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Designing and implementing procurement requirements for carbon reduction in infrastructure construction – international overview and experiences

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Carbon emissions emanating from infrastructure construction are substantial, and public infrastructure clients have begun to include carbon reduction goals in their procurement requirements. This is a new and complex field where practices vary and are still developing. Based on project documentation and interviews we map and analyze the design and implementation of carbon reduction requirements in projects by leading infrastructure clients in Australia, the Netherlands, Sweden, the US and the UK. Procurement requirements were influenced by concerns for tender competition, transaction costs and innovation, and further adapted to project delivery models, market maturity and client capabilities. Increasing awareness of practical and contextual constraints often led to modified strategies. This paper identifies factors that should be considered when designing carbon policies and requirements. This knowledge is important for clients and governments in order to develop more effective strategies for learning between contexts. Policies and future research should address client capabilities to drive long-term innovation.

KEYWORDS: Embodied carbon mitigation; transport infrastructure; construction industry; green public procurement; cross-country study

1. Introduction

The infrastructure construction sector is increasingly recognized as a major source of carbon emissions. In the UK, the Infrastructure Carbon Review (HM Treasury 2013) estimated that the construction, maintenance and operations of infrastructure assets account for 1/6 of the nation's total carbon dioxide emissions. Thus, this sector has a significant role in meeting national and international carbon reduction targets. An important share of the emissions – for some infrastructure assets up to 90% – stems from capital carbon (Huang *et al*. 2015), which includes carbon embodied in construction materials as well as energy for transport of masses, site operations and

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maintenance (Huang *et al*. 2018). This implies that measures to achieve carbon reduction in infrastructure construction involve a wide range of decisions and activities performed by different participants. Such measures include: developing and selecting new construction materials, optimizing designs to reduce volumes of construction material (primarily cement and steel) and energy use over the life cycle, coordinating use of masses within and between projects, minimizing emissions from transport and site operations, as well as documentation, reporting and verification of requirements (ENCORD 2012; Wong, Thomas Ng, and Shahidi 2013).

Construction activities generally take place in temporary project organizations comprising large numbers of firms that are related to each other by contracts (Gruneberg 2019). The clients are key actors in this system, since their requirements not only shape the facilities being constructed but also the responsibilities and incentives of contractors, designing engineers and, in the longer term, manufacturers of construction material (Brandon and Lu 2008; Loosemore 2015). Large buyers may not only influence emissions stemming from their own purchasing but also create lead markets for new products and services. In the infrastructure sector, public clients such as road and railroad administrations, publicly owned bodies, municipalities and county councils represent a large proportion of the total demand. Public procurement is therefore critical in driving development in general in this sector, also in the field of carbon reduction (OECD 2016).

Several types of procurement requirements combine in forming the total procurement strategy in a construction project: selection criteria, award criteria and various types of contract specifications and risk/reward mechanisms. The strategy is adapted to needs, goals and the institutional context of the project, including factors such as uncertainty, risks, time restrictions, available competence and local contracting culture (Naoum and Egbu 2016). Especially in the public sector, policies to encourage societal goals such as social sustainability or innovation may influence criteria and strategies (Grandia and Meehan 2017).

Infrastructure clients in various countries have begun to include requirements related to carbon emission management and reduction when procuring contractors and other suppliers. Previous research has shown that sustainability requirements are often seen as secondary objectives that may be discarded to achieve cost savings (Varnäs, Balfors, and Faith-Ell 2009). However, carbon reduction is increasingly urgent as a policy goal, meaning that it is important to investigate how procurement strategies and requirements should be designed to move from a "nice to have" domain to effectively encourage and incentivize new practices in the industry. This paper provides an overview of procurement requirements for carbon reduction used in projects carried out by leading infrastructure construction clients in five countries world-wide: Australia, the Netherlands, Sweden, the UK and the US. The background to the requirements as well as experiences gained in the development and implementation process are also investigated. Factors that affect design and implementation are identified and the conclusions address opportunities and pitfalls when transferring practices between contexts and driving long-term innovation.

2. Overview of the field

2.1. Public procurement as policy instrument

In the European Union and other OECD countries, the focus on public procurement as a policy instrument to achieve so-called secondary objectives, primarily sustainability and innovation, has increased in recent years (European Commission 2017; Grandia

and Meehan 2017). The field of research is also emerging with the majority of articles on both green public procurement and low-carbon procurement published the last decade (Cheng *et al*. 2018). Much of this research has focused on mapping practices of green or sustainable procurement more broadly. For example, a widely cited survey by Brammer and Walker (2011) encompassed procurement practices in all sustainability dimensions and in all sectors in 20 countries. However, conditions differ substantially between different sustainability goals and contexts. This means that broad studies are less useful for understanding and analyzing factors that drive development in a particular area. Thus, Correia *et al*. (2013) argued that profound knowledge of the field in focus, "carbon literacy", is needed to design efficient procurement policies for carbon reduction. To provide such deeper understanding of a specific field, deeper cross-country studies are called for (Brammer and Walker 2011; Wong, Thomas Ng, and Shahidi 2013; Wanzenböck *et al*. 2019). This study responds to this demand within the field of infrastructure construction.

In introducing new procurement requirements, demand-side strategies have been found to interact with supply-side development over longer periods of time (Brammer and Walker 2011; Uyarra *et al*. 2017; Wanzenböck *et al*. 2019). Accordingly, research has emphasized the importance of awareness, competence and capacity on the buyer side (Correia *et al*. 2013; Igarashi, de Boer, and Pfuhl 2017; OECD 2016; Testa *et al*. 2016). An important component is to establish collaboration between the purchasing department and environmental units (Testa *et al*. 2016). On the supply side, front-runner suppliers have a key role since a lack of green products and services on the market is one of the main obstacles to innovation-oriented green public procurement (Brammer and Walker 2011; OECD 2016; Wong, Kit San Chan, and Wadu 2016). In general, specifications that prescribe certain solutions or materials are perceived to be important obstacles to innovation, and instead functional requirements are encouraged (Uyarra *et al*. 2014).

2.2. Green requirements in construction

Since procurement is so central in defining the incentives and driving development in the construction sector, many general articles on sustainability in this sector emphasize the role of clients and their procurement requirements. A recent comprehensive review of the literature on green public procurement in construction, with specific focus on low-carbon procurement, is found in Sparks (2018). Here, we summarize the main themes in this research field.

