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Supply-chain collective action towards zero CO_2 emissions in infrastructure construction: mapping barriers and opportunities

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Abstract. Successful decarbonisation of the supply chains for buildings and infrastructure, including the production of basic materials, will involve the pursuit - in parallel – of measures to ensure circularity of material flows, measures to improve material efficiency, and to radically reduce CO_2 emissions from basic materials production. Emphasis in this work has been on how "intangible" factors such as implicit or explicit constraints within organisations, inadequate communication between actors in the supply chain, overly conservative norms or lack of information, hinder the realisation of the current carbon mitigation potential. Although this work draw primarily from experiences in Sweden and other developed economies we believe the focus on innovations in the policy arena and efforts to develop new ways of co-operating, coordinating and sharing information between actors (SDG17) and on practices and processes that could enable more sustainable resource use in infrastructure construction may be of relevance also elsewhere. Not the least, since there are still many regions of the world where much of the infrastructure to provide basic services remains to be built (SDG6-7, SDG9, SDG11) a challenge that must be handled in parallel with efforts to reduce/erase the climate impact from infrastructure construction (in line with the Paris Agreement and SDG13).

1. Introduction

Recent estimates suggest that the construction sector accounts for nearly one quarter of global CO_2 emissions [1]. In this paper we explore barriers linked to supply chain interactions and associated institutional factors which limit progress towards zero carbon emissions in infrastructure construction. The discussion builds on and synthesizes earlier studies on carbon abatement opportunities, technologies and organisational strategies across important supply chains of infrastructure construction projects [2-5]. In a Swedish context, Karlsson et al. [4] found that it is possible to cut transportation infrastructure construction CO_2 emissions by 50 percent by applying best available technologies and measures, such increased use of sustainable biofuels, optimization of material use and mass handling, increased recycling of steel, asphalt and aggregates and increased use of alternative binders in concrete. However, reaching closer to zero CO_2 emissions would require more transformative technological shifts including electrification of machinery/transports and electrification of and/or implementation of carbon capture (CCS) in basic industry. Unlocking the full abatement potential of these emission reduction measures will involve not only technological innovation but also innovations in the policy arena combined with new ways of cooperating, coordinating and sharing information between actors.

2. Aim and method

Although many major infrastructure projects have much in common when it comes to roles, routines, equipment and key materials and products, there are often also important differences in terms of culture, policies, contracting practices and capabilities in the national, organisational and local context. Whereas the technical emissions abatement measures and their costs are known to a large extent [4] the barriers for their implementation are less clear. The aim of this work is to provide a basis for a structured mapping of the relations between the different emissions abatement measures and associated barriers and to discuss how these can be overcome so that the full emission reduction potential can be realised in the shortest time possible.

Previous studies by the authors demonstrate that decarbonisation of infrastructure construction will require efforts to identify and manage both soft (organisation, knowledge sharing, competence) and hard (technology and costs) barriers. “Intangible” factors such as implicit or explicit constraints within organisations, inadequate communication between actors in the supply chain or overly conservative norms, frequently hinder the realisation of the current carbon mitigation potential.

The analysis in this study is predominantly based on the synthesis of data from three projects:

- The Impres project [3] which investigated procurement requirements used to drive greenhouse gas (GHG) emission reduction in large infrastructure projects in Australia, the Netherlands, Sweden, the UK and the US, in the context of various institutional and organisational contexts, policies and implementation strategies.
- The Mistra Carbon Exit project, which identifies and analyses pathways to net zero GHG emissions in the supply chains of buildings, transport and transport infrastructure, specifically involving one study investigating opportunities and barriers for mitigating carbon emissions in building and infrastructure construction supply chains [2] and one study assessing the potential for achieving net-zero emissions from road construction projects [4].
- The Climate improvements in infrastructure project [5] which is a Swedish project aimed at collecting and spreading practical examples and descriptions of opportunities to reduce the climate impact from infrastructure construction.

