

# Emission-free Construction Sites

Knowledge Gaps and Research Needs



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# Preface

This project is part of the Nordic Sustainable Construction programme initiated by the Nordic ministers for construction and housing and funded by Nordic Innovation. The programme contributes to the Nordic Council of Ministers' Vision 2030 by supporting the Nordics in becoming the leading region in sustainable and competitive construction and housing with minimal impact on the environment and climate.

The programme supports the green transition of the Nordic construction sector by creating and sharing new knowledge, initiating debates in the sector, creating networks, workshops, and best practice cases, and helping to harmonise Nordic regulations on the climate impact of buildings.

The programme runs from 2021 to 2024 and consists of the following focus areas:

- WP1 – Nordic Harmonisation of Life Cycle Assessment
- WP2 – Circular Business Models and Procurement
- WP3 – Sustainable Construction Materials and Architecture
- WP4 – Emission-free Construction Sites
- WP5 – Programme Secretariat and Capacity-building Activities for Increased Reuse of Construction Materials

This report is one of the WP4 deliverables.

The work has been conducted by a multidisciplinary working group with participants from the Green Building Council in Iceland in collaboration with the Icelandic Ministry of Infrastructure, the Housing and Construction Authority of Iceland, and the University of Iceland. The Icelandic Ministry of Infrastructure is the responsible party.

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# Executive summary

Conventional solutions have to be challenged, and new innovative solutions need to be developed and tested in real projects.

This report seeks to emphasise the urgency of identifying current obstacles and essential solutions for reducing greenhouse gas emissions during construction. The report advocates research-backed decisions among stakeholders, recognising the industry's need for extensive research, testing, and pilot projects to drive change.

Each chapter provides key research recommendations, which are compiled in chapter 8, Summary and Recommendations. Significant emphasis is placed on the crucial roles of planning, design, and material choices in minimising construction emissions and advancing sustainable practices. The section on the Assessment of Environmental Impact in particular highlights the need for a comprehensive measurement and assessment framework for transportation and construction. The emphasis of the section is on the pivotal role of Life Cycle Assessment (LCA) in estimating environmental impact, especially greenhouse gas emissions, and on advocating the integration of transport (module A4) and installations (module A5) into forthcoming regulations in the Nordic countries.

The report stresses the importance of harmonising LCA methodologies across the Nordic countries in order to facilitate low-carbon solutions in construction. Furthermore, it emphasises the dire need for improved data collection, particularly in relation to transport-related emissions and waste during construction.

Moreover, it explores the importance of optimising energy efficiency and investigating cleaner energy options such as battery electrification and hydrogen technologies in construction processes. However, it also acknowledges the barriers that exist, such as infrastructure limitations and cost challenges, associated with these advancements. Overall, the report highlights the necessity of gathering emissions data, stepping up dialogue and co-operation among stakeholders, and harmonising regulations and their interpretation.

# 1. Introduction

This report on future research needs for emission-free construction sites describes the Work Package 4 (WP4) perspective on the future of construction with respect to reducing the climate impact from the transport of materials and construction installation. We describe the solutions that we have identified as being necessary and that are in the process of being implemented in projects, where there is a need for improvement and where technological innovation and policy support are needed.

Understanding which barriers are hampering the developments that are needed and finding solutions to them is crucial for reducing greenhouse gas emissions from construction sites. In addition to emissions from the production of materials, construction site emissions include upfront emissions that need to be addressed now. In contrast, other emissions can be influenced over a building's lifetime.

Some of the solutions come up against systematic barriers which prevent them from being used in projects. Organisations and processes in construction do not traditionally consider greenhouse gas emissions as an important parameter. Emissions reductions based on system-level solutions can be very cost-effective.

Market conditions often limit the feasibility of new solutions. Cost is usually the dominant factor determining the choice of a material or process. New alternatives need to be deliverable at a competitive cost if they are to become widely used.

Stakeholders can decide to use a less carbon-intensive product, material, or process as an alternative to a conventional solution. Such decisions are preferably based on research or experience.

The construction sector is taking a more conservative approach due to the risks and consequences of buildings and infrastructure not functioning as planned. Research and pilot projects can be used to minimise the risks and uncertainties involved in using new methods and tools.

