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Achieving infrastructure emission reductions through supply chain collaboration: challenges and opportunities

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Abstract

Purpose: Achieving ambitious cuts in carbon emissions through the lifetime of an infrastructure asset will require collaboration between a large number of diverse stakeholders. This paper explores the challenges faced by the construction industry in reducing carbon emissions throughout the infrastructure supply chain and investigates how collaborative approaches could overcome these challenges.

Design/methodology/approach: Case studies from a variety of sectors and countries were compared to determine the key challenges faced by organisations seeking to reduce emissions through supply chain collaboration, and how these challenges were overcome. This was supplemented with insights from construction sector participants through interviews and engagement workshops.

Findings: The three most important factors in successful collaborations to reduce supply chain emissions are strong leadership, the ability to share information, and correctly designed incentive mechanisms to align stakeholder behaviour with the overall objective. Based on these factors, the paper develops recommendations for how stakeholders can more effectively collaborate on construction projects to reduce infrastructure emissions.

Practical implications: The findings of this paper can be applied by organisations seeking to collaborate with their supply chain to minimise emissions through the lifetime of an infrastructure asset.

Originality/value: The study provides new insight into the challenges and opportunities for collaboration to reduce emissions throughout the infrastructure supply chain. It develops a conceptual framework showing how the construction industry can move away from the traditional, linear, transaction-based model towards a collaborative approach to achieving emission reductions.

Key Words: Supply chain collaboration; infrastructure; construction; emission reductions; incentive mechanisms; information sharing.

1 Introduction

The need to improve collaboration in the United Kingdom (UK) construction industry has been identified as a priority since at least the early 1990s. The Latham (1994) and Egan (1998) Reports, commissioned by the UK Government in response to extensive job losses in the industry during the 1990-1991 economic recession, identified partnering and collaboration as keys to reform and improved productivity. Nevertheless, the industry has been relatively slow to respond to these recommendations. The latest Government-commissioned review of the industry's current and future state (The Farmer Review - Farmer, 2016), still points to a lack of collaboration as one of the critical symptoms of failure and poor performance in the industry. A recent study commissioned by the Home Builders Federation (Graver et al., 2016) likewise identifies increased supply chain collaboration as the key to unlocking the sector's growth potential.

A new and urgent imperative to collaborate across the construction industry has emerged in recent years, driven by the growing requirement to reduce the industry's impact on the environment, particularly with respect to climate change. Although direct greenhouse gas (GHG) emissions from the UK construction industry are relatively small (13.4 $MtCO_2e$ in 2017, or 2.4% of the UK's national GHG emissions on a production basis (ONS, 2019)), this rises to 48 $MtCO_2e$ when embodied emissions in construction materials are included (UK GBC, 2018), and up to 515 $MtCO_2e$ when emissions from the operation and use of all UK infrastructure are included – 53% of the UK's national emissions on a consumption basis (Mott Macdonald, 2013). This has led the UK Government – through Construction 2025 (HM Government, 2013) – to call for a 50% reduction in emissions from the sector by 2025.

Achieving such ambitious cuts in emissions will require significantly enhanced collaboration across infrastructure asset supply chains, for the simple reason that emissions arise at different stages over the lifetime of an asset, including direct emissions from construction of the asset, emissions embodied in the materials used, emissions from operation and decommissioning of the asset and emissions associated with third party use of the asset. The proportions vary for different projects, but on average across the UK, around 30% of total infrastructure emissions are considered to be under the control of the asset owner (construction and operation emissions, including embodied emissions), while the remaining 70% can be influenced to some degree (end-user emissions) (Mott Macdonald, 2013). When client-industry and contractor-supply chain relationships are adversarial, there is little chance of effective control or influence being exercised over lifetime project emissions: as Benjaafar et al. (2013, p.99) observe, "Multiple actors taking actions based on their own self-interests, and without coordination with others, are not likely to make decisions that minimize emissions for the entire supply chain."

Given this imperative, it is notable that supply chain collaboration to reduce emissions in the construction industry remains an understudied topic. A recent review of the emerging literature on low carbon supply chain management (Das and Jharkharia, 2018) identified nine papers on supply chain collaboration, and a further 16 papers on supply chain coordination, of which none focussed on the construction sector, and only one paper (Toptal and Çetinkaya, 2017) made any reference to construction, simply listing it amongst other sectors with high emissions. Addressing this gap, in this paper we investigate the necessary conditions for achieving infrastructure emission reductions, the role of supply chain collaboration in these conditions, and how similar collaboration has been achieved in other sectors, thus providing a basis for understanding how the unprecedented level of collaboration required to achieve steep cuts in infrastructure GHG emissions might be achieved.

The remainder of the paper is structured as follows: section 2 reviews the literature on collaboration success factors; section 3 provides important context on the infrastructure supply chain and challenges associated with emission reductions; and section 4 describes our research methodology. Section 5 summarises the results of our analysis of case studies on the challenges and opportunities for supply chain collaboration to reduce emissions, while section 6 provides evidence drawn specifically from the construction industry. Finally, section 7 suggests opportunities to overcome these challenges; and section 8 concludes.

2 Collaboration success factors

Collaboration between organisations aims to accomplish a desired outcome that no single organisation could achieve acting by themselves (Wood and Gray, 1991). In her seminal work on collaboration, Gray (1989, p.5) defines collaboration as:

> a process through which parties who see different aspects of a problem can constructively explore their differences and search for solutions that go beyond their own limited vision of what is possible.

Since then, many other definitions have been developed by researchers. From these definitions Bedwell et al. (2012, p.130) develop an overarching definition, describing collaboration as:

> an evolving process whereby two or more social entities actively and reciprocally engage in joint activities aimed at achieving at least one shared goal.