Kadefors et al.’s [3] analysis builds on interviews with key partners on the client side and in the project supply chain combined with project and policy documents. Rootzén and Johnsson [2] and Karlsson et al. [4] combine quantitative analysis methods, including scenarios and stylised models, with participatory processes involving relevant stakeholders in the assessment process as to identify and analyse measures, policies and key decision points required to achieve net-zero emissions.

Similar to the work by Rootzén and Johnsson [2] and Karlsson et al. [4] this work takes departure in the supply chain of construction projects, i.e. the activities involved from production of basic materials (e.g. cement) to end products (e.g. a road).

To provide a framework for the further discussions of opportunities and barriers in the links between actors and sectors, we have developed a stylized ‘model’ (see Figure 1) illustrating key chains of decision-making. Stakeholders/actors involved in infrastructure construction from early planning to finalisation include e.g., legislators/regulators, clients and governmental agencies, consultants, contractors (and sub-contractors), material suppliers and material producers.

As transport infrastructure projects typically have to fulfil multiple sub-goals (cost efficiency, safety, sustainability) and are technically and organisationally complex, the ambition has not been to provide an all-encompassing account of opportunities and barriers but rather to highlight hot spots where a lack of alignment between strategies and organisational resources combined with poor communication and co-ordination between actors, tends to hinder measures to reduce emissions. In the problem definition and analysis, we draw primarily from the Swedish context and from Swedish experiences, but when discussing options to overcome barriers to emissions reductions we lend inspiration from international experiences. From our previous work [3] we also know that the focus on innovations in the policy arena and efforts to develop new ways of co-operating, coordinating and sharing information between actors (SDG17) and on practices and processes that could enable more efficient use of existing assets, circular and sustainable resource use in infrastructure construction is of relevance also in an international context.

