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# Procurement for zero-emission construction sites: a comparative study of four European cities

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**Abstract**
The public sector has a vital role in reducing emissions from construction activities and achieving environmental goals. Therefore, it is vital to investigate the opportunities for reducing the construction industry's emissions through its procurement practices. This paper explores the opportunities and challenges of using green public procurement (GPP) to orchestrate stakeholder ecosystems, including public buyers, construction companies, subcontractors, and equipment suppliers, to achieve zero-emission construction sites—that is, ecosystems for zero-emission construction sites (EZEMCONS). The multiple case study methodology is employed to examine four European cities' practices and experiences. The findings suggest that cities can improve low-emission machinery infrastructure, promote better networking for builders, and enhance cooperation through early market dialogues. Conversely, EZEMCONS pose challenges to innovation ecosystem (IE) orchestration, particularly when managing large-scale zero-emission infrastructure projects. Cities can use these findings to understand general IE implications for developing more mature EZEMCONS. More specifically, this study summarizes the potential opportunities and challenges of GPP for building mature IEs. GPP has been the subject of much environmental policy and sustainable production research; however, its application to EZEMCONS is limited. Consequently, this research contributes to the emergent literature on EZEMCONS, within the GPP context, by examining its opportunities and challenges.

**Keywords** Ecosystems for zero-emission construction sites · Green public procurement · Innovation ecosystem · Construction industry · Non-road mobile machinery

## 1 Introduction

The global construction industry is responsible for nearly 40% of energy- and process-related emissions. The final energy demand of buildings rose 1% from 2018 and 7% compared to 2010 (Desouza et al. 2020; Huang et al. 2018; World Green Building Council (WGBC) 2019). In addition, the capitalized carbon embedded in construction materials and emitted from the construction activities and maintenance can be substantially high, in some cases up to 90% of the total emissions (Kardefors et al. 2021). Therefore, the building and construction industry must accelerate its decarbonization efforts to achieve the aims of the *Paris Agreement* and United Nations Sustainable Development Goals.

In this paper we focus particularly on the emissions from construction activities. Non-road mobile machinery (NRMM), such as excavators but also trucks and cranes which is essential in any construction project, is a critical emission source in the construction sector (Desouza et al. 2020). The European Commission has regulated NRMM emissions since 1997, and the Clean Vehicles Directive sets procurement targets for public authorities in the member states to purchase "clean vehicles."

The construction industry coordinates an enormous variety of products and services and their transformation into infrastructures such as roads, airports, office buildings, and hospitals, and the process involves a range of actors, such as contractors, material/equipment suppliers, architects, and builders (Sariola 2018; Zhu et al. 2019). While describing the complexity of the industry, Marceau et al. (1999) claimed that it could be considered a system rather

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than a supply chain, where the number of relevant actors perpetually increases. Thus, the industry consumes substantial resources but does not fully address sustainable clean resources, warranting a paradigm shift to models that aim to conserve resources (Hossain et al. 2020). An ecosystem model that incorporates a wide selection of relevant actors (e.g., governments, professional associations, private capital suppliers, certification bodies, end users of public infrastructure, distributors, and educational institutions) could encourage a successful shift to sustainable construction practices (Adner 2006; de Vasconcelos Gomes et al. 2018; Dubois and Gadde 2002; Gann and Salter 2000; Shin et al. 2020).

Construction projects are complex due to the multilayered supply chains and machinery/building material logistics (Tepeli et al. 2021; Winch 1998). Further, the industry is project-based, which can affect the relationships between actors. Gann and Salter (2000) highlighted that complex network interactions often occur because construction industry projects require organizations from different industrial sectors. Dubois and Gadde (2002) described these relationships as loose couplings. Therefore, the project-based nature of the industry weakens organizations' (and the industry's) abilities to learn and use innovative solutions (Blayse and Manley 2004). This is particularly important when orchestrating ecosystems for zero-emission construction sites (EZEMCONS) since the technology and the construction practice are novel and needs to be innovative and fast developing to succeed. Mapping the EZEMCONS can provide support for early upstream suppliers to explore opportunities and assess the risk in promoting and leveraging green innovation, and further influence public actors' use of policy instruments (Stokke et al. 2022). Moreover, the public sector is a major customer in the construction industry (Nærings og Fiskeridepartement [NFD] 2018; Varnäs et al. 2009). This provides increased opportunity to reduced emissions and better resource use in construction activities across European cities, contributing to the achievement of climate and environmental goals. Public buyers could use its strong purchasing power to drive the adaptation of emission-free equipment and technology in construction industry that otherwise might not emerge (Preuss 2009; Ruparathna and Hewage (2015). Therefore, it is necessary to investigate the opportunities available to reduce the construction industry's emissions through its procurement practices, particularly focusing on the industry's direct on-site emissions, which are the largest contributor and have been paid little attention in the past (Huang et al. 2018).

Public procurement (PP) is considered an effective tool for ensuring that the construction industry contributes positively to achieving climate and environmental goals (Braulio-Gonzalo and Bovea 2020; European Commission 2016). Hence, preformulated environmental requirements and criteria are prepared, for example, which can be included in public tenders under many procurement categories, such as roads and housing (European Commission 2016). European governments increasingly emphasize that developing and using more environmentally sustainable building machinery will be an essential contribution to achieving climate and environmental goals (NFD 2018). Moreover, the innovation ecosystem (IE) has emerged as a helpful perspective for considering zero-emission construction sites (ZEMCONS) because it enables examinations of the industry's supply chain and the interacting actors and factors involved (Adner 2006; de Vasconcelos Gomes et al. 2018). A ZEMCON is here defined (Bellona 2019) as a construction site in which construction activities are carried out exclusively with zero-emission construction machinery or equipment, and all transport of goods and people to and from the site using zero-emission vehicles. The providence of the energy carrier is not included.

The IE perspective allows a closer inspection of the systemic relationships between specific construction sites and the network of public and private actors involved in striving to reduce the emissions produced on-site (and to and from the site), thereby forming an EZEMCON. However, the available literature on green public procurement (GPP) has not given such an ecosystem perspective much attention to date. The adoption of GPP is greatly varied across regions internationally (Brammer and Walker 2011). In their comprehensive review of the GPP literature, Cheng et al. (2018, p. 781) concluded that "innovation is still a topic that lacks relevant re-searches, either empirical or theoretical." Further, the GPP literature is also silent on how a city, or city therein, could ensure integrated marketing of its EZEMCONS. These shortcomings, and the need to consider the topic in different socioeconomic contexts, are a clear gap in the literature. We aim to contribute to the extant literature by focusing on the IE perspective for applying GPP, and more specifically, how a city can reduce emission at construction sites by applying EZEMCONS. The construction industry in any given city accounts for a large proportion of the total greenhouse gas (GHG) emissions annually, with a significant proportion originating from construction machinery and materials (Huang et al. 2018). This study examines the development of EZEMCONS in four European cities (Budapest, Copenhagen, Helsinki, and Trondheim). Further, it focuses on how PP can help reduce these emissions and move the industry toward zero-emission construction machinery and materials. This lens is justified because the public sector is a major customer in these cities' construction industries (NFD 2018) and has a greater responsible for safeguarding the sustainability perspective than the private sector (Dragos and Neamtu 2014; Walker and Brammer 2009).