More generally, studies have shown that environmental performance of contractors is not strongly driven by internal ambitions, but requires explicit regulations (Wong, Thomas Ng, and Shahidi 2013; Ruparathna and Hewage 2015) or green client requirements (Lam *et al*. 2011; Liu and Cui 2016; Wong, Kit San Chan, and Wadu 2016). Environmental Management Systems (EMS) are often included as award (MEAT) criteria in the tendering process (Lam *et al*. 2011; Varnäs, Balfors, and Faith-Ell 2009), and general research emphasizes the role of an EMS in working strategically with green procurement (Testa *et al*. 2016). However, in the construction sector, the relationship between organization-level EMS and practices on the project level is often weak (Lam *et al*. 2011; Gluch and Räisänen 2012). Therefore, other types of green specifications are needed. For example, databases with standard criteria may be developed for wider use by clients. Bratt *et al*. (2013), however, found that criteria

development processes lacked in rigor and consideration of the implementation context. Further, award criteria related to sustainability have been found to not discriminate between tenders (Varnäs, Balfors, and Faith-Ell 2009). To increase the effects of green requirements systematic monitoring with follow-up routines is suggested (Lam *et al.* 2011; Sanchez, Lehtiranta, and Hampson 2015).

Carbon accounting is another important basis for setting requirements, although research has showed that knowledge is still immature compared to, for example, that for energy efficiency (Wong *et al.* 2019). Lam *et al.* (2011) emphasize the indirect effects of requirements and carbon accounting: tools and disclosure of carbon data may increase understanding and affect priorities of project managers. Accordingly, Varnäs, Balfors, and Faith-Ell (2009) suggest that an important function of green requirements is to signal high environmental ambitions. In line with general research on green public procurement, many authors emphasize the need for education of procurement professionals (Bratt *et al.* 2013; Giesekam, Barrett, and Taylor 2016).

Criteria and tools also need to be adapted to the procurement strategies and risk allocation in a project (Ruparathna and Hewage 2015; Sanchez *et al.* 2014; Butt, Toller, and Birgisson 2015). For example, many important parameters are not known at the time of procurement, and suppliers are involved too late to influence selection of material and solutions. However, research that develop tools and models does not always address applicability in practice. In the study by Liu and Cui (2016) on optimal bid discounts for carbon reduction, for example, tendering costs are excluded and the model assumes extensive client knowledge. To avoid systemic lock-ins, Wesseling and Van der Vooren (2017) state that policy measures should be implemented in a specific order. The need for such long-term perspectives to promote innovation are also advocated by Bratt *et al.* (2013) in the field of standard criteria development.

Overall, research on green criteria in construction tends to highlight difficulties and obstacles relating to immaturity and lack of competence, project-based organization, poor attention to the implementation context and a lack of long-term perspective. Green specifications are called for, but it seems difficult to find forms that are effective in practice.

2.3. Contracts and incentives in construction

Procurement is a central topic in construction management research. The bulk of this research focuses on project delivery models and governance (see Rahmani, Maqsood, and Khalfan 2017). Decision-making in projects follows a strict process of consecutive stages toward completion, which differ depending on the delivery model. In traditional design-bid-build (DBB) models, the design is specified in detail before the contractor is procured to carry out the construction. However, for many years there has been an international trend that such detailed, prescriptive specifications are replaced with design-build (DB) contracts based on performance requirements (Zhang *et al.* 2019; Brochner, Ang, and Fredriksson 1999). This way, design and construction can be integrated and overlap in time, and design responsibility gives the contractor more freedom to innovate (Zhang *et al.* 2019). However, there are also limitations of performance requirements: all client goals may not be specified in terms of performance requirements, and costs for measurement and verification can be substantial (Brochner, Ang, and Fredriksson 1999). Further, shortage of time may prevent involvement of subcontractors, material suppliers and maintenance divisions (Eriksson and

Szentes 2017; van Berkel, Ferguson, and Groenewegen 2016). This is a disadvantage, since it is often suggested that specialist contractors and material suppliers are the parties most likely to provide novel solutions (Wesseling and Van der Vooren 2017; Gruneberg 2019).

Contractor selection is generally highly price-based, using lump sum or fixed price contracts. However, there are many sources of uncertainty in construction projects, and specification changes during the contract period are priced by negotiation. Changes therefore tend to induce opportunism, conflicts, distrust and costs for monitoring performance (Kadefors 2004; You *et al*. 2018; Haaskjold *et al*. 2019). Thus, a major theme in construction procurement research deals with possibilities to enhance collaboration in this traditionally adversarial and fragmented industry. There is increased use in many countries of flexible, integrated models that involve contractors earlier in the process (Lahdenperä 2012; Wondimu *et al*. 2018). Such strategies often comprise procurement criteria to select contractors based on other dimensions than price, collaborative project management measures and payment systems designed to share risks (Eriksson 2015).

In collaborative projects, open book target cost contracts are common. Such contracts imply that gains and losses in relation to a target cost are shared between the client and the contractor (Perry and Barnes 2000; Bresnen and Marshall 2000). However, studies have shown that target cost contracts do not always produce collaboration, especially not when uncertainty is high. This is because contractors are motivated to inflate target costs in order to reduce risk and maximize incentive payment. Conflicts may therefore arise both in setting the target cost (Boukendour and Hughes 2014) and when negotiating target cost adjustments resulting from scope changes and other new circumstances occurring during the contract period (Bajari and Tadelis 2001; Kadefors and Badenfelt 2009). Although research often emphasizes that goals should be relevant, clear and verifiable, reflect all important objectives and not be too easy or too hard to attain, such criteria are often hard to meet in practice (Akerlof and Kranton 2005). Thus, when studies of collaborative projects report favorable effects of risk-reward schemes, authors often conclude that this is due to a combination of contract provisions and adequate non-contractual, relational governance mechanisms (Rose and Manley 2010; Love *et al*. 2011).

Collaborative contracts with early contractor involvement increase the opportunities for innovation by integrating various disciplines and have been found to benefit carbon reduction (Sanchez *et al*. 2014). However, both collaborative contracts and performance-based contracts only motivate innovation in a single project, while many innovations need systemic innovation processes that span over longer time and several projects (Eriksson and Szentes 2017, Wesseling and Van der Vooren 2017). This implies that procurement requirements in individual projects have to be considered in their contexts, where requirements also reflect the drivers, opportunities and restrictions present at a specific point in time.

3. Method

Since this is an emerging field where it is important to understand the context, an explorative case-based approach was chosen. Five countries or regions with high ambitions for carbon reduction were selected: Australia/New South Wales, the Netherlands, Sweden, the UK and the US/California. Interviews were performed with client

Table 1. Cases and interviewees.

