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A chronological development of a framework for emission free construction sites in Norway

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A chronological development of a framework for emission free construction sites in Norway

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Abstract. The building and construction sector is responsible for 3.4% of total GHG emissions in Norway. Around 95% of these emissions arise from the combustion of fossil fuels for the operation of construction machinery and transport. This highlights the importance of transitioning to renewable energy sources for the operation of construction sites. To facilitate this transition, a new concept is emerging in Norway, called emission free construction sites. To fully implement this concept, a clear and consistent definition of emission free construction sites and a commonly agreed stepwise approach to decarbonisation of construction activities is required. This paper presents a chronology of the development of emission free construction sites in Norway to further develop a framework. First, a review of experiences from different research and on-going national activities are presented as a background. The results from applying this framework on construction sites in Norway are presented and issues around harmonisation of definitions, standards, and system boundaries are discussed. The results of this paper are relevant for actors within the construction industry that are interested in reducing GHG emissions from construction works. In conclusion, this paper presents the first steps towards the decarbonisation of construction sites in Norway and demonstrates how Norway has become a testbed for the electrification of construction machinery on construction sites.

1. Introduction

Around 23% of global greenhouse gas (GHG) emissions originate from the construction industry, whereby 5.5% relate to the activities on construction sites [1,2]. Construction emissions are released during a short period of time during the early stages of a building's life cycle and consist of emissions from transport and construction works [3]. Construction emissions are significant in comparison to use phase emissions which occur over the lifetime of a building, typically over 50-years. Considering that energy and environmental performance of the use phase have been ambitiously tackled over the past decade, the focus increasingly shifts to environmental performance during construction [4]. This is an important measure for limiting global warming to below 2˚C. Construction machinery are responsible for other pollutants to air (NOx, SOx and particulate matter) and sound, which can have a significant negative impact on the health of construction workers and citizens [5]. The construction industry needs to utilise effective measures to reduce emissions and optimise energy use. Many countries have set long term plans to achieve specific energy and environmental objectives especially regarding construction sites and construction machineries. In the EU, 16 member states report GHG emissions relating to construction machineries [6]. However, there is no EU policy to address GHG emissions from construction machines and equipment, as it is not included in the Clean Vehicles Directive [1].

Construction sites rely heavily on fossil fuels as the driving force of heavy construction machinery. In Norway, Oslo municipality, contractors, suppliers, and construction machinery manufacturers have taken initiative to advance zero-emission machinery powered by batteries, fuel cells or direct electrification. In the EU, the Non-Road Mobile Machinery (NRMM) Regulation sets limits on emissions and imposes approval requirements for NRMM engines with the goal of "stimulating innovation, improving air quality, reducing health costs and increasing life expectancy" [7]. This regulation goes far in terms of improving air quality but does not have specific considerations regarding climate goals. There is a need to regulate GHG emissions from NRMM and set new policies and standards.

C40 Cities is a network of mayors from nearly 100 world-leading cities and though its Clean Construction Declaration, it sets targets to develop net-zero emission buildings and infrastructure. Through this declaration, the mayors of Oslo, Los Angeles, Mexico City and Budapest pledged in November 2020 to halve GHG emissions from all construction activities in their cities by 2030 [8]. The EU DG Grow Big Buyers Initiative (an initiative by the European Commission (EC) for promoting collaboration between big public buyers in implementing strategic public procurement for sustainable solutions) has also a working group on Zero Emission Construction Sites consisting of Amsterdam, Brussels, Budapest, Copenhagen, Helsinki, Lisbon, Oslo, Trondheim, and Vienna [1]. These cities are promoting zero emission construction sites by focusing on alternatives to diesel NRMM. The Big Buyers Initiative has published a joint statement of Demand for Emission free Construction Site Machinery. This includes requirements for fossil free construction machinery in 20% and 50% of public projects from 2025 and 2030 respectively. The EC adopted a package of legislative proposals, "Fit for 55" as part of the EU Green Deal, which aims to provide a coherent and balanced framework for reaching the EU's climate objectives. Fit for 55 refers to the EU's target of reducing net GHG emissions by 55% by 2030, whereby alternative fuel infrastructure, renewable energy, and energy efficiency are the most relevant topics for emission free construction sites [9].

