



# Embedding co-production of nature-based solutions in urban governance: Emerging co-production capacities in three European cities

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## ABSTRACT

This paper seeks to understand how co-production can become embedded as a collaborative governance practice by which city governments plan, deliver and steward nature-based solutions. To these ends, the paper analyses how policy officers manifest capacities for co-production in three European cities – Genk (Belgium), Glasgow (United Kingdom) and Poznań (Poland) – while experimenting with co-production to develop and scale nature-based solutions. Co-production capacities include conditions and activities to (1) create space for co-production, (2) safeguard inclusive and legitimate co-production, and (3) link co-production processes and results to contexts. The results demonstrate how policy officers in the three cities have mobilised and created resources, skills, institutional support and partnerships to implement diverse processes to co-produce nature-based solutions. While these conditions mark starting changes in urban governance, engaging with and embedding co-production causes tensions between the dynamic and diffuse nature of co-production and existing formal governance settings and processes. Lessons for strengthening the capacities to embed co-production as a collaborative governance practice in nature-based solutions planning, delivery and stewardship are: (1) embedding a tailor-made approach for inclusive co-production to meaningfully engage diverse actors in place-based settings, (2) embedding open-ended co-production with long-term benefits, and (3) embedding new relations and roles to sustain co-production.

## 1. Introduction

Co-production is booming as a mode of collaborative governance to develop and implement nature-based solutions in cities (Langemeyer and Baró, 2021; DeLosRíos-White et al., 2020; Mees et al., 2018; van der Jagt et al., 2019; Fors et al., 2021). Nature-based solutions refer to innovative and cost-effective solutions bringing more and more diverse

nature and natural features and processes into cities for dealing with multiple urban sustainability challenges simultaneously (Raymond et al., 2017; Connop et al., 2016; IPBES, 2019; European Commission, 2015). Co-production is premised to help urban policy officers deal with the complexities of nature-based solutions, as well as to engage and activate citizens' ideas and knowledge for restoring and reconnecting with nature in cities (Kabisch et al., 2022; Frantzeskaki, 2019; Basnou

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et al., 2020). Co-producing nature-based solutions can contribute to a broader transformation of urban governance by facilitating continuous engagement, empowerment, and co-stewardship (Guemes and Jorge, 2019; Boothroyd et al., 2017).

Despite these promises, co-production is not yet a common urban governance practice, and presents several challenges to policy officers who aim use it for nature-based solutions planning, delivery and stewardship. Co-production is neither a ready-made nor easy-to-implement approach and relates to ambiguous definitions and diverse manifestations such as urban living labs or real-world laboratories (Ascione et al., 2021; Bulkeley et al., 2016; Nesti 2017). Particularly when co-production is led by policy officials, there is a risk that it mirrors existing ills of incumbent urban governance settings like prioritisation of expert knowledge and focus on short-term results (Brandsen et al., 2018; Sorrentino et al., 2018; Hölscher and Wittmayer, 2018). Most co-production interventions take temporary, project-based forms focused on specific, mostly design-related aspects of nature-based solutions implementation, rather than considering how to enable lasting partnerships and continuing engagement (Zingraff-Hamed et al., 2020; Basnou et al., 2020; Jaspers and Steen, 2019). Past experiences show that co-production, if not properly implemented, risks reinforcing participation fatigue, limited representation and power imbalances (Turnhout et al., 2020; Wamsler et al., 2020; Bussu and Galanti, 2018; Muñoz-Erickson et al., 2017).