The focus on emissions from construction processes and the construction site itself is fairly recent and many questions remain unanswered. A knowledge base is gradually being established across the Nordic countries. More research is needed if we're to accelerate the reduction in emissions. This report aims to identify areas where more knowledge is needed in relation to emission reductions on construction sites.

## 1.1. Overview

The previously published report "Emission-free Construction Sites: Definitions, Boundaries, and Terminology – Current Status in the Nordic Countries" (Ólafsson, Steingrimsdóttir, and Einarsdóttir 2023), describes the status in the field and is used to identify barriers and needs for further innovation and research.

Based on the previous work, the field has been divided into the following key areas for emission reductions on construction sites:

- Planning and design
- Assessment of environmental impact
- Energy in construction and transport
- Waste and material resources
- Regulation and financial incentives
- Sustainability

For this report, stakeholders in the Nordic construction industry were asked for their input on barriers and gaps in knowledge in relation to emission-free construction. A literature review of current research was then conducted, and information was gathered on innovative new construction technologies. This has resulted in a list of current research needs that funding bodies should give special attention to. Each chapter starts with a summary of the main research recommendations.

## 2. Planning and design

- **Look at how the pre-construction phases affect emissions during construction.**
- **Examine whether and how urban planning can reduce the transport of materials.**
- **Study the influence of building types and material choices on emissions during construction.**

Planning and development in urban areas is increasingly addressing sustainability and the natural environment. The initial planning and design phases dictate most of the emissions in a building or an infrastructure project. The planning of construction starts at the policy level, where objectives are set in terms of quantity, location, and general design. All have an impact on construction emissions. Infrastructure planning affects the transport of materials and the supply of clean energy for construction.

When a decision has been made about building a structure of a certain size and type, there are many options for minimising climate impact in the design phase. Material choice is often the most obvious means of reducing carbon emissions. Choosing bio-based construction materials over concrete and steel reduces emissions from material production, but also vastly changes the construction process and the emissions from transportation and on-site emissions.

### 2.1 Urban planning and infrastructure

Current trends in environmental urban planning primarily consider the biggest impacts, such as those from the in-use phase of the built area. The planning phase often dictates material choices and the repurposing of buildings, which affects construction emissions (Ameen, Mourshed, and Li 2015). Construction activities and the transport of building materials are, however, rarely mentioned. Considerations in the planning phase may pave the way for simple and cost-effective solutions that reduce emissions during construction. Decisions made during planning can greatly influence transportation and energy use, which are major factors in construction emissions. Such measures include using earth materials inside the local area to reduce the need for transportation and choosing construction methods, materials, and project locations that require less extensive groundwork or additional infrastructure. Such measures can reduce energy consumption, and thereby emissions, considerably.

Infrastructure for clean energy during construction and for effective waste management should also form part of urban planning. It is often not possible to charge battery-electric machinery and trucks on construction sites. Energy for heating is often needed and should be considered at an early stage in areas where district heating is available. Storage areas can be helpful for the better management of building materials and waste.

These are a few examples of how the planning phase can help reduce emissions. Further knowledge is needed about the influence of urban planning on emissions during construction.

## **2.2 Structural design and material choice**

When designing low-emission buildings, the focus has traditionally been on energy efficiency and, more recently, building materials. The incorporation of reusability in design is now emerging. In the future, this has the potential to reduce construction waste and the need for virgin materials.

Design choices also have a considerable influence on carbon emissions during the construction phase. As with urban planning, cost-effective emission reductions can be achieved at this early stage of construction (Malmqvist et al. 2021; Zimmermann et al. 2021).

The use of prefabricated elements is one such method that can impact emissions from the construction process. Although less waste can be expected on the construction site, waste production may increase at the point of manufacture. Prefabricated elements are transported differently to raw materials, which also impacts emissions. Prefabricated elements are thought to improve the utilisation of materials and reduce waste compared to on-site manufacture (Hao et al. 2020). The reasoning is that the production site is better suited for the manufacture of the elements, and the personnel there are often more qualified to handle certain elements.

More studies are needed to assess the energy use of and waste production from the different construction methods and materials currently used. In this way, design choices can more easily be assessed with regard to construction emissions, rather than only considering emissions from material production and in-use energy emissions.