First, this paper explains ZEMCONS and how PP can aid their development. Second, the conceptual framework of innovation systems and their applicability to this study are discussed. The data collection procedure is described, followed by a case description. Next, the findings are presented and discussed. Finally, we present our conclusions, point to the limitations of our study, and suggests avenues for further research in this area.

## 2 Developing zero-emission construction sites

Cities have become major contributors to climate change. According to UN-Habitat, although cities account for less than 2% of the Earth's surface, they consume 78% of the world's energy and produce more than 60% of its GHG emissions. Therefore, cities have a crucial role in the global movement toward cutting emissions. Initiatives such as C40 Cities Climate Leadership Group, Climate-KIC, and ICLEI are making great efforts toward a more sustainable and decarbonized future. In Europe, many countries have made strategic plans to achieve their climate and energy objectives, especially regarding construction sites and NRMM.

However, only 16 out of 28 European Union (EU) countries report GHG emissions from construction machinery (UN Climate Change n.d.). The 12 counties that do not report their GHG emissions from construction machinery are Cyprus, Czechia, Estonia, France, Greece, Ireland, Italy, Malta, Poland, Portugal, Romania, and Slovakia. Compared to the significant decrease in EU air pollution emissions from construction machinery, there are various patterns of GHG emissions in different countries. While countries like the United Kingdom, Bulgaria, Latvia, Lithuania, and Slovenia have decreased their GHG emissions, Austria, Belgium, Finland, Luxemburg, Sweden, and Norway show different levels of increasing GHG emissions (Desouza et al. 2020; UN Climate Change n.d.).

Desouza et al. (2020) examined the 2016 London Atmospheric Emissions Inventory, estimating that the construction industry contributes 34% of overall particulate matter (PM10) and 7% of overall nitrogen oxides ($NO_x$), constituting the largest and fifth-largest sources, respectively. Moreover, current on-road light-duty diesel vehicle emission tests have revealed substantial variances between real-world $NO_x$ emissions and findings from laboratory-based regulatory tests. Desouza et al.'s (2020) study aimed to quantify the actual tailpipe NOx, carbon dioxide, and particles released by 30 of the most frequently utilized construction machines in the London area. The highest $NO_x$ emissions (g/kWh) were observed from older engines (Stage III-A ~ 4.88 g/kWh and III-B ~ 4.61 g/kWh), which condensed substantially (~ 78%) in more modern engines (Stage IV ~ 1.05 g/kWh) because of exhaust after treatments and more advanced engine management systems (Desouza et al. 2020).

While this study's focus is not the specific emissions from NRMMs in different cities, the varying degree of emissions provides a context for approaching the development of ZEMCONS. Local and national governments can combat these variable emissions by using PPs more effectively to enact sustainable measures. PP expenditures amount to 13% of Organisation for Economic Co-operation and Development countries' gross domestic products; hence, PP is recognized as an important instrument for facilitating emission reductions and adopting innovative and sustainable technology. PP can drive low-carbon solutions from the demand side by creating a lead market. With other demand-side tools, such as regulations and standards, the emergent practice of GPP can be adopted as a critical tool to achieve climate goals.

GPP is an often-used demand-side environmental policy instrument (Braulio-Gonzalo and Bovea 2020; Cheng et al. 2018). It is considered a relevant framework for this study for two reasons. First, this study focuses on construction sites striving for innovative green solutions. Second, the construction industry has a significant environmental footprint and is of high budgetary importance to public actors. The public sector characterizes the industry as having the opportunity to influence the market and provide an ever-increasing number of green alternatives (European Commission 2016). Its relevance is emphasized because the European Commission (2016) designated the construction industry as one of four sectors that should be utilized for GPP. Material and equipment selections for construction projects were highlighted for having great potential for improvements regarding their environmental footprints (European Commission 2016). It is crucial to thoroughly examine environmental requirements and criteria to understand how GPP practices can benefit cities and their development of ZEMCONS (Igarashi et al. 2013, 2015).

While the construction industry is all-encompassing, our scope is only on the construction sites, which pertains to the construction process not the actual roads or buildings, or emission from specific materials. While recent studies have examined PP in terms of carbon embodied in construction materials, such as low-carbon cement (Stokke et al. 2022), as well as energy for transport of masses, site operations and maintenance (Huang et al. 2018; Kadefors et al. 2021), little extant research exists on NRMM and the actual construction sites.

Furthermore, if existing market solutions cannot deliver the environmental performance that the public sector necessitates for these construction sites, the public sector can use its procurement practices to demand more environmentally sustainable solutions. Such a procurement process would be both green and innovative (Organisation for Economic Co-operation and Development 2011; Rainville 2017). Thus, this study applies the innovative GPP theme to understand cities' (as procuring organizations) processes to succeed with green innovation in the market.

## 3 Innovative ecosystems for zero-emission construction sites

The IE concept is discussed to understand the prospects of an innovative solution for integration into the market. Section 3 aims to theoretically envisage how the general IE concept can inform studies of EZEMCONS.

The IE concept stipulates that the success and safeguarding of each innovation activity will depend on many actors' abilities to collaborate in the EZEMCONS. Innovation ecosystems are comprehensive; however, this paper focuses on two aspects. The first aspect addresses the importance of knowledge sharing and information flow—that is, how cities' knowledge is made available and applied internally and externally. This implies that it is crucial that cities and other actors in the IE fully understand knowledge sharing when developing EZEMCONS. The second aspect concerns the influencing factors in the construction industry. The construction industry is complex, which affects the prerequisites for pursuing innovation. The IE concept makes it possible to consider many relationships and potential ripple effects between actors and their concurrent activities, which can help answer this study's main query. Ecosystem relationships are critical for innovation in the construction industry to facilitate knowledge sharing and information flow (Blayse and Manley 2004; Miozzo and Dewick 2002). Strong relationships between actors in an ecosystem can increase the degree of information flow between cities and companies. The flow of information can, for example, occur through interactions concerning early market dialogues, product integrations (between builders, fitters, and installation technicians), and sale settlements (Blayse and Manley 2004). The construction industry's "loose" ecosystem relationships can enable any project to be considered an experimental arena where innovations are developed in response to project requirements. Therefore, temporary coalitions can lower the threshold for initiating ZEMCONS projects. The complexity of the construction industry indicates the high uncertainty and risks of the innovation system. Cities must be able to identify a project's innovation risks to successfully integrate green, innovative practices into the supply chain by influencing public policies (Adner 2006). This, coupled with insights into how construction projects can use dynamic capabilities, which is the capability to integrate, build and reconfigure internal and external competences (Linde et al. 2021), to reduce risk factors which is considered crucial for a project's success.