Country	Project	Actors interviewed (no of individuals in parenthesis)	Number of interviews
Australia	Sydney Metro Northwest	Client (3), Contractor (1), Designer (2), Steel Supplier (1)	4
Australia	Newcastle Light Rail	Client (1), Contractor (1), Designer (4)	2
The Netherlands	A6 Almere	Client (2), Contractor (1)	1
Sweden	3 projects and other interviews	3 project interviews + interviews with clients (23), consultants (16), contractors (22) and suppliers (15).	17
UK	Anglian Water, Grafham WTW Resilience and Dalton Piercy WTW	Client (2), Contractor (1), Designer (1), other (1)	1
UK	HS2	Client (3), Contractor (1)	2
USA	California High-Speed Rail	Client (4), Contractor (1), Designer (1), Supervisor (1), Steel supplier (1)	5
USA	SFO AirTrain Extension	Client (1), Contractor (2), Designer (2)	3

representatives and other parties in the supply and value chains, primarily contractor and consultant representatives, but in some cases also manufacturers of construction materials. In general, interviews lasted for 2-3 h and involved several interviewees. In Australia and the US, the study encompassed one mega project and one large but more standard project; in the UK, one long-term alliance and one mega project; and in the Netherlands one mega project. The Swedish case study was coordinated with a project to follow-up the experiences from a recently introduced carbon reduction model, and the number of interviews and projects was higher. A summary of cases and interviews is presented in Table 1.

The interview guideline covered the following areas:

- procurement requirements for carbon reduction in the project,
- the background to the requirements, organization and processes for implementing and following up requirements,
- mechanisms for learning and improvement, and
- experiences and perceived key success factors/barriers.

All interviews were voice-recorded and transcribed. Key documents such as design guidelines, sustainability policies, sustainability assessment schemes, project specifications, calls for tenders and other procurement documents were reviewed. Case summaries were developed and sent back to interviewees for fact-checking and comments (see Kadefors *et al*. 2019).

The procurement requirements were classified according to the following categories:

1. Qualification and award criteria (Most Economically Advantageous Tender, MEAT, criteria)
2. Technical specifications and other requirements pertaining to the finished asset, the production process or organizational/individual competence. This category includes both prescriptive/specific/closed and regular functional/performance requirements.

3. Rating schemes/Sustainability Assessment Schemes, where the infrastructure asset or supplier organization may receive a certification or label provided that certain product and/or process criteria are fulfilled: CEEQUAL, BREEAM Infrastructure, the IS rating system, Envision, PAS 2080, CO_2 Performance Ladder.
4. Carbon reduction requirements, which specify or reward reduction of emissions, often as a percentage reduction in relation to a reference case (baseline).

4. Procurement requirements and implementation experiences

This section provides an overview of the results. For each country/region studied, the types of procurement requirements used are summarized, followed by a brief description of key interviewee experiences and views, including a few illustrative quotes.

A comprehensive summary of all carbon-related procurement requirements in each country/region is provided in Table 2.

4.1. Australia, New South Wales

4.1.1. Procurement requirements

In New South Wales in Australia, the major public infrastructure client Transport for New South Wales (TfNSW) has been driving development in sustainability for many years, and the more recently established Sydney Metro Authority (SMA) is a lead client aiming for world class sustainability performance. Both clients have primarily used prescriptive requirements, raised over time, to drive sustainability. TfNSW have developed their own Sustainable Design Guidelines (SDGs), which have been updated several times. On the national level, the IS Rating Scheme has been established by the Infrastructure Sustainability Council of Australia (ISCA). ISCA rating was voluntary initially but is now compulsory for certain categories of large and/or significant transport projects financed by the State of New South Wales and several other public clients. Requirements for reduction of carbon emissions in relation to a baseline are included in both ISCA and the SDGs and both systems include calculation tools. The client sets the required level for each contract, usually between 15 and 25 per cent reduction in relation to the baseline. There are no clear penalties or bonuses associated with fulfilling rating requirements.

4.1.2. Experiences and views

Rating schemes, including the SDGs, were important for disseminating new sustainability practices in New South Wales. Such systems require substantial documentation and reporting by contractors and subcontractors, and compliance should be followed up by the client. However, this was a new task and interviewees perceived difficulty in engaging client procurement functions in following up. Another issue was that rating systems (and corresponding paperwork) for stations (buildings) and tracks (infrastructure) partly overlapped. The SDG and ISCA systems also had such overlaps, and it had been decided that projects which were required to be ISCA rated did not have to comply with the SDG requirements.

Rating systems were, however, less relevant in the case study projects, which all had higher ambitions. When explaining the practice to rely on prescriptive

Table 2. Overview of procurement requirements for carbon reduction in case study projects (Anglian Water business model described in text).

Type of requirement	Sydney Metro Northwest, Australia	Newcastle Light Rail, Australia	Motorway A6 Almere, NL	Swedish Transport Administration	High Speed 2, UK	California High Speed Rail, USA	SFO Airtrain Extension, USA (buildings)
Selection and award criteria (qualification and MEAT criteria)	Questions about carbon management capabilities included in Prequalification Questionnaire and weighted in tender evaluation	None	Max 5 + 5% fictive tender discount based on CO2 Performance Ladder rating and calculated DuboCalc Env.Cost Indicator perf.	None	PQ req: ISO 14001 compliance Award crit: Design challenge evaluated on bidder's carbon mgmt capability	None	None
Technical specifications and specific requirements (functional, detailed, process, competence)	Requirement for replacement of cement depending on strength classes, 30% or more. Min. 60 % of bar and mesh produced through energy reduction processes such as Polymer Injection Technology. Min 15 % of reinforcing steel from suppliers that use optimal off-site fabrication techniques such as engineered reinforcing bar carpet, engineered/customised mesh or prefabricated reinforcing cages.	Requirement for replacement of cement depending on strength classes, 30% or more. At least 25 % of site-based electricity energy from Green Power or renewable sources. Use of TfNSW's Carbon Emissions Reporting Tool (CERT) – requirement from SDG 3.0. 100 % green energy requirement for operation, by offsetting	"Energy Neutral" operation – PV panels have to be installed to compensate for operation energy need.	For early design contracts (project budget above 5 MEUR): Perform carbon calculation with Klimatkalkyl. Describe implemented reduction measures and recommend measures for next project phase For projects below 5 MEUR: Max. carbon emission levels for cement/ concrete and reinforcement steel. EPDs for material and construction steel. Min 20 % of energy for equipment and vehicles based on renewable fuel or renewable energy	Carbon management plan PAS 2080 compliance within 12 months of contract award (Tier 1 contractors) Euro 6 vehicles (air quality)	Where practicable, use recycled products and materials or waste materials. Evaluate the use of all reasonably feasible renewable energy sources. Use renewable energy when feasible Provide EPDs from suppliers and manufacturers for concrete mix designs and all steel. Provide a Sustainability Management Plan (SMP), including establishing a baseline against which progress shall be tracked.	Requirements for stations include: - Plan to minimize ecological footprint and life cycle carbon emissions. - Reduce carbon emissions from natural gas consumption in HVAC systems. - Assign LCC for carbon emissions. Provide LCA data to inform design and product selection - Provide whole building LCA at each design phase. Provide LCA data using EPDs for the major products and systems.
Sustainability Rating Schemes	Green Star rating for stations, IS rating for infrastructure	IS rating (Excellent), SDG 3.0 Gold rating	None	None	BREEAM New Constr./ Infrastruc-ture Excellent	None for infrastructure	None for infrastructure
Carbon reduction requirements	LCA req. for 15-25 % reduction of whole of life embedded carbon for material, where a part is reduction from cement. The LCA requirement is demonstrated by using Greenstar LCA-tool or ISCA materials calculator. 20 % carbon reduction from electricity use and major fuels, during construction, by offsetting.	Requirement of reduction of carbon emissions, including development of baseline - a part of IS rating requirement	Included in DuboCalc requirement	DB contracts above 5 MEUR with start of operation 2020-2024: – 15 % (start of operation 2020-2024) resp. 30% (start of operation 2025-2029) carbon reduction compared to baseline. Verified by carbon declaration by end of project, and EPDs for cement/concrete, reinforcement steel, and construction steel.	Reduction in carbon impact in relation to baseline. 50% reduction for main civil works, 30% for enabling works.	Reduce emissions and energy use below regulatory requirements and the estimated baseline by: - use of cleaner engines - use of cleaner fuels, efficient use of fuel, renewable diesel - efficient energy practices, efficient construction practices, materials delivery streamlining - other Contractor identified initiatives	- Calculate carbon emissions from construction activities and take specific measures to reduce these emissions - Perform whole building LCA showing minimum 10% improvement for three impacts including climate change compared to a reference building meeting 2010 CEC requirements.