# 3. Assessment of environmental impact

- **Develop and harmonise a Nordic framework for measurement and assessment.**
- **Improve knowledge on emissions related to modules A4 and A5.**

The environmental impact of the construction sector is the result of countless processes in the stages of the building life cycle. Material processing and energy use are key factors and sometimes interrelated. The transport of materials and on-site energy use and waste are prominent environmental impacts during construction. Efforts to reduce greenhouse gas emissions from construction must be based on measurements and estimates. Measures to reduce emissions in the construction phase may have an impact on other phases, such as material extraction and processing. Life cycle assessment (LCA) has become the favoured tool in the industry. It systematically estimates the environmental impacts of the different phases in the construction of a building. LCA relies on the measurement of real processes and a systematic collection of such data.

## 3.1. Harmonised LCA data and methods

LCA is established in the construction industry as a tool for estimating environmental impacts, including global warming impact. The methodology and standards are also used as a basis for the forthcoming limit values for emissions in construction in the Nordic countries and measurements of actual emission values from construction (Nordic Innovation 2023).

The outcome of an LCA can reveal the impact of various building elements and life cycle stages within a typical reference study period, usually spanning 50 years. In the upcoming regulation on climate declarations in the Nordics, LCA will be used for the calculation and declaration of climate emissions in new construction and will be used to document that limit values have not been exceeded where these are introduced (Nordic Innovation 2023). Since 2018, Nordic building authorities have been discussing climate emission regulations and pursuing harmonised LCA methods for buildings. The concept of LCA for evaluating the total carbon emissions of buildings is gaining traction in the Nordic countries and Estonia. The EU is also planning similar legislation. As LCAs and climate declarations are new,

the Nordic countries have the opportunity to align and share their practices in this evolving field. (Nordic Innovation 2023). It is beneficial for the Nordic countries to align their LCA content, and also crucial to track and keep pace with developments in Europe and beyond.

By aligning methods and rules in the Nordic countries, construction firms will be able to offer low-carbon solutions and expand their markets beyond national borders. This will also assist policymakers in supporting each other's climate goals in regulations, procurement, and policy development.

In 2022 and 2023, the building authorities of the Nordic countries and Estonia published a roadmap - Harmonising Nordic Building Regulations Concerning Climate Emissions. Although the roadmap spans the period 2023 to 2030, the joint funding from the Nordic Sustainable Construction Programme is only until the end of 2024. It would be beneficial to establish a follow-up programme to sustain efforts in sustainable construction.

## 3.2 Estimation of emissions from construction

Emissions from the construction process were, until recently, regarded as less important than operational emissions. There are still gaps in knowledge regarding the amount of emissions, both at the building level and accumulated at the regional level (Kanafani et al. 2023).

There is a limited number of studies about construction phase emissions at the building level. Furthermore, buildings vary widely in their size and construction.

Emissions from construction at the national level are also an important metric. Reductions at the building level may be outweighed by the increase in the number of new buildings and built areas, as is further discussed in Chapter 7 about sustainability.

The roadmap mentioned in the previous chapter collates the life cycle modules that the Nordic countries are including. Only Norway and Sweden have already implemented or will implement modules A4 and A5. Denmark, Estonia, Finland, and Iceland have proposed to include A4 and A5 in the scope of their future regulations. The reason for them not being included now is partly due to a lack of data. We need to collect more data on emission figures for parts A4 and A5 to be able to set a limit value for these modules. The development of default values for modules A4 and A5 would benefit the process for designers (Frischknecht et al. 2023).

A recently published study presents an analysis of the carbon emissions of 61 Danish construction sites based on their energy consumption, waste production (module A5), and transport to the site (module A4). It also collates existing studies on carbon emissions in modules A4 and A5. The analysis states that only a few

studies investigate emissions generated from transporting materials to sites or from construction site processes. This demonstrates the need for a major case study covering multiple cases in order to improve knowledge on emissions related to these modules (Kanafani et al. 2023).

The transportation of building materials should be considered a part of the construction process and the environmental impact attributed to that phase. Measuring and estimating carbon emissions from transportation is, however, challenging as data is often missing and the boundary is difficult to define. The current machine fleet needs to be analysed, while current emissions and fuel consumption need to be estimated, as does the distribution of emissions according to the type and size of machinery. This could all help in the design of policies and other measures.