Moreover, because IE theory increases the number of relevant actors, the focal entity (e.g., a city) must consider the theory to succeed in its innovation (Adner and Kapoor 2010). IE theory is considered appropriate for examining a set of actors' collective abilities to innovate and a city's opportunities (using its procurement powers) to mobilize and activate its surroundings. Local and national governments have a vital role in orchestrating EZEMCONS. Shin et al. (2020) explained the underlying reason for this:

> Private suppliers experience various obstacles when they launch, develop, and finally commercialize the innovations. One of the main challenges is associated with the market uncertainty associated with the expected demand for potential innovation outcomes. If the expected demand for innovative goods is low, the potential profits and returns from the investments associated with the development and commercialization of new products and processes are low. Therefore, it is difficult for private firms to decide whether to invest … However, the public sector with the purchasing power under the public procurement for innovation (PPI) scheme can reduce uncertainty by guaranteeing and enlarging the size of future demand for innovative solutions. (p. 193)

Both innovative and green solutions are necessary for ZEMCONS to function optimally. This ranges from the availability and logistics of zero-emission machinery to innovative PP processes. Building on Shin et al.'s (2020) model, we propose that governments and, in this study, cities could act as intermediaries to developing EZEMCONS by managing the direct and indirect effects of procurement, as illustrated in Fig. 1. The IE context is applied to assess direct and indirect methods for the city to influence actors (Gomes et al. 2018; Kapoor and Furr 2015), where indirect methods of influence can be just as effective as direct ones (Shin et al. 2020). This is assumed to be applicable, for example, if the city has a close connection with a local contractor with overlapping interests and a relatively weak relationship with builders. The indirect effect is considered one of the major contributions from the IE context. Other actors can also wield influence, in particular public actors such as national ministries and research institutes or universities. Moreover, indirect customers, such as contractors who can provide input that affects a construction site's environmental ambition, or component suppliers may, in turn, influence cities with sustainable development. As such, IE theory emphasize that the focal city can influence a range of different actors, either directly or indirectly (Gomes et al. 2018; Kapoor and Furr 2015). The respective city's potential for direct and indirect influence could be reinforced by relations between actors in the innovation ecosystem. This potential is contingent on the degree to which the city can utilize PP instruments and their understanding of the dominant aspects that affect their own innovation ecosystem.

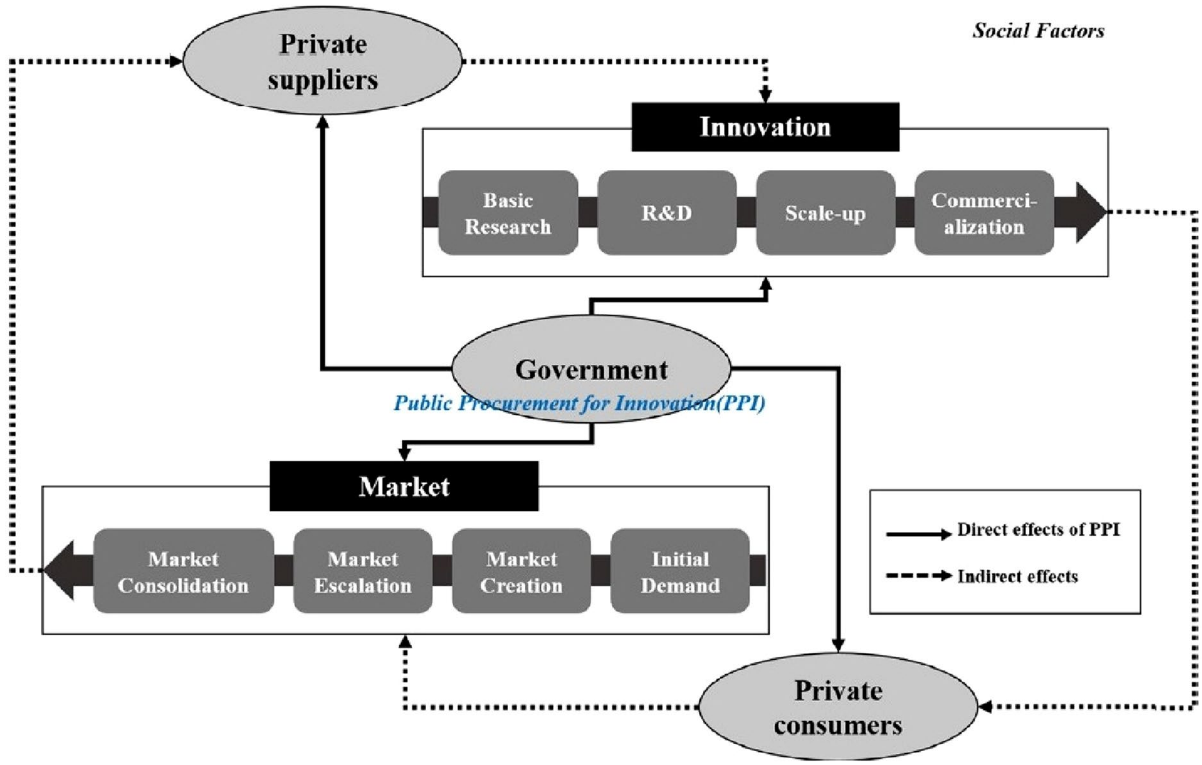


**Fig. 1** Innovation system approach to understanding the effects of public procurement for innovation (PPI); R&D = research and development (Shin et al. 2020)

Shin et al.'s (2020) model is highly relevant for EZEMCONS as it builds on PP research as mission-oriented innovation systems policy (Edquist and Zabala-Iturriagagoitia 2012; Edquist et al. 2015). Adopting this systemic method to interpret EZEMCONS barriers and opportunities, it is expected to offer generalized and conceptual context to realize the system-wide impacts of EZEMCONS, which can be applied to undertake more systematic assessments of the relevant policies. Moreover, it can inform the orchestration and operational process of future EZEMCONS projects with explanations of both the barriers and opportunities. In addition, the dynamics of multifaceted socio-technical, and environmental conditions related with the PP procedures are included (Shin et al. 2020). With this conceptual framework, policymakers and researchers can identify barriers and opportunities for socio-technical and system transitions (Lingegård et al. 2021; Sourani and Sohail 2011; Trindade et al. 2017; Vejaratnam et al. 2020), and implement tailored policy interventions to overcome system failures when designing and evaluating EZEMCONS policies in practice (Shin et al. 2020).

In sum, the construction industry and ZEMCONS projects are characterized with high complexity, uncertainty and risks, which calls for public buyers to be actively engaged to influence GPP, so as to impose change in the ecosystem from the supplier side. Many cities use GPP to stimulate innovations thereby encouraging sustainable development in the construction industry. However, there is a lack of systematic understanding of how GPP practices shape innovation processes and affect other components of the system (Liu et al. 2019; Rainville 2017; Shin et al. 2020). Therefore, there is a need to examine both the direct and indirect effects associated with GPP to better understand the orchestration within the innovation ecosystem. All actors in an EZEMCON can, in theory, interact with one another, and those interactions form the structures for developing the construction practices for GPP interventions. Hence, this study strives to conceptualize innovation ecosystem structures and how GPP is diffused through the interactions between the various actors within an EZEMCON. Consequently, this study examines the influence of GPP on the respective EZEMCONS, including its direct and indirect effects, to map and evaluate potential changes within innovation ecosystems.