Many scholars have attempted to explain why some attempted collaborations succeed, whereas others fail, and what this implies for the factors required to build strong partnerships. Our review of this literature reveals eight 'factors' (also referred to as 'dimensions', 'themes', or 'activities') that frequently appear: trust; common aims; structure; leadership; administration; incentive mechanisms; information sharing; and shared resources. It should be noted that these eight factors were not the only ones that appeared in this literature, but featured most often. These factors are presented in Table 1, and summarised below.

Table 1 - Common factors for successful collaborations

	Trust	Common Aims	Structure	Leadership	Administration	Incentives	Information Sharing	Shared Resources
Anbanandam et al. (2011)	x		x		x	x	x	
Bedwell et al. (2012)			x					
Cao and Zhang (2011)		x				x	x	x
Ho et al. (2017)		x				x	x	x
Huxham (2003)	x	x	x	x				
Matopoulos et al. (2007)	x		x		x	x	x	x
Mayer and Kentor (2016)	x	x	x	x	x			x
McNamara (2012)	x		x		x		x	x
Patel et al. (2012)	x	x			x	x		
Simatupang & Sridharan (2004)						x	x	x
Soosay et al. (2008)					x		x	x
Thomson & Perry (2006)	x			x	x		x	

Achieving significant cuts in infrastructure emissions will require successful collaboration throughout asset supply chains. As we will discuss in section 3, information sharing and incentives stand out as two pre-eminent conditions which must be met in order for such collaboration to be successful, due to the distribution of emissions, as well as associated costs, benefits and risks, across many different parties in asset supply chains. We therefore discuss these two success factors in greater detail below.

2.1 Trust

Trust should be established early in the project and can be defined as a mutual understanding required to sustain relationships. Each party must have confidence that each other member will act in the best interest of the group and not just themselves. Mayer and Kentor (2016) identify trust as critical to a stakeholder's willingness to share information and resources.

2.2 Common Aims

Huxham (2003, p.404) states that it might be 'common wisdom' that a collaborative group must have common aims or a shared vision, encouraging each party to commit to work to the greater good.

2.3 Structure

A stumbling block for many collaborative partnerships is a lack of structure, resulting in stakeholders not being aware of what each member is doing (Huxham, 2003). A clear structure, for example involving a clear division of work and definition of roles between the parties involved, facilitates the development of long-term relationships between different stakeholders.

2.4 Leadership

Leadership is vital for the success of collaboration and developing the greater good (Sullivan et al., 2012). Strong leadership adds legitimacy to the collaborative process and aids the ability of a group to make joint decisions.

2.5 Administration

Effective administration enables the implementation of decisions and management of collaboration. An administrative structure can help the collaborative parties move from governance to action (Thomson et al., 2009).

2.6 Incentive Mechanisms

Appropriate incentive mechanisms reward behaviours that promote the achievement of common aims, and can compensate for differences in exposure to the costs, risks and benefits of collaboration. There are a variety of ways in which buyers can incentivise suppliers, such as long-term contracts, paying prices above the market value or by providing training and education (Pakdeechoho and Sukhotu, 2018). Other forms of incentive could include the buyer penalising suppliers who do not meet specific targets, or the buyer entering into a cost-sharing agreement with the supplier where the costs and rewards of reducing the emissions are shared between each stakeholder. Another form of incentive is coercion, where a manufacturer may tell a supplier they cannot supply for them unless they reduce emissions, or a supplier may tell the manufacturer they will not supply them unless they reduce their emissions. Incentives may also be categorised as co-option, where the stakeholders come together to work on emission reductions under a voluntary standard.

However, it is important to make sure the correct structure is in place. Incentive misalignment occurs when one stakeholder makes a decision about how to increase their own profit margin without considering the margin of the wider supply chain (Simatupang et al., 2000). In their paper on incentive alignment in the supply chain, Narayanan and Raman (2004) warn about how easily incentives can become misaligned. They give an example of a bread manufacturer who paid their delivery team to make sure the shelves in a shop remained full. As such, the deliverers kept re-stocking shops despite sales being low, which resulted in a lot of bread going off and being thrown away. The deliverers still made money by delivering more whilst the manufacturer lost money. Had the incentive been designed more effectively then the deliverer could still have made extra revenue but the manufacturer would not have lost stock.

2.7 Information Sharing

Information sharing is the ability to view, and use, data from other parties that if not for collaboration would not have been shared, in the pursuit of achieving shared objectives. The sharing of information between supply chain members can lead to benefits and improvements for all members of a supply chain, including improvements in forecast predictions (Wu et al., 2014), allowing organisations to react more quickly to demand (Ganesh et al., 2014), and leading to cost savings across the supply chain (Ramanathan, 2014). However, despite this, there can be a reluctance for organisations to share information with their supply chain due to unequal distributions of risk, cost and benefits (Manatsa and McLaren, 2008).

Rai et al. (2006) describe three levels of information sharing between organisations: *operational*, where information is shared regarding the flow of materials and finished goods; *tactical*, where partners can collaboratively work to manage the activities based upon the data; and *strategic*, where the information is used by members to develop a collective competitive advantage over rival supply chains to strengthen the impact of the partnership. Using this typology and considering emissions, operational information may include the amount of carbon emitted in producing an item. Tactical information sharing could occur when stakeholders work together to create efficiencies in design and use of materials during the construction of an asset, while strategic information sharing can enable parties to consider the whole of life impact of the asset and how it will be used through its lifetime.

There are many challenges that organisations face regarding information sharing. From a review of the literature on the subject, Lotfi et al. (2013) find several barriers that limit information sharing in supply chains including issues of privacy in sharing the required information, trust in the accuracy of the information and the timeliness of the information. A similar review by Kumar and Pugazhendhi (2012) cite several other challenges to information sharing including poor IT infrastructure to store data, a lack of trust and a risk of information tampering from competitors, and fear of authority loss due to sharing data. Even if there is willingness to share data, Simatupang et al. (2000) find that having access to information will only be of benefit if participants are then willing to work together as a team to address an area of concern. To encourage this teamwork, incentives may be required to motivate each party.