In terms of waste from construction, the amount of materials that become waste during new construction is often underestimated (Fufa et al. 2023). Here, generic estimations of typical waste ratios of different building materials during the construction phase would be helpful in the LCA process.

## 4. Energy in construction and transport

- **Find ways to build using less energy and improve energy efficiency in material transport and construction processes.**
- **Investigate more clean energy options for emission-free construction sites.**
- **Invent new methods to manage energy and new energy infrastructure at construction sites.**

Energy use in the transportation of building materials as well as on-site processes is considered to be a major emitter of greenhouse gases on construction sites (Kanafani et al. 2023). Fossil fuels are used for heavy transport and construction machinery. Many on-site processes, such as heating, drying and ventilation, are based on fossil fuels. In addition to carbon dioxide emissions, the combustion of fossil fuels results in more localised air pollution and noise.

In the Nordics, the main measure in curbing emissions from construction sites is the introduction of emission-free and carbon-neutral energy sources. There is a focus on the battery electrification of machinery and transport, and to some extent, biofuels are also used. Biofuels and district heating are promoted for heating.

The first action in reducing energy-related emissions is to use less energy. This translates to improved energy efficiency as there is less energy used per unit of built area or volume. This is often very simple and cost-effective, especially if planned during the design phase or implemented by way of improved management. The efficiency of machinery and other equipment that uses energy can also be improved.

Where energy is used in construction, it should be emission-free or at least carbon-neutral. Emission-free energy options are emerging for transport and on-site machinery. Nevertheless, barriers remain, such as price and lack of infrastructure. Questions such as "Is there enough energy for a big construction project to use only electric machinery?" and "Can we make sure that a grid connection is in place before construction work starts?" are increasingly being asked in the Nordics.

## 4.1 Energy efficiency

The transport of building materials could be more efficient. Although there is limited literature on this subject, private stakeholders are finding ways to reduce transport to lower costs. The same approach can be applied in the planning and design phases of a construction project.

It is well known that public transport systems are more efficient than cars for the movement of people. Systems for material logistics probably use similar methods on a larger scale. There might, however, be opportunities to optimise the distribution of materials to construction sites and the transport of waste from sites.

As with the transport of materials to and from sites, improved on-site logistics and other changes can reduce energy use during construction (Norwegian Environment Agency 2023). A large part of on-site energy use stems from moving materials. Heating, drying, and lighting are also major energy consumers. There is the potential to reduce energy use in these activities, although there is uncertainty around how much.

## 4.2 Clean energy carriers

Fossil-free and emission-free construction sites use technologies that were first developed for road transport. Consequently, research in renewable energy for transport benefits the construction industry directly. Stationary power generation on construction sites uses similar technologies as in transport. Diesel generators on construction sites have the same engines as the machinery. Battery technology is already making its way into the construction industry with trucks and machines available in electric versions. However, the high upfront cost and limited usable range are drawbacks of battery technology. Smaller machines and trucks, especially on short transport routes, can benefit from this technology. Biofuels remain an option for fossil-free construction sites. This energy carrier is very efficient for heating and can be useful where electricity for charging is not available and in order to utilise fleets of older equipment. Hydrogen is also now becoming a viable fuel in transport, both by way of fuel cell technology and in modified combustion engines (Norwegian Hydrogen Forum 2023; Sadik-Zada et al. 2023). Hydrogen vehicles and machinery alleviate the range limitations of battery technology. Hydrogen is considered a promising fuel for large trucks and machines as well as for stationary power generation.

The construction industry can benefit from the development of new technologies for transport, as has been the case with the battery electrification of construction

machinery. Equipment manufacturers are actively increasing their offering of battery-powered machines, as well as trucks for transportation. The development of hydrogen trucks for long-distance goods transport will directly benefit construction. The integration of hydrogen technologies into construction machinery should be investigated, based on experience from battery conversions.

Biofuels are being developed further, with sustainability issues being addressed by way of second-generation feedstock. This addresses the shortcomings of first-generation feedstocks such as vegetable oil that compete with food production and are not grown sustainably. Biomass, such as waste from forestry and agriculture, could become important feedstock for sustainable biofuel production. This is, however, a very limited resource compared to the demand for renewable energy. Advanced biofuels are typically produced as drop-in fuels and therefore this is a potential short-term solution for utilising existing vehicle and machine fleets on fossil-free construction sites.