This paper aims to understand how co-production can become embedded as a collaborative governance practice for planning, delivering and stewarding nature-based solutions in cities. Existing research that provides guidelines and checklists for facilitation, participant selection and communication (Reed et al., 2014; Frantzeskaki, 2022; Jansen and Pieters, 2017) does not identify how urban policy officers can develop the type of institutions, skills, and organisational resources needed to make co-production a viable approach (Turnhout et al., 2020; Cousin, 2021; Howlett and Ramesh, 2017). A particular concern is sustaining co-production as a continuous collaborative process by which city governments involve differing and diverse groups of actors for lasting collective stewardship as well as in processes of scaling nature-based solutions (Jaspers and Steen, 2019). Embedding co-production requires attention to the changes necessary to support the design and implementation of co-production, including not only technical knowledge and dedicated funds, but also in terms of how problems are defined, solutions are sought and new organisational hierarchies towards shared responsibility (Torfing et al., 2019; Hölscher et al., 2019a; Brandsen and Honingh, 2018). Indeed, research has shown that experiences with novel co-production practices and tools cultivate institutional structures and cultures, expertise, and relations supporting co-production (Hölscher et al., 2023; Malekpour et al., 2021; Schraam et al., 2018; Krkoška Lorencová et al., 2021). Thus, embedding co-production requires a process-based understanding of the ongoing, incremental processes of creating and re-forming the institutional and organisational conditions of existing governance arrangements that determine how nature-based solutions are planned, delivered and stewarded in cities.

The research objective is addressed by examining how policy officers in three middle-sized European cities – Genk (Belgium), Glasgow (United Kingdom) and Poznań (Poland) – have experimented with co-production of nature-based solutions, and, in doing so, have revealed, nurtured and built governance conditions that manifest in capacities for co-production. Section 2 presents three capacities for co-production that encompass distinct governance conditions supporting the co-production of nature-based solutions, as well as the activities by which policy officers mobilise and create them. Section 3 describes the method for analysing and comparing whether and how co-production capacities are emerging in the three cities. Section 4 presents the findings on how policy officers in the three Genk, Glasgow and Poznań have materialised and developed capacities for co-production. Section 5 discusses lessons and research directions for embedding co-production in governance

capacities. Section 6 concludes on the future of co-production as a mode of collaborative governance for nature-based solutions.

## 2. Capacities for co-producing nature-based solutions

This section defines co-production as a mode of collaborative governance for nature-based solutions planning, delivery and stewardship, and outlines three capacities that facilitate co-production, and that provide a direction for its embedding in urban governance.

### 2.1. Co-production of nature-based solutions as collaborative governance mode

It is widely understood that nature-based solutions rely on collaborative governance shared between inter- and transdisciplinary urban actors (Frantzeskaki et al., 2023; Kabisch et al., 2022; Malekpour et al., 2021; Ossola and Niemela, 2018). Collaborative governance refers to “governing arrangements where one or more public agencies directly engage non-state stakeholders in a collective decision-making process” (Ansell and Gash 2008: 544). Collaborative governance approaches buttress the principles of nature-based solutions: bringing together diverse stakeholders harbouring different forms of – otherwise fragmented – knowledge and resources can generate new knowledge, solutions and partnerships that align nature-based solutions with environmental, political, social and economic needs and priorities (Dorst et al., 2022; Kabisch et al., 2017).

Co-production is a distinct mode of collaborative governance, because it targets the joint production of a concrete public service. Public administration and environmental governance literatures define co-production as “the interactive process through which the providers and users of public services apply their different resources and capabilities in its production and delivery” (Torfing et al., 2019: 802). The co-production of nature-based solutions encompasses the production of their technical, ecological, social, economic and institutional components and the multiple services they provide (e.g. mental health, storm water retention) (ibid.). This makes co-production different from co-creation, because the objectives (i.e., nature-based solutions) are pre-defined, while concrete characteristics and (all) the types of services are not (cf. Brandsen and Honingh, 2018). The co-production of nature-based solutions and their services can facilitate context-sensitive and inclusive approaches that incorporate user demands and needs and deliver multiple benefits in an equitable way (Cousin, 2021; Basnou et al., 2020; Zingraff-Hamed et al., 2020; Frantzeskaki, 2019).

As a specific mode of collaborative governance, co-production goes beyond mere participation and emphasises the active engagement of diverse actors that provide and use public services, including practitioners, civil servants, entrepreneurs, scientists, and citizens. It involves creating ‘activity spaces’ for social learning, whereby participants collectively shape discourses, imaginaries and solutions (Cousin, 2021; Jaspers and Steen, 2019; Puerari et al., 2018). Thus, in co-producing nature-based solutions, new relationships are fostered and community actors can be activated and empowered to take active roles in developing and managing nature-based solutions (Jaspers and Steen, 2019; Brix et al., 2020; Guemes and Jorge, 2019; Boothroyd et al., 2017).