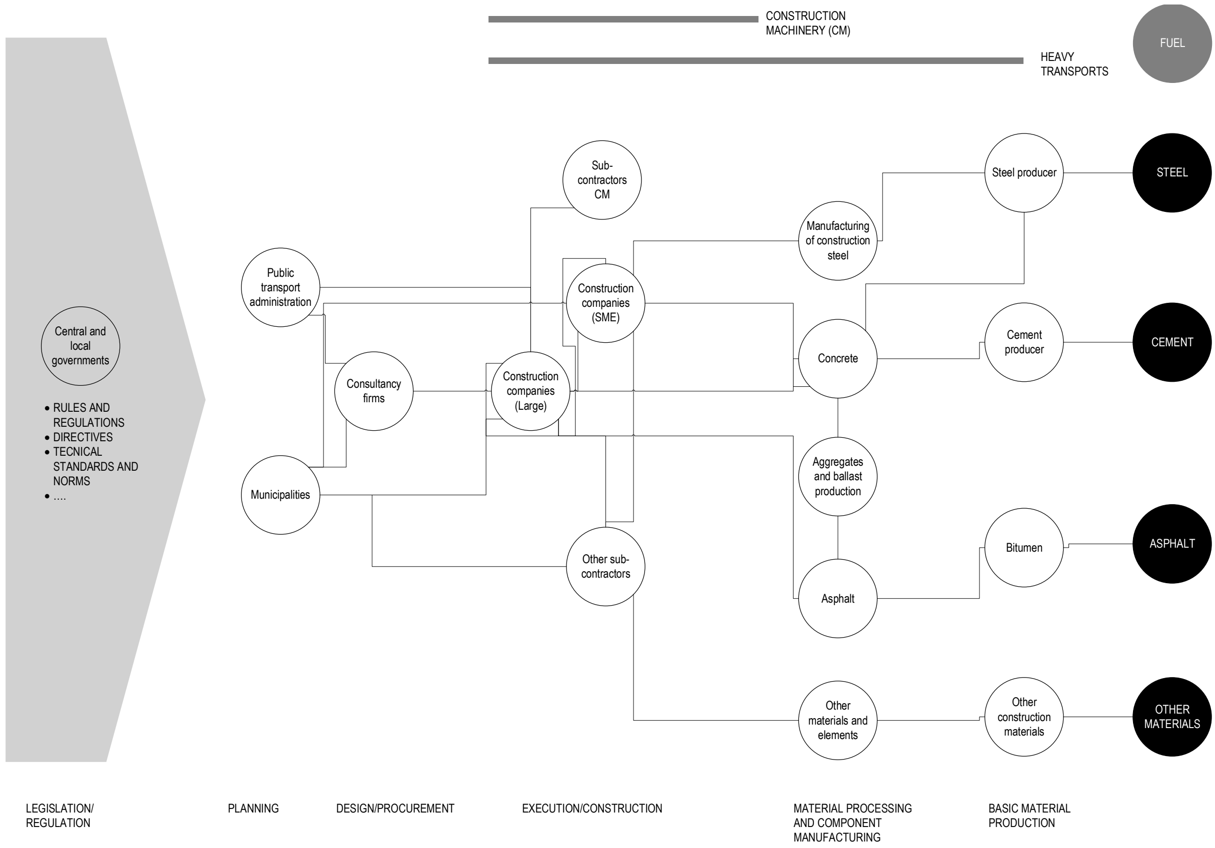

Figure 1. Stylised 'model' of five main supply chain activities (Planning, Design/Procurement; Execution/Construction; Material processing and component manufacturing, Basic materials production), two support activities (Construction work (i.e., Construction Machinery); Heavy transportation) and describes four material supply chains (Steel, Cement/Concrete, Asphalt, and Other materials).The lines represent exchanges of information and/or material and services.

Since decisions and prioritisations regarding construction, maintenance and renewal of transport infrastructure are mainly governed by central and local governments and public agencies, we begin by briefly assessing how national and sectoral goals, priorities and resources facilitate and/or set the boundary conditions for what is possible to achieve with respect to reductions of CO_2 emissions from infrastructure construction. We then discuss the role and importance of collaboration and coordination across the supply chain to improve innovation, information sharing and capacity building. Finally, we discuss barriers to a selection of specific measures to reduce the climate impact from material use.

3. Factors affecting barriers to and opportunities for collective action

3.1. Legislative and regulatory context

What is possible to achieve in terms of emissions reductions from infrastructure construction, in general and in a specific project, ultimately depends on the wider organisational and institutional setting and the priorities, policies and goals at the national, regional and organisational level. In the Swedish context, there is consensus both in politics and industry that Sweden should be at the forefront of climate action, but the details of what this commitment should entail are still under negotiation and the actual emissions reductions have therefore so far been limited. In 2017, the Swedish parliament decided on a climate policy framework for Sweden [7]. The framework consists of three parts: a long-term goal of net-zero GHG emissions by 2045; a planning and monitoring system which stipulates that climate policy goals and budget policy goals should be aligned, and that the Government should, every four years, present a climate policy action plan which describes how the climate targets are to be achieved; and an independent climate policy council with the task to assess if the overall policy of the Government is compatible with the national climate targets.

In 2015 the Swedish Government also initiated the Fossil Free Sweden initiative which encouraged industries and business sectors to define emission reduction goals aligned with the national goal and develop roadmaps outlining when and how each industry will reach the goal, technical developments and investments needed, and what barriers exist. So far thirteen roadmaps have been presented, with varying levels of detail and ambition. Among these, there are six roadmaps with direct relevance for transport infrastructure construction: the cement industry, the concrete industry, the aggregates industry, the steel industry, the heavy haulage industry and the construction and civil engineering sector.

The construction and civil engineering sector Roadmap for fossil free competitiveness [8] calls on the government and parliament to act both as legislators and regulators, and as clients, to ensure high ambitions, transparency and predictability in the climate transition. In the Government's first climate policy action plan [9], 3 out of 132 proposed measures directly targets construction and civil engineering. Among other things the Government highlights the role of carbon requirements in procurement and proposes a review of unclear and hindering waste regulation. The action plan also announces continued R&D support to incentivize development of low-CO_2 technology in the basic industry (including cement and steel) and a combination of standards and subsidies to increase the use biofuels and lay the foundation for electrification of heavy transports and construction machinery.