2.8 Shared Resources

Finally, as well as sharing information, it is important to share other resources, for example people or the use of IT systems, that can enhance the competitive position of all parties involved, enabling the creation of something greater than a single party can create on their own (Mayer and Kenter, 2016).

3 Achieving Infrastructure Emission Reductions: The Challenge

A variety of actors are involved in each stage in the life of an infrastructure asset, as shown in Figure 1. Typically, at the start of the construction process, a client will outline their desire for an asset and engage a consultant to design a proposal of the completed asset. Following this, the client will invite contractors to tender for the work to oversee the construction of the asset. The successful contractor will then arrange deals with suppliers and sub-contractors to perform certain parts of the project. At the completion of the asset, it will be handed over to the owner (or if chosen, an operator) who has control over the operation and maintenance of the asset, whilst there will typically be multiple third party end users who use the asset. At the end of the asset's life, it will typically be the owner who is responsible for decommissioning.

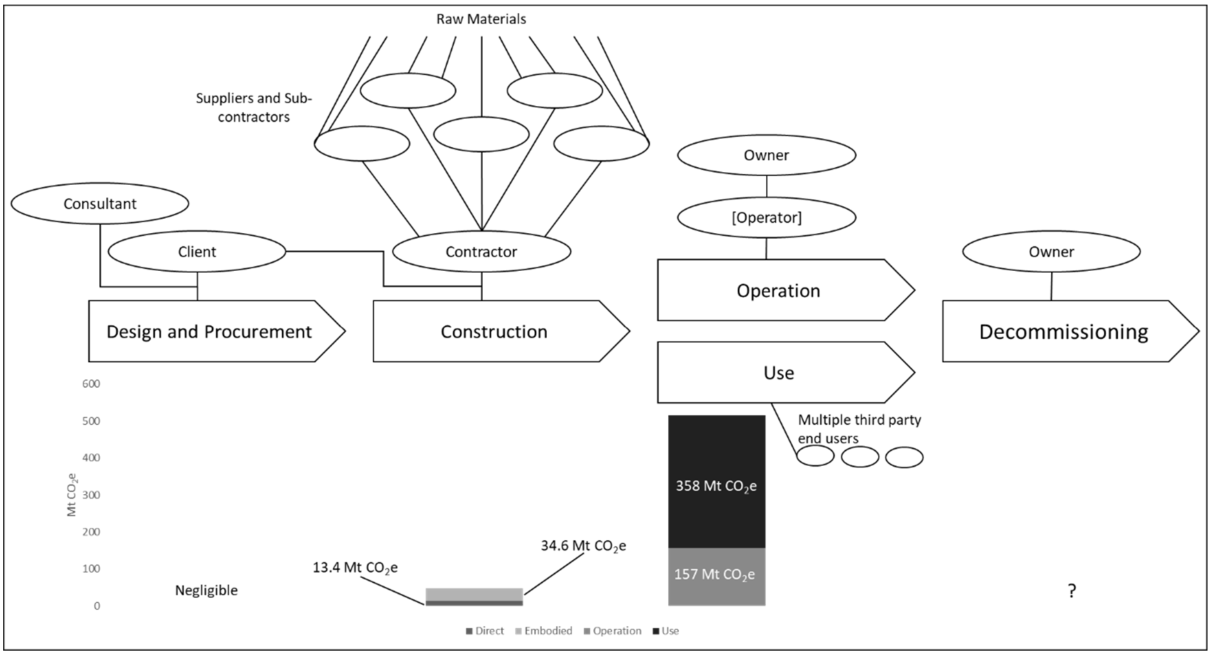

Figure 1 - Stages in the life of an infrastructure asset and the parties involved, and the UK's annual emissions (on a consumption basis) at each stage. (Sources for emissions: Mott Macdonald, 2013; ONS, 2019; UK GBC, 2018).

As Figure 1 also shows, for UK infrastructure in general, direct emissions from construction are less than the embodied emissions in construction materials, while both are dwarfed by emissions from use and operation of the asset. Emissions during decommissioning or disposal of the asset are seldom estimated, but likely in most cases to be less than construction phase emissions, and given the long lifetimes of assets, it is often simply assumed that the structure will be left in place (e.g. Inui et al., 2011). Although the emissions profiles of individual assets vary, similar relative contributions can be found across many different types of asset, from roads and ports to residential and commercial buildings. We therefore define infrastructure asset supply chain emissions those arising over the whole lifetime of the asset, not just those from the construction phase. Emissions, and potential emission reductions, should ideally be measured using consequential methods (Brander and Ascui, 2015) that consider the system-wide changes in emissions actually resulting from implementation of an action, compared with a baseline scenario. Limiting consideration of emissions to any single phase, or not considering broader systemic effects, can lead to perverse outcomes. For example, Jackson and Brander (2019) highlighted the risk of burden shifting between phases in a case study of a railway tunnel, where design changes to reduce the tunnel diameter to minimise emissions in the construction phase led to an increase in use phase emissions, as each train required more energy to get through the tunnel due to increased resistance. An example of systemic consequential emissions could be an increase in emissions from people commuting longer distances, due to new road infrastructure shortening travel times.

Achieving the ‘right’ or desired level of emission reductions is not simply a case of identifying the option with the lowest possible emissions in total across the asset supply chain, however. Consideration must also be given to a variety of other objectives and constraints, such as cost, standards, regulatory requirements and stakeholder expectations. Furthermore, because costs and other effects may accrue to different parties at different times over the asset life, the importance of these factors may be weighted differently by each party – as opposed to GHG emissions, which have essentially the same global impact regardless of where or when they are emitted. The ‘right’ strategy for emission reductions therefore also depends on the extent to which the needs and perspectives of stakeholders other than the decision-maker are taken into account.