Rather than being a one-off intervention, co-production as a collaborative governance mode includes a plurality of interventions and processes that continuously engage different and differing (groups of) actors in alignment with an overarching strategy for nature-based solutions planning, delivery and stewardship (Hölscher et al., 2022a; Collier et al., 2023; Mahmoud and Morello, 2021). For instance, urban living labs are particularly used for the planning phase, and collaborative monitoring approaches during stewardship (cf. van der Jagt et al., 2022; Raymond et al., 2017). The diversity of co-production processes in Genk, Glasgow and Poznań resonates the understanding of co-production as a collection of processes, including different sets of actors, for different phases and scales of nature-based solutions implementation. The different processes

were inductively clustered into strategic, tactical and operational co-production processes, which address different goals, corresponding governance settings and actors involved (Loorbach, 2010; Frantzeskaki et al., 2014). *Strategic* co-production was used in the cities to develop strategic agendas for nature-based solutions at the city level and connect these to broader city strategies and agendas across sectors and associated departmental siloes. *Tactical* co-production is evident in the cities' efforts to specify action agendas and establish governing arrangements for the coordination of context-specific nature-based solutions implementation. *Operational* co-production includes the planning, delivery and stewardship of concrete nature-based solutions.

2.2. Embedding co-production: co-production capacities

As a mode of collaborative governance, city governments play key roles in setting up and leading the co-production of nature-based solutions, yet there is often insufficient institutional leeway and agility to account for the time investments and allow for more open discussions about designs, intended services and ways of provisioning (Brandsen et al., 2018; Sorrentino et al., 2018; Hölscher et al., 2019a). Enabling policy officers to engage with co-production therefore requires the embedding of co-production into urban governance mechanisms, procedures, and organisational resources (Adams et al., 2023; Chatterton et al., 2018).

Capacities for co-production are defined as ‘the abilities of actors to mobilise, develop and change the conditions (e.g. organisational resources, institutional settings, knowledge, skills, partnerships) that enable the design and implementation of co-production’ (cf. Hölscher et al., 2019b; Hölscher, 2020). This understanding differs from that of van Kerkhoff and Lebel (2015) and Wyborn (2015), who define ‘coproductive capacities’ solely as the context conditions (e.g., scientific resources, cognitive capabilities) that support collaborative work. Rather, capacities are emergent properties, which are uncovered, nurtured or developed by policy officers acting as institutional entrepreneurs to incrementally incorporate co-production into urban governance instruments and regulations, skills and networks (Hölscher et al., 2023). As thus, co-production capacities are both an enabler and outcome of co-production: they manifest in and are reinforced through the activities and learning processes by which policy officers interact with their contexts to materialise co-production, and, by doing so, embed co-production in changing urban governance structures, cultures and practices (cf. Chatterton et al., 2018; Hölscher, 2018). The capacities represent collective and context-dependent properties, resulting from specific contexts’ needs, institutional arrangements, and cultures as well as the skills and capabilities of all actors involved (cf. Howlett and Ramesh, 2017; Sorrentino et al., 2018).

Table 1 presents three capacities for co-production with corresponding enabling conditions and activities to create and mobilise them. The capacities are grounded in co-production theory and practice: they were iterated with the co-production experiences and lessons of policy officers experimenting with co-production of nature-based solutions in Genk, Glasgow and Poznań (see Section 3). The framework was used to facilitate and trace the learning of the policy officers in experimenting with co-production, by exploring the existing conditions for co-production in the cities, identifying how to address barriers and opportunities for co-production, and structuring continuous reflections on lessons with the cities.

