

# Optimizing the carbon footprint: Theoretical approaches and practical insights from a construction site case study

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**ABSTRACT:** In the village of Horn at the Swiss side of Lake Constance, a former industrial site is undergoing transformation into a large-scale residential area. Over the past 10 to 15 years, the site has seen systematic demolition and comprehensive soil remediation, utilizing both replacement drillings and surface soil replacement to address contamination. The native subsoil is characterized by soft, fine-grained fractions with limited bearing capacity, further complicated by stratified deltaic deposits overlying silty-clayey lake sediments. These conditions, combined with a stable but low-permeability hydrogeological regime, present significant geotechnical challenges. Given the inadequate external bearing capacity and the disproportionate material demand and CO<sub>2</sub>-equivalent emissions associated with conventional deep pile foundations, an early project decision was made to adopt vibro replacement columns. This ground improvement method, designed and executed by Keller-MTS AG, leverages locally sourced aggregate and maximizes both ecological and economic advantages by substantially reducing the need for concrete and steel. Throughout the project, more than 86,000 meters of stone columns were installed, making it the largest vibro jobsite in Switzerland over the past decade. Aligned with Keller's sustainability strategy, the approach emphasizes systematic elimination, reduction, and substitution of emissions. The project documentation details how the adoption of the vibro replacement method avoided substantial emissions, minimized resource consumption (including diesel, materials, and transport), and underscores the critical role of early, holistic planning in achieving these outcomes. Furthermore, the substitution strategy included the use of HVO biodiesel, addressing procurement and operational challenges specific to Switzerland. Upon completion, the project's carbon footprint will be rigorously quantified using the EFFC/DFI Carbon Calculator, establishing a benchmark for sustainable geotechnical solutions in similar contexts.

**KEYWORDS:** Sustainability, design and built, ground improvement, GHG Protocol, Hydrotreated Vegetable Oil (HVO)

## 1 INTRODUCTION

Sustainability in geotechnical engineering and ground improvement is a key focus at Keller. Vibro stone columns using natural, locally available aggregates offer strong ecological advantages. However, in large-scale and long-term projects, even these favorable conditions can be challenged by high resource demands and limited availability. This prompted a fundamental reassessment of common practices in Switzerland—exploring untapped potential and rethinking established processes.

## 2 PROJECT AND BOUNDARY CONDITIONS

### 2.1 Location and Project

In the village of Horn, at the Swiss side of Lake Constance, a former industrial site is being transformed into a residential area. Various demolition and deconstruction works have been carried out at that location over the last 10 to 15 years. The contaminated soils were remediated by means of extensive replacement drillings and surface soil replacement. The natural soil conditions are characterized by soft, fine-grained soil fractions.

The project covers a total area of 18,260 square meters and consists of nine apartment buildings, each with four to five floors. The total characteristic load amounts to 1,03 MN, with the surface load for the buildings ranging between 80 and 95 kN per square meter.

### 2.2 Soil conditions

The geological and hydrogeological conditions of the project area are characterized by sandy deltaic deposits overlying silty-clayey lake sediments, which exhibit low bearing capacity and

high settlement sensitivity down to depths exceeding 50 meters. The groundwater level is closely linked to Lake Constance, with low permeability in the delta deposits and protective cover layers above, resulting in limited groundwater flow and a stable hydrogeological regime.

### 2.3 Design variants

The geological boundary conditions at the site largely rule out the implementation of a technically and economically viable pile foundation. Due to the low external bearing capacity of the subsoil, achieving the required load-bearing performance would necessitate disproportionately large pile shaft surfaces - resulting in increased pile lengths and diameters, and consequently higher consumption of concrete and steel. This would lead to a significant rise in material use and associated CO<sub>2</sub>-equivalent emissions, while the internal load-bearing capacity of the piles would remain largely underutilized.