In Norway, the construction industry is responsible for approximately 3,4% of national GHG emissions which corresponds to around 2,170,000 tCO_2e [10]. Around 5% of these emissions are related to the heating and drying of structures during construction, with the remaining 95% coming from transport of heavy-duty vehicles (HDV) and operation of construction machineries [11]. In Oslo, NRMM is estimated to account for ca. 7% of the city's total GHG emissions [12]. Oslo municipality has developed a climate strategy for Oslo towards 2030. This strategy aims to reduce direct GHG emissions by 95% by 2030 and 50% by 2025, compared to 2009 levels [13]. In 2025, all of Oslo municipalities public construction sites will be emission free, and in 2030 all construction sites in Oslo (also private) will be emission free. Other Norwegian and EU cities are also setting ambitious goals for achieving emission free construction sites [14]. Despite these developments, there is currently no national or international consistent definition of fossil free and emission free construction sites or agreed-upon system boundaries.

The aim of this paper is to present a chronology of the development of emission free construction sites in Norway. In terms of scientific novelty, the paper develops a new framework for the decarbonisation of construction activities. This novelty is useful for new knowledge discovery in the harmonisation and standardisation of definitions and system boundaries for emission free construction sites, which will provide a common understanding of what a fossil free and emission free construction site is. The paper is relevant for actors within the construction industry that are interested in reducing GHG emissions from construction works and provides a transparent framework that can be implemented in construction and used for data collection.

2. Background

In 2016, a study by the research centre on zero emission buildings (FME ZEB) on an administration building at Campus Evenstad found that once an highly energy-efficient building has optimised embodied GHG emissions from material use, then the embodied GHG emissions from the construction phase lasting one year can equal the embodied GHG emissions from operational energy in the use phase over 60-years [15,16]. GHG emissions that occur today are more important to reduce now than emissions occurring in 60 years' time if we are to meet climate goals in 2030. Campus Evenstad is the first building in Norway to document GHG emissions from the construction phase and made a first attempt of establishing a system boundary of the construction activities to be included in the assessment.

In 2017, a research project on public procurement of emission free construction sites gave a first overview of definitions and system boundaries for fossil and emission free construction sites [17]. The project presented construction site activities by harmonising activities from life cycle modules A4 - transport and A5 – construction installation process as presented in the European standards EN 15804 for products [18] and EN 15978 for buildings [19] environmental performance assessment and the Norwegian standard NS 3720 for GHG emission calculation of buildings [20] (which was a draft document at the time). Lia nursery school, which was the first fossil free construction site in Norway, was used as a case study where GHG emissions from construction site activities were conducted using the actual data collected from construction site activities [21]. The project also presented a suggestion for Oslo municipality on how to set ambitious but achievable requirements for emission free construction sites [22]. The requirements focused on specific topics (building processes, optimisation, energy use and life cycle assessment (LCA)), objectives and important stakeholders through all project phases. The results from Lia nursery school and Campus Evenstad highlight the importance of good planning in the early phase, utilisation of LCA to quantify the actual environmental performance of emission reduction measures, cooperation between stakeholders, clear definitions of requirements and ambitious goals and sharing knowledge and experiences [23]. Shortly afterwards, Oslo municipality implemented fossil free construction requirements in all public procurement criteria. These fossil free construction sites have been evaluated in different studies [24–27].

Construction machinery is one of the main sources of GHG emissions from construction site activities. A lack of emission free construction machinery in the market, lack of information on available machinery, high investment costs, and lack of infrastructure have been some of the major challenges that hinder the development of emission free construction sites. In 2018, the zero-emission digger (ZED) project produced some of the first large electric excavators which were tested out on the first emission free construction sites, Olav Vs Street, Biri care home and Oslo A&E in 2019 [28–30]. The ZED project demonstrated that it is possible to use electric excavators under real conditions on Norwegian construction sites, and that they perform either as good as or better than their diesel counterparts.