requirements to drive development in carbon mitigation and sustainability in general, the interviewees referred to difficulties associated with other methods. Award criteria, for example, were considered less useful due to time and scheduling issues:

> "Weighting is tricky and depends on the project, and there's not much time in the tendering process. It's too early to ask questions about concrete, steel etc. and where they are going to get it from (…). You don't have enough info then." (Client)

Functional carbon reduction requirements were included in the rating schemes, but with no penalties for non-compliance. Interviewees perceived that such requirements carried too much uncertainty to drive cutting-edge development. In particular, they raised concerns that contractor performance was too dependent on how and at what point in the project's lifecycle the base case was defined, and that baselines could easily be "fattened" to reflect a worst-case scenario:

> "The challenge of emission balance and reductions are always about what is the original base case. (…) It's driving you to think – what would be the worst possible case? Baselining is really a challenge to the rating schemes". (Designer)

The interviewed client representatives had played a very active role in raising sustainability goals over several public transport projects in New South Wales, much driven by personal commitment. Providing training and support were important parts of their strategy, and they were highly engaged in raising awareness about sustainability throughout the project supply chains.

4.2. The Netherlands

4.2.1. Procurement requirements

In the Netherlands, the main road and waterways client Rijkswaterstaat (RWS) and the Dutch Public Procurement Expertise Center PIANOo have developed the CO_2 Performance Ladder certification scheme (for a description, see Rietbergen, Opstelten, and Blok 2017). Companies may be certified on five levels based on their management efforts and systems to reduce carbon caused by their internal activities and processes. Depending on the certification level, tenderers are given a tender reduction of up to 5%.

For several years, there has been a strong policy in NL to use performance requirements in construction procurement. Environmental requirements in specific projects are also expressed in terms of performance. The client does that by establishing a baseline for environmental impact, including carbon, using the calculation tool DuboCalc, and sets a reduction goal. The goal is expressed in terms of maximum and minimum levels for tender discounts, where the awarded level (up to 5%) depends on how far below the baseline the contractor offers to go.

For very large projects such as the A6 motorway project, the delivery model comprises private finance and maintenance responsibility (a DBFM contract). The Competitive Dialogue procurement model is used, where parallel teams develop their tenders over a period of, in total, around 9 months before the winner is selected. Environmental impact is included in the award criteria, and the proposed reduction levels of the winning tenderer become part of the contract. In the A6 motorway project

studied, the maximum discount was set at 50% of the baseline. Environmental impact is audited in several steps by independent institutes and there are substantial penalties if tendered goals are not met: 1.5 times the awarded discount.

4.2.2. Experiences and views

The CO_2 Performance Ladder has raised competence levels in industry and all contractors are now certified on the highest level. This was seen as a positive thing, but also meant that there was no incentive for these companies to go further in developing practices. Moreover, the system had been questioned with respect to the costs for certification. The lengthy Competitive Dialogue procedure and DBFM contracts with financing and maintenance responsibilities were also being reconsidered due to high transaction costs, which also resulted in too low interest from contractors at times when the demand for construction services increased.

The DuboCalc tool in combination with the Competitive Dialogue model included third-party verification and penalties for non-performance. However, not even this rigorous system was perceived to fully eliminate the risk for opportunistic behavior, and setting the reduction percentages right was considered to require high client competence:

> "If you make it too smart you get sort of the calculation tricks, and if you don't make it smart enough nothing is going to happen. (…) The smarter you make it, the more you get tricks I think." (Contractor)

Performance-based requirements were also questioned more generally. The development of carbon-related criteria had been driven project by project by a few environmental experts within Rijkswaterstaat, and client interviewees described a learning process where they had moved from using performance requirements only to prescribing solutions that had been proved successful in previous projects, for example LED-lightning and low-carbon asphalt:

> "A few years ago, that is 10 years ago, we said well functional requirements that's it, and really leave it to the contractors to think. Now we are just thinking: well, when we want something, we have to ask them."

4.3. Sweden

4.3.1. Procurement requirements

In Sweden, the Swedish Transport Administration launched their carbon reduction requirements in 2016. Reduction targets apply to all projects with a contract sum over 5 Million Euro. Inspired by a model used by the EU Commission to reduce CO_2 emissions from light passenger and commercial vehicles, target levels depend on the year when the constructed facility will be taken into operation and are raised over time matching the pace of national carbon emission goals (15% 2020-2024 and 30% 2025-2030). A baseline is developed using the calculation tool Klimatkalkyl. If targets are met or exceeded the contractor is awarded a bonus of a maximum of approximately 1% of the contract sum. Important objectives have been to be technology neutral and

stimulate the implementation of the most cost-effective measures first. To transfer responsibility and initiative to the contractors was also in line with a general "pure client" policy, within the Transport Administration, aiming to substantially increase the use of design-build contracts. For smaller projects, however, specific requirements are used. No guidelines or training for low carbon design and planning had been provided before implementing the system, neither for client representatives nor for the supply chain. Sustainability rating schemes have not yet been required in Sweden.