For example, Sodagar and Fieldson (2008), reviewing the challenges facing the construction industry in meeting the required reductions in GHG emissions set by the UK Government, observe that environmental designs have financial, and often social, costs that must balance out to justify the construction of low-carbon structures. In some cases there may be ‘win-win’ solutions that meet multiple objectives: a phrase often used within the construction industry is ‘reducing carbon reduces cost’ (Mott Macdonald, 2013, p.3), based on the premise that building efficiently, e.g. re-using already excavated materials and using fewer virgin materials, and reducing transportation and energy demands, also tends to reduce costs. However, in their report looking at how to reduce GHG emissions on infrastructure projects through improved procurement requirements, Kadefors et al. (2019) argue that as such measures are cost efficient they would, or should, already have been undertaken during the design process. In other cases, measures taken to reduce emissions lead to an *increase* in cost: for example, a report on the costs and benefits of green buildings by Davis Langdon (2008) highlights that there may be a cost premium as high as 9 to 11% in achieving the highest standards. Although this may lead to lower energy consumption and costs for the owner and end users, it leads to higher costs up-front for the client and contractors. As costs and savings will not accrue equally, some level of incentive may be required for the client and contractor to consider the extra costs.

An example of the influence that other standards or regulatory requirements can have on the ability to reduce emissions can be seen in the case of eco-efficient cements. Cement is used in the production of concrete and is one of the most carbon-intensive building materials. A recent study by Seo et al. (2016) found that almost a quarter of on-site CO_2 emissions during the construction phase of a project came from concrete and cements. To reduce the impact of concrete, eco-efficient cements have been developed. However, cements are subject to stringent national and international standards, which means that making modifications to adapt them for environmental purposes can be very difficult (Scrivener et al., 2018). High standards are set to ensure quality and safety requirements are met, but these can act as a barrier to the development of more efficient cements. The industry has realised the need to improve the environmental quality of materials and in recent years, standards for eco-efficient cements have been developing relatively rapidly compared to the general pace of standards in the construction materials industry (Provis, 2018). However, it will take time to optimise standards for all materials to make significant reductions in emissions associated with building materials.

The need to balance emission reductions against cost and other considerations, which may vary in importance for different stakeholders, means that decision-making will always be highly context-specific and subjective. Nevertheless, if both emissions and other factors are properly taken into account over the whole asset supply chain, and other systematic consequences are also considered, then decision-makers will be in a position to make better informed decisions, balancing the trade-offs between emission reductions, costs and technical specifications according to their priorities for each of these.

4 Methodology

As a first step, a case study analysis was performed to understand how organisations had engaged with their supply chains to reduce GHG emissions. Cases were found using online search engines including Google, Google Scholar, and Web of Science using search terms such as ‘supply chain collaboration’, ‘sustainable supply chains’, ‘energy efficiency’, ‘emission reductions’ and ‘case study’. Using this search criteria, 41 case studies were identified highlighting how organisations had collaborated with their supply chains. These studies were analysed and studies where the primary focus of the collaboration was another form of green or environmental practice, such as sourcing sustainable materials or waste management, were eliminated. This left 31 studies specific to an organisation’s efforts to collaborate around reducing GHG emissions or creating energy efficiency. Studies focussing on the latter were retained as energy consumption is usually highly correlated with emissions and because it can be divided into similar components across a supply chain (e.g. direct, embodied and operational energy consumption). Further analysis was performed and studies that did not provide sufficient information were excluded. Examples of these were studies which stated that collaboration had taken place to reduce emissions but used phrases similar to ‘we worked with our supplier on initiatives to reduce emissions’ or ‘collecting data allowed us to identify risks and develop a plan' without directly stating what had happened, the steps undertaken and the final outcome. At this stage a further 15 studies were excluded leaving a total of 16 studies that were used and described below.

The cases examined came from several countries and many industry sectors giving a wide understanding of approaches that had worked to reduce emissions. A well acknowledged method of analysing reports and other textual data is a content analysis (Duriau et al., 2007). A thematic content analysis (Anderson, 2007) was performed on these studies to find common themes which could be used to describe the challenges faced when collaborating, challenges with reducing environmental impact, and the different approaches used to overcome these challenges.

To complement the findings of the case studies, data were gathered from numerous interactions with a wide range of stakeholders in the construction industry over the course of a three-year research project involving both of the authors. In particular, one of the authors, acting as a participant observer, attended two supply chain workshops hosted by a contractor aiming to encourage suppliers and sub-contractors to engage with emission reductions on major construction projects. During these workshops data was gathered using an audience interaction tool (Sli.do) which gave polling data from pre-set questions, and recorded questions and comments from the participants throughout the sessions. The output from the interaction tool was recorded in nVivo which was then used to create categories and sort the relevant data.

Following on from these workshops, four semi-structured interviews (Bryman, 2008), averaging approximately 45 minutes each, were performed with the contractor, two with members of the supply chain team, as well as an estimator and a designer. One of the authors was also present for follow-up meetings with two suppliers and a client of the contractor. As these meetings discussed commercially sensitive subjects they were not recorded or transcribed, however detailed notes were taken by the researcher of the conversations relevant to this research and in each case the participants of the meeting gave their consent for the typed notes to be used for research purposes. The interview transcripts and meeting notes were again coded in nVivo and categorised as with the case studies.

5 Case Studies of Collaborative Solutions for Supply Chain Emission Reductions

A number of academic and consultancy cases studies were examined (see Table 2 for summary) to understand how organisations were collaborating to implement emission reductions strategies through their supply chains. The studies examined organisations ranging in size from large global entities such as Walmart (see Plambeck, 2012) to much smaller organisations like Muntons, a malt manufacturer (see Koh et al., 2013). The organisations studied were based in different countries within North America, Europe and Asia, and covered a wide range of sectors including retail, utilities, food, car manufacturing and information, communications and technology (ICT). In each study, the principal aim was to understand how efficiencies could be made to improve carbon emission and energy performance throughout the supply chain, although each study looked at this challenge in a different way. For example, some organisations had limited knowledge on their suppliers and wanted to have a better understanding of their suppliers' emissions, whilst other organisations wanted to find the most appropriate methods to engage with their suppliers in emission reduction ideas and go beyond simply reporting emissions.

