyond carbon emissions alone. The tool follows internationally recognised LCA categories (ISO 14040/44; CML, 2001).

Table 1. LCA Indicators.

Environmental indicator	Unit
Climate Change Total	kg CO_2e
Climate Change Fossil	kg CO_2e
Climate Change Biogenic Removals and Emissions	kg CO_2e
Climate Change Land Use and Land Use Change	kg CO_2e
Ozone Depletion	kg CFC11e
Acidification	mol H+e
Eutrophication Aquatic Freshwater	kg PO_4e
Eutrophication Fresh Marine	kg Ne
Eutrophication Terrestrial	mol Ne
Photochemical Ozone Formation	Kg NMVOCe
Abiotic Depletion- Minerals and Metals	kg Sbe
Fossil Fuels	MJ
Water Use	m^3e depr.

Resource use indicators	Unit
Use of renewable primary energy excluding renewable primary energy resources used as raw materials	MJ
Use of renewable primary energy resources used as raw materials	MJ
Total use of renewable primary energy resources (primary energy and primary energy resources used as raw materials)	MJ
Use of non-renewable primary energy excluding non-renewable primary energy resources used as raw materials	MJ
Use of non-renewable primary energy resources used as raw materials	MJ
Total use of non-renewable primary energy resources (primary energy and primary energy resources used as raw materials)	MJ
Use of secondary material	kg
Use of renewable secondary fuels	MJ
Use of non-renewable secondary fuels	MJ
Net use of fresh water	m3

Biogenic carbon indicators	Unit
Biogenic carbon content in the product	kg CO_2
Biogenic carbon content in packaging	kg CO_2

Table 2. Waste & output indicators.

Waste & output indicators	Unit
Hazardous waste disposed	kg
Non-hazardous waste disposed	kg
Radioactive waste disposed	kg
Components for re-use	kg
Materials for recycling	kg
Materials for energy recovery	kg
Exported energy	MJ

By automating these calculations, our tool enables a multi-dimensional sustainability assessment. Instead of focusing solely on carbon, decision-makers gain a holistic view of environmental performance. This allows trade-offs to be evaluated (e.g. lower Climate Change Total vs. higher water use), supporting more balanced and sustainable design choices.

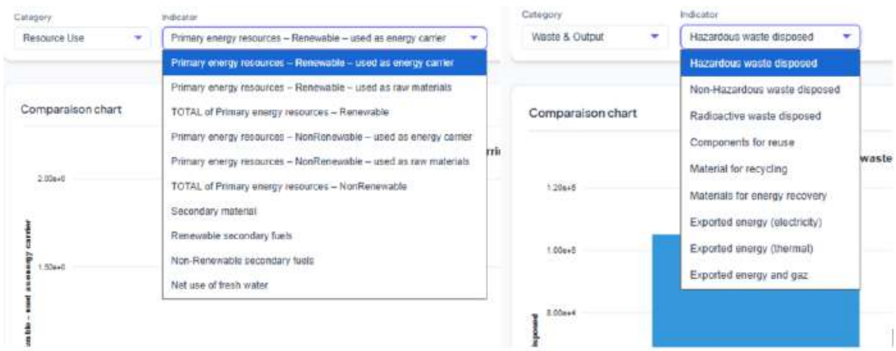

Fig. 2. Indicators by Category.

5. Eco-Design Integration

In today's infrastructure landscape, environmental performance is no longer a secondary consideration—it is a core design requirement. Yet, the greatest opportunities to reduce a project's carbon footprint are often missed at the very earliest stages, well before construction begins. Traditionally, material selection within BIM (Building Information Modelling) platforms has been guided by cost or technical criteria, with sustainability assessed only at the project's conclusion—when change is most difficult and costly.

EcoScan overturns this outdated approach. Purpose-built for modern design and construction, the tool empowers project teams to make environmentally conscious choices from the outset, turning every material selection into an opportunity to minimise impact.

At its core lies a dynamic, adaptable material database—far more than a static catalogue. This resource encompasses a wide spectrum of materials, including concrete mixes, steel grades, and insulation types, each one accompanied by comprehensive life cycle data: CO_2eq, embodied energy, recyclability, waste generation, and other vital sustainability indicators. What distinguishes EcoScan is its flexibility: users can customise the database, add new materials from local suppliers, and integrate low-carbon innovations to suit specific project needs. Continuous updates ensure that assessments reflect the latest developments in sustainable design.

