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A data-driven approach for early phase CO2 quantification of geotechnical measures in linear projects.

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ABSTRACT: This paper presents a methodology for early-stage evaluation of alternative alignments for linear infrastructure projects in areas with varying ground conditions, focusing on greenhouse gas (GHG) emissions from geotechnical measures. The approach integrates proposed alignment geometry, terrain and bedrock models, and initial subsurface assessments to estimate CO_2 emissions from required ground improvements—primarily lime-cement stabilization. A case study from central Norway, using three alternative road alignments, demonstrates the method. Existing public datasets—including terrain, geological maps, and borehole information—are compiled and processed in GIS to define generalized soil classifications. These data are then imported into a parametric modeling environment (Rhino/Grasshopper), where alignments are analyzed against soil conditions to determine the extent of ground improvement required. The model dynamically updates results when alignment parameters change, enabling rapid comparison of alternatives. The methodology provides visualizations and BIM-ready models of required geotechnical measures, along with estimated GHG emissions based on national emission factors. Results from the case study show significant differences in emissions between alignment options, underscoring the potential of this approach to influence early-stage design decisions. The workflow's flexibility, speed, and integration of climate impact assessment support its use as a decision-making tool in sustainable infrastructure planning.

KEYWORDS: Parametric modelling, Early phase planning, Visualization of greenhouse gas emissions, ground improvement.

1 INTRODUCTION

This paper presents a methodology for the early-stage assessment of alternative alignments for linear infrastructure projects in areas with varying ground conditions. The evaluation is based on the integration of the proposed geometry of the future road or railway, a terrain model, a potential bedrock model, and an initial assessment of subsurface conditions along the alignments. The goal with the assessments are to get data on which alignment that gives tha largest CO2 emissions because og geotechnical measures.

A case study from central Norway is used to demonstrate the methodology. Although the project data has been anonymized, the alignment paths are based on real alternatives, and the geotechnical data employed are authentic and publicly available.

The case-study uses three different alternative alignments. All three of them starts in the west from a major road going north-south, but the exit from this major road is in two different locations. The end-point of the road in the east is similar for all the three alternatives.

The methodology leverages parametric programming to facilitate the assessment process. Parametric programming involves the use of variables and rules to define geometric objects and their interrelationships, enabling automatic updates to the model when parameters are modified. This approach allows for the creation of flexible and dynamic models, where changes to a single parameter—such as length, elevation, or quantity—automatically propagate throughout the model. This capability supports the exploration of multiple design alternatives, automation of repetitive tasks, and ensures consistency across the model. In this study, the parametric programming was implemented using the Rhino/Grasshopper platform.

It should be noted that this paper builds upon a methodology previously presented at the Nordic Geotechnical Meeting in 2024 (Hansen et. al. 2024). However, the approach has been further developed, and the case study used in the modeling has been updated.

2 INITIAL DATA ANALYSIS WITH GIS

2.1 *Step 1 - Compilation of existing data in GIS*

In the early phase of a project, we often do not have that much data available, so the first thing we must do is try to collect as much relevant data as possible for the project area. In our example there are some public data available as WMS services, as shown in Figure 1. This is mainly terrain data and the National Geological service map over superficial deposits (NGU. 2025)

In addaition there is a national database for site investigations in Norway, NADAG, where a lot of data is accsiable and free to use. In the area of the projects there are carried out a lot of site investigations, and these investigations are used in the assessment.

We also have some pre-defined quick clay zones in the area of the project (NGU, 2025), these are also included in the initial data analysis.

All the existing data is compiled in a GIS-software, to prepare the data for further use in the analysis.

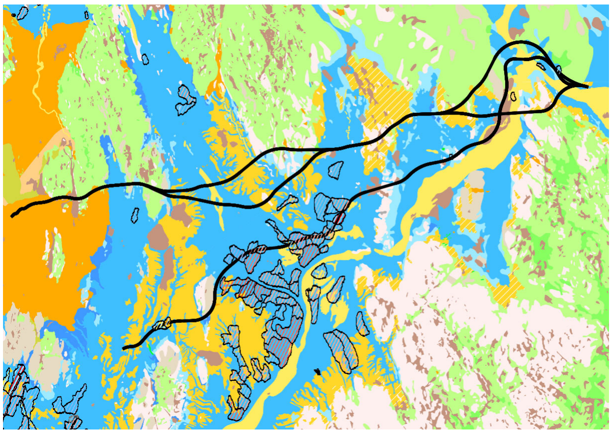


Figure 1. Project area with current WMS-data shown in QGIS.

