

# Sustainable Excavation Support Systems: The Role of Sheet Pile Walls in Achieving Climate Neutrality

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**ABSTRACT:** The selection of excavation support systems has significant influence on carbon emissions, underscoring the need of systematic comparison of their life-circle impacts. This paper examines sheet pile walls, as an environmentally favourable shoring solution and proposes design strategies that align with sustainability objectives, drawing on recent findings (Kamm, 2023, Gasser, 2023). The first study (Kamm, 2023), "Application of Life Cycle Assessments (LCA) in specialist foundation engineering in Switzerland", evaluates approaches for minimizing emissions and environmental impacts in construction. It compares two LCA methodologies: one based on a single environmental indicator and another employing a comprehensive ecological scarcity approach. While both approaches are applicable in specialist foundation engineering, the findings indicate, that the ecological scarcity method generally offers greater advantages when methodological flexibility is permitted, highlighting the critical role of method selection in influencing the assessment outcomes and supporting more sustainable decision-making. The second study (Gasser, 2023), "Investigation of the effects of sheet piles as single and double planks for U-profiles", explores the structural performance and environmental implications of using single versus double sheet pile configurations. It further describes design options for enhancing the load-bearing capacity of single sheet pile walls and presents practical case studies demonstrating real-world applications and benefits. Building on these findings, this paper argues that for sheet pile walls constitute an effective and sustainable solution for excavation supports. It provides a comparative analysis of CO<sub>2</sub> emissions from various shoring -system types and introduces innovative approaches to greener construction practices. Overall, the paper aims to deliver valuable insights into how the adoption of sheet-pile systems can significantly improve environmental outcomes in specialist foundation engineering and foster a transition towards climate-neutral and resource-efficient construction.

**KEYWORDS:** Sheet pile walls, sustainable construction, LCA methodologies, climate neutrality, observational method, CO<sub>2</sub>-balance

## 1 INTRODUCTION

In early 2025, Switzerland introduced the standard SIA 390/1:2025, "Climate Path – Greenhouse Gas Balance over the Life Cycle of Buildings.". This standard specifies reduction trajectories and target values aimed at reducing emissions from both the construction and operation of buildings to zero by 2050 (SIA, 2025). Meeting these objectives necessitates a paradigm shift among all stakeholders throughout the design and execution phases. The implications of these requirements are particularly significant for the design and implementation of earth-retention and excavation-support systems, which now demand a more intricate balance between economic feasibility, sustainability, and compliance with safety regulations. Consequently, geotechnical design methodologies must adapt to these evolving conditions. Given the absence of a universally optimal solution for sustainable excavation support and the lack of a standardized approach in specialist foundation engineering, individual projects must develop and evaluate multiple design alternatives. These alternatives should integrate both cost analyses and sustainability assessments. Such assessments are commonly carried out using Life Cycle Assessment (LCA), a systematic methodology for quantifying the environmental impacts across the entire life cycle of a product or system - from raw material extraction to end-of-life disposal (Frischknecht, 2020). The subsequent sections outline the methodological frameworks available for performing LCAs on excavation support systems and summarizes findings from studies on selected, completed projects.

## 2 SELECTION OF THE LIFE CYCLE ASSESSMENT METHODOLOGY

Swiss practice permits several LCA methodologies, which can be broadly categorized into partial evaluations of individual environmental indicators, fully aggregated approaches such as Ecological Scarcity method), and damage-oriented methods, such as ReCiPe 2016 (FOEN, 2021). Comparative analyses of these methods are indispensable for understanding their respective strengths, limitations, and suitability for geotechnical applications. Such comparisons not only reveal methodological differences and similarities but also clarify how each approach accounts for key influencing factors, thereby shaping the interpretation of results. The following discussion focuses on two particularly relevant approaches. The first is the partial assessment which concentrates on non-renewable primary energy consumption and greenhouse gas emissions, as outlined in SIA guidelines 2040 (SIA, 2011) and 2032 (SIA, 2020). This approach represents an inventory analysis, a simplified form of LCA that excludes the impact assessment phase and limits the evaluation to compiling and analyzing the life cycle inventory. The second approach is the Ecological Scarcity Method, which exemplifies a fully aggregated methodology. "Full aggregation" entails the application of weighting factors during the impact assessment phase, enabling the consolidation of multiple environmental impacts into a single composite score (IEA & UNEP, 2018). Unlike inventory analysis, this method incorporates the impact assessment phase and therefore qualifies as a complete LCA study.