These case studies highlight many of the factors required for successful collaboration as described in section 2. As an example, several cases demonstrated the need for the focal company to be active in leadership to encourage collaboration on emission reductions. For large multinationals such as Kimberly-Clark (see EPA, 2010) and Best Buy (see PWC, 2012) there was an expectation from stakeholders that they would take on a leadership role in reducing emissions in their supply chains, with both organisations looking not only at how they could reduce their own impact, but also that of their supply chain. Several other studies showed that it was organisations being proactive and engaging their supply chain that led to collaboration, whilst others showed the requirement of buy-in from the organisation's top leadership to align business functionality with sustainability targets, which led to performance targets also being set for suppliers.

The case studies are also particularly useful in understanding the challenges surrounding the gathering and sharing of information, and how incentives can be used to overcome these issues. The remainder of this section explores some of the issues that arise from the case studies and looks at how these issues can be overcome to improve emission reduction efforts throughout the supply chain.

5.1 Information gathering and sharing

5.1.1 Problems

In several cases the focal organisations were keen to reduce their environmental impact, but to do so required information from their suppliers. For example, Muntons (see Koh et al., 2013), were keen to reduce its GHG emissions but needed to understand the carbon hot-spots along their supply chain in order to do so. Kellogg (see CDP, 2018) wanted to identify the sources of emissions throughout their supply chain, however challenges arose as they only had information regarding their first-tier suppliers

Table 2 - Summary of case studies cited in this paper. ('-' represents information not stated)

Focal Company	Reference	Sector	Country	Company Size	Issue raised by case and how collaboration helped supply chain efficiencies and emission reduction
Company X	Ballot & Fontane (2010)	Food / Logistics	France	-	Study showed that by sharing logistics, two companies could reduce their freight carbon emissions. However, due to the greater cost involved in this the option was not taken.
Company Y	Hassini et al. (2012)	Utilities	Canada	Large	Found that a lack of trust over data confidentiality made suppliers wary of sharing data. Designed indicators to highlight levels of trust to work on improving issues and build trust with suppliers.
BAe Systems	Gopalakrishnan et al. (2012)	Defence	UK	Large	Wanted to manage their supply chain emissions and keep their supply chain accountable. Designed a code of conduct for suppliers to sign up to stating how they would continue to reduce emissions on an annual basis.
Best Buy	PWC (2012)	Retail	USA	Large	Found that due to position in the market and being able to influence downstream users, upstream suppliers were expecting them to take a leadership role in collaborating to reduce emissions.
BMW	Carbon Trust & BSR (2017)	Motor	Germany	Large	To get a better understanding of the emissions of their products, engaged with suppliers to sign up to CDP to get a better understanding of their system-wide emissions with the ability to then collaborate at building efficiencies.
Braskem	Carbon Trust & BSR (2017)	Chemicals	Brazil	Large	Wanted to raise their supplier’s awareness of the need to reduce emissions. To do this they hosted workshops and provided training to their suppliers who could then develop plans to cut emissions.
Carlsberg	Carbon Trust (2019)	Beverages	UK	Large	Wanted to reduce direct and indirect emissions associated with their products. Worked with an NGO to target key suppliers and then worked collaboratively to reduce emissions.
Canadian Tires	PWC (2012)	Retail	Canada	Large	There was a need to reduce emissions and waste from packaging. Worked with supply chain to reduce waste, resulting in cost and carbon savings on the finished products.
Cisco	Carbon Trust & BSR (2017)	ICT	USA	Large	Wanted to know the best way to reduce emissions in their supplier’s manufacturing plants. They shared resources by installing thousands of sensors throughout the plants to pin-point emission hotspots and worked together to reduce emissions.
Hyundai	Lee (2011)	Motor	S. Korea	Large	Had limited knowledge on the source of emissions of their products. Engaged with supply chain to map where emissions came from on

					each product and collaborated with supply chain partners to reduce emissions.
Kellogg	CDP (2018)	Food	USA	Large	Were not sure how best to measure emissions from all their suppliers. Engaged with NGOs to provide support which led to a greater level of trust from suppliers willing to cooperate.
Kimberly-Clark	EPA (2010)	Personal Care	USA	Large	Realising that reducing their emissions required their supply chain to act as well, they took a leadership role, engaging and encouraging their supply chain to sign up to CDP to measure and monitor their impact and worked together to reduce their emissions.
Muntons PLC	Koh et al. (2013)	Food	UK	Small	Had no data from suppliers on the source of their emissions. Started using a data platform and engaged with suppliers to give data. Were then able to work collaboratively to reduce carbon hotspots.
Pepsi Co	EPA (2010)	Food / Beverages	USA	Large	Wanted information on their supplier’s emissions. Offered a specialist team of people to help suppliers reduce their emissions once the data had been gathered.
Walkers	Carbon Trust (2006)	Food	UK	Large	Misaligned incentives meant opportunities to reduce energy consumption were missed. Redesigned contract so that both them and their suppliers could save money on same quantity of material supplied.
Walmart	Plambeck (2012)	Retail	USA	Large	They wanted to improve energy efficiency but were not willing to pay a higher price for efficient products. They incentivised their suppliers through longer contracts for higher quality products.

and lacked information about organisations further up the supply chain. Other challenges organisations found were that not all suppliers shared information, for example about one third of BMW's supply chain had not submitted data on their emissions (Carbon Trust and BSR, 2017).