2.2 *Step 2- Data analysis and soil classification*

Reviewing the available data, it was decided to divide the soil conditions along the alignments into three different soil classification categories, these are presented in Table 1. This division in different soil types is basis for the later assessment of the amount of geotechnical measures.

This is a rather simple division and will of course not be precise enough in later stages of the project. But experiences show that for early phase assessments this will give a good indication of the differences between the different alignments.

Table 1. Soil classification.

Name	Colour in model	Description
Good	Green	Friction soils, stiff clays
Medium	Yellow	Soft clay
Poor	Red	Quick/sensitive clay

It is also worth mentioning that the methodology has a large flexibility when it comes to defining soil classification. Her both the number of types and the description of the soil types can be changed, both for different projects but also for parallel assessments within one given project.

The soil classification is defined as 2D surfaces in a GIS-software, as shown in Figure 2. We export the polygons as shape-files (*.shp) for further use in Grasshopper.

It must be mentioned that the division of these areas obviously will be a very general assessment and such classification should always be performed by someone with geotechnical expertise.

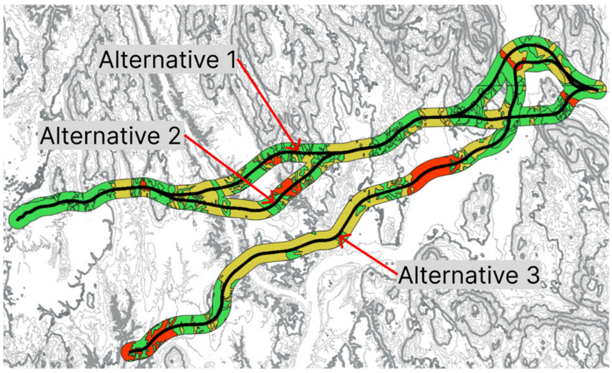


Figure 2. Areas defined by different soil classes together with road alignment alternatives in QGIS.

3 PARAMETRIC ANALYSIS IN GRASSHOPPER

3.1 *Step 3 - Analysis of road alignment in Grasshopper*

With the defined soil class areas in place these areas are imported into a script in Grasshopper, see Figure 3.

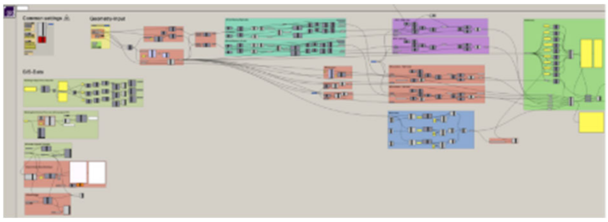
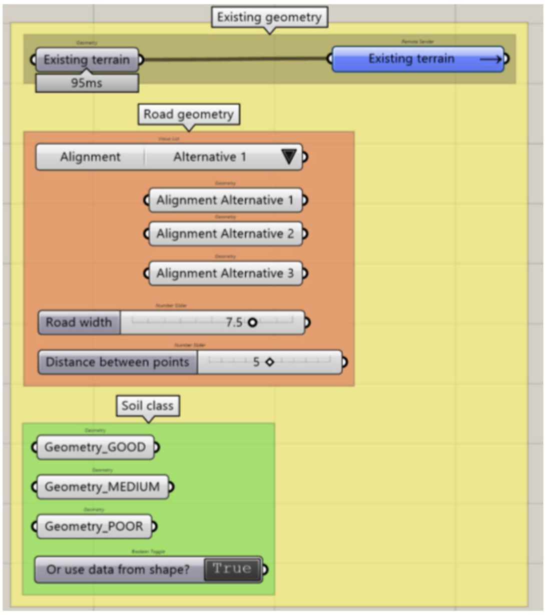


Figure 3. Grasshopper script for alignment analysis.

Further on we need to define the existing terrain, an alignment as geometry with the desired width as well as slope for filling and excavation.



Alignment Alternative 1
Alignment Alternative 1
Alignment Alternative 2
Alignment Alternative 3
Road width 7.5
Distance between points 5
Geometry_GOOD
Geometry_MEDIUM
Geometry_POOR
Or use data from shape? True

Figure 4. Geometry input in the Grasshopper script.

This script now analyzes the selected alignment and divides this line into points with a user-defined spacing, resulting in “smart points” containing information such as height or depth to terrain, soil class etc. along the alignment. This information is valuable for doing the necessary selection of parameters.