## 4 Methodology

This research adopted a pragmatist research paradigm and used a multiple case study methodology for mapping, primarily relying on interviews, participatory observations, and document studies (Yin 2018). This mapping provides the "baseline" of current practices in the industry. Four European cities contributed to the research as part of a project funded by the EU Horizon 2020 program, including Copenhagen, Helsinki, Trondheim, and Budapest. Hence, number and the choice of cases was informed by the design of the EU project and can therefore be regarded as a convenience sample. Still, the specific choice for these cities was made by the funding body of the EU and not influenced by the researchers. Furthermore, with the exception of Trondheim the researchers had no previous collaboration with the cities, further limiting the drawbacks of convenience sampling in general. The number of four cities was manageable in terms of available resources, while providing a variety in the context for each case, both in terms of relative size, geopolitical location and environmental conditions. The authors were involved in the project as researchers and facilitators of several meetings in which the cities exchanged experiences and knowledge regarding their efforts toward developing EZEMCONS. An important project activity for each of the four cities was planning and conducting an early market dialogue event concerning ZEMCONS. Each city was approached for semi-structured interviews, both prior to and after the market dialogue events. The interviews covered the following three main topics:

1. the cities' current general strategies for sustainability and procurement, and in particular in relation to construction;
2. procurement methods and criteria in tendering for lower emission/fossil-free construction sites;
3. barriers and critical success factors of cities' PP for enabling EZEMCONS from the buyer's perspective.

## 4.1 Data collection

The data collection for this study occurred in three phases: (1) pre-interviews (before early market dialogues); (2) participatory observations of actual dialogue events; and (3) post-interviews (after early market dialogues). The first interviews with the representatives from Budapest, Copenhagen, and Helsinki were conducted through Skype in November 2019, and the data collection phase was concluded in April 2021 (see Table 1). The city of Budapest started planning a dialogue event, but ultimately did not carry out such an event, and hence, no specific follow-up interviews were held with this city. In this study we used purposive sampling for how the initial list participants were created, and the selection of final interviewees was based on several criteria: (1) the informants needed to have practical experience with EZEMCONS; (2) the informants needed to be managerial staff within the respective departments; (3) the informants had to have experience with implementing GPP in their respective cities.

**Table 1** Overview of interview and dialogue schedule

| City | Pre-interviews | Early market dialogue | Post-interviews |
|---|---|---|---|
| Budapest | November 2019 | N/A | N/A |
| Copenhagen | November 2019 | November 2020 | April 2021 |
| Helsinki | November 2019 | December 2020 | April 2021 |
| Trondheim | December 2019 (written form) | November 2020 | April 2021 |

**Table 2** List of interviewees

| No | City | Department |
|---|---|---|
| P01 | Budapest | Group for Project Preparation |
| P02 | Budapest | Procurement Department |
| P03 | Budapest | Department of Development and Project Management |
| P04 | Copenhagen | Finance Department |
| P05 | Copenhagen | Climate Secretariat |
| P06 | Copenhagen | Department of Construction |
| P07 | Copenhagen | Building Section |
| P08 | Helsinki | Urban Environment Division |
| P09 | Helsinki | Urban Environment Division |
| P10 | Helsinki | Urban Environment Division |
| P11 | Trondheim | Department of Procurement |
| P12 | Trondheim | Environment Unit |

The interviews were conducted in two phases with each city. In our sampling strategy we determined that saturation is more significant than size. The respective sample size and selection of uniquely qualified informants reinforced the qualitative data (and subsequent analysis) with in-depth interpretations of the emergent factors in developing EZEMCONS (Antos and Ventola 2008; Carson et al. 2001; Miles and Huberman 1994). Having these kinds of common denominators between informants allowed for synthesized data among interviewees to achieve consistency, but also allowed us to control for and manage dissenting views. This is because the informants were uniquely positioned to recount contemporary challenges and experiences with the respective themes in our study, and were therefore also more relevant than the sample size, since they could extrapolate detailed knowledge relevant to EZEMCONS developments. This type of specific expertise has not been incorporated in preceding empirical research in this particular topic-area.

The list of interviewees and their roles are shown in Table 2. Each interview was one and a half hours. They were recorded and subsequently transcribed. The participants received draft transcripts and were allowed to proofread them. Due to planning difficulties, it was impossible to gather the necessary participants from Trondheim at the same time for one interview. Therefore, the Trondheim representatives gathered the information internally by contacting colleagues in the city and answering the questions from the interview guide in written form. Next, the main points from the interview transcripts were summarized in a series of tables, capturing the answers from each city.

According to our interviews, all four cities have long-term urban climate and energy strategies (see Table 3), such as Budapest 2030 Long-Term Urban Development Concept, Carbon–Neutral Helsinki 2035 Action Plan, and Trondheim energy and climate plan.

## 5 Case study results

Section 5 describes and analyzes the data gathered for this study. First, a conceptual model for EZEMCONS is provided, outlining how different types of actors, both internal and external, are positioned vis-a-vis each other and interact with each other. Second, interview excerpts and observations from the market dialogues carried out by Trondheim, Copenhagen and Helsinki are presented. Third, the data regarding the cities´ PP strategies and ecosystem orchestrations are summarized.

### 5.1 Conceptual model

Based on the interviews and observations of the early market dialogues, a general conceptual model of establishing EZEMCONS was developed (see Fig. 2). The ecosystem contains an internal section, shown within the circle on the right-hand side of Fig. 2, comprising the different internal actors in a city, typically a purchasing unit, environmental management unit, real estate division, engineering/technical unit, and politicians. The conceptual model was developed based on the interview data and the model consolidates the findings from the interviews from the different cities. As such, we analyze the findings using the conceptual model as the common denominator.

Although cities and government agencies at the regional level are typically considered "buyers" in GPP literature, it is important to recognize the internal complexity of these actors. The external part of the ecosystem (see the left-hand side of Fig. 2) includes what is usually referred to as the supply chain: the construction firms, their subcontractors, and upstream equipment suppliers. However, as Fig. 2 demonstrates, the supply chain is far from linear, and it can be more accurately described as a network. There are also additional external members of the ecosystem, consisting of electricity providers and related infrastructure and services. The circular arrows in the center of Fig. 2 show the interactions between the internal and external parts of the ecosystem, which are facilitated by early market dialogues. However, the top of Fig. 2 shows that such interactions may also (simultaneously) occur at higher system levels (i.e., regional, national, and international levels).