The first capacity is about *creating institutional space for co-production*, i.e. the ability to develop and mobilise political and institutional support, including resources, for designing and implementing co-production as a mode of collaborative governance that is embedded in urban policy and planning. Co-production processes require substantial resources (e.g. financial, time, infrastructure) to effectively engage with participants, organise venues (including e.g. ICT infrastructure), analyse discussions and follow-up on agreements (Frantzeskaki, 2022; Jaspers and Steen, 2019; Chatterton et al., 2018). Since co-production departs from conventional policy and planning processes, supportive

**Table 1**  
Capacities and corresponding enabling conditions and activities for co-production.

| Capacity for co-production                           | Enabling conditions, associated activities and supporting sources                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                   |
|------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Create institutional space for co-production         | <b>Awareness about (benefits of) co-production:</b> Communicating co-production goals and benefits for policy and planning goals (e.g. making use of momentum and opportunities and inviting decision-makers to experience co-production) (Bussu and Galanti, 2018; Muñoz-Erickson et al., 2017; Chatterton et al., 2018; Voorberg et al. 2014; Hölscher, 2018; Ferlie et al., 2019)<br><b>Goals and procedures for co-production in policy and planning processes:</b> Defining goals and procedures for using co-production as part of policy and planning processes (e.g. making co-production part of policy programmes, clarifying roles and responsibilities) (Bussu and Galanti, 2018; Wamsler, 2017; Ferlie et al., 2019; Torrens and von Wirth, 2021)<br><b>Resources (funding, infrastructure):</b> Identifying, mobilising and providing funding sources (e.g. grants, existing project opportunities) for preparation, implementation, adaptations, and follow-up (e.g. ICT infrastructure, spaces for engagement)) (Frantzeskaki, 2022; Boros and Mahmoud, 2021; Jaspers and Steen, 2019; Brandsen et al., 2018; Sorrentino et al., 2018; Ferlie et al., 2019; Hölscher et al., 2018; Wamsler, 2017; Reed et al., 2014)<br><b>Skills for design, organisation and facilitation:</b> Mobilising and investing in co-production skills to engage actors, facilitate knowledge exchange and integration, and mediate conflicts (e.g. establishing institutional position for co-production, hiring external partners with the skill set needed, providing training) (Frantzeskaki, 2022; Djenontin and Meadow, 2018; Bussu and Galanti, 2018; Chatterton et al., 2018; Muñoz-Erickson et al., 2017; Ferlie et al., 2019)<br><b>Procedures and methods for inclusive and transparent process designs and facilitation:</b> Ensuring representation of diversity of actors for candid and constructive exchange (e.g. identifying actor selection criteria with attention to ‘voiceless’ or disadvantaged actors, co-defining goals, rules, responsibilities, tailoring process to different needs and capabilities) (Zingraff-Hamed et al., 2020; Basnou et al., 2020; Bussu and Galanti, 2018; Ferlie et al., 2019; Chatterton et al., 2018; van der Jagt et al., 2019; Hölscher et al., 2018; Turnhout et al., 2020; Dentoni et al., 2016; Voorberg et al. 2014; Reed and Abernethy, 2018; Djenontin and Meadow, 2018; Miller and Wyborn, 2018)<br><b>Adaptability:</b> Allocating time, space and methods to continually reflect on, deliberate and adjust assumptions and goals, process implementation, barriers and opportunities and necessary adaptations (Miller and Wyborn, 2018; Muñoz-Erickson et al., 2017; Frantzeskaki and Kabisch, 2016; Ferlie et al., 2019; Puerari et al., 2018; Djenontin and Meadow, 2018; Chatterton et al., 2018; Djenontin and Meadow, 2018)<br><b>Knowledge about and relations with diverse urban communities:</b> Building and harnessing relationships with local communities and identifying links to urban needs, strategies, agendas, initiatives (e.g. by conducting field visits, studies) (Ferlie et al., 2019; Jaspers and Steen, 2019; Hölscher, 2018; Hölscher et al., 2019a; Muñoz-Erickson et al., 2017; Chatterton |
| Safeguard inclusive and legitimate co-production     |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |
| Link co-production processes and results to contexts |                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                     |

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Table 1 (continued)

| Capacity for co-production | Enabling conditions, associated activities and supporting sources                                                                                                                                                                                                                                                                                                                                                                                                                                              |
|----------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|                            | et al., 2018; Campbell et al., 2016; Reed et al., 2014)                                                                                                                                                                                                                                                                                                                                                                                                                                                        |
|                            | <b>(Continued) societal support for co-production process and results:</b> Showcasing and disseminating co-production process and results tailored and accessible to different target audiences, participating in and hosting engagement, networking, best practice, and knowledge exchange events (Djenontin and Meadow, 2018; Hölscher, 2018; Mahmoud and Morello, 2021)                                                                                                                                     |
|                            | <b>Partnerships for (lasting) place-based engagement:</b> Establishing and nurturing (capabilities of) formal and informal networks, platforms and partnerships to (continuously) build trust and social relations, and engage in mutually beneficial exchange, participatory management and maintenance (Frantzeskaki et al., 2023; Frantzeskaki and Kabisch, 2016; Chatterton et al., 2018; Hölscher, 2018; Jaspers and Steen, 2019; Mahmoud and Morello, 2021; Jaspers and Steen, 2019; Buijs et al., 2018) |