As well as a lack of information, uncertainty in the information or a lack of knowledge on how to use the information can be a problem. As an example, one of the biggest challenges faced by Hyundai (see Lee, 2011) was determining what emissions came from which supplier, how the emissions could be measured and how they as an organisation could manage them. Hassini et al. (2012) state that a lack of trust can stem from the fear that confidential data may be compromised and was identified as a barrier to information sharing in some cases (Danloup et al., 2015).

5.1.2 Solutions

In their report on how to manage GHG emissions in the supply chain, the EPA (2010) list several cases where organisations successfully engaged with their suppliers to gather information on emissions and potential emission reductions. In the majority of these cases the focal organisation asked suppliers to fill out a survey or questionnaire on their emissions, hoping that would kick-start the suppliers into considering emission reductions. However, administering a survey or questionnaire becomes more difficult for organisations with extensive or complex supply chains. With an vast supplier list, to ensure consistency of the information from their suppliers, BMW (see Carbon Trust and BSR, 2017) asked their suppliers to sign up to the Carbon Disclosure Project (CDP). This encourages the supplier to set annual targets and makes it easier to monitor progress. BMW employed modes of persuasion and mandate to promote supplier collaboration, developing pilot projects with key suppliers who engaged and imposing targets on their highest emitting suppliers who were yet to sign up.

To help develop a shared understanding of emission sources throughout the supply chain, Koh et al. (2013) developed an analysis tool to map carbon hot-spots along the supply chain, which enabled Muntons and their suppliers to identify areas requiring attention. This collaboration led to the creation of a centralised barley drying and storage unit which cut 1,700 vehicle movements and reduced emissions by 650 tCO_2e per year. The use of tools like this helps minimise the time required to collect the data, which in turn helps address supplier concern about the cost of gathering the data. The use of ICT was also championed by Cisco (see Carbon Trust and BSR, 2017) who were able to install thousands of sensors in one of their manufacturers' plants. The use of big data enabled the organisations to work together to create efficiencies which led to emission reductions and cost savings.

To overcome the issues of uncertainty regarding their emissions, Lee (2011) shows how Hyundai adopted the WRI/WBCSD GHG Protocol which helped them set scopes and boundaries for their emissions. They asked their 10 top suppliers to follow the same protocol and were able to use the information they provided to create a carbon process map, which allowed them to accurately calculate the emissions of their products.

By teaming up with an NGO, Kellogg (see CDP, 2018) found that having an external, trusted organisation to partner with helped provide legitimacy to their desire for emission reductions, and help build trust with suppliers who were encouraged to engage and share data. Similarly, Carlsberg (see Carbon Trust, 2019) collaborated with the Carbon Trust to identify and engage with key suppliers to work in collaboration to drive down emissions outside Carlsberg's direct control.

5.2 Incentive Structures and Reward Mechanisms

5.2.1 Problems

In their paper modelling costs and carbon emissions across the supply chain, Benjaafar et al. (2013) observed that both costs and emissions could increase for some suppliers even if the overall emissions decreased. This was highlighted in the case study of Company X by Ballot and Fontane (2010) who discovered that despite finding emissions could be reduced by up to 25% by sharing freight logistics with other organisations, there were significant differences between the cost efficiency and emission efficiency for each partner, which led to the opportunity to reduce emissions not being taken. Traditionally, collaboration in the supply chain has tended to create economic benefits mainly for the focal organisation. It is therefore important to develop mechanisms that help the focal company to share these financial gains with their suppliers (Gunasekaran et al., 2015).

Other issues could be that incentives become misaligned. Walkers Crisps (see Carbon Trust, 2006) found that by purchasing potatoes based on their weight suppliers were keeping the potato moisture content high, thus using extra energy to keep the potatoes refrigerated. Walkers then also had to use more energy drying the potatoes out, meaning that the process was very energy intensive and expensive for both the supplier and Walkers.

5.2.2 Solutions

In the case of Walkers, the contract between the purchaser and supplier was changed to make price paid based on the dry weight of the potato. As such, the cost per potato did not change but both parties reduced energy demand which led to cost savings. Similar savings to both energy and cost were found by Canadian Tires (see PWC, 2012) whilst working with their supply chain to improve efficiencies.

So that incentives are not misaligned, incentives have to be created to meet the specific challenges that arise from each partnership, realising that each stakeholder will have different motivations for how and why they are willing to collaborate. For example, Scholtens and Kleinsmann (2011) found that some subcontractors were extrinsically motivated to engage in emission reductions, driven by regulatory compliance and costs, whilst others were intrinsically motivated, driven by environmental awareness and relationship building. As previously outlined, incentive mechanisms can take many forms including financial incentives, coercion and co-option. A review of the case study literature reveals several examples of different incentive mechanisms and how they have been used to engage supply chains to reduce their GHG emissions and increase energy efficiency.

One option is for the focal organisation to pay a price premium to their suppliers for providing environmentally superior products. Kogg (2003) describes how this may be required for some smaller companies who do not have the power to coerce their supply chain. In contrast to this case, Walmart, a multi-national wholesaler, was able to use its size and purchasing power to pressure suppliers into improving the energy efficiency of their products. Plambeck (2012) explains how Walmart refused to pay a price premium for their goods, instead offering longer contracts to those who could show they had improved the efficiency of their products. This meant that Walmart did not have to spend more money on higher quality products, while the suppliers could use the certainty of a longer contract to invest more resources into product development. Coercion can also be in the form of making your suppliers sign up to standards. For example BAe Systems (see Gopalakrishnan et al., 2012) who demanded their suppliers to agree to their code of conduct. This meant their suppliers had to state their emissions and show each year what they were doing to reduce these.