### 5.2 Interviews and market dialogues

Each of the four case study cities has GPP strategies. During this study, the Budapest Department of Procurement was actively preparing a sustainable, green, innovation public procurement strategy based on their previous experiences and knowledge of GPP. The department was also preparing an innovative green responsible and social procurement strategy, hoping for it to be accepted in early 2020. Regarding the current sustainability strategies and challenges concerning EZEMCONS (overall goals and practices) in Budapest, an interviewee answered:

> I will summarize the middle- and long-term development of Budapest's climate-related strategies. First, I would like to highlight that the city of Budapest or the city system or the subgovernment system is peculiar in Budapest. We have 23 district cities. There's no hierarchy between the city of Budapest and district cities. (P02)

**Table 3** Sustainability strategies in the four cities

| Cities | Sustainability strategies |
|---|---|
| Budapest | Budapest 2030 Long-Term Urban Development Concept, Integrated Urban Development Strategy (Budapest 2020), Climate Strategy (with GHG emission goals), Sustainable Energy and Climate Action Plans, Smart Budapest, Green Surfaces program |
| Copenhagen | CPH 2025 Climate Plan: carbon dioxide neutrality by 2025, including energy consumption, energy production, green mobility, and city administration (one of many plans to support sustainability initiatives) |
| Helsinki | Carbon–Neutral Helsinki 2035 Action Plan: carbon–neutral by 2035 (Action 46 addresses emission-free construction sites); City of Helsinki environmental policy (2012): nine life cycle goals for all public service building projects, including new buildings and renovations |
| Trondheim | Trondheim energy and climate plan: reduce GHG emissions by 80% by 2030 based on 1991 emissions; the council is expected to pass a zero-emissions goal for all municipal construction activities by 2023 |

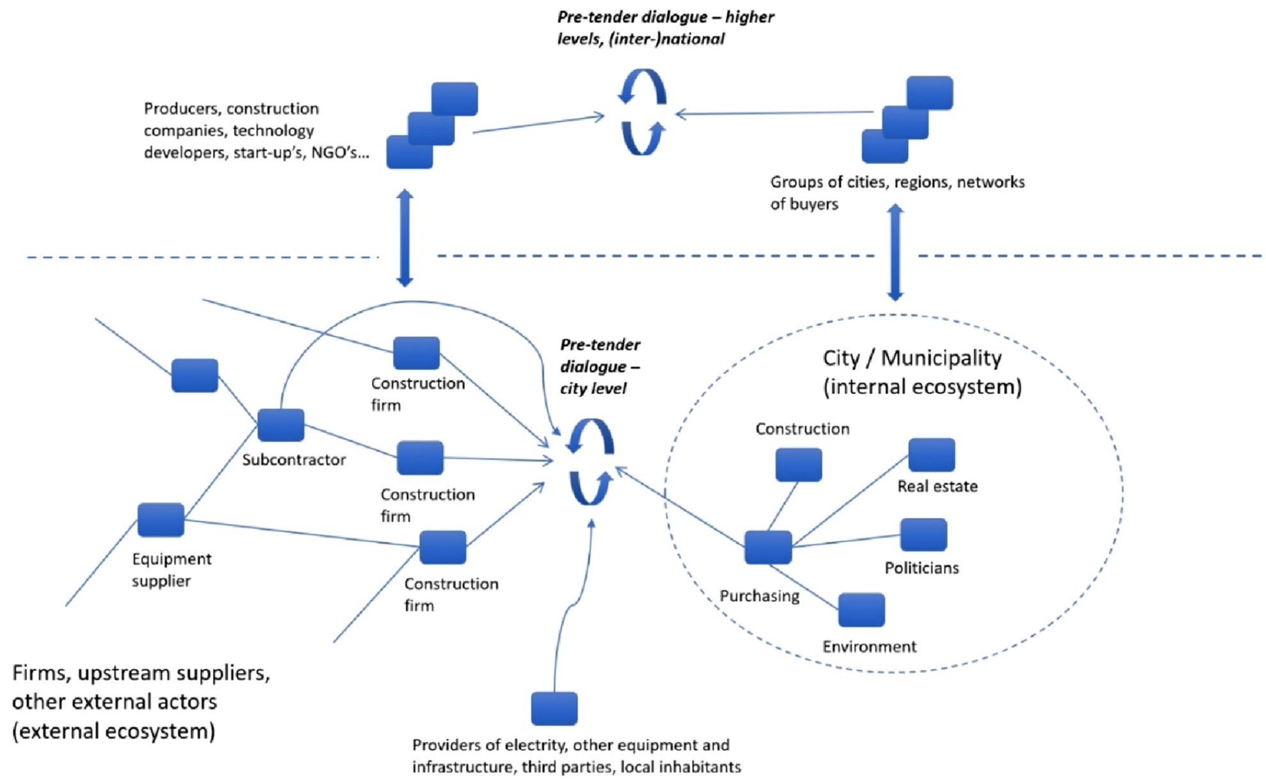


**Fig. 2** Conceptual model of ecosystems for zero-emission construction sites (created by the authors)

This non-hierarchical structure warrants an open negotiation procedure when dealing with complex systems:

> Yes, [an] open procedure for sure. I would also mention that if the procedure and nature of the contract require complex systems, it's the negotiation procedure which is likely to be used … Throughout the tendering phase, I would highlight that in Hungary, since 2016, there's an electronic public procurement system, which is closed to the economic operators. (P01)

Copenhagen has also established sustainability standards for construction and civil work since 1998, and the new procurement policy from 2019 has dedicated a whole chapter to sustainability and sustainable procurement. Moreover, Copenhagen follows a national guideline for the life cycle costs of buildings in Denmark. Regarding building and construction, the Green Building Council Denmark applies the DGNB certification process in Copenhagen (similar to the German certification system for buildings) for measuring the sustainability of buildings and urban areas. Copenhagen focuses on collaboration both internally within the cities' departments and with other external actors in the innovation ecosystem:

> It is an open forum, everyone who is broadly interested in this topic is welcome, ranging from machinery manufacturers and machinery lenders to contractors, industry organizations, other builders, other buyers, and it has grown through word-of-mouth and external actors have often contacted us asking to participate. (P05)

The market dialogue observations from Copenhagen showed that they implemented it as a cooperation forum, which is ongoing. The forum strives to connect the city with academia, small businesses, larger builders like Construction Copenhagen (Byggeri København), and industry associations, such as Danish Construction Industry (Dansk Byggeindustri). Dansk Byggeindustri is an industry association in DI Byggeri, where member companies have industrial productions and processes and supply materials/solutions to the construction industry. The focus of these industry associations is strengthening the productivity of individual members and throughout the value chain. Dansk Byggeindustri supports interdisciplinary collaborations between the sections and fellowship and creates value for the members. The scope, scale and proactive nature of the market dialogues are addressed:

> It was limited to focus on NRMM within the construction sites … and in relation to the timeslots we were to meet, there was a willingness to meet 3-4 times a year, or as needed, so that we could have proactive access to this agenda and the main purpose we have to restructure the entire construction industry to use fossil or emission free machinery. (P05)

In Helsinki, the environmental policy states that all procurement processes must include environmental criteria. The procurement department has also created strategies focusing on environmental aspects and demands set by programs such as the Carbon–Neutral Helsinki 2035 Action Plan. An interviewee explained:

> This is the way we are developing our criteria and the way we are doing the construction work future. Yes. That's the point of the ecosystem to all come together and The Benchmark and learn from each other … Some are more constant; some cities have their constraints specific to that city, which has to find a new solution, [a] new way. (P08)

The early market dialogue connected entities in Helsinki, including the Green Building Council Finland, technical traders, professional property owners, real estate investors, corporate real estate managers and construction clients, and Motiva, which coordinates voluntary Finnish Green Deal agreements to reduce emissions at construction sites. Moreover, the pre-market dialogue demonstrated that Helsinki had already established an urban environment division for prioritizing responsible procurement and enhancing cooperation:

> We have this responsible procurement group, the urban environment division. So that group has on its again … to prioritize procurement categories, which these criteria should be developed. So, we are on the way and processing it with experts. And I know [they] don't know the results yet. But I think that there will be the kind of scheduling of the procurement for which different kind[s] of responsibility criteria will be developed. And then, we also try to define the way to cooperate between different entities. (P10)

Moreover, the ambitious approach to low-emission standards in Helsinki was further discussed after the early market dialogue:

> All the cities can use tighter criteria. For example, roadworks are quite tight; it's fossil-free, even though the Green Deal say[s] that it's from 2023, most are now from private contractors, and everything should be fossil-free, all our worksites, from 2025. So, in infrastructure roadworks, they are already asking for fossil-free and tighter emission standards. (P09)

In Trondheim, the procurement department had finished a new set of environmental requirements and criteria for construction procurements. It was also expected that the city council would decide that all construction in the city must have zero-emissions by 2023. Regarding construction projects in Trondheim city, the main steps and departments involved in the EU's procurement procedures and the city's current strategies were discussed:

> On average, we mostly use open procedure[s], but we occasionally also use negotiation procedure[s]. Further, the city also looks into innovation partnership[s], but this is not commonly used yet. (P11)

The following examples were described regarding changes to the city's procurement processes, which can support the inclusion of higher environmental standards and innovations in urban development projects:

> A new set of environmental requirements and criteria for construction is currently being finished … The refurbishment of the city square is done using fossil-free NRMM. It also attempted to use an electric excavator, but this failed due to a lack of infrastructure … This project also included requirements regarding fossil-free transportation to and from the construction site, and district heating was used instead of diesel generators for heating purposes. In the Granåsen ski arena, electricity is used as a heat source instead of diesel generators. Reports of all transportation have led to some changes in transport of personnel to and from the construction site. (P12)

The early market dialogue from Trondheim also illustrated the central role of the city's largest energy supplier, Tensio, in providing infrastructure for builders and NRMM. In the post-interview, it was revealed that the early market dialogue yielded some pilot projects for a new ZEMCONS project in the city.

Regarding the application of environmental criteria in GPPs, Copenhagen, Helsinki, and Trondheim have started including environmental criteria for GPPs. Budapest was not using environmental criteria; however, both cities have a committed plan for doing so in the near future.

## 5.3 Public procurement strategies

In Table 4, the findings regarding the cities´ PP strategies are summarized, also specifying key features of their practice in terms of the GPP procedures used, the methods for assessing environmental performance by the bidders and actions aimed at innovation ecosystem (IE) orchestration. Table 4 shows the specific picture for each city, but overall, we see that in each of the cities, a certain strategic or policy requirement or target exists to which GPP processes can be aligned.

**Table 4** Public procurement strategies in the four case study cities

| Cities | PP strategies and key features of the pp practice regarding construction projects |
|---|---|
| Budapest | Planning a sustainable, green, PP innovation strategy and preparing new green, responsible social procurement strategy<br>*GPP procedure* mostly open, with negotiation when contracts require complex systems; few market dialogues with suppliers, but with promising results; follow European Commission's GPP guidelines, Hungarian eco-label guidelines, and PP best practices<br>*GPP method* "Best value procurement," 70% price and 30% quality, and no environmental criteria; total ownership cost and LCC/analysis not used; Pathfinder project on LCC/analysis conducted in 2019<br>*IE orchestration* Flat hierarchy for connecting government departments and cities; loose engagement and knowledge sharing with wider actors (e.g., innovation intermediaries, small businesses, and research institutions) to develop ZEMCONS |
| Copenhagen | Sustainability standards for construction and civil work (since 1998); new procurement policy (2019) with a chapter about sustainability and sustainable procurements; national guidelines for LCC; DGNB certifications for measuring the sustainability of buildings and urban areas<br>*GPP procedure* Few innovative partnerships (mostly open, competitive dialogue, or closed); some market dialogue but not within a larger strategy; one successful, larger event for all actors in the value chain (e.g., suppliers demonstrating equipment)<br>*GPP method* Assessment criteria usually 60% to 70% price, 20% environment, and 10% traffic<br>*IE orchestration* Dense connections between key actors, particularly builders, ranging from large public builders to small businesses; knowledge perpetually shared between internal stakeholders within the city and with surrounding cities; ongoing cooperation forums allow actors to develop a "shorthand" with other actors, facilitating the development of mature EZEMCONS; knowledge sharing and increased cooperation with Oslo |
| Helsinki | Environment policy stipulates that all procurement processes must include environmental criteria; responsible procurement group creates strategies focusing on environmental aspects and aims of programs (e.g., Carbon–Neutral Helsinki 2035 Action Plan); procurement strategies for different levels (e.g., city procurement strategy, Urban Environment Division's strategy for sustainability)<br>*GPP procedure* Mostly open; some negotiation and competitive dialogues, and, to a lesser degree, innovation partnerships and alliance models<br>*GPP method* Housing sector has a sustainable residential construction procedure based on the RTS Environmental Classification; ~ 50% of procurements include environmental criteria; new criteria are added on a case-by-case basis; city aiming for greener PPs; some testing of LCC and carbon footprinting; some market dialogue (open meetings and sometimes surveys) but not always including environmental aspects<br>*IE orchestration* Underpinned by machine bureaucracy that connects government departments and third-party knowledge organizations; loose engagement and information flow with a broader group of actors in EZEMCONS, including innovation intermediaries, small businesses, and research institutions |
| Trondheim | New environmental requirements and criteria for constructions currently being finished<br>*GPP procedure* Mostly open, occasionally negotiation; innovative partnerships not commonly used; the need for pre-tender market dialogue being considered to assess the market situation and obtain feedback from suppliers about the intended procurement approach (e.g., how to apply environmental requirements); no established dialogue strategy<br>*GPP method* "Best value procurement" and "total costs of ownership" used to some extent; 70% cost and 30% quality or guarantee on technical inspection; no specific weight for environmental-related criteria (usually 12.5% for building projects); a larger weight of environmental criteria for PP is expected in the future<br>*IE orchestration* A dense network of key actors in EZEMCONS, particularly builders and energy infrastructure/suppliers; knowledge is shared between internal stakeholders within the city and other cities; wide range of actors involved in early market dialogues allows healthy information flow, aiding the development of EZEMCONS; knowledge sharing and increased cooperation with Tensio (energy supply and infrastructure); wide range of (third-party) environmental agencies |

*IE* innovation ecosystem, *PP* public procurement, *GPP* green public procurement, *ZEMCONS* zero-emission construction sites, *LCC* life cycle cost, *EZEMCONS* ecosystems for zero-emission construction sites

The cities typically employ different EU PP procedures, but the traditional methods, in particular the open bidding procedure seem to dominate. At the same time, each of the cities also mentions the use of alternative procedures and some form of dialogue with market partners. When awarding contracts (as part of GPP method), none of the cities purely awards solely on price, but the inclusion of environmental criteria differs among the cities. Each of the cities can be said to either have started to develop knowledge about it (e.g., exploring the use of life cycle cost (LCC)) or using environmental award criteria to some extent. Regarding IE orchestration, the cities exhibit varying degrees of how comprehensive and dense the connections between different ecosystem actors are, but again, each city at least operates with a certain level of orchestration activity toward some external actors, for example intermediaries, small business and research institutions.