## 2.1 Data Basis

The Coordination conference of the building authorities and property authorities of public building contractors (Koordinationskonferenz der Bau- und Liegenschaftsorgane der öffentlichen Bauherren, KBOB) provides publicly accessible Life Cycle Inventory (LCI) specifically tailored for the construction sector (KBOB, 2022). These datasets constitute the recommended basis for LCAs in Switzerland, as stipulated in SIA-Datasheet 2032 (SIA, 2020). The LCI datasets are continuously updated to reflect the latest scientific findings and policy developments, and to incorporate environmental indicators for new technologies. The KBOB datasets are subject to continuous revision to incorporate the latest scientific insights, regulatory developments, and environmental indicators associated with emerging technologies. They are nationally standardized and adhere to the Ecoinvent Data Quality Guidelines v2 and the Ecoinvent database v2.2, supplemented and updated by KBOB to ensure sector-specific applicability. The most recent version, the 2022 revision, serves as the reference framework for all calculations and comparative analyses presented in this study.

## 2.2 Balancing based on non-renewable primary energy and greenhouse gas emissions

Non-renewable primary energy refers to energy sources from finite that resources, such as fossil fuels (coal, oil and natural gas) and nuclear fuels (e.g., uranium, which are inherently limited and subject to eventual depletion). When evaluating this environmental indicator, all relevant inputs must be systematically accounted for and expressed in a standardized reference unit. The aim of the method is to collate all inputs or outputs and present them in a reference value. Two of the most widely used terms for benchmarking CO<sub>2</sub> emissions as well as for comparing embodied-energy across materials and systems is the carbon footprint equivalent (kg CO<sub>2</sub>-eq) for greenhouse gases and the kilowatt-hour oil equivalent (kWh oil-eq) for non-renewable primary energy sources. This creates a common reference value that is easy to understand and suitable for comparison and interpretation.

## 2.3 Life-Cycle Inventory Based on Non-Renewable Primary Energy and Greenhouse Gas Emissions

Within the Ecological Scarcity Method, all relevant inputs and outputs of the defined product system are systematically considered and aggregated into a single composite result. The methodology is comprehensively documented in the publication by the Swiss Federal Office for the Environment (IEA & UNEP, 2018). To quantify environmental impacts, the Ecological Scarcity Method applies a weighting approach based on eco-factors, which express the relative environmental significance of emissions and resource uses. These eco-factors are calculated using the following formula (IEA & UNEP, 2018):

$$Eco - Factor = K * \frac{1EP}{F_n} * \left(\frac{F}{F_k}\right)^2 * c \quad (1)$$

K = Characterisation factor of a pollutant or resource

F<sub>n</sub> = Normalisation flow: current annual flow, relative to the respective country

F = Current flow; current annual flow (emission or consumption) in relation to the reference area

F<sub>k</sub> = Critical flow: critical annual flow which is, a legal limit value in relation to the reference area

c = constant (10<sup>12</sup>/y): It ensures that easy-to-represent numeral values are obtained

EP = Eco-point: unit for the assessed environmental impact

Using this formula, an eco-factor can be determined for each environmental intervention for which statutory limits or policy target exist. The method comprises three key components: characterization, normalization, and weighting.

## 2.4 Comparison of Methods

The two methods—Ecological Scarcity and partial inventory assessment based on a selected environmental indicator—are compared in this chapter with respect to their application in geotechnical construction using a scoring approach. Each is evaluated against selected criteria on a scale from very positive (++) to very negative (--), with neutral being marked as “0”. The evaluation results are presented in Table 1 below. This table is based on experience from CO<sub>2</sub> accounting for special underground engineering works.

Table 1. Comparison of Methods of ecological scarcity

Evaluation criterion	Ecological scarcity method	Partial balancing of an environmental indicator
Completeness	+	-
Comprehensibility of the results	+	++
Simplicity of use	++	++
Possibility of interpretation	+	++
Transparency	++	+
Support for decision making	+	0
Trustworthiness	++	+
International application	+	++
Regional application	+	--
Costs of preparing the balance sheet	++	++
Update option	++	++
Possible valuation gaps	-	-
Non-ecological influences	-	+
Long-term statements	-	--
Standardisation	+	+
Weighting option	++	--
Application in special underground engineering	++	++

In principle, both methods are very well suitable for use in geotechnical applications. Having established the comparative strengths of the Ecological Scarcity Method and partial inventory analysis, the next step is to demonstrate how these principles translate into practical decision-making.

## 3 COMPARISON OF ENVIRONMENTAL IMPACTS ACROSS DIFFERENT EXCAVATION SUPPORT SYSTEMS

As previously noted, a direct comparison between different support systems is rarely feasible, due to the influence of project-specific conditions. To achieve a more robust and meaning evaluation, benchmarking is required. In practice, comparisons among design variants, typically rely on life-cycle inventory data to corresponding to the modules “Construction” (module A1–A3), “Transport” (module A4) and “Installation” (module A5), as defined in EN 15804 (2019). For preliminary benchmarking, the KBOB database (KBOB, 2022) provides average empirical values for each support-system type, offering a standardized reference point for initial assessments.