Synthetic fuels made from green hydrogen and carbon dioxide, also known as electrofuels, may be used in the construction sector. Methanol is the first electrofuel to be commercially produced ('CRI - Carbon Recycling International' 2022). Although synthetic diesel would be most suitable for the construction sector, uncertainties remain regarding its price and availability.

New technologies come with new challenges and research should also address this. Nordic construction sites may present harsh conditions that put stress on battery and fuel-cell systems. With the rapid growth in battery-electric vehicles, comparable growth in battery recycling will soon be needed. Unforeseen problems may appear, making it important to continually gather and share knowledge in the industry.

### **4.3 Infrastructure for clean energy**

The distribution and storage of new forms of energy calls for new solutions in infrastructure. Construction sites that use battery-electric machinery may easily overload existing utility systems. The production, storage, and distribution of hydrogen require new infrastructure.

With the advent of battery-electric trucks and on-site machinery comes the need for charging. Large construction machines such as excavators require powerful charging stations on the site itself. The electrical power supplied to the site may not be sufficient for charging, or several parallel construction projects in an area may overstretch the local grid. This problem could be mitigated by way of a combination of solutions. Trucks are not restricted to charging only on the construction site and can be moved to dedicated charging points if the on-site supply is overstretched. Work can be scheduled so that charging is distributed over longer periods to limit

power peaks. On-site stationary power packs are becoming available and can be used to distribute power use over time (Big Buyers Initiative 2022; Eric Rambech, Rebecca Briedis, and Sigrid Møyner Hohle 2021).

Green hydrogen production via electrolysis is an established industry, and therefore distribution and refuelling in the construction sector is a primary interest. Hydrogen for vehicles is now typically supplied to refuelling stations in high-pressure cylinders. Hydrogen can be transported to construction sites in the same manner. On-site storage and refuelling is, however, a new technical challenge.

## 5. Waste and material resources

- **Clarify and analyse the overall quantity of waste, its management, and emissions.**
- **Gain insight into how building design impacts the generation of construction waste.**
- **Enhance the reuse and recycling of material on construction sites.**

Construction waste, often referred to as construction and demolition waste (CDW), consists of the materials used in construction and packaging. The largest constituent of CDW is so-called inert material (e.g. soil, sand, gravel, crushed concrete). However, timber, tiles, metals, and plastics also play considerable roles in the mix. A commonly overlooked aspect, despite its significant contribution to CDW, is inert material.

Emissions from waste within the boundary of the construction site are defined as greenhouse gas emissions from the production and handling of materials before and after they become waste (CEN 2011). The production of waste on the construction site adds to the total transport of building materials.

The total amount of waste generated, how it is handled, and total emissions need to be clarified and require further analysis. This is part of the recommendations made in Chapter 3 - Assessment of Environmental Impacts.

Traditionally waste management was considered a way to dispose of waste economically and without too much harm to the environment. This has changed and there is now considerable interest in finding ways to minimise waste generation and maximise reuse and recycling. Both circular economy frameworks and European waste hierarchy principles are based on waste prevention and that no waste should enter disposal solutions such as landfills (Zhang et al. 2022).

Emissions can be reduced by preventing waste by minimising excess material or reusing and recycling the material so that it does not become waste.

## 5.1. Construction methods for waste prevention

Preventing waste from being produced in the first place should be the objective in all phases of the construction of a building. Waste reduction should be taken into account in planning and design to provide the scope for proactive and cost-effective solutions. Reactive waste prevention on the construction site is more difficult and typically limited to the reuse and recycling of unused materials.

More knowledge is needed about how the design of buildings affects the generation of waste during construction. Prefabricated building elements are one example of a construction method that reduces cut-offs and therefore waste (Mamo Fufa, Venås, and Kjendseth Wiik 2021). In the same vein as prefabrication, using standard factory dimensions for elements and products can also reduce cut-offs. Many other design choices, with similar quality and cost (or lower cost), can influence the quantity of production waste.

## 5.2 Material reuse and recycling

Although construction waste cannot be eliminated, its environmental impact can still be reduced. As discussed before, decisions made during the planning and design phases have a considerable influence on the construction site. The design of buildings should facilitate the cost-effective reuse and recycling of construction waste.