We present the following typology (Table 5) from the findings (Table 4) to improve shared learning for other cities regarding GPP and EZEMCONS:

Across the four cities, the following summary of actions was observed. Trondheim has begun the electrifying process of construction machinery with several pilot projects in the cities, and Helsinki began its first pilot project in 2020. Budapest does not own any fossil-free or fossil-lower emission/hybrid/electrical NRMM; however, some utility

**Table 5** Public procurement typology for EZEMCONS

| | PP strategies and key features | IE orchestration |
|---|---|---|
| GPP procedure | Open—with negotiations<br>Innovation partnerships<br>Market dialogues<br>Competitive dialogues<br>Alliance models<br>Feedback from suppliers | Flat hierarchy for connecting departments<br>Dense connections between key actors (builders)<br>Broad network of key actors in EZEMCONS<br>Ongoing cooperation |
| GPP method | Best value procurement<br>Assessment criteria<br>Total costs of ownership<br>Environmental classification<br>Focus groups<br>Surveys | Loose engagement and knowledge sharing<br>Cooperation forums with stakeholders<br>Dependent on the form of bureaucracy<br>Knowledge shared between internal stakeholders |

companies owned by the city do possess such equipment. Copenhagen does not have a policy regarding low-/zero-emission NRMM; however, there is a "spearhead" project regarding NRMM in the city's climate plan. Helsinki planned to have its first zero-emissions construction site pilot by 2020, aiming to increase the use of electrical machinery. In Trondheim, NRMM accounts for approximately 20% of the total direct emissions in the city. Currently, Trondheim has a few fossil-/-emission-free construction sites and a few electrical NRMMs (but these are not for construction purposes).

## 6 Findings: barriers and drivers

Construction sites are a significant contributor to air pollution and GHG emissions, especially in urban areas. According to this study's observations and interviews, the four cities have already raised awareness about the importance of reducing emissions from construction site machinery and have implemented greener construction measures in varying degrees. Through innovation ecosystem theory, it was observed that the cities have different approaches to their functions as intermediaries and, in turn, how they orchestrate complementary actors and knowledge sharing in the system. This influences the effectiveness of information flow and readiness of cities' low-emission machinery infrastructure, connectivity for builders, and cooperation through early market dialogues. While the conceptual model (Fig. 2) illustrates the common denominators for orchestrating EZEMCONS there are differing barriers and critical success factors between the cities.

Zero-emission construction machinery is a more environmentally sustainable solution for construction projects; however, it is still relatively new and expensive. Further, it requires sufficient energy supplies at construction sites. Based on the interviews in this study, the four cities have identified several barriers to adopting zero-emission construction machinery. The first barrier concerns high costs (Budapest, Copenhagen, and Trondheim), which are related to the expense of the machine itself; it can also be costly if the machine uses biofuel (Copenhagen and Helsinki). The high cost of the machinery also leads to a limited market because few buyers or procurers can afford it (Budapest).

Second, the technical barriers are critical (Budapest and Trondheim). The Budapest representatives mentioned the technical barriers of using low-/zero-emission construction machinery, and the lack of relevant knowledge can be challenging. The high technical barriers also lead to a limited number of electrical machinery suppliers in the market (Copenhagen and Helsinki), and it may be anticompetitive when there are few suppliers (Budapest).

Third, low-emission construction machinery requires local infrastructure support (Helsinki and Trondheim). When the demand increases, the charging infrastructure in the construction sites and their expenses can also increase (Helsinki). Further, not all construction sites have access to high-voltage power supplies; thus, the lack of infrastructure can be problematic (Trondheim). This barrier also applies to biofuel machinery: the site may encounter biofuel delivery problems, especially if the demand increases (Helsinki).

Finally, public authorities have a critical role in overcoming these barriers (Budapest, Helsinki, and Trondheim). Political cooperation is required to adopt innovative solutions (Budapest), and strong political will from local authorities is critical (Trondheim). Moreover, adopting low-/zero-emission machinery means that the local procurement department must adjust its current procurement strategy to include related criteria in the procurement process (Helsinki and Trondheim).

Some critical success factors were identified in the interviews in this study (see Table 6). First, raising awareness of the market and decision-makers about ZEMCONS is critical for adopting zero-emission machinery (Budapest). It is important to emphasize the advantages of ZEMCONS to local authorities and the market, such as the economic gains, reducing GHG emissions, and decreasing construction site noises (Copenhagen). Second, local contractors must

**Table 6** Barriers and critical success factors

| Cities | Barriers and CSF |
|---|---|
| Budapest | *Barriers* Limited market, technology, lack of knowledge, and anticompetitive environments (few companies have non-emission NRMMs in Hungary)<br>*CSF:* raising awareness (for the market and decision-makers) |
| Copenhagen | *Barriers* High costs, political cooperation, and limited suppliers of electrical machinery<br>*CSF:* economic gains, reducing GHG emissions and construction site noise, and considering local contractors |
| Helsinki | *Barriers* High biofuel costs, possible biofuel delivery problems (especially when demands increase), lack of electrical machinery, sourcing electrical machinery, charging infrastructure, and related expenses<br>*CSF* Using market dialogues to determine possibilities for the market and testing different procurement methods |
| Trondheim | *Barriers* Lack of infrastructure, costs of NRMM, political cooperation, new procurement routines, and technology |

*CSF* critical success factors, *NRMM* non-road mobile machinery, *GHG* greenhouse gas

be considered for promoting ZEMCONS to increase local competitiveness (Copenhagen). Third, effective market dialogues with suppliers are an efficient way of discovering the possibilities in the market (Helsinki). Moreover, sustainable PPs can be an excellent way to promote zero-emission construction machinery.

### 6.1 Summary of findings

The case study analysis identified that cities may have lower practical GPP competence than larger building companies, mainly because they have limited resources and expertise in the field (although this is increasing). Consequently, environmental considerations are prioritized less frequently. In practical terms, this observation is a barrier to formulating environmental requirements and criteria and assessing the procurement's environmental impacts. This finding indicates that cities should consider the client's size when selecting potential actors for construction projects (directly or indirectly). Similarly, cities can encourage and facilitate increasing the competencies of builders and contractors, regardless of their size. However, builders and contractors must have a satisfactory degree of dynamic capabilities to adapt to a changing environment in their daily operations.

## 7 Discussion

By adopting a multiple case study approach and applying the PPI model by Shin et al. (2020), this study aimed to aid in the development of mature EZEMCONS and extend the GPP literature. While it was observed that each city encountered challenges regarding EZEMCONS, there were also some common denominators. The findings suggest that cities can improve their low-emission machinery infrastructure, connectivity between builders, and cooperation through early market dialogues.