4.3.2. Experiences and views

The general industry attitude toward the Klimatkalkyl model has been positive, partly because it aligns with other government initiatives to develop sector roadmaps for carbon reduction. However, implementation turned out to be less straightforward than expected. First, reduction targets and bonuses were initially set so low that contractors could easily gain full bonus by conventional design optimization to save costs. Further, the tool was designed to produce a fictive baseline to measure against, which meant that some methods and data used in the tool did not reflect current practice. Although the tool fulfilled its purpose, its conservatism caused engineers to question its legitimacy. Moreover, the work involved in calculating baselines and recalculating them when the scope was updated was found to require significant resources. Focus then landed more on calculation issues than on actions for reduction, which also limited involvement of sub-contractors and material suppliers. Suppliers of, for example, cement, concrete and steel products had, so far, seen no demand for their low-carbon products from contractors in infrastructure projects.

It was suggested that the requirements should be more specific regarding, for example, expected meetings, roles and processes for carbon management, to help consultants and contractors make realistic estimations of the resources needed to implement climate reduction requirements and price them more correctly in the tender. Most interviewees also mention a need for more knowledge and support on how reduction measures can be implemented:

> "It is important to have checklists and tools, because it is difficult for us to know what we can do more than optimising masses. What more could you think about? I would like a list. You could go through the list in a project meeting and say, 'have you done this?'" (Designer)

It was also considered important that the client, especially the project management, shows leadership regarding priority and implementation of reduction measures. Dedication and knowledge were perceived to vary between different departments in the client organization, resulting in contradictory goals and requirements. As expressed by a consultant:

> "Perhaps you duck from this question at times and go on with business as usual. I think it is a part for the client side too, to push for the necessary implementations to be performed, so you can't duck from it."

The carbon reduction model had already been evaluated in 2018-2019. The suggested changes aimed to reduce the resources required for baseline calculation by

focusing on the most important areas and also to speed up dissemination of best practice by using prescriptive specifications similar to those in the smaller projects. In parallel, the STA "pure client" policy emphasizing design-build contracts was replaced by a best-for-project contract policy that also includes collaborative contracting models.

4.4. UK

4.4.1. Procurement requirements

In the UK, the Government's industrial strategy from 2013, Construction 2025, sets a target for 50% reduction in carbon emissions in the built environment by 2025, from a 1990 baseline. The Infrastructure Carbon Review (HM Treasury 2013) emphasizes the need to establish "stretching" targets and baselines for carbon impact to measure against and explicitly recommends the use of performance and outcome specifications before traditional specifications.

The private water company Anglian Water has focused on carbon reduction for more than 10 years. The company has established a long-term (up to $5 + 5 + 5$ years) alliance with key suppliers for their larger construction projects. Carbon reduction has been a main strategic goal and a key message is that reducing carbon also reduces costs ("cut carbon, cut costs"). Baselines are set project by project using their own tool, but an incentive payment is issued based on yearly and 5-year performance evaluations. This way, Anglian Water have exceeded their initial goal to meet a reduction level of beyond 50% and has become an industry role model.

The mega project High Speed 2 (HS2) was formally required by government to minimize its carbon footprint "as far as practicable" and be an "exemplary" project for sustainability. Based on the figures in Construction 2025 and the experiences of Anglian Water, the project set its goals at a minimum of 50% carbon reduction. A collaborative two-stage Early Contractor Involvement model was used for the four major civil construction contracts. No separate carbon bonuses were included. Apart from the reduction requirements, carbon competence was part of an award criterion, and contractors tendering for Stage 1 had to submit an assessment of the carbon impact of a set of exemplar assets relevant to each section (viaduct, embankment, boxes, etc.). Contractors were further required to be certified according to the publicly available specification on carbon reduction PAS 2080 within a year of contract award, and the asset will be certified according to BREEAM Infrastructure.

4.4.2. Experiences

In the UK cases, strategies emphasized collaboration and fundamental behavioral changes leading to innovation.

> "50% means that you have to do something completely radical. You have to change the very essence of what you and the industry currently do to provide that. Because there is no other way to do that, you will never reach anywhere near the 50% target otherwise." (Client, AW)

Anglian Water combined this goal with active client leadership and a transparent incentive system for their suppliers, which was enabled by the long-term alliance

relationship. Development and recurrent use of standard solutions were an important success factor.

In HS2 also, the 50% target was considered highly aspirational. Sharp responsibilities could, however, not be clearly defined at this early stage in the collaborative and flexible contract model, and the target rather indicated the level of ambition. The contractor's carbon specialist said that the aim was to "make sure that everyone was pushed to their limits" and that the contractors needed to demonstrate that they did all they could to minimize carbon "as far as practicable", in line with the government requirement. A key feature, then, was that the baseline should be realistic and not a worst-case scenario. However, in line with the collaborative intentions, the carbon target was perceived as a joint goal and the client provided active support to the contractors:

> "… we are working collaboratively with our supply chain and will direct innovation capacity and capability via our Innovation Programme to help the supply chain to overcome barriers to the realisation of the carbon reduction target." (Client, HS2)

However, calculating and updating of baselines were onerous tasks and there was limited time to involve sub-contractors and material suppliers. Four contractor joint-venture teams should agree on how to calculate baselines, perform calculations, and work on reduction opportunities:

> "It may sound straightforward to put together these workshops and meetings, but in order to coordinate with 350 people and make sure anything will actually propagate it has to go through a lot of stages, a lot of people, and it needs a lot of chasing to get it through." (Contractor carbon specialist, HS2)

Concerning award criteria, client interviewees said that it is often hard to assign enough incentive power to any single area to gain impact on contractor strategies:

> "There are lots of things that are important to HS2, but the more important things there are, the more questions we need to ask, and the more questions we ask, the less each question is worth. So you need to find the balance of having enough value to a question, to make it worthwhile asking."

However, there were also indirect effects of such award criteria. For example, to produce exemplar low carbon designs, this required that members with a high carbon competence were included in the contractor tender teams.

4.5. US, California

4.5.1. Procurement requirements

Although the US federal administration has withdrawn commitment to the Paris Agreement, the state of California has adopted a target to reduce carbon emissions to 40% below 1990 levels by 2030. The Buy Clean California Act from 2017 further requires public authorities involved in procurement of infrastructure projects to request Environmental Product Declarations (EPDs) from contractors and suppliers of steel, glass and mineral wool. Public clients also have to reduce their emissions from these

materials over time. The American Public Transportation Association (APTA) encourages transport authorities to measure their carbon footprints and follow sustainability practices as set out in ISO 14001.