The Swedish Transport Administration (STA), the Government agency responsible for planning and developing new infrastructure and maintaining existing assets, is (together with the largest cities - Stockholm, Göteborg and Malmö) responsible for the procurement of the majority of new transport infrastructure projects in Sweden. The STA has so far been the frontrunner on the client side with respect to climate ambitions, with a goal for construction, operation and maintenance of national infrastructure to be carbon neutral by 2045, while applying carbon reduction requirements in its procurement of projects since 2016. According to the requirements, design-build contracts with estimated start of operation in the period 2020-2024 need to reduce carbon emissions by 15% compared to a baseline and the reduction requirements will be tightened, gradually, up to 2045. A first evaluation of STAs carbon reduction requirements [10] shows that most stakeholders are positive towards the initiative. However, while the requirements are perceived to contribute to creating long-term game rules for the industry, their impact on carbon reduction has so far been limited and several possibilities to further improve the impact and effect of the requirements are identified. Also inspired by the international examples identified in the Impres project [3], the evaluation report highlights the importance of cooperation among stakeholders to comply with the climate requirements, recommends investments in specific pilot projects to drive innovations for reduced carbon emissions and proposes that functional reduction requirements are complemented with more targeted requirements for specific materials or components. It is clear, however, that reducing CO_2 emissions related to transport infrastructure is a recently added priority that still needs to be embedded and aligned with other priorities and goals for transport infrastructure.

Consequently, the importance of using a combination of measures, including carbon pricing, subsidies and climate requirements in procurement [11] to incentivise emission reductions related to the production, supply, and use of materials in transport infrastructure construction are slowly beginning to take root. In addition to steering through environmental economic policy instruments and regulations [12], i.e., innovation support, subsidies, taxes and standards, the central and local governments and public agencies have unique positions (and the responsibility) to unlock some of the barriers and contribute towards reducing the CO_2 emissions from infrastructure construction through:

- *The power to decide what and how much new transport infrastructure that is being built*
  From the perspective of the national parliament and city councils (and voters and taxpayers), new infrastructure investments are, while often debated, also viewed as positive goods: instruments for growth, improved accessibility and ways to encourage modal shifts (e.g. from aviation to rail). However, since construction also causes CO_2 emissions, legislators could more clearly recognise in budget and project prioritisations and directives, the importance of minimising new infrastructure, where possible, and of more efficient use of existing assets.
- *Providing new arenas for public/private collaboration and knowledge sharing*
  Despite high political ambitions on a general level, there is a lack of relevant initiatives to drive innovation and learning between projects in the Swedish infrastructure construction sector. Inspiration can be drawn from international examples where industry level platforms have been established to facilitate collective learning and knowledge sharing to reduce the climate impact from construction. In the UK, for example, the Infrastructure and Projects Authority (IPA) [13] provides a bridge between the government and industry, overseeing and providing expertise in major projects. Together with platforms like the Construction Leadership Council [14], the Constructing Excellence platform [15] and the Infrastructure Industry Innovation Partnership [16] the IPA provides an ecosystem for collaboration, coordination and knowledge sharing for public/private stakeholders across the construction supply chain.
- *Providing policy coordination and clear responsibility for monitoring and follow up of progress*
  Significant public and private resources are allocated to industry-level initiatives such as the Fossil Free Sweden roadmaps and the climate policy framework. However, stakeholders from both industry and public agencies have raised concerns about a lack of coordination and sub optimisation between different priorities and goals on a national level. Responsibility for national and sector-wide follow-up of progress and alignment to national goals, sector goals and industry roadmaps needs to be clarified. The Swedish Environmental Protection Agency has together with the Swedish National Board of Housing, Building and Planning [17] initiated a process to improve the methods used develop scenarios for future emissions from the construction and real estate sector. To provide well-grounded decision support, sufficient resources and competence needs to be allocated so that development of emissions can be properly evaluated.
- *Education and research*
  Securing new competence by prioritising low-CO_2 building and construction as a central part of the curriculum in construction-related programs in upper secondary school and higher education, as well as in training of active practitioners. Here, inspiration may be found for example in the Supply Chain Schools organised in the UK and Australia [3].