Table 2. Comparison of environmental impacts of the various support-system types according to KBOB (2022).

Nr.	Excavation support system	[-]	EP'21	Embodied Energy	Emissions
			Total EP	Total kWh oil-eq	Total kg CO <sub>2</sub> -eq
1	Sheet pile wall, braced	m <sup>2</sup>	162'000	412	95.7
2	Sheet pile wall, cantilevered	m <sup>2</sup>	287'000	732	169
3	Soldier pile wall, braced	m <sup>2</sup>	305'000	637	187
4	Soldier pile wall, anchored	m <sup>2</sup>	319'000	641	197
5	Sheet pile wall, anchored	m <sup>2</sup>	321'000	793	187
6	Soldier pile wall, cantilevered	m <sup>2</sup>	436'000	874	270
7	Diaphragm wall, 400 mm	m <sup>2</sup>	777'000	1'160	423
8	Bored pile wall, anchored	m <sup>2</sup>	846'000	1'390	535
9	Bored pile wall, not anchored	m <sup>2</sup>	1'230'000	1'940	821
10	Bored pile wall, braced	m <sup>2</sup>	1'300'000	2'120	861
11	Diaphragm wall, 800 mm	m <sup>2</sup>	1'380'000	2'080	809

Among the various shoring systems, sheet piles are generally considered to exhibit comparatively favorable environmental performance. The subsequent section provides a detailed analysis of the CO<sub>2</sub> accounting associated with this system type, examining its life-cycle emissions.

#### 4 SHEET PILE CLASSIFICATION - ENVIRONMENTAL IMPACT PERSPECTIV

To enable more accurately assessment of the environmental impact of sheet piles, the following classifications should be considered:

##### 4.1 Manufacturing

Sheet pile producer ArcelorMittal offers the following sheet pile profiles:

- EcoSheetPile™ Plus – EAF. – 370 kg CO<sub>2</sub>e / t Sheet pile
- EcoSheetPile™ – EAF - 520 kg CO<sub>2</sub>e / t Sheet pile
- Cold-formed sheet piles – BF/BOF - 2440 kg CO<sub>2</sub>e / t sheet pile
- Hot-rolled sheet pile sections – BF/BOF – 2550 kg CO<sub>2</sub>e / t sheet pile

The choice of manufacturing rote – Electric Arc Furnace (EAF) versus Blast Furnace / Basic Oxygen Furnace (BF/BOF) – has an decisive influence on the carbon footprint. Procuring sheet piles produced under the most resource-efficient conditions can substantially reduce the overall greenhouse gas emissions of the geotechnical construction works.

##### 4.2 Delivery Type

Sheet piles can be delivered in two forms:

- Single sheet pile
- Double sheet pile

Traditionally, sheet piles are designed and installed as paired sheets due to their superior load-bearing capacity compared to

single sheet. From an environmental perspective, however, the advantage a double sheet pile wall is less clear. Single piles, owing to their smaller cross-section, generally require lower installation forces and can often be driven to greater depths without additional measures such as soil loosening or replacement drilling. Furthermore, large stocks of single pile sections are already available on the market. Reusing of these existing sections reduces environmental impact by avoiding the production of new double sheet piles.

##### 4.3 Installation method

Depending on the ground conditions, different methods of installing sheet pile walls can be employed:

- Driven
- Vibratory driving
- Installation assisted by soil-loosening boreholes
- Installation with the aid of replacement boreholes

The installation method significantly affects the system's carbon footprint. Wenn soil-loosening or replacement boreholes are required, emissions increase substantially. Soil-loosening operations typically necessitate an additional diesel-powered drilling rig, while replacement drilling introduces further impacts through the transport and disposal of the excavated material (muck) and the handling and emplacement of new fill material.

##### 4.4 Reusability

The reusability of the sheet piles can be defined as follows:

- Sheet piles left in place (not recovered)
- Sheet piles that are partially recovered (dismantled and retrieved)
- Sheet piles that can be fully dismantled and recovered.

From an environmental perspective, sheet piles should be dismantled and reused whenever possible.

#### 5 ENVIRONMENTAL PERFORMANCE COMPARISON OF SHEET PILES: SINGLE VS. DOUBLE SHEETS

To illustrate the practical implications of the discussed LCA methodologies, a case study from the Zurich region is presented. This example shows how life-cycle inventory data and emission factors are used to evaluate alternative sheet pile configurations, highlighting the environmental trade-offs between single and double sheet piles. The project under consideration involves the installation of a sheet pile wall incorporating one level of internal bracing. This example serves to demonstrate the application of life-cycle inventory data and benchmarking principles in evaluating the environmental performance of alternative design variants.