institutional structures and mindsets for collaborative work, including awareness about the benefits of co-production and clear goals of co-production for policy and planning, are essential to secure resources, protect co-production from political pressures, and allow flexibility for iterative engagement (Sorrentino et al., 2018; Bussu and Galanti, 2018; Voorberg et al., 2014; Hölscher, 2018).

The *capacity to safeguard inclusive and legitimate co-production* refers to the ability to comply with procedural standards to ensure that diverse actors are involved on an equal basis, with the aim to explicitly go beyond the ‘usual suspects’ and include disadvantaged and ‘voiceless’ actors (e.g. nature, future generations) (Frantzeskaki and Kabisch, 2016; Djenontin and Meadow, 2018; Ferlie et al., 2019). This demands a dedicated skill-set to reach out to and facilitate constructive exchange between diverse actors (Frantzeskaki, 2022; Djenontin and Meadow, 2018), as well as procedures and methods to systematically identify relevant actors (van der Jagt et al., 2019; Zingraff-Hamed et al., 2020), questioning who has access and which capabilities to participate. Transparent process designs tailored to capabilities of actors ensure clarity about purpose, procedures, roles and results and nurture trust and ownership (Campbell et al., 2016; Reed and Abernethy, 2018; Ferlie et al., 2019). Adaptability allows responding to new insights, demands and needs by continuously reflecting about goals, rules, actors involved, engagement methods or meeting schedules (Basnou et al., 2020; Reed et al., 2014; Dentoni et al., 2016). This remains relevant in the stewardship phase, which requires ongoing adaptation of co-production for participatory management and maintenance of the nature-based solution to continuously changing contexts (Collier et al., 2023).

The *capacity to link co-production processes and results to contexts* manifests in the ability to ensure (lasting) societal relevance of the co-production process and results. This addresses the need to position the contents of co-production processes in (e.g. institutional, cultural, political, socio-economic, technological) contexts, such as local needs, neighbourhood characteristics, land-use regulations, and ongoing community-based initiatives and projects (Reed et al., 2014; Chatterton et al., 2018; Campbell et al., 2016). Co-production processes and their results need to gain wide societal support to ensure salience and continued engagement in using and stewarding nature-based solutions (Mahmoud and Morello, 2021; Hölscher, 2018; Reed et al., 2014; Djenontin and Meadow, 2018; Frantzeskaki, 2019). Explicit attention is needed to develop and sustain (new) forms of collaboration and partnerships to (continuously) build trust and social relations, and engage in mutually beneficial exchange, participatory management and

maintenance (Frantzeskaki et al., 2023; Jaspers and Steen, 2019; Mahmoud and Morello, 2021; Chatterton et al., 2018).

### 3. Method

This section first introduces the three case studies and then describes how data was collected and analysed. The qualitative case study research was done in a highly collaborative and reflexive process between researchers and policy officers from the partnering city governments, in order to co-design the co-production processes and reflect on and learn from the experiences in the cities. This provided in-depth insights about how policy officers in the cities were able to engage with co-production and, in doing so, manifested co-production capacities.

#### 3.1. Case studies: co-producing nature-based solutions in Genk, Glasgow and Poznań

The research took place within the Connecting Nature project<sup>3</sup> that sought to scale nature-based solutions from innovating and implementation at a demonstration scale to widespread roll-out in European cities. The three cities were frontrunner city partners in the project, because of their demonstrated experience in nature-based solutions and commitment to scaling nature-based solutions in their policy and practice. To these ends, the three cities developed different types of nature-based interventions that form the basis for green urban networks (see Connop et al., 2021 for an overview of the nature-based solutions in the three cities).