In the California High Speed Rail (CHSR) mega project, senior management have committed to reduce carbon emissions beyond the California requirements. Ambitions were raised between successive subprojects, starting with disclosure and "when feasible" requirements. Regarding EPDs, the CHSR Authority accept generic EPDs since producing product-specific EPDs requires investments that risk excluding small and medium-sized suppliers. Contractors were also required to develop a carbon baseline and to reduce carbon impact, but there were no specified targets or rewards/penalties. Instead, analyses and possible measures to consider were listed, and the contractors were required to develop Sustainability plans and also to report reductions, measures undertaken and final data on fuel, energy and materials in a contract close-out document.

The city of Los Angeles has, since 2016, adopted the ISI's Envision Sustainability Assessment Scheme as a policy and eligible projects will thereby be certified. In the SFO AirTrain Extension project the ambitions for sustainability were high and the building parts were to be net-zero and LEED Gold certified, which includes carbon reduction. For the infrastructure parts not covered by LEED there were, however, no carbon reduction requirements.

4.5.2. Experiences and views

The high sustainability ambitions of the CHSR Authority were driven by a few key individuals, primarily the (then acting) CEO and the Sustainability Manager. There was a clear strategy to use the large scale of the project to advance the level of sustainability performance in the industry, since this would induce contractors and suppliers to invest in more sustainable procedures and machinery. The CEO considered this to be an obligation for a major public client in a state with high sustainability ambitions:

> "I think it is a unique opportunity but also on some level a responsibility to try to take advantage of that opportunity."

The strategy was strongly influenced by concerns not to exclude small and medium-sized suppliers. For example, the CHSR Authority accepted generic EPDs since producing product specific EPDs requires investment by suppliers. This was, however, part of a strategy to raise requirements over time, also involving other actors. Thus, CHSR requirements for EPDs preceded the state requirements, but were enabled by industry awareness following on from implementation of LEED sustainability certification schemes in the building sector. Another important part of the strategy was to apply leading edge, but well tested, requirements and technology:

> "I think the power of what we're doing is utilising existing standards, not creating them, it's utilising them, and utilising many of them in combination." (Sustainability Manager, CHSR)

New requirements needed approval of many functions within the Authority and the Board made the final decision. The use of established and objective standards, known

to the industry, facilitated for the requirement-setting team to obtain such internal agreement. The importance of standards in disseminating new practices was also illustrated by the SFO case, where the client relied on LEED certification for buildings but no system for carbon management for the infrastructure parts.

The CHSR Authority Sustainability Manager found it important to explain the sustainability requirements within the Authority and to suppliers. This had worked well in the first subproject, but as the organization had grown and time pressure increased the Sustainability Manager saw a risk that sustainability requirements and activities lost in importance:

> "people know it in the back of their mind, but they barely have time to take a deep breath, so …"

She found it difficult to put enough resources in place to obtain organizational alignment, especially since a distance between the central Authority and the projects had emerged as the organization had grown.

5. Discussion

The study has identified a range of procurement requirements that were used to drive carbon reduction in the cases. In Table 2, these criteria are summarized for each case according to category: selection and award criteria, technical specifications and other specific requirements, sustainability rating schemes and carbon reduction requirements. Although there were both similarities and differences between the countries and cases, the basic concerns were the same: procuring entities needed to ensure that there was sufficient competition and that transaction costs for tendering and follow-up of requirements were not too high. Moreover, clients had ambitions that procurement strategies and requirements should encourage innovation. Below, we outline how four considerations – competition, transaction costs, innovation in projects and long-term innovation – affected and constrained procurement requirements and strategies for carbon reduction in the studied cases. The discussion is illustrated in Figure 1.

5.1. Ensuring competition

In order to ensure that enough contractors would submit tenders, criteria that might exclude too many potential suppliers were avoided. This may explain why we did not find any carbon-related qualification criteria. Award criteria are less risky from this perspective: such criteria do not exclude contractors from tendering, but the more capable contractors will have an advantage. However, although there were some award criteria relating to carbon competence and performance, interviewees also stated practical limitations. First, award criteria may require both resources and high competence to evaluate. Also, being a sub-criterion in the sustainability field, carbon reduction can hardly be assigned enough incentive power to strongly affect which supplier is awarded the contract. Still, award criteria may be important to signal ambitions and raise awareness among suppliers (Varnäs, Balfors, and Faith-Ell 2009; Lam *et al*. 2011). An example of this kind of consideration was the requirements in HS2 for carbon analyses and alternative designs, where the intention was not that these should be built, but to induce contractors to include carbon specialists in their tendering teams.

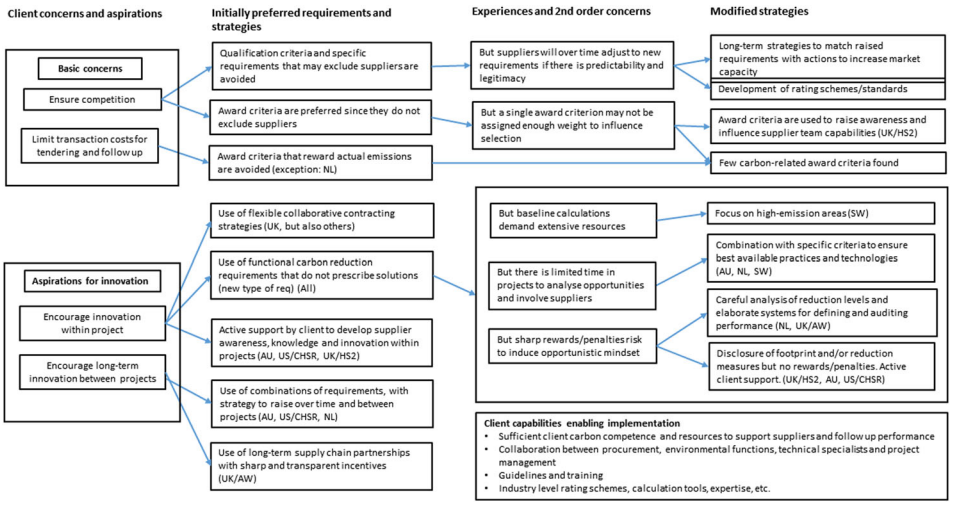

Figure 1. Schematic illustration of how client preferences/requirements/strategies were influenced by basic concerns and ambitions, and of how initial models were modified (or discarded) over time. Client capabilities form the background to these developments.