Construction site material management can greatly reduce waste and ensure that as much as possible is reused and recycled. The careful sorting of waste is becoming standard practice on Nordic construction sites. Material management is improving, which is reducing the amount of damaged materials. Nevertheless, there is still room for improvement considering the amount of waste from construction and the diversity of this material. While management at the construction site can be improved, such as by limiting excessive ordering, procuring the right dimensions of materials and proper waste sorting, design can also help and there may be regulatory barriers that need to be removed.

## 6. Regulations and incentives

- **Establish ambitious yet attainable criteria.**
- **Encourage private companies to integrate emission reductions into their tender requirements.**
- **Establish a binding follow-up mechanism**

Authorities and public entities can influence the construction industry through regulation and taxes as well as financial incentives. Private stakeholders can also use incentives to promote green construction. These methods are already being put into use as can be seen in the development of limit values for emissions from construction in the Nordic countries. Meanwhile, public procurement is being used to propel emission-free construction by way of rewards for low-emission construction. Private investors and financial institutions now often require sustainability in financed projects to be reported on or offer lower interest rates for sustainable construction projects. Nevertheless, current construction regulations can hinder emission reductions, especially in respect to waste and material reuse. Regulations and carbon taxation that aim for the decarbonisation of transportation also influence the construction industry.

### 6.1. Financial incentives

At the national and regional levels, financial initiatives must promote emission-free construction sites. It is especially important that private stakeholders, such as banks, take action against climate change. Part of the solution to achieve this is the creation of private and public loans to improve the sustainability of construction. A good example of such an initiative is the green residential loan established by Arion Banki in Iceland. Arion Banki has allocated special financing for several sectors with "green" eligibility criteria that both facilitate and support responsible investments in Iceland. The green residential loan established by Arion Banki has a list of criteria to determine whether a building can be considered "green" pursuant to Icelandic standards. Similar criteria lists could be established for emission-free construction sites.

- Carbon emissions:  $\leq 6.84$  kgCO<sub>2</sub>/year/m<sup>2</sup> required.
- Proximity: Must be within 750m of public transit.
- Climate resilience: Elevation data not used.
- Waste/recycling: Excluded if in non-recycling areas.

## 6.2. Green procurement

In relation to emission-free construction sites, several questions arise regarding procurement processes. In addressing these critical questions surrounding procurement in emission-free construction, a delicate balance is needed between ambition and practicality, market integration, incentivisation, strict oversight, and transparent validation methods in order to foster emission-conscious construction practices.

A key challenge is determining how to establish ambitious yet attainable criteria aimed at achieving emission-free construction sites. This involves defining clear and practical benchmarks that can drive the reduction of emissions in construction practices. An important concern is the realism of these criteria. Feasibility within the construction industry must be evaluated, considering technological advancements, available resources, and the practical limitations faced by construction companies. This should involve engaging in dialogue with stakeholders.

It is imperative to explore potential incentives in order to encourage private companies involved in procurement projects within the construction industry to integrate emission reduction into their tender requirements. In turn, it is essential to identify mechanisms that motivate and reward companies for integrating emission-reducing measures within their bids. This could involve fiscal incentives, preferential treatment in procurement processes, or public recognition for sustainability efforts.

The simultaneous co-ordination of tender requirements for emission reductions across both the public and private sectors is hugely significant. Aligning criteria and standards between these sectors streamlines the bidding process for contractors. Such co-ordination fosters a more consistent and standardised approach, making it easier for contractors to engage with and bid on projects across various sectors. Ultimately, this synchronisation promotes wider participation.

An equally critical aspect is the establishment of a binding follow-up mechanism to enforce compliance with procurement requirements. A significant challenge comes in the form of determining the level of oversight required and how it should be executed. This could involve stringent monitoring, reporting, periodic audits, or random on-site inspections of a select number of construction sites coupled with the imposition of penalties for non-compliance to ensure adherence to the procurement requirements.

### 6.3. Regulation

The limit values for emissions from construction that are being developed and implemented in the Nordic countries address emissions from construction sites as a part of the embodied carbon of buildings (Boverket 2023; VCBK 2023). A similar regulation is in place in France ('Réglementation environnementale RE2020' n.d.). Legislation for waste handling is in place in the Nordic countries, which promotes waste prevention and reuse, leading to less construction emissions (Fufa et al. 2023).