3.2. Coordination, cooperation and collective action along the supply chains

Due to their size, visibility and competence of project members, there are often high expectations on large infrastructure projects to act as forerunners and drivers of innovation. However, such projects are typically both technically and organisationally complex and are frequently associated with high risks and multiple goals. Thus, studies referenced here in [3, 5] found that the willingness to add the risk of developing and testing new work processes or technologies to these already risky and complex projects was often limited. There are also practical difficulties as tight project schedules seldom leave room for developing, testing and approving new solutions, even with time from design to execution being long.

Further, efforts to reduce emissions may affect the entire planning, execution and construction process and most of the actors involved in it. In construction, the different sub-processes, i.e., planning, design, procurement, execution, are often owned and lead by separate actors and teams. The traditional contract models do not encourage collaboration and knowledge integration. Thus, a recurring subject in our interviews and workshops as well as in industry climate strategy documents [8, 18] is the importance of overcoming silo-thinking and integrating the supply chain in order to speed up the transition to low-CO_2 processes and practices. Kadefors et al. [3] and WSP [5] conclude that it is important to design and implement procurement requirements and contract forms that enable balanced risk sharing, involve contractors early in the planning and design process and support collaboration. In particular, it is desirable to develop of institutional capabilities that enable and legitimise long-term, strategic collaborative alliances. This kind of formalised relational contracting models have been frequently used in the infrastructure construction sectors in many other countries (such as Australia, UK and Finland) as well as in Swedish building construction. In Sweden, the STA has recently used Early Contractor Involvement in a few large projects, but the resources allocated to develop models, educate personnel and support implementation have been scarce and experiences are mixed so far. Clearer government policies in this direction would help the STA to assign the resources that are required in order to transform industry practices and culture towards increased collaboration.

Another aspect relates to competence. Given the organisational complexity and the wide range of carbon abatement measures, it may be difficult for project members or teams to get an overview of the full range of opportunities and consequences. Increased knowledge about the entire construction process and an understanding that changes in one part of the supply chain can have consequences, which in turn can pose challenges and require adjustments for other actors, is required. At the project level, it is therefore important that carbon abatement attain clear legitimisation and prioritisation from project management and top management together with allocation of sufficient resources, competence and time. At the industry level, guidelines, tools and training programs to help build industry capabilities needs to be developed and responsibilities for hosting and updating these appointed. Moreover, the international study by Kadefors et al. [3] found that support systems and forums for outreach and dialogue towards sharing of case studies, best practices and knowledge development to effectively roll over learning from project to project were key success factors.

3.3. *Material efficiency and decarbonisation of material production*

Many studies have suggested [4, 18, 19] an untapped potential for improving material efficiency and implementing circularity principles by extending the life of existing asset and incentivising reuse and recycling of materials and components. However, risks and tight project schedules involved in many infrastructure projects, lack of information and inadequate communication between actors in the supply chain (as discussed in Section 3.2), combined with what is perceived as conservative regulations and norms, tend to limit the willingness to innovate and try out alternative solutions, designs and materials. Examples of hot spots are:

- *Circularity*
  A major hurdle in the Swedish context in view of increasing recycling and reuse of masses and materials within and between projects, has been that excavated material is classified as waste under the current waste regulation. The Swedish Governments new climate policy action plan [9] proposes a review of the waste regulation. However, underutilisation of the potential to reuse masses and materials is also exacerbated by poor communication and information sharing, which could be facilitated by increased digitalisation of material properties data, logistics and materials flows. Finally, circular material flows could be further incentivised in permitting and procurement requirements.
- *Material efficiency/Material substitution*
  The greatest potential for improving material efficiency typically arises during the early design phase, including measures to reduce the need for structures (e.g. bridges and tunnels), optimising design of structures that cannot be avoided, and by minimising the need for ground reinforcement [3, 5]. In the execution/construction (and material supply) phase, priorities includes measures to limit the binder intensity in concrete and to substitute cement clinker with alternative binders. Similarly, measures to minimise the use of construction and reinforcement steel (and increase the use of recycled steel) will be important. Deviations from established practices comes at a cost and