This issue was recognized at an early stage by the project team, leading to a forward-looking decision aimed at conserving resources and reducing the carbon footprint. As a result, Keller developed a ground improvement concept using the vibro replacement method, offering both ecological and economic benefits for the project, the client, and the executing contractor. The concept that “everything that saves us money also reduces our carbon footprint” has proven to be true in this context, as the decision to improve the subsoil using vibro replacement columns was made early in the project based on a holistic evaluation of sustainability and cost-efficiency.

### 2.4 Vibro replacement – Design and built

The executed ground improvement was carried out with depths ranging between 16 and 20 meters. As part of these measures, the following key performance indicators were achieved, which

serve as the basis for further technical analyses and evaluations in this report:

- Column length: approx. 86,000 linear meters
- Diameter (DN): approx. 65 cm
- Gravel quantity installed: approx. 45,300 tonnes
- Execution duration: on average 2 rigs, each operating for 145 shifts

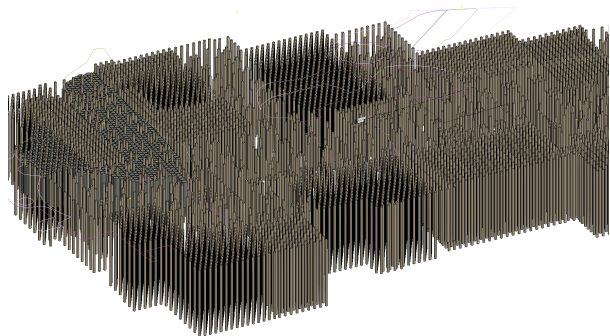


Figure 1. Revit Visualization of vibro stone columns.

The visualization shown in Figure 1 was created using Autodesk Revit. The use of three-dimensional modelling enabled precise capture of all geometric parameters, supporting both quality assurance and accurate quantity tracking for material consumption and performance metrics.

Design and as-built comparisons were monitored and documented using Keller's proprietary software tools: Keller Site Data Manager (KSDM) and VibroScan (Falk et al., 2011; Zöhrer et al., 2012).

In addition, the geological representation and the three-dimensional geometry of the contamination remediation were used as supporting tools. These visualizations provided essential decision-making support for technical and planning-related issues during execution.

### 3 SUSTAINABILITY THEORY AND STRATEGY

#### 3.1 Scopes

In the measurement and reporting of greenhouse gas emissions, these are categorized into three scopes according to the Greenhouse Gas Protocol:

- **Scope 1:** Direct emissions from company-owned sources (e.g. machinery and vehicles on construction sites)
- **Scope 2:** Indirect emissions from purchased energy (e.g. electricity consumption)
- **Scope 3:** Other indirect emissions across the value chain (e.g. suppliers, materials, business travel, transportation)

Within the Keller Group, emissions analyses (Keller group plc 2024) have shown that **fuel consumption** of construction equipment (Scope 1) and **transport** and travel activities (Scope 3) are significant contributors. However, in most projects, the emissions from installed **construction materials** - classified under Scope 3 - have by far the greatest impact on the overall carbon footprint.

For this project, we also found this insight to be true and continued to pursue it in the development of our strategy.

#### 3.2 Early engagement

Early engagement offers the best opportunity to fully realize the potential for reducing CO<sub>2</sub> emissions. In the referenced project, we were able to make decisive contributions as early as the conceptual phase by supporting the feasibility study with our expertise. After being awarded the contract as a design-and-build project, we not only had greater decision-making

freedom, but also assumed greater responsibility for the overall project and for our environmental obligations.

The greatest carbon savings potential, however, lies in the careful preparation of the construction site – especially in the design, the selection of alternative fuels, and the choice of suitable equipment. Another important aspect was the optimization of the supply chain for the gravel material.

From the very beginning, it was our central concern to actively monitor the construction processes and respond flexibly to changes. Our goal was to ensure that all emissions savings achieved do not result in economic disadvantages for the client and our company.