Our findings illustrate that Shin et al.'s (2020) model is highly relevant for an EZEMCONS analysis as it builds on PP as mission-oriented innovation systems policy (Edquist and Zabala-Iturriagagoitia 2012; Edquist et al. 2015). Adopting this systemic model, we were able to better generalize the system-wide impacts of EZEMCONS, and undertake a systematic assessment of the relevant methods and procedures. Furthermore, it informed our own model, and as a result, the IE orchestration of future EZEMCONS projects with explanations of both barriers and opportunities. With this conceptual framework, our contribution aids policymakers and researchers to identify barriers and opportunities for both socio-technical and system transitions pertaining to EZEMCONS (Lingegård et al. 2021; Sourani and Sohail 2011; Trindade et al. 2017; Vejaratnam et al. 2020), and, as such, help tailor policy interventions to overcome system failures when designing and implementing EZEMCONS policies in the future (Shin et al. 2020).

The study examined both the direct and indirect effects of GPPs in the innovation ecosystem. A city's supply chain can be used to directly influence a public client's contract choices. GPP can be an effective tool for creating direct market demands to encourage potential suppliers to invest in research and development and production innovation (Shin et al. 2020). Cities with purchasing powers can apply PPI schemes to reduce the market uncertainty of future demands on ZEMCONS to encourage strong commitments from builders to invest in electric NRMM and other machinery. Further, by establishing pilot testing of ZEMCONS, cities can raise awareness and receive feedback from builders and contractors, which can also encourage suppliers.

The study showed that early market dialogues with builders and contractors are the most used tool for direct effects. In this context, a green-focused contractor should have almost as much influence as a public developer. If a builder cannot directly influence a contract in an early market dialogue, the dialogue with EZEMCONS actors can still be considered for discussing the advantages and disadvantages of different implementation models. If there are no possibilities via traditional supply chain actors, an alternative is establishing relationships with green contractors using innovation intermediaries.

Regarding indirect effects, the study found that supply chain actors can collaborate with other green-focused actors to influence supply chain actors (or third parties) with overlapping interests and, thus, public actors. This is because existing relationships have been identified within EZEMCONS. However, an even more frequent theme for indirect influence was various innovation intermediary engagements. This was observed mainly in Trondheim and Copenhagen, where the former acted as an intermediary by engaging large numbers of key infrastructure actors and the latter engaged in ongoing interactions with key actors within the innovation ecosystem. Both successfully included imperative actors from academia, public institutions, builders, governments, small businesses, and independent contractors. However, the effects and factors involved in these engagements need to be studied further.

Regarding which method was most effective, it can be argued that the cities with direct influence had better control over the message expressed than those with indirect influence. This requires that cities have direct relationships with the relevant green actors, which can be challenging to achieve, as the case studies have illustrated. Conversely, it can be argued that indirect influence can be more effective than direct influence. The case studies show that this applies, for example, when a city has been involved in influencing a public client's environmental ambitions through interactions arranged by an intermediary. Given that the city has either a weak or non-existent relationship with the green actor, this example illustrates how indirect influence can be more effective than direct influence. The observations regarding the effectiveness of indirect relationships strengthen this case for applying an innovation ecosystem framework because it enables the actors to capture such links.

Another aspect of the various methods of influence that does not emerge from the framework is that the methods will, to varying degrees, be resource-intensive for the cities. This applies to both direct and indirect methods. For example, the data showed that early market dialogues with a broad number of actors in the ecosystem are time-consuming because of planning, execution, and follow-ups. How resource-intensive the work is for the city may be related to how resource-intensive the use of GPP is for public actors and vice versa.

The findings also showed that construction project procurements might involve many departments, functional areas, management, and political levels in the city, increasing the complexity of the innovation ecosystem. First, cities should map the ecosystem locally and devise a dependable roadmap for achieving mature EZEMCONS. Second, cities must be eager to learn from each other and share experiences (peer-to-peer learning) at the technical/environmental adviser and political leadership levels, constituting a higher-level national or international ecosystem.

## 8 Conclusions, limitations and further research

Despite clear progress in reducing emissions related to construction sites and using NRMMs in the EU, there has been no trend toward lower GHG emissions in the EU for the past 10 years. Therefore, there is a clear need to address this emission category, which requires a shift from fossil-fuel-driven propulsion technology to technology using renewables, such as electricity, biogas, or hydrogen. This study revealed that accurate emissions measures from construction projects are lacking. Although the NRMM emissions category is a reasonable indicator, it does not necessarily only measure emissions from construction sites but also includes the use of NRMM in other areas. Further, the measures are typically available nationally and not immediately available for individual cities. There is also a need to develop more precise and local measurement systems, as expressed by the representatives from Trondheim; thus, aiding the process of developing key information flow and knowledge sharing between entities within cities and externally.

The four cities in the project had sustainability strategies and, as part of those strategies, a focus on reducing GHG emissions but not necessarily on using NRMM on a large scale. The cities had also started including environmental criteria in their PP practices for construction projects, and several cities had begun using different forms of dialogue with the ecosystem actors, albeit to a varying extent. Regarding the realization of ZEMCONS, the experience is limited to Trondheim and Copenhagen; however, Helsinki has projects planned in the coming years, and Budapest expressed a clear intention to develop its capabilities. The findings suggested that dialogues with the wider innovation ecosystem are essential for successful procurement processes aimed at achieving ZEMCONS.

The innovation ecosystem perspective for ZEMCONS proposed by this article provides the cities a method to unfold not only the supply chain, but also strategic information, potential opportunities, barriers, and risk. By taking a holistic and dynamic view of the whole ecosystem, the cities can identify actors that influence the EZEMCONS both directly and indirectly, and the relational paths among them (Stokke et al. 2022). The EZEMCONS perspective also introduces the "loose" ecosystem relationships, which offers an experimental arena where innovations are developed in response to project requirements. Comparing to traditional supply chain management strategies, the innovation ecosystem perspective emphasize the loose and temporary coalitions, which can lower the threshold for initiating ZEMCONS projects.

The findings, combined with cities' views on the perceived barriers and drivers of achieving ZEMCONS, underline the importance of a larger ecosystem perspective, connecting internal and external stakeholders. This study has demonstrated that cities' most important measures are improving low-emission machinery infrastructures, networking for builders, and cooperation through early market dialogues. While this study contributes to PP research and EZEMCONS policy implementations, we also recognize certain limitations of the work and some areas that require further research. This study selected four European cities; however, it was challenging to generalize policies and managerial implications to larger regional and national areas, partly because EZEMCONS is a nascent field with varying degrees of equipment availabilities and best-practice guidelines. We believe, however, that our methodology may provide a good basis for further replication and validation by other researchers focusing on similar, but other cities. Also, due to limited resources, we interviewed some of the key actors involved in the EZEMCONS work in the cities, and overall, we captured a variety of functions and departments, but surely other interviewees from other departments could have shed more light on the matters discussed. More clear and direct pathways to orchestrating EZEMCONS can be drawn from future research as it becomes more mature and prevalent in cities throughout Europe and the world. It may also be useful to examine the relationships between ecosystem actors and procurement practices to help policymakers estimate the effects on green construction practices more precisely.

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## Declarations

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