(real or perceived) risks and uncertainties associated with new designs and materials currently limit efforts to optimise material use. Early involvement of designer and material suppliers in the planning process, use of pain-gain sharing arrangements to incentive/de-risk innovations, combined with investments in specific innovation projects, provision of implementation support and development of industry guidelines are examples of strategies that have proven to lower the bar. As labour costs (and other costs) often overshadow material costs in infrastructure projects, clients need to prioritise and reward material efficiency/substitution in procurements and cascade requirements and incentives down the supply chain – for example through combining functional and specific requirements – to drive material efficiency and shifts to low-CO_2 materials.
The need to revise and future proof, what is perceived as, conservative standards and specification for concrete is often high-lighted as a priority if to limit the use of cement clinker. Learnings and experiences from international adoption of cement clinker substitutes can be applied to manage potential technical challenges around production control (due e.g. to longer hardening times for certain applications) and concerns around concrete properties and guaranteeing durability.

- *Transformative technological shifts*
High up-front costs, long lead times and an uncertain policy regime slow down investments in development and deployment of technologies that would allow electrification of and/or implementation of carbon capture (CCS) in basic industry. Whereas a heavy burden falls on the government to adapt legislation, provide R&D support, plan and finance/de-risk support infrastructure, collective action through buyers coalitions [20] or transformation funds [21] could allow actors along the supply chains for basic materials to collectively contribute to secure financing and de-risking investments in low-, zero- or negative emission technology.

For a more comprehensive review of opportunities and barriers see [3-6]. Measures to reduce diesel use in construction processes and material transports through, initially, increasing the use of biofuels, and subsequently, electrifying of heavy transports and construction machinery is also instrumental if to decarbonise infrastructure construction. Karlsson et al. [4] and Toktarova et al [6] provide more thorough discussion of opportunities and barriers for carbon reductions in these fields. Karlsson et al. [4] also discusses options to reduce CO_2 emissions associated with the production and use of bitumen and asphalt.

4. Concluding remarks

This work is an initial attempt to map out and discuss "intangible" factors that may hinder or facilitates collective action towards realising ambitious CO_2 emissions reduction goals in infrastructure construction. The assessment shows the importance of: overcoming compartmentalization in traditional organisational structures to encourage coordination and collaboration within and between projects and across the supply chain; de-risking material innovation and incentivising material efficiency, material substitution and circular practices and measures in permitting and procurement requirement. The work also highlights the importance of legislators and regulators stepping up and realizing their power (and the responsibility) to contribute towards reducing the CO_2 emissions from infrastructure construction, not only through environmental economic policy instruments and regulations, but also through; the power to decide what and how much new transport infrastructure that is being built; providing new arenas for public/private collaboration and knowledge sharing; providing policy coordination and clear responsibility for monitoring and follow up of progress; and prioritizing low-CO_2 building and construction in education and research.

Although this work draw primarily from experiences in developed economies, many of the challenges that must be overcome to achieve a transition to zero-CO_2 production and practices in the infrastructure supply chain, are universal [18, 22] From a global perspective, this is important, not the least, since there are still many regions of the world where much of the infrastructure to provide basic services remains to be built [22, 23]. Thus efforts to develop new infrastructures/services (shelter, water/sanitation, electricity/heat, mobility/transportation) important for basic economic development (SDG6-7, SDG9, SDG11) must thus go hand in hand with efforts to reduce/erase the climate impact from infrastructure construction (in line with the Paris Agreement and SDG13) through more efficient use of existing assets, circular and sustainable resource use, and through technical shifts.

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