### 4 APPROCHE, EXPERIENCE AND RESULTS

#### 4.1 General

The greatest potential and highest flexibility for CO<sub>2</sub> reductions lies in Scope 1 - which is where we placed clear emphasis in this project. The most significant share of CO<sub>2</sub> emissions arose from materials and their transportation, with our ability to act being largely determined by the suppliers' capacity. Nevertheless, we consistently ensured that transportation routes were as short as possible. It is also important to note that using natural aggregate in the vibro replacement process results in a significantly lower CO<sub>2</sub> footprint compared to concrete or steel. In chapter 5 results of CO<sub>2</sub> calculations are discussed to quantify this effect.

#### 4.2 Equipment and fuel

The three milestones of our global strategy for decarbonizing our facilities provided us with guidance on how to proceed:

##### 4.2.1 Efficiency improvements

In selecting the equipment, a conscious effort was made to use optimally suited machines with appropriate capacity. Equipment that was not available internally was rented locally to minimize transport distances. The goal was to achieve a homogeneous equipment structure in both vibro equipment groups in order to simplify monitoring—particularly regarding fuel consumption, performance, and quality assurance.

#### Experiences and Results

It is generally known that an air compressor is inherently low in efficiency. Monitoring fuel consumption revealed that the distribution of the total amount per equipment group during the entire construction site is as follows:

- Rig: 30 %
- Generator: 30 %
- Compressor: 30 %
- Wheel loader 10 %

Given that we also wanted to gain experience with HVO100 consumption, all participants paid close attention to fuel usage. After just a few days, it became clear that compressed air production accounted for a disproportionately large share.

The targeted use of compressors with lower output led to significant savings in fuel consumption and thus a reduction in CO<sub>2</sub> emissions. Through this optimization, the daily consumption was reduced from up to 250 litres to 150 and even as little as 75 litres. On a construction site without systematic monitoring of fuel quantities, hardly anyone would have considered evaluating the minimum required air volume or the smallest possible device that would still ensure neither performance nor quality losses.

#### 4.2.2 Alternative fuels

It was beyond question that the use of alternative fuels such as HVO100 enables a significant reduction in CO<sub>2</sub> emissions according to the manufacturer, by as much as 85 %. However, the procurement situation in Switzerland has so far proved difficult, as the import process is subject to strict approval procedures. Nevertheless, thanks to the large fuel requirement on the construction site and a nearby supplier only about 50 kilometres away, we had the opportunity to use HVO100. Despite the economic challenge - the price is about 15 to 20 % higher than conventional diesel - the decision was made in favour of the alternative fuel. In addition, a larger on-site tank capacity was created before the project started to minimize the number of transport runs.

#### Experiences and Results

The experiences at the construction site showed that HVO100 can easily be mixed with fossil diesel and does not require any additives in winter. In previous tests on basement construction sites, the consumption of HVO100 was sometimes up to 20 % higher than that of diesel, which we aimed to minimize by using modern engine types.

Over a period of almost eight months, the daily fuel consumption of all equipment was recorded. This resulted in a comprehensive data set for optimizing future projects. Around 8 % of the site's total fuel consumption was from fossil diesel. This switch was made to enable a direct comparison with HVO100.

Under comparable ground conditions, using the latest generation of equipment (Stage V engines) and within a weekly production period, the consumption was almost identical. A clear increase in consumption can be seen between engine generations Stage IV and Stage V. The Rig (VibroCat) with the older engine system and diesel particulate filter had an almost 30 % higher HVO100 consumption related to production time. One side effect noticed with the diesel particulate filter was lower contamination. During the eight-month construction phase, the filter only needed to be burnt out twice. The average AdBlue consumption when using HVO100 was about 2.7 % of the fuel quantity. Compared to experiences with fossil diesel, AdBlue consumption is lower.

#### 4.2.3 Alternative equipment

Initial considerations were made regarding which equipment might be replaced by, for example, electric devices at a later stage. A compressor was chosen as a possible test run for this purpose. However, the topic could only be pursued further once the actual need for air during production had been verified.