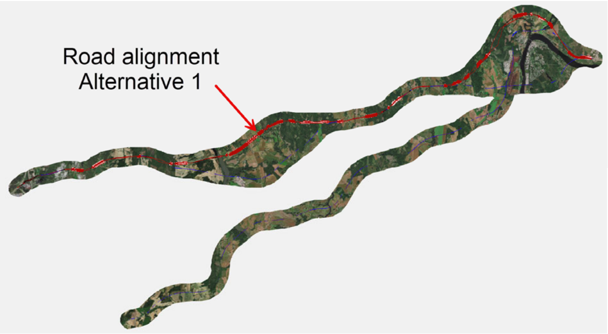


Figure 5. Analyzed points displayed in red in the Rhino 3D viewport.

3.2 *Step 4 – Evaluating the need for ground improvement.*

For each “smart point” along the road alignment, we have now extracted details that will enable us to determine if ground improvement by use of lime-cement columns is required or not.

For this study, a set of criteria are defined in Grasshopper using the Expression-component to categorize parametrically how much, if required, ground improvement should be installed. The chosen criteria need to be established for each individual project and are in this case selected for demonstrative purposes only.

For points within the poor (red) soil class:

- If depth < 2m (cut) or height < 2m (fill), no lime-cement is required.
- If depth > 2m (cut) or height > 2m (fill), install Ø600mm lime cement columns with 40% area coverage and single-column ribs.

For points within the medium (yellow) soil class:

- If depth < 4m (cut) or height < 4m (fill), no lime-cement is required.
- If depth > 4m (cut) or height > 4m (fill), install Ø600mm lime cement columns with 40% area coverage and single-column ribs.

For points within the good (green) soil class:

- No lime-cement columns are required.

The area coverage and spacing between ribs is calculated in accordance with guidelines from The Norwegian Public Roads Administration. (2014). For this study, a mixing ratio of 50/50 lime-cement with a binder dosage of 60kg/m3 is used.

The smart points are split categorized in accordance with the criteria. Next, line objects for the lime-cement ribs are created to enable the creation of column volumes.

3.3 *Visual representation of greenhouse gas emissions.*

By changing the alignment, either sideways and/or in height, it will also change the need for geotechnical mitigations, which again will affect the emissions. The modelling in Rhino/Grasshopper is fully dynamic, helping the engineers to easily compare the emissions caused by the different potential alignment choices.

The visual representation is shown as an example in Figure 6 below.

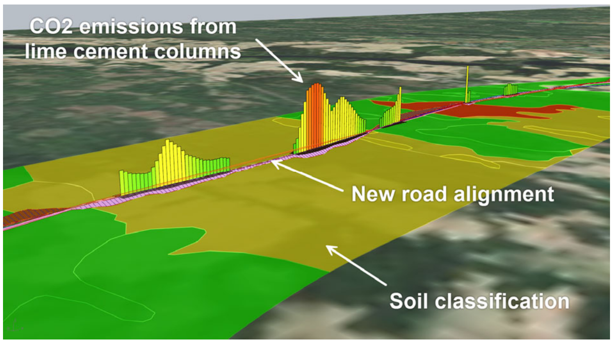


Figure 6. Visual representation of greenhouse gases from ground improvement along route alt 1.

For each defined interval of the road/railroad the amount of greenhouse gases is illustrated as columns. In areas with, for example, a large amount of lime/cement columns, the expected calculated emissions will be high. In areas with only some smaller cuts or fillings, the illustration will indicate much lower future emissions. A figure with the emissions for all 3 routes is shown in Figure 7.

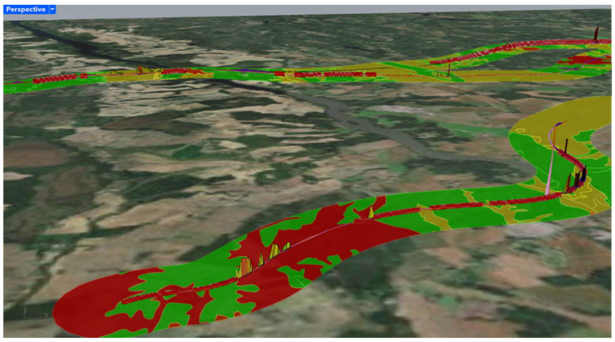


Figure 7. Visual representation of greenhouse gases from ground improvement together with defined soil classes.

Emission factors are based on data from VegLCA (The Norwegian Public Roads Administration, 2024) which, in Norway, must be used on large road projects to calculate greenhouse gas emissions. A summary of the estimated emissions for each route option is given in Table 2.