Table 3. Calculation of the environmental impact for the different sheet pile types (General information)

Description	Unit	Variant 1	Variant 2
Sheet Pile section		PU22	PU22
Sheet Pile length	m	12	12
Sheet Pile surface area	m <sup>2</sup>	2'400	2'400
Sheet Pile weight per m <sup>2</sup>	kg/m <sup>2</sup>	144	144
Sheet Pile type		Single sheet pile	Double sheet pile
Recoverable sheet piles		yes	yes
Replacement borehole		no	yes
Calorific value of Diesel	kWh/l	9.8	9.8
THGE-Diesel	kg CO <sub>2</sub> -eq/h	0.32	0.32

Table 4. Calculation of the environmental impact for the different sheet pile types (Detailed)

<b>Transport Sheet Pile to and from site</b>			
Environmental impact (E.i.) of total transport	kg CO <sub>2</sub> -eq	<b>6'206</b>	<b>6'206</b>
<b>Inbound and outbound equipment transport</b>			
E.i. of total transport	kg CO <sub>2</sub> -eq	<b>316</b>	<b>632</b>
<b>Installation of sheet piles</b>			
Performance	m <sup>2</sup> /day	100	200
Pile-driving equipment		Liebherr LRB 125	
Diesel consumption (Estimated value)	l/h	89	89
E.i. of sheet piles installation	kg CO <sub>2</sub> -eq	<b>65'028</b>	<b>32'514</b>
<b>Recovery of sheet piles</b>			
Performance	m <sup>2</sup> /day	100	200
Pile-driving equipment		Liebherr LRB 125	
Diesel consumption (Estimated value)	l/h	89	89
E.i. of sheet piles recovery	kg CO <sub>2</sub> -eq	<b>65'028</b>	<b>32'514</b>
<b>Execution of replacement boreholes</b>			
Performance	m <sup>2</sup> /day		50
Drilling rig			Bauer BG24
Diesel consumption (Estimated value)	l/h		59
Number of replacement boreholes, d = 80 cm & L = 12m	Pcs.		335
E.i. of drill cuttings disposal (including transport)	kg CO <sub>2</sub> -eq/t		11
E.i. of gravel (including transport)	kg CO <sub>2</sub> -eq/t		20
E.i. replacement boreholes	kg CO <sub>2</sub> -eq		212'926
Total E.i.	kg CO <sub>2</sub> -eq	136'579	288'793
E.i. per m <sup>2</sup> of sheet pile	kg CO <sub>2</sub> -eq/m <sup>2</sup>	57	120

The environmental-impact data were sourced from the KBOB database (KBOB, 2022). In the selected case study, the double-sheet pile configuration exhibits more than twice the environmental burden compared to single sheet pile variant. This difference is primarily attributable to the additional requirement for replacement boreholes in the double sheet pile, with significantly increases resource consumption and associated greenhouse gas emissions.

The result of this assessment underscores the importance of installation-related factors, as emphasized in the methodological framework. By linking emissions to specific design choices, the case study demonstrates how LCA-based evaluations can guide sustainable excavation support strategies.

## 6 CONSTRUCTION APPROACHES FOR ENHANCING THE LOAD-BEARING CAPACITY OF SINGLE SECTION SHEET PILES

As illustrated in the case study presented in Chapter 5, single sheet piles represent an environmentally advantageous alternative to double sheet piles. The following approaches can be adopted to improve performance:

- Pre-installation pairing: Interlocking and welding two single sheet piles into a double sheet pile.
- Post-installation pairing: Welding two single sheet piles into a double sheet pile.
- Incorporating head beams or walers to improve structural integrity.
- Achieving form-fit composite interaction between the waler (if present) and the sheet pile.

Through detailed structural analyses tailored to project-specific requirements, one or a combination of these measures, can be employed to increase the load-bearing capacity of single sheet piles to levels comparable with the double sheet piles. In complex scenarios requiring localized reinforcement or precise performance evaluations, the entire system — including the sheet pile, longitudinal stringers, and welded connections — can be analyzed using FEM (Finite Element Method).

## 7 CONCLUSIONS

Sheet piles represent a viable and environmentally favorable solution for earth-retention system, supporting the transition of shoring designs in specialist foundation engineering projects towards climate neutrality. While they do not constitute a universal solution for all geotechnical applications, sheet pile walls offer broad adaptability across diverse project contexts. Their inherent significantly contributes to the principles of circular economy and to achieving long-term climate-neutral objectives. Furthermore, the use of single sheet piles, particularly those manufactured through resource-efficient and low-carbon processes, provides an additional opportunity to enhance environmental performance of construction projects without compromising structural integrity.

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