#### Experiences and Results

With the knowledge that a compressor in the range of 6-7 m<sup>3</sup> was sufficient, the experiment with an electric compressor was launched. The device used can be operated with different power modes. Depending on the available power connection (16 A, 32 A, 63 A), the maximum output is reduced. After several trials, it turned out that operating at 32 A provides enough air. By recording the electricity consumption, the following result can now be presented:

$$200 \text{ kWh} \times 0.057 \text{ kg CO}_2 / \text{kWh} = 11.4 \text{ kg CO}_2 \quad (1)$$

$$55 \text{ l} \times 3.3 \text{ kg CO}_2 / \text{l} = 181.5 \text{ kg CO}_2 \quad (2)$$

$$125 \text{ l} \times 3.3 \text{ kg CO}_2 / \text{l} = 412.5 \text{ kg CO}_2 \quad (3)$$

The potential savings on this construction site—if both groups of equipment operate with the smallest compressor type

(2) and are each replaced by an electric device—amount to nearly **50 tCO<sub>2</sub>e**.

## 5 CARBON HIERARCHY

### 5.1 General

The results presented in the previous section can be directly transferred to the carbon hierarchy (Figure 2). The following section now shifts the focus back to the overall project. In doing so, processes that have not yet been explained in detail are also considered, but which also contribute to the total emissions balance. For example, the verification of the design between the offer phase and execution, or the consistent installation control and calibration of the gravel quantities based on the data pool of equipment and production data.

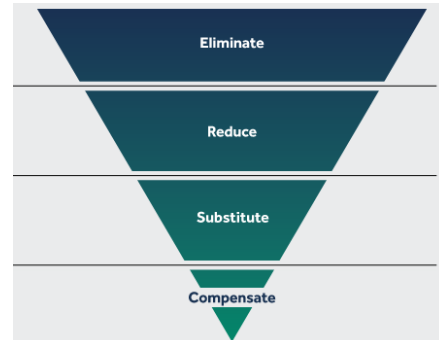


Figure 2. Carbon hierarchy (Keller group plc, 2024)

### 5.2 Elimination

By choosing ground improvement using vibro stone columns, the use of concrete, steel and contaminated excavation for foundation measures was largely avoided.

### 5.3 Reduce

Internal planning and design of ground improvement, along with precise - sometimes three-dimensional analysis of the complex subsurface conditions, led to a reduction in the required gravel volume and the number of transports, especially when compared to the originally assumed values from the bidding phase. This was primarily due to Keller's extensive experience with design-and-build projects.

Through continuous monitoring and the use of optimal equipment with modern engines, fuel consumption was noticeably reduced. Additionally, increasing the on-site tank volume further minimized the number of necessary deliveries.

### 5.4 Substitute

A particularly effective contribution to reducing emissions was achieved by consistently replacing diesel fuel with HVO100 (Hydrotreated Vegetable Oil). Despite the higher procurement costs of HVO100 compared to conventional diesel, targeted optimization of consumption and deliberate use on this construction site allowed at least partial compensation of the additional costs. This measure not only noticeably reduced emissions, but also sent a clear signal of innovation and willingness to anchor sustainable alternatives in construction practice.

Furthermore, a significant step was taken by replacing a diesel-powered compressor with an electric model. The initial experience with this change was extremely positive and will be further expanded on future construction sites.

## 5.5 Compensate

The offsetting of additional emissions was not pursued in this project.

## 6 CO<sub>2</sub> BALANCE USING THE EFFC/DFI CARBON CALCULATOR

The EFFC/DFI Carbon Calculator (EFFC/DFI, 2023) is a recognised tool for determining CO<sub>2</sub> emission values and is available to the specialised geotechnical engineering sector. Various cases and variants have now been calculated and compared for the Horn project.

### 6.1 Alternative solution with Rigid Inclusion

The example presented here serves as an illustrative overview of how a comparable foundation system with similar deformation characteristics and static structure could have been implemented. The analysis of project-specific boundary conditions clearly shows that a foundation using unreinforced concrete columns constructed with the full-displacement method (Rigid Inclusions) is only suitable to a limited extent. In this context, this type of foundation does not represent a perfectly equal alternative.