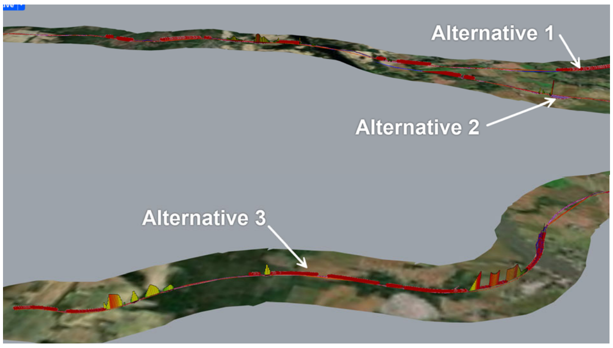


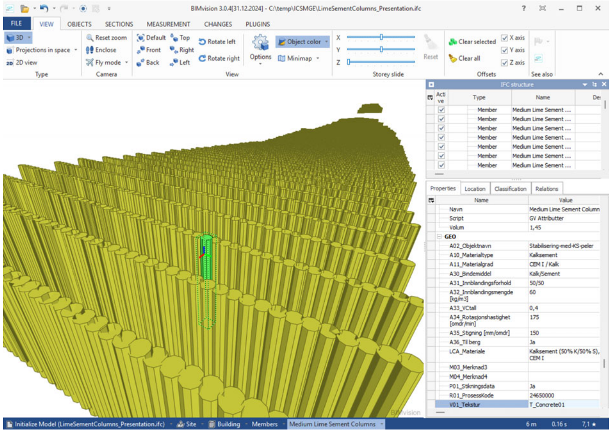
Figure 8. Visual representation of greenhouse gases from ground improvement for all routes.

Table 2. Greenhouse gas emissions from ground improvement for all routes options.

Route	Total emissions (kg)
1	4 138 439
2	3 386 123
3	6 053 530

4 BIM MODELS

The final product is not only a visualization of the emissions, but you will also get detailed generated BIM models of the assumed necessary measures in the early phase of a project. Using developed property set scripts in Grasshopper, all objects are now assigned with discipline- and project-specific properties such as mixing ratio, binder dosage and Model Maturity Index (MMI) among others. Se Figure 8, which is a part of the model from alternative 1, below as an example.



Active	Type	Name	De
☑	Member	Medium Lime Sement ...	
☑	Member	Medium Lime Sement ...	
☑	Member	Medium Lime Sement ...	
☑	Member	Medium Lime Sement ...	
☑	Member	Medium Lime Sement ...	
☑	Member	Medium Lime Sement ...	
☑	Member	Medium Lime Sement ...	

Name	Value
Navn	Medium Lime Sement Column
Script	GV Attributter
Volum	1,45
GEO	
A02_Objektnavn	Stabilisering-med-KS-peler
A10_Materialtype	Kalksement
A11_Materialgrad	CEM I / Kalk
A30_Bindemiddel	Kalk/Sement
A31_Innblandingsforhold	50/50
A32_Innblandingsmengde [kg/m3]	60
A33_VCtall	0,4
A34_Rotasjonshastighet [omdr/min]	175
A35_Stigning [mm/omdr]	150
A36_Til berg	Ja
LCA_Materiale	Kalksement (50% K/50% S), CEM I
M03_Merknad3	
M04_Merknad4	
P01_Stikningsdata	Ja
R01_ProsessKode	24650000
V01_Tekstur	T_Concrete01

Figure 9. Ifc-model of lime-cement stabilization with specific properties for each Lime Sement Column shown in BIMvision.

5 CONCLUSIONS

This preliminary study shows that the proposed workflow quickly provides a coarse estimate of the need for ground improvement by use of lime-cement columns along the alignment. The fact that we can quickly change various parameters and see the consequences of this in a few seconds will change the way we plan alignments in the future. We also believe that it will increase the focus on the climate effect from groundwork and its importance during early phase planning of a project.

As ground improvement often is a significant part of the emission factor, these figures can, as showcased, be used as a basis for assessment in the early phase of a project. However, this must of course be seen together with emission figures for all other disciplines as well to get a comprehensive overview of the total greenhouse gas emissions for the entire project.

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7 REFERENCES

Hansen, N. B., Kahlström, M., Rømoen, M. 2024. Early-phase modelling of lime-cement columns to reduce carbon footprint. NGM 2024, Gothenburg, Sweden.

NGU. Maps of geology. 2025, https://www.ngu.no/en/geologiske-kart.

The Norwegian Public Roads Administration. 2024.Bruk av VegLCA: https://www.vegvesen.no/fag/fokusomrader/klima-miljo-og-omgivelser/utslipp-av-klimagasser/bruk-av-veglca/.

The Norwegian Public Roads Administration, 2014. Håndbok V221 Grunnforsterkning, fyllinger og skråninger.