A study from Bellona, a Norwegian environmental organisation, estimates that up to a 50% emission reduction can be achieved through better planning and operation of construction material deliveries [31]. In 2018-2022, the MIMIC project developed solutions to facilitate logistics to, from and on urban construction sites to reduce potential negative impacts. MIMIC developed possible construction logistics scenarios and strategies to improve understanding of construction logistics [32], and used stakeholder analysis and construction logistics to identify needs and support discussions on the evaluation of potential impacts of construction logistic activities. MIMIC developed an impact assessment framework to evaluate the environmental, economic performance of both on-site and off-site construction logistic scenarios [33], and developed an overview of legal and political recommendations to strength policy framework related to construction logistics requirements in the early planning phases [34].

In 2020, Bellona developed a national database for electric construction machineries and equipment [35]. In 2020, Oslo municipality introduced standard climate and environment requirements for public procurement of construction sites. In 2021, a metropolitan declaration was signed by the largest cities in Norway: Bergen, Drammen, Kristiansand, Oslo Stavanger, Tromsø and Trondheim committing to fossil free municipal construction sites in 2021, emission free municipal construction sites in 2025 and all emission free construction sites in 2030. In 2022, a mapping of Oslo municipality's construction sites and impact assessment was conducted [11]. The mapping found that at least 36 construction sites in Oslo use electric construction machinery in 2021, and that electrification of small construction machinery and equipment is unproblematic, whilst there are some challenges relating to energy supply and charging logistics [36]. The impact assessment estimates future energy demands for zero emission building and construction sites in Oslo will be in the region of 77-97 GWh by 2030 [36]. The impact assessment also demonstrated that important driving forces for Oslo to achieve its climate goals by 2030 include international market uptake and better energy infrastructure [36].

In 2022, a scenario analysis was conducted for a pedestrian street in Tromsø to evaluate the GHG emission reduction potential of measures from construction activities [38]. The results show potential GHG emission savings with alternative fossil free solutions for construction machinery, heating and drying, and mass transport, which can also lead to additional costs for the project. Tromsø municipality is planning to use the findings to make an informed decision on choosing fossil and emission free solutions. A recent trend shows the spread of emission free construction sites to the districts in Norway. A roadmap for a construction machinery supplier in Rogaland analyses the investment costs required to electrify half of their machine fleet by 2030 and documents the GHG emission savings and operational cost savings that can be achieved by converting from diesel to electric [39].

One current approach is to use fossil or emission free construction site terms in projects, where only one or few construction activities are considered, without giving detailed information about the activities included or whether direct or indirect emission are considered. In 2021-2022, a stepwise approach for fossil and emission free construction site ambition levels was developed (Figure 1) [11,36]. This stepwise approach provides a minimum ambition level for fossil free operation of construction machinery, energy use and internal transport in Step 1, to a completely emission free construction site in Step 6. There have been some issues with the implementation of this stepwise approach since stakeholders have instead adopted a more flexible definition and system boundary, whereby they pick and choose construction activities and scope of emissions. It is therefore necessary to renew the stepwise approach for fossil free and emission free construction sites so that stakeholders can more easily adopt the framework and so that the framework is transparent, flexible, and easy to understand and communicate to others.

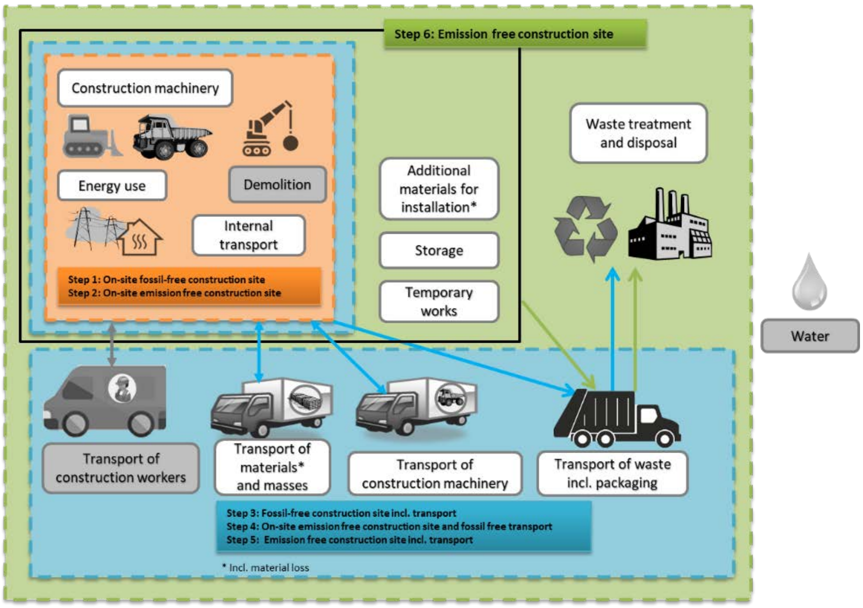

Figure 1. Stepwise approach for fossil free and emission free construction sites [11,36].