#### Key parameters:

- D = 0.53 m
- L = 15 m
- Concrete (Cement: 55 kg/m<sup>3</sup> Column)
- Waste: 1 to / column

The total greenhouse gas emissions amount to approximately **15,000 tCO<sub>2</sub>e**. Material accounts for almost 94 % of this total.

### 6.2 Vibro Stone Columns

#### 6.2.1 General

Before the start of the project, almost 70 tCO<sub>2</sub>e were saved through design optimizations and more precise assumptions.

#### 6.2.2 Execution – Diesel

In reviewing this case study, all data from the execution phase were considered (2.4). The amount of HVO100 was calculated together with the emission values for diesel.

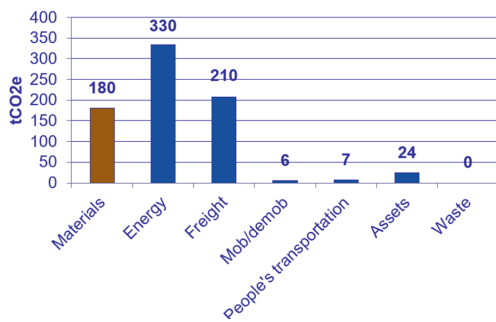


Figure 3. Emissions by Source — Diesel

The calculation results (Figure 3) in total greenhouse gas emissions of **760 tCO<sub>2</sub>e**. Of this, 24 % is attributable to materials and 43 % to energy requirements. This ratio differs from the average values stored in the EFFC Carbon Calculator for stone columns: there, the share of materials is 43 %, while energy requirements account for just under 40 % of total emissions.

#### 6.2.3 Execution – HVO

In this scenario, the actual variant carried out was considered and the construction site situation was recalculated accordingly.

The electricity provided by the client for the site containers was, as in all scenarios, not taken into account. The remaining energy costs were allocated proportionally to the type of fuel used. For the HVO100 fuel applied, an emissions factor 85 % lower than that of conventional diesel was used.

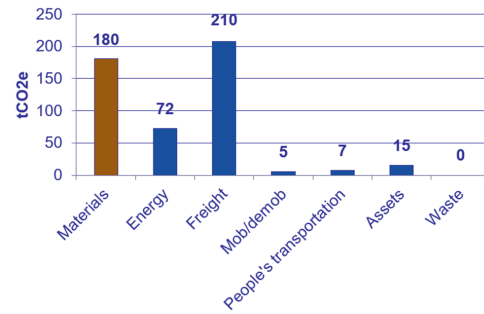


Figure 4. Emissions by Source — HVO

The calculation results (Figure 4) in total greenhouse gas emissions of **490 tCO<sub>2</sub>e**. Of this, 37 % is attributable to materials and 15 % to energy demand. The largest share in this analysis is due to freight (43 %), which can be explained by the enormous amount of gravel and a total of nearly 1,700 trips with an average distance of 55 km.

### 6.3 Summary

The use of HVO100 fuel for ground improvement with stone column reduced total CO<sub>2</sub>e emissions from **760 tCO<sub>2</sub>e** to **490 tCO<sub>2</sub>e (-36 %)** compared to conventional diesel. With HVO100, energy-related emissions decreased while **freight** accounted for the largest share (**43 %**) due to extensive gravel deliveries. The results highlight the significant impact of fuel choice and logistics on overall carbon emissions in geotechnical projects.

## 7 CONCLUSIONS

Early consideration of emission reduction is crucial. In addition to established optimization measures, a solid data basis is essential for informed decision-making. Especially the targeted use of suitable equipment and a possible switch to electrically powered machines are central insights that are often underestimated. All these aspects contribute to making investments economically successful through innovation, controlling, and high-quality data in reporting. Recording energy and material consumption should be as low-threshold and as automated and digital as possible in order to enable well-founded decisions.

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