Alternatively, an organisation may choose to enter into a cost sharing agreement with their suppliers. Zeng et al. (2019) examine the difference between purchase price incentives, and cost sharing incentives on a construction megaproject. Although they found that both mechanisms were of benefit to supplier development (the efforts of an organisation to work with suppliers to improve the capabilities and performance of the supplier to meet the needs of the organisation), they found that cost sharing between the collaborating stakeholders had a greater effect on quality than purchase price incentives. This was due to the fact the supplier would benefit from reduced costs involved in the supplier development process and be more competitive in future markets. As well as cost sharing, Benjaafar et al. (2013) explored how a supply chain performed under an emission sharing cap. They found that collaboration led to a greater emission reduction under a shared emission cap, as opposed to each supplier being limited by an individual emissions cap, and led to more cost-effective emission reductions.

Penalties are an alternative to incentives. In a study of over 300 firms from a wide variety of sectors, Porteous et al. (2015) found that fewer than 10% of organisations offered price premiums for improving social and environmental performance, whilst the majority of organisations incentivised through training or increased business. They also analysed the effectiveness of three types of penalties (fines, reduced business and termination of contract) on suppliers who fail to meet efficiency targets. They found the most common penalty was a warning followed by reduced business. Despite penalising suppliers who had violated their contracts, they found that fewer than 30% of organisations actually terminated the contracts of those who failed to meet the standards.

Finally, there are other non-financial methods to incentivise the supply chain to engage and collaborate around supply chain emission reductions. Braskem (see Carbon Trust and BSR, 2017) were keen for suppliers to engage but found there was a lack of knowledge on how to report and reduce emissions. For this reason Braskem delivered workshops to their suppliers to train and equip them on how to measure and manage emissions. Similarly, Pepsi Co. (see EPA, 2010) gave suppliers access to a full-time specialist who could help them develop strategies on how to improve their efficiency. By sharing their company's resources, Pepsi Co. could encourage their suppliers to do much more than they could have achieved by themselves.

6 Challenges for Collaboration to Reduce Infrastructure Emissions

The construction industry has been described as one of the most diverse and unstable sectors within the UK economy (Dainty et al., 2001), frequently suffering from cost overruns, programme delays and poor productivity (Briscoe et al., 2004). Improved supply chain collaboration has frequently been identified as necessary to resolve these problems, given that suppliers and sub-contractors are typically responsible for at least three-quarters of the work on a construction project (Segerstedt and Olofsson, 2010). However, there are several factors that limit collaboration in the construction industry. One of the most commonly described difficulties is the lack of long-term relationships in the construction supply chain, which can be contrasted with the situation in manufacturing (e.g. Fulford and Standing, 2014; Papadopulos et al., 2016; Skitmore and Smyth, 2009). Whereas supply chains in manufacturing are typically characterised by ongoing processes at a central location, aimed at creating efficiencies and reducing cost over a period of time, construction projects are often short-term, focussing on one-off designs which are built onsite. The temporary nature of projects means that organisations fail to develop meaningful relationships, which leads to short-term thinking where each stakeholder tries to do what is best for them rather than working together (Behera et al., 2015).

Another challenge is the degree of fragmentation in the construction industry, with a large proportion of small and medium sized enterprises (SMEs) which have entered the market due to low barriers to entry (King and Pitt, 2009). A typical large building project in the UK (£20-25 million range) may involve the main contractor managing over 70 sub-contracts, of which a large proportion may be for £50,000 or less (Mott Macdonald, 2013), and at times, the number of supply chain partners involved in a project can run into the hundreds (Wibowo et al., 2018). Typical contract models and procurement strategies also have considerable influence on low levels of collaboration in the industry. Procurement strategies based on competitive pricing award work to the lowest bidder (Yuventi et al., 2013) which encourages a race to the bottom and leads to compromises in the quality of work (Hoonakker et al., 2010) in order to increase profit margins. Finally, issues surrounding trust may hinder collaboration. In their study of the relationships between contractors and subcontractors in the Netherlands, Broft et al. (2016) found that there was distrust between contractors and subcontractors which was leading to reluctance of each stakeholder to take the first step towards collaboration. Likewise Dainty et al. (2001) suggest there is mistrust between contractors and their suppliers, with the latter believing there will be no mutual benefits in collaborating.

These challenges are arguably even greater when it comes to the unprecedented level of collaboration required to achieve significant emission reductions across the life of an infrastructure asset. The fact that the bulk of emissions typically occur during the operation and use of the asset, which can be a period of many decades for long-lived infrastructure and involve a multitude of end users and succession of owners, further exacerbates the problems of short-term relationships, fragmentation and trust, while traditional contracting models have not adequately dealt with emissions as a fundamental metric of performance in the past. Below we evaluate empirical evidence from construction sector interviews and workshops to investigate whether reducing emissions raises any new challenges.

During an interview with an estimator, when asked about how to start reducing emissions, they stated the need for:

> a central library [of carbon factors], so that you only need to look in one place. I don't know how you do that, you'd ideally need to get your suppliers to get on board and list their materials.

To encourage their supply chain to engage on emission reductions targets, the contractor hosted workshops asking suppliers and subcontractors to share emissions data with the aim of collaborating to create accurate carbon baselines so that projects could be designed to minimise emissions.

After being asked to share information regarding their emissions, one of the major concerns raised by suppliers at the engagement workshop was around trust. One supplier was very sceptical about sharing data with the contractor, and at a follow-up meeting stated the concern was that the data could be used to estimate a cost breakdown which would lead to the supplier losing their intellectual property and unique selling point. As a result of this they didn't want to share their data stating that they would rather collaborate directly with the client as they could be trusted with the data.

At the request to share information, some suppliers were put off by the lack of a standard approach throughout the industry, with one participant asking:

> Are [your organisation] looking to work collaboratively with other organisations to drive a consistent approach?

The concern raised here was that there are several different standards that focal organisations sign up to, such as CDP, Science Based Targets, Carbon Net Zero, and specifications such as PAS 2080 and ISO 14001. If each organisation asked their supply chain to comply with their approach, it led to a duplication of effort for the suppliers as on each tender they submitted they had to show compliance with a different standard.