This legislative framework is aimed at reducing greenhouse gas emissions on construction sites as well as in construction in general. The legislation does not, however, aim for emission-free construction sites. The emission limits start out as something close to the current industry average and there are no goals set for reaching zero emissions. However, the intention is for these limits to become stricter over time.

Specific regulations can be developed for the construction process to speed up the transition to truly emission-free construction sites. In this regard, construction waste can be targeted, as can the use of fossil fuels.

Examples of such regulations include the restriction of fossil fuels in certain areas, such as for electricity generation and heating. Limiting sales of fossil fuelled construction machinery is another possible avenue. Stricter regulations on construction waste and regulations for circularity could limit waste-related emissions (Krzysztof Pikoń et al. 2023).

# 7. Sustainability

- **Measures that can be implemented at construction sites to deliver results quicker.**
- **Consider the negative consequences of changing resource use in construction projects.**
- **Increase the industry's interest in degrowth thinking.**
- **Identify ways to translate Planetary Boundaries into specific reduction targets.**

Although the need to reduce greenhouse gas emissions is widely understood and agreed upon, less widely appreciated is the need to reduce resource consumption in tandem. This is due to several factors, from the energy and carbon embedded within resources and their extraction to the pollution caused by waste resources and the reduced capacity of the environment to absorb emissions due to changes in land use.

Pursuing emission-free construction sites is just one part of transitioning the construction industry to more sustainable practices. Consequently, construction activities must be related to the broad scope of sustainability.

## 7.1 The pace of emission cuts in construction

Current policies to reduce the emission of greenhouse gases are unlikely to keep global warming within safe levels (IPCC 2023; UNEP 2023). The time frame for reaching near-zero emissions is only a few decades away. Keeping global warming below 1.5°C requires net-zero emissions in the energy sector by 2050 (IEA 2021). The construction sector also has to reduce emissions at a similar pace, requiring significant emissions cuts every year from now on. At the same time, the demand for new housing is growing with the floor area of buildings expected to increase by 75% globally between 2020 and 2050 (IEA 2021).

The Nordic countries are implementing limit values for the climate impact of buildings as the primary legislative climate action (Boverket 2023; VCBK 2023). General carbon taxes, such as those on fossil fuels, also affect construction. In time, the limit values will also apply to construction sites. The first proposed limits are based on current construction materials and practices and will not result in any significant reduction in emissions per built square metre within the next few years.

The recent and soon-to-be implemented limit value in the Nordics stipulates no limit on the number of new square metres built, so this regulation and other actions may fail to reduce emissions from construction.

At the same time, private entities state that faster emissions cuts in construction are needed. The “Reduction Roadmap” is a Danish initiative that aims to serve as a practical tool for the construction industry. Its purpose is to translate the planetary boundary for climate change into a reduction target for new residential construction in Denmark. The Reduction Roadmap aims to create a tool and establish a target to facilitate the transition towards construction practices that adhere to the planetary boundaries. However, discussions are and should remain ongoing regarding the prerequisites and methods required to translate the planetary boundaries into specific reduction targets (Reduction Roadmap 2022; Steffen et al. 2015).

The Reduction Roadmap presents reduction pathways, based on the CO<sub>2</sub> budget for limiting global warming to 1.5°C. The most effective pathway is to simultaneously reduce the carbon footprint for an area and total build area.

The Science Based Targets initiative (SBTi) is another tool, which provides companies with a path to reducing emissions in line with the goals of the Paris Agreement (‘Science Based Targets Initiative’ 2023). The achievement of the goals of the Paris Agreement has been calculated on the basis of everyone taking responsibility for their share and setting goals. However, without universal participation in goal-setting and regular updates, achieving the goals of the Paris Agreement appears unlikely.

Total emissions from construction activities, including construction sites, need to be systematically monitored as proposed in Chapter 3. This allows for the possibility of adjusting actions and legislation to the climate ambitions of the construction industry and governments. The expected emissions gap should then be addressed by exploring more rapid emission cuts based on existing knowledge related to construction and construction sites. Carbon pricing is considered to be an effective way of incentivising the market to cut emissions (Boyce 2018). Circular economy methods are already being explored in the construction sector (Hossain et al. 2020). Perhaps the most effective means of achieving the goal is degrowth thinking and respecting planetary boundaries (Birgisdóttir, H. et al. 2023). Although degrowth is a concept that is currently not salient in mainstream economics or the political arena, it still deserves further attention.