Each city conducted diverse co-production processes to engage different urban actors in the development of specific nature-based solutions and their alignment with an overarching strategy of (city-wide) nature-based solutions design, delivery and stewardship (Table 2, Figs. 1–6, see Supplementary Material A for a detailed overview). We inductively clustered the diversity of co-production processes into strategic, tactical and operational processes (Section 2.1).

In Genk (Belgium, population around 65,000 capita), policy officers from the Department of Environment and Sustainable Development led the Stiemer programme to transform the Stiemer valley from a neglected corridor into a multi-functional blue-green urban valley. Co-production was used to collect knowledge, enhance social cohesion, nurture an enthusiastic community, and build partnerships for shaping the Stiemer valley together. Strategic co-production was implemented to develop the spatial masterplan of the valley, including different city departments, experts, and regional governmental institutions. Citizens were involved through diverse activities, including bicycle tours and neighbourhood dialogues. Tactical co-production sought to develop new partnerships and connections for the implementation of the Stiemer programme. For example, the ‘Friends of the Stiemer’ is a group of engaged citizens that serve as ambassadors of the programme and mediate between the city government and citizens. Operational co-production was conducted for four pilot projects to deliver the Stiemer programme vision: the ‘Gardens of Waterschei’ (restoration of a natural water system), ‘SUDS & SODA’ (rain gardens and other sustainable urban drainage systems (SuDS)), ‘Slagmolen’ (redesign of green-blue infrastructure, and redeveloping a former mill into an arts and information centre), and the ‘Valeiroute’ (active travel route through the valley).

The city of Glasgow (United Kingdom, population around 590,000 capita) focused on the development and implementation of its Open Space Strategy (OSS), which provides a vision of a well-connected and well-managed network of open spaces. Policy officers from the Council’s Development Plan Group implemented largely strategic and operational co-production to engage various stakeholders in the development of the OSS as well as its implementation through various local projects.

<sup>3</sup> [www.connectingnature.eu](http://www.connectingnature.eu)

**Table 2**

Overview of co-production processes in Genk (Belgium), Glasgow (United Kingdom) and Poznań (Poland).

| Co-production processes                                                 | Co-production settings & goals                                                                                                                                                                                 | Actors involved                                                                                                                                                                                                                                                                                                                                 |
|-------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Genk</b>                                                             |                                                                                                                                                                                                                |                                                                                                                                                                                                                                                                                                                                                 |
| Development of the spatial masterplan of the Stiemer valley (2016–2018) | <i>Strategic:</i> Developing the spatial masterplan of the Stiemer valley, and connecting it to the Stiemer programme and other city strategies                                                                | City departments, external experts, citizens, regional governmental institutions                                                                                                                                                                                                                                                                |
| Friends of the Stiemer (created in November 2018)                       | <i>Tactical:</i> Setting up public-private partnerships to collect ideas about goals and implementation, mobilise actors to participate, communicate and inform about citizen agenda                           | Citizens who are linked with the city government and external experts in advisory boards                                                                                                                                                                                                                                                        |
| Stiemer Deals (created in 2019, officially launched in September 2020)  | <i>Tactical:</i> Tailor-made voluntary agreements between stakeholders and the city of Genk to stimulate social innovation initiatives through which stakeholders take an active role in the Stiemer programme | Stakeholders (e.g. citizens, entrepreneurs, other city departments), Stiemer team (city of Genk)                                                                                                                                                                                                                                                |
| Gardens of Waterschei (Since September 2019, development still ongoing) | <i>Operational:</i> Develop design study to implement the vision on the Gardens of Waterschei                                                                                                                  | Economy Department (city of Genk), Stiemer team (city of Genk), nature conservation NGO, Friends of the Stiemer, citizens, Department of District Development (city of Genk), engineering company, entrepreneurs of the shopping street Stalenstraat, Thor Park Science and Business Park, Strategic City Development Department (city of Genk) |
| Junior Team idea generation (2018)                                      | <i>Operational:</i> Involve pupils (6th grade) in making the Stiemer child-friendly                                                                                                                            | Students (6th grade), Stiemer team (city of Genk), Youth Department (city of Genk), LUCA School of Arts                                                                                                                                                                                                                                         |
| Development of Schansbroek park (2013–2019, park was opened in 2019)    | <i>Operational:</i> Design neighbourhood park in the source area of the Stiemer                                                                                                                                | Citizens, city departments, neighbourhood managers                                                                                                                                                                                                                                                                                              |
| Re-development of Slagmolen (2016, development still ongoing)           | <i>Operational:</i> Re-development of Slagmolen area and the historic Slagmolen building                                                                                                                       | Experts, citizens, entrepreneurs, nature conservation NGO, city departments, regional landscape agency                                                                                                                                                                                                                                          |
| SUDS & SODA project (2021, ongoing)                                     | <i>Operational:</i> Implementing sustainable urban drainage systems for local water retention and reuse                                                                                                        | City departments, experts, citizens, designers, architects, Vlaamse Land Maatschappij                                                                                                                                                                                                                                                           |
| Stiemerlab project (2020–2022)                                          | <i>Operational:</i> a citizen science project in which scientists and citizens worked together to map the water quality of the Stiemerbeek by collecting data with sensors and taking water samples            | Stiemer team (city of Genk), LUCA School of Arts, VITO, CMK – Centre for Environmental Sciences (University of Hasselt), Flanders Environment Agency with support from the Flemish Government.                                                                                                                                                  |
| <b>Glasgow</b>                                                          |                                                                                                                                                                                                                |                                                                                                                                                                                                                                                                                                                                                 |
| Development of Open Space Strategy (OSS) (since 2009/2010,              | <i>Strategic:</i> Development of Open Space Strategy (OSS) for the                                                                                                                                             | Glasgow City Council (GCC) departments, Glasgow & Clyde Valley                                                                                                                                                                                                                                                                                  |