In the case of the Dutch CO_2 performance ladder, the 5% weighting assigned to this criterion was sufficient to incentivize contractors to invest in carbon management competence to obtain certifications. However, this award criterion no longer discriminates between tenders, since all suppliers are now on the same level (see also Rietbergen, Opstelten, and Blok 2017), illustrating the dynamic interaction over time between demand side requirements and market maturity (Brammer and Walker 2011; Uyarra *et al*. 2017; Wanzenböck *et al*. 2019). In several cases, innovation processes were adapted to the limits set by competition concerns. Thus, clients could begin with voluntary or disclosure requirements that would not exclude suppliers and communicate that requirements would be raised over time to give suppliers time to adjust. This was the case, for example, for EPDs in CHSR and for sustainability rating schemes in the UK and Australia. When it came to carbon management systems, such as PAS 2080 in the UK and the CO_2 ladder in the NL, tenderers were allowed time to comply after being awarded a contract. There was also interaction between markets, so that LEED certification requirements in the building sector prepared suppliers for similar requirements in infrastructure. Both rating systems and large projects played important roles in disseminating well-tested practices broadly in the industry.

5.2. Limiting transaction costs for tendering and follow-up

Another basic concern is that new procurement requirements should not entail significant increases in transaction costs, for example for developing tenders or following up performance. Transaction costs and competition are related: especially in times of high demand, contractors will be less interested if tendering costs are high. Consequently, new procurement requirements need to fit with the logic and timeline of the chosen project delivery model (Ruparathna and Hewage 2015; Sanchez *et al*. 2014). Measures to reduce carbon emissions in construction projects are manifold and only some of them are readily taken account of at the time of tendering. As stated by an Australian

interviewee, contractors have normally not yet performed detailed design or production planning, or involved all suppliers, when developing tenders for a design-build contract. Using actual carbon emissions as a sharp award criterion would therefore require more elaborated tenders, which also must be followed up. These transaction costs can be illustrated by the Dutch system, where the Competitive Dialogue model was used for very large DBFM projects. Tenders were developed by parallel contractor teams in two stages over a total of 9 months, and environmental performance was calculated and followed up by independent auditing institutes based on the standard tool Dubocalc. In effect, the issue of transaction costs had been raised both in relation to the DBFM/CD model in general and for the CO_2 performance ladder, which builds on a certification process (Rietbergen and Blok 2017). The carbon reduction requirements in Sweden and the UK were also found to entail substantial costs for setting, updating and following up baselines.

Especially for complex and uncertain projects, flexible collaborative contracting methods with early involvement of the contractor can be an option. In line with findings by Sanchez, Lehtiranta, and Hampson (2015), several interviewees suggested that this type of collaborative contract would be the most promising way to enable carbon reduction, since many reduction measures require collaboration between disciplines and companies. The UK cases were based on such models, but it was clear from both Anglian Water and HS2 that although tendering costs and supplier risk allowances may be lower, there is a need for extensive client engagement and also supplier resources for communication and participation in joint innovation processes.

5.3. Encouraging innovation in projects

Specifications that prescribe certain solutions or materials are often perceived to be important obstacles to innovation, both in procurement in general (Uyarra *et al*. 2014) and in construction contracts (Zhang *et al*. 2019; Brochner, Ang, and Fredriksson 1999). Especially in the UK, Sweden and the Netherlands there was a strong belief on the policy level in functional, performance-based requirements as measures to encourage innovation and cost efficiency in construction projects (see also Eriksson *et al*. 2019). In the field of carbon reduction, such preferences led to requirements or bonuses/penalties that were linked to percentage reductions in relation to a carbon footprint baseline.

However, these reduction requirements were associated with significant complications and costs. As mentioned above, transaction costs for calculating baselines and following up performance were substantial. In the NL, these processes were planned for, and incorporated within, the design development and dialogue phase of the Competitive Dialogue model. In Sweden and HS2 in the UK, however, the resources required for planning and executing baselining work were unveiled over time. Baseline calculation work also tended to crowd out efforts by carbon specialists and engineers to find ways to reduce carbon impact. Moreover, in line with findings in research on innovation in construction in general (Eriksson and Szentes 2017; van Berkel, Ferguson, and Groenewegen 2016), opportunities for involving sub-contractors and material suppliers in finding innovative solutions were limited by the lack of time. In the very large project HS2, the coordination of the various functions that needed to be involved in carbon reduction work was found demanding.

Both contractor and client respondents also warned that high risks or rewards for carbon reduction could give rise to speculation and creative calculation with little effect on carbon emissions, for example by basing baselines on worst-case scenarios. Such opportunistic strategies bear high resemblance to experiences from implementing target cost contracts, only that the baseline is related to carbon instead of cost. For example, "fattening" baselines mirror strategies to inflate target costs (Boukendour and Hughes 2014). Also, discussions about updating carbon baselines to meet scope changes have a clear parallel in those for adjusting target costs (Bajari and Tadelis 2001; Kadefors and Badenfelt 2009). To avoid too much focus on this kind of non-value adding negotiations, research on performance requirements (Zhang *et al*. 2019; Brochner, Ang, and Fredriksson 1999) recommend that the terms of exchange are transparent and unambiguous. Apart from the Anglian Water alliance, further discussed below, the model used in NL came closest to this ideal. Still, the NL client interviewees emphasized the difficulties and importance of setting baselines and targets exactly right in order to match opportunities for reduction in each project. This issue was supported by the Swedish experiences, where reduction goals had initially been set too low to impact behavior and carbon performance.

This does not imply that less stringent reduction requirements do not have effects. Research suggests that incentives may be used primarily to signal which aspects are important and what behavior is expected (Bresnen and Marshall 2000; Kadefors and Badenfelt 2009). In the Swedish case, the requirements had clearly raised awareness in industry, which is an important initial stage in a learning process. In the collaborative HS2 project, the strategy aligned with the collaborative project delivery model, which would have been hard to combine with sharp incentives in this early stage. The ambitious 50% reduction target was described as "aspirational". It was not based on elaborated analyses of what level was achievable and realistic, and there were no clear incentives or penalties. Accordingly, the goal was interpreted by contractors as a signal that the client expected fundamental changes in mindsets and practices. They therefore focused on developing and demonstrating innovative practices, where realistic baselines were an important part. Moreover, the client took the role of a supportive partner in reaching the goals.