Suppliers were also concerned about the increased time and resources required in collecting the required information, with one participant stating:

> I can't see what I get from this. I can see my company putting in a lot of effort and I'm not sure what I get back?

This shows that there is a requirement to incentivise the supply chain to engage and share data. Similarly, there was a concern that the contractor was wanting the data so that they could be rewarded for reducing emissions by using the information gained from the supply chain. One participant asked:

> If [your organisation] gets financial reward at a project from a client for carbon savings, will you pass or share that on to the supplier who offered the carbon saving?

As highlighted previously, developing the right incentive mechanism to encourage suppliers to engage is very important. A solution is required that benefits each collaborating participant for the work they have done.

Finally, as well as the challenges to leadership, information sharing and incentive mechanisms discussed, suppliers were concerned with the boundaries set for the emission reductions, with one participant asking:

> If [your organisation] are making a new road or bridge, but don't have the maintenance contract for that asset how will they manage CO_2, will they just focus on embodied CO_2?

This highlights the concerns of burden shifting raised by Jackson and Brander (2019) and raises questions about how to engage not only with upstream suppliers, but downstream operators and end users.

7 Opportunities for Collaboration to Reduce Infrastructure Emissions

Based on the generic success factors for collaboration identified in section 2, although all are important, we suggest that three stand out as necessary conditions for achieving emission reductions across an infrastructure asset supply chain. First, there is a need for strong leadership to build trust and encourage suppliers to engage with emission reductions. Second, there is a need for adequate information on the potential to reduce emissions across the whole life cycle of the asset to be gathered and made available to the key decision-makers, in order for them to make informed decisions. Third, to encourage information sharing and action to be taken, there is a need for incentive mechanisms to be developed at key transaction points that are aligned with achieving whole of life emission reductions.

To overcome the challenges to collaboration in the construction industry, we propose a non-linear framework to show how parties could successfully collaborate (shown in Figure 2). This is in contrast to the traditional construction model which follows a linear design-bid-build which discourages collaboration and encourages competitive pricing and limited quality (Hoonakker et al., 2010). Given the importance of trust and leadership, we propose the client acts as a facilitator in the partnership with each stakeholder engaging and supporting with their areas of expertise. Due to the nature of the industry, we suggest the client is the only stakeholder who is capable of providing the necessary leadership in this time, although we note that there are still issues with a client-centric approach if the client is not the intended long-term owner of the asset, or if they are not motivated to look at emission reductions through the infrastructure supply chain.

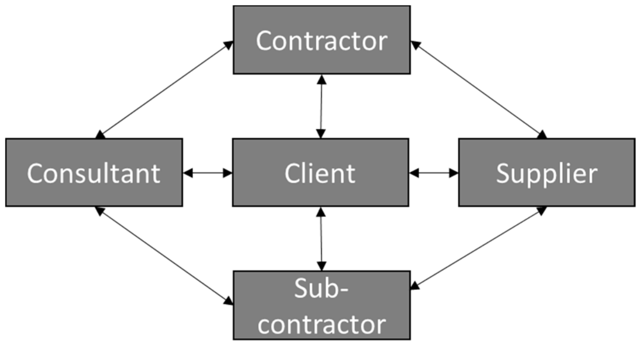

Figure 2 - A framework for collaboration in the construction supply chain.

As Skitmore and Smyth (2009) state, it is the client that has control over the programme of investment and who is best placed to create incentives and encourage collaboration. It has been suggested that traditional procurement methods in the construction industry do not support collaboration and that incentive-based contracts, where partners share the risks and rewards, are better for facilitating collaboration (Osipova and Eriksson, 2011). The proposed framework is well structured to allow for this by rewarding each stakeholder involved for the value that the collaborative process brings. As highlighted earlier, when looking at emission reductions throughout a project, costs and emissions are unlikely to accrue equitably across stakeholders and it is possible that costs and emissions may rise for some stakeholders even if the overall project emissions are reduced. As such, future research should consider the best structure of incentives to drive down emissions throughout the infrastructure supply chain.

A limitation with this framework is the underlying issue of the project driven nature of the construction industry. Even if this framework were successful at improving some aspects of collaboration on a project, on future projects stakeholders could change and the knowledge amassed may not be transferable. This is a much larger problem than just looking at how to reduce emissions throughout the infrastructure supply chain and requires the industry to consider new business models such as Project 13 (ICE, 2018) which take the industry away from traditional transactional arrangements to consider whole life options. Future research should explore how these models could be implemented in the industry.

A final area requiring attention is the issue of standardisation throughout the industry. As touched on briefly, there are several standards that organisations can sign up to such as CDP and Science-Based Targets. As contractors then expect their supply chain to sign up to, or comply with, each of these targets there was a concern amongst suppliers about a lack of consistency and duplication of effort. Future research should examine if there are benefits to developing a consistent approach on how measure and manage emissions throughout the supply chain and how this could be implemented to improve performance throughout the industry.

8 Conclusion

The construction industry faces a great challenge in reducing its environmental impacts, in particular GHG emissions. To achieve deep cuts in emissions a diverse variety of stakeholders will have to work collaboratively to develop solutions to these issues. Based on a case study analysis and observations from a contractor and their supply chain, we have shown that several challenges exist that hinder the development of collaborative relationships, including a lack of access to data and trust around how the data will be used, higher costs associated with more carbon efficient solutions, misalignment of incentives, and the fragmented nature of the project driven construction industry. To overcome these challenges we suggest three key factors of collaboration are essential: strong leadership; sharing of information and data; and incentive mechanisms that encourage stakeholders to consider emissions through the asset's lifetime. Using these factors, we develop a framework to show how collaboration can be improved in the construction industry, led by the client acting as the facilitator to build trust, to allow for information to be shared, and incentivise the other stakeholders to engage in whole life emission reductions.

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