**Table 2 (continued)**

| Co-production processes                                                                                                   | Co-production settings & goals                                                                                                                                                                                                                                   | Actors involved                                                                                                                                                                                                                        |
|---------------------------------------------------------------------------------------------------------------------------|------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <i>officially approved in February 2020)</i>                                                                              | improvement and maintenance of open space, linking the OSS to on-going city strategies in Glasgow (e.g. Strategic Development Plan, Local Biodiversity Action Plan) and to different stakeholders                                                                | Green Network, Greenspace Scotland, Central Scotland Green Network, Scottish government, housing associations, Glasgow City Region, City Deal, National Heritage Council, citizens, politicians                                        |
| Friends of Parks Groups <sup>a</sup> (ongoing)                                                                            | <i>Tactical:</i> Link groups where citizens organise themselves to enhance local parks and open spaces, supported by GCC, to OSS                                                                                                                                 | Citizen groups, GCC                                                                                                                                                                                                                    |
| Pollok Park Transformation Project – Partnership Plan (Since November 2018, development ongoing)                          | <i>Tactical:</i> Develop Partnership Plan to engage local communities in the development of nature-based solutions in Pollok Park and build collaboration between the communities on the different sides of the park                                             | GCC, Green Space Scotland, Glasgow Life, citizens                                                                                                                                                                                      |
| Stalled Spaces (2010–2020)                                                                                                | <i>Operational:</i> Support community groups and local organisations across the city develop temporary projects on stalled sites or under-utilised open spaces                                                                                                   | GCC, community council, owners, local artists, community of interest                                                                                                                                                                   |
| Demonstration garden at Bellahouston Park (part of Food Growing Strategy) (opened in 2011, ongoing maintenance of garden) | <i>Operational:</i> Setting up demonstration garden in the walled garden at Bellahouston Park – feedback about social, environmental, health and economic benefits to inform Food Growing Strategy to address food poverty and growing demand for new allotments | GCC Neighbourhoods & Sustainability, charities, education establishments, citizens                                                                                                                                                     |
| Growchapel community garden in Drumchapel (part of Food Growing Strategy) (since 2018, launched in 2021)                  | <i>Operational:</i> Development of a community garden on a previously vacant and derelict site in Drumchapel                                                                                                                                                     | GCC departments, Greenspace Scotland, Drumchapel Police, education establishments, G15 Youth Group, local organisations (housing associations, social enterprises, health organisations, GP practice), citizens                        |
| <b>Poznań</b>                                                                                                             |                                                                                                                                                                                                                                                                  |                                                                                                                                                                                                                                        |
| Open garden in kindergarten no. 42 in the Wilda District (2017–2018, 21 <sup>st</sup> March 2018: official opening)       | <i>Operational:</i> Designing and implementing an open garden and natural playground at Kindergarten no. 42 in the Wilda District                                                                                                                                | Citizens, kindergarten directors, teachers, parents, children, Project Coordination and Urban Regeneration Office (city of Poznań), Department of Education (city of Poznań), architect, police, ecologists                            |
| Green Classroom (2020 planned but put on hold due to COVID-19, ongoing search for funding currently)                      | <i>Operational:</i> Developing a green classroom in one preschool so residents and children can have space to connect with nature during the winter period                                                                                                       | Project Coordination and Urban Regeneration Office (city of Poznań), preschool director, teachers, other preschools, district council, residents (including parents, children, senior residents), architects, interior designers, NGOs |