3. Method

The method involves taking the chronological development of a framework for fossil free and emission free construction sites in Norway (as presented in the Background) and create a new framework according to feedback from pilot testing (lessons learnt) in construction projects and further harmonisation of system boundaries and definitions according to national and international standardisation (EN 15978, EN 15804, NS 3720, and SN/TS 3770) [18–20,40]. All this information has been systematised into a new framework for fossil free and emission free construction sites. The use of the framework is demonstrated by applying it to a construction project from the mapping of 36 emission free construction sites in Oslo during 2021[11], namely Tåsenveien. Tåsenveien is a 3m by 1.3km cycle path constructed using 8t, 17t, 25t electric excavators, <8t wheel loader, compressor, lift, vibrator plate, concrete pump and 27t truck for mass transport. The implications of the lessons learnt, and new framework are then discussed.

4. Results

Efforts have been made to harmonise the definition of construction activities across national and international standards [18–20,40]. Relevant life cycle modules include A4 - transport and A5 – construction and installation for new constructions, B3 - repair, B4 - replacement and B5 - refurbishment for rehabilitation, and C1 – deconstruction/demolition, C2 - transport, C3 – waste processing and C4 - disposal for demolition. Life cycle module D may also be relevant if construction materials are being reused, recovered, recycled, or used for exported energy. Water is not included in the system boundary. Construction activities have been divided into three main categories by harmonising differences between the construction site activities included in these standards:

- *On-site:* includes operation of mobile and stationary construction machinery and equipment (including internal transport) and energy use (related to hardening and drying of concrete and other building materials, frost protection, direct energy use for providing heat demand and dehumidification of construction related tasks and energy related to the lighting of construction sites and comfort heating of construction offices).
- *Transport*: includes transport of construction workers to and from the construction site (door to door), transport of materials from the production gate to the construction site, transport of surplus material from the construction site, mass transport to and from the construction site (to the final destination and not midway mass hotels), transport of construction machinery and equipment to and from the construction site (door to door), transport of wastes from the construction site to final waste treatment.
- *Other activities*: includes construction site activities which have not been categorised by any of the aforementioned categories, such as waste management processes, storage of products including provision of heating, cooling, and humidity control, temporary works including temporary works located off-site, activities relating to material losses during transport and construction activities (including the production, transport, and waste management of products and materials used to replace damaged ones), and installation of materials into the buildings.

A construction site is defined as the area affected by building and construction works including the construction site activities mentioned above. Fossil free means using energy carriers without fossil CO_2 emissions (e.g., bioethanol, biogas or biodiesel), whilst emission free means using energy carriers that do not directly emit GHG emissions (e.g., electric or hydrogen) [40]. Fossil free construction does not use any fossil fuels in any of its construction site activities, whilst emission free construction does not have direct GHG emissions from any of its construction site activities. Direct emissions occur at the construction site from construction site activities, whilst indirect emissions occur throughout the value chain of construction site activities [40]. According to the Global Protocol for GHG inventories [41], Scope 1 covers the direct emissions from operations, Scope 2 covers indirect emissions from purchased energy, and Scope 3 covers indirect emissions from upstream and downstream activities. The current focus of Norwegian construction sites is on reducing direct emissions (Scope 1).

A flexible framework for fossil free and emission free construction sites based on these definitions and system boundaries has been refined and is presented in Table 1. The framework includes fossil free (scope 1) and emission free (scope 1) construction sites for the three categories of construction activities defined above (on-site, transport and other). In Table 1, the green frame represents Oslo municipality's current definition of emission free. The framework can be used to ascertain the scope of definition and system boundary and can be used to set target percentages with a clear description of the construction site activities included. An example of how this framework can be used is demonstrated by the percentages in Table 1. These percentages are the results from Tåsenveien, whereby 59% of on-site construction machinery, 100% of on-site energy use and 29% of mass transport to and from the construction site is electric and emission free (Scope 1). The remaining on-site construction machinery (41%) and mass transport to and from the construction site (71%) is fossil free. N/A implies construction activities that have not been assessed.