EcoScan's intuitive workflow keeps environmental impact central to every decision. If a model element lacks material data, the tool prompts designers to select from the database. As alternatives are considered, EcoScan instantly analyses each option's effect on the project's carbon footprint—enabling rapid, informed comparisons before any material is locked in. This immediate feedback loop drives smarter, greener choices from the very beginning.

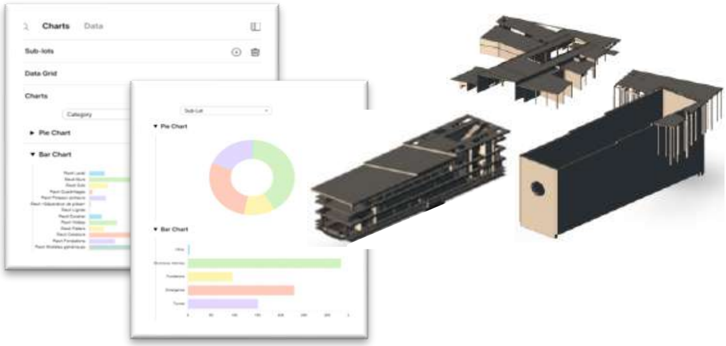

Fig. 3. Work environment.

Once a model is accurately populated with material data, EcoScan elevates optimisation to a new level. Teams can generate and compare multiple design scenarios in minutes, with environmental indicators—such as CO_2eq and energy use—recalculated at every iteration. Whether refining a single element or undertaking a comprehensive redesign, the tool delivers detailed impact assessments at both the component and project levels. Life cycle analyses that once took days now take less than an hour, empowering agile, iterative design.

Fig. 4. Ensuring Results and Data Transparency for Project Stakeholders

But EcoScan is more than a number-crunching tool. It translates sophisticated sustainability metrics into compelling, actionable visuals: bar charts that highlight the results of each optimisation, and dynamic 3D colour-coded BIM models that pinpoint areas of greatest environmental impact. These outputs can be exported as PDFs or images, making it easy to engage stakeholders and communicate the value of sustainable design.

By transforming complex technical data into practical, accessible insights, EcoScan enables project teams to integrate eco-design seamlessly into every BIM workflow. For the tunnelling and infrastructure community, EcoScan is not just a digital tool—it is an engine for a more innovative and sustainable future.

Fig. 5. Optimising Digital Data Through Targeted Approaches.

6. Challenges and Future Outlook

While EcoScan represents a significant leap forward in environmental assessment for tunnel and underground infrastructure projects, the journey is ongoing. Integrating diverse data sources, maintaining consistent data quality, and keeping pace with evolving regulatory standards require sustained collaboration and development across the sector. Moreover, as digital tools become ever more advanced, continuous training and upskilling are essential to ensure project teams can fully harness their potential.

Looking to the future, EcoScan is set to evolve alongside breakthroughs in BIM, machine learning, and real-time analytics. Forthcoming enhancements may include increased automation, expanded environmental metrics, and even deeper integration with project management platforms. With AI-powered capabilities, the tool will soon enable early-stage estimations for major infrastructure projects—even before detailed models are completed.

By embracing these digital innovations, the industry is moving towards truly sustainable infrastructure, where environmental stewardship is embedded at every phase of the project lifecycle. EcoScan stands at the forefront of this transformation, empowering engineers and decision-makers to deliver projects that are not only efficient and cost-effective, but also responsible stewards of our shared environment.

7. Conclusion

In the spirit of bold innovation and quiet resolve, EcoScan brings together a suite of digital tools and stands as more than a technological leap—it is a call to reimagine what responsible engineering can achieve. By weaving environmental stewardship directly into the fabric of infrastructure design, this tool offers not just efficiency but a principled path forward. It equips engineers and designers with the clarity and conviction to shape a built environment that honours both progress and the planet. As we face the pressing challenges of our age, EcoScan reminds us that true leadership is found not in following trends, but in setting the standard. The future of sustainable engineering, quietly and confidently, starts here.

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