5.4. Encouraging long-term innovation

Another important aspect to consider is that the logic of innovation is different in a project-based industry compared to sectors with more continuous production. While functional requirements in a single project may encourage some types of innovation, especially radical innovations need to be developed and tested incrementally over a longer period involving several projects (Eriksson and Szentes 2017). To enable long-term learning and influence actors further out in the supply and value chains, several interviewed clients relied on prescriptive specifications or standard solutions. The Australian clients used prescriptive requirements to meet very high sustainability ambitions and respondents from the Dutch client Rijkswaterstaat described a learning process where they had moved from only using performance requirements to prescribing solutions that had been proved successful in previous projects. In line with the findings of Sanchez, Lehtiranta, and Hampson (2015), several interviewees also suggested that combinations of small pilot projects for quick testing of new solutions and large projects for broad dissemination should be more useful than to confine all innovation

ambitions to large, long projects with high risks and complex decision-making. The success of the Anglian Water alliance in meeting goals for both carbon emissions and cost was, to a considerable extent, based on the ability to develop standard solutions used repeatedly in multiple projects. These long-term relationships also allowed for contractual incentives which combined sharp monetary incentives, based on carbon reduction performance in a range of projects, with the more open incentive of a renewed contract for another five years.

Thus, to purposefully drive innovation in the construction sector there is a need for clients to go beyond functional requirements in single projects and implement more long-term strategies. This way, clients may also communicate directly with the most innovative actors when setting requirements and bypass large players with vested interests in current technology (Wesseling and Van der Vooren 2017). When it comes to wider dissemination of well-tested practices, sustainability assessment schemes based on standard specifications play an important role.

5.5. Client capabilities

The role of buyer competence in driving development through procurement is often highlighted in the literature (Igarashi, de Boer, and Pfuhl 2017; OECD 2016; Testa *et al*. 2016). Correia *et al*. (2013) emphasize that the "carbon literacy" needed to formulate relevant procurement requirements and strategies often involves deep knowledge of the specific context.

Accordingly, sustained client leadership and commitment was a key theme in the case studies. In all the leading projects, client environmental functions had played an active role in informing and engaging with the supply chain to encourage innovation and help them maintain focus on carbon reduction. Tools, guidelines and training were also important in disseminating knowledge. These strategies were long term: especially interviewees in Australia, the UK and CHSR described how small groups of individuals had worked strategically for around ten years to advance practice by building knowledge, capacity and legitimacy widely in the industry. In Sweden, where the new carbon reduction requirements were implemented in a large part of all STA projects, contractors perceived that the competence and engagement of the individual client representatives strongly influenced the level of importance assigned to reduction requirements in practice. Trust and constructive collaboration between project managers, environmental functions and procurement units was important, since new sustainability requirements had to pass internal review processes to establish the impact on construction costs and tender competition. The need to educate procurement teams and engage them more actively in requirement formulation and follow up was stressed (cf Testa *et al*. 2016). Relating to carbon reduction in infrastructure construction, this includes knowledge of the technical opportunities to reduce carbon emissions in relation to the specific project in focus, but also of costs for various measures, current supply side capabilities and project delivery methods.

Further, as emphasized by Wesseling and Van der Vooren (2017) and Bratt *et al*. (2013), clients also needed a system for challenging and updating standard specifications. Some client organizations (HS2, AW, SMA, CHSR) were independent bodies, which allowed them more freedom in setting project-specific requirements than clients that were part of government agencies.

6. Conclusions and recommendations

Following trends to outsource public activities, the role of procurement in driving societal goals such as carbon reduction is increasingly emphasized. The construction industry stands for a high share of carbon emissions, and construction activities are almost entirely outsourced by clients. Thus, it will be essential to change procurement practices in order to meet carbon mitigation goals. This study has investigated the design and implementation of procurement requirements for carbon reduction carried out by leading infrastructure clients worldwide.

Procurement requirements are seductive in their apparent simplicity: on the surface, requirements are just pieces of text that may easily be transferred between tendering documents, clients and settings. This study, however, clearly demonstrates that design of procurement requirements is often more complex and context dependent than decision-makers tend to assume. As illustrated in Figure 1, increasing awareness of practical constraints in the implementation context led to modification of initial, more common sense-based strategies. Since the clients studied were experienced, such complications were often discovered and adhered to already in the procurement planning stage. In some cases, however, modifications followed from experiences gained when implementing a new type of requirement. In particular, this happened when performance requirements were introduced based on general policy-level preferences or experiences from other sectors. So, functional reduction requirements in relation to a baseline were found to be associated with various issues, such as high transaction costs and risks for opportunism. Also, although performance requirements in general were introduced to drive innovation, concerns for long-term learning between projects led clients to reconsider prescriptive specifications. Accordingly, the modified strategies were often based on unorthodox and flexible combinations of requirements. There was also a tendency that softer initiatives, such as disclosure requirements, reporting of measures taken to reduce carbon reduction, and client support for innovation and knowledge development, were preferred before seemingly sharper, but perhaps more risky, approaches.

Since basic concerns for competition and transaction costs were important, strategies were adapted to contextual factors such as client competence and resources, project delivery models, market maturity and the institutional environment. This implies that what may be considered adequate combinations of requirements and measures will vary not only between contexts, but also over time in a local implementation setting. Many types of requirements and best-practice examples are therefore difficult to directly transfer between countries, regions and clients. Standard criteria are valuable to create legitimacy and predictability in a market, but their effects in practice are dependent on client competence and resources for following up requirements. Such client competence is, however, demanding to develop, since it involves not only one organizational role but the combined capacity of procurement functions, environmental functions and project management. An alternative is that both criteria setting and follow-up are performed by external bodies on the industry level, for example by sustainability rating schemes. To drive development, there should be an interaction over time between cutting-edge testing and broader dissemination of practices. Public infrastructure clients with responsibilities spanning large project portfolios are inevitably key actors in such development processes – ideally, but in reality not always, as innovation leaders.

As for policy implications, this means that any higher-level procurement policy for carbon reduction has to support development of carbon competence, especially among government sector clients. However, in infrastructure construction, the potential to reduce carbon emissions is highly associated with regular optimization in design and construction. In particular, collaborative project delivery models and schemes that allow for integration of competence are important enablers of carbon reduction. Policies therefore need to address infrastructure clients' general capabilities to drive resource efficiency and innovation in their projects, including capabilities to implement collaborative contracting models.

7. Contributions, limitations and future research

This study responds to general calls raised in research within green public procurement for more focused cross-country comparisons. It is the first systematic case study of international experiences within procurement for carbon reduction in infrastructure construction. A main contribution to research in green procurement is that the study goes beyond mapping of requirements and best practice and identifies factors that need to be considered by clients and policy makers in order to drive carbon reduction in a specific context. Thus, the study provides a foundation for developing more sophisticated learning processes which are attentive to limitations in transferring practices and policies between contexts. This knowledge is important for both clients and governments. Future research should address client capabilities to drive long-term innovation and strategies for learning between contexts.

The study has some limitations. First, this study had an explorative, interview-based design. Future studies should employ structured methods to examine decision processes and learning capabilities in this field. Second, the focus has been on front-runner projects in western countries. More studies are needed on the role of procurement to reduce carbon emissions from infrastructure construction in non-western and developing economies.

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