Table 1. Framework for fossil free and emission free construction sites

Construction activity	Fossil free (Scope 1)	Emission free (Scope 1)
On-site		
- Construction machineries	41%	59%
- Energy use	0%	100%
Transport		
- Masses	71%	29%
- Construction workers	N/A	N/A
- Construction machineries	N/A	N/A
- Materials	N/A	N/A
- Wastes	N/A	N/A
Other		
- Waste treatment and disposal	N/A	N/A
- Additional materials for installation	N/A	N/A
- Storage	N/A	N/A
- Temporary works	N/A	N/A

5. Discussion

Currently, the concepts of fossil free and emission free construction sites are under development, and there is still no clear and consistent international understanding of these concepts considering the system boundary and activities included. This study presents a new framework for transparent communication of these concepts. In addition, efforts have been made to harmonise the system boundaries for construction activities in different national and international standards. However, it is important to avoid mismatches and double counting when different national and international standards are used. Among the Norwegian standards, there is a mismatch in the assessment system boundaries in NS 3720 [20] and SN/TS 3770 [40]. SN/TS 3770 gives a suggestion of construction activities to include, and can include demolition and person transport, whilst NS 3720 excludes demolition. However, the framework presented in this paper includes demolition as a construction site activity to highlight GHG emissions from this activity and encourage circular economy measures such as rehabilitation and reuse.

In practice, there is a lack of consistency in reporting construction activities between different stakeholders. For example, in some projects, the demolition and construction activities are reported separately, whilst in other projects they are reported together. Mass transport can include both material transport (e.g., delivery of asphalt or hardcore) or waste transport (e.g., excavated contaminated masses). Internal transport can be interpreted as both on-site construction machinery and on-site mass transport. These discrepancies can result in double counting or exclusion of some activities and their associated impacts. Using the framework proposed in this study can help clarify the reporting of activities.

The definition of fossil free and emission free construction sites is currently limited to direct (Scope 1) GHG emissions. Achieving a net zero emission construction site, including both direct and indirect (Scope 1-3) GHG emissions will be challenging. According to ISOs recent *IWA 42:2022 Net zero guidelines* [42], net zero emissions can be achieved through emission reduction strategies and then offsetting the residual carbon emissions through carbon mitigation measures such as reforestation afforestation, building with biomass, direct air carbon capture and storage, habitat restoration, ecosystem restoration, soil carbon capture, enhanced weathering, bioenergy with carbon capture and storage, biochar. Not all measures may be applicable to construction sites, but the guidelines give some idea of how measures can be implemented to achieve a net zero emission balance. This highlights scope for further work. It may be necessary to expand the scope of the system boundary to the whole life cycle of the building or infrastructure to achieve net zero emission construction and avoid problem shifting.

In Norway, public actors are the main drivers for emission free construction site activities through their public procurement procedures. Lack of national and international regulation supporting emission free construction activities is one of the main barriers for wider implementation of emission free solutions and technologies. For example, Norwegian building regulations (TEK) have recently introduced a requirement for reporting GHG emissions from production (A1-A3), transport (A4), construction (A5), maintenance (B2) and replacement (B4) building life cycle stages. However, in TEK A5 is limited to GHG emissions related to the production and transport of materials that become waste [43]. Further work is needed on following up construction sites after procurement to ensure testing, refinement and implementation of the framework presented in this study. The spread of emission free construction sites is dependent on a common understanding and continued technological development and penetration to the international market. The findings from this paper are useful and can be adopted by other countries to implement emission free construction sites.

6. Conclusion

In conclusion, this paper presents a flexible framework and first steps towards the decarbonisation of construction sites in Norway and demonstrates how Norway has become a testbed for the electrification of construction machinery and construction sites. This knowledge is transferable and is already being adapted by other Nordic countries through the Nordic Sustainable Construction project.

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