## 7.2 Clean energy and its side effects

Clean energy is a limited resource in the same way as the ability of the ecosystem to absorb carbon dioxide is a limited resource. The overconsumption of fossil fuels can easily be replaced by overconsumption of other natural resources. The demand for energy seems to be insatiable and may never be fulfilled sustainably.

Replacing fossil fuels with renewable energy sources is no simple task and is bound to have all kinds of adverse consequences. These concerns are widely discussed and nicely summed up by Seibert and Rees (2021), for interested readers.

The shift towards more sustainable construction practices must not only take into account clean energy and direct emissions but also sustainability in a broader and longer-term context (Kanafani et al. 2023; Johnsson et al. 2020).

The energy and material resources needed to achieve emission-free construction sites include huge quantities of biomass and renewable energy. Sustainable biofuels are a limited resource as organic waste and by-products are limited, as is the land available for the cultivation of energy crops (Karlsson, Rootzén, and Johnsson 2020). In addition, replacing fossil fuels with biofuels or electricity on the construction site can add to the environmental impact in other areas. In the case of electric cars, the embedded carbon in their production is greater than for conventional combustion engine cars (Dillman et al. 2020). The same is expected to apply to trucks and machinery.

These are only examples of the possible side effects of the energy transition in construction. Work in the field of emission-free construction sites should always consider the possibility of negative consequences of transitioning to clean energy.

## 8. Summary and recommendations

Greenhouse gas emissions related to activities during construction are the result of decisions made at several stages in the value chain. The greatest impact comes from the decision to build, or not to build. Planning, design, construction, and demolition (where applicable) all influence emissions on construction sites.

Environmental impact estimates are also included as measurements are needed in order to understand and monitor emissions. Sustainability is a topic also raised here in order to look at construction emissions on a broader plane. This report has investigated the current status in these fields, with a focus on construction sites.

It finds that further research and development in all stages of construction can benefit emission-free construction sites. It follows that co-operation and knowledge-sharing between stakeholders is important for implementing positive changes.

### Urban planning and building design

These are the first phases in the construction of a building and is where the most important decisions are made about the construction and its environmental impact, such as emissions during construction.

- Look at how the pre-construction phases affect emissions during construction.
- Examine whether and how urban planning can reduce the transport of materials.
- Study the influence of building types and material choices on emissions during construction.

### Assessment of environmental impact

Closely related to the design phase is the assessment of the environmental impact the building will have. The industry standard is the life cycle assessment (LCA) methodology. A better understanding is needed of emission sources in the construction process.

- Develop and harmonise a Nordic framework for measurement and assessment.
- Improve knowledge on emissions related to modules A4 and A5.

## Energy in construction and transport

Emission-free construction sites must phase out fossil fuels and replace them with clean energy sources, both on-site and in material transport. This is a key area that calls for research into new technologies and new methods in energy management.

- Find ways to build using less energy and improve energy efficiency in material transport and construction processes.
- Investigate more clean energy options for emission-free construction sites.
- Invent new methods to manage energy and new energy infrastructure at construction sites.

## Waste and material resources

Construction waste causes emissions attributable to the construction site. Waste needs to be minimised and its management improved. New thinking and methods are needed to reduce these emissions and conserve material resources.

- Clarify and analyse the overall quantity of waste, its management, and emissions.
- Gain insight into how building design impacts the generation of construction waste.
- Enhance the reuse and recycling of material on construction sites.

## Regulations and incentives

Financial incentives and green public procurement are tools that can accelerate the transition to emission-free construction. The regulation of emissions from construction is underway in the Nordic countries.

- Establish ambitious yet attainable criteria.
- Encourage private companies to integrate emission reductions into their tender requirements.
- Establish a binding follow-up mechanism

## Sustainability

The construction industry must become sustainable just as any sector of industry. Emissions must be reduced rapidly in all sectors to avert the severe consequences of climate change.

- Measures that can be implemented at construction sites to deliver results quicker.

- Consider the negative consequences of changing resource use in construction projects.
- Increase the industry's interest in degrowth thinking.
- Identify ways to translate Planetary Boundaries into specific reduction targets.

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