(continued on next page)

Table 2 (continued)

| Co-production processes                                                                        | Co-production settings & goals                                                                                      | Actors involved                                                                                                                                                                |
|------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| Partnerships for scaling nature-based solutions e.g. natural playgrounds (since 2019, ongoing) | Tactical: Selecting other kindergarten partners in order to implement and upscale natural playgrounds within Poznań | Project Coordination and Urban Regeneration Office (city of Poznań), Department of Education (city of Poznań), kindergarten directors and teachers, private actors (companies) |

<sup>a</sup><https://www.glasgow.gov.uk/article/19165/Friends-of-Parks-Groups>



Fig. 1. Stiemerlab: Scientists and citizens work together to take water samples of the Stiemerbeek (September 2020, photo credit: Boumediene Belbachier).



Fig. 2. Junior Team idea generation: the members of the Junior Team 2018 present their ideas on the Stiemervalley to other children, parents, the mayor, the alderwomen of youth and the local press (May 2018, photo credit: City of Genk).

Strategic co-production sought to develop the OSS by generating a vast knowledge base about open spaces in Glasgow, connecting nature-based solutions to multiple city agendas and breaking down internal silos within the GCC. Local communities and citizens were involved through online questionnaires and participatory data collection to identify and assess open spaces in the Open Space Map: an interactive map showing open spaces, their quality, and opportunities. Operational co-production with local communities and organisations took place within small-scale open space pilot projects – including Pollok Park, Growchapel



Fig. 3. Drumchapel community engagement (photo credit: Glasgow City Council)(



Fig. 4. Mosaic resulting from workshop in Growchapel, Glasgow (February 2020, photo credit: Sean Kelly).



Fig. 5. Visioning workshop with preschoolers in preschool no 87 in Poznań (June 2018, photo credit: City of Poznań).

community garden and the city’s Stalled Spaces programme – to develop locally contextualised nature-based solutions. Additionally, through tactical co-production, GCC aims to connect with existing ‘Friends of Parks’ groups that are local people who organise activities in open spaces to check quality assessments of open spaces and identify key priority areas and needs.

Poznań (Poland, population around 540,000 capita) aimed to

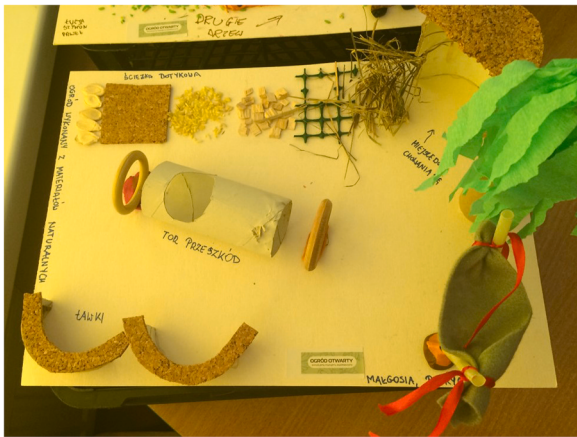


Fig. 6. Visioning in preschool no 42 in Poznań (September 2017, photo credit: City of Poznan).

develop and replicate small-scale nature-based solutions in different parts of the city to create a rich, accessible and multifunctional green network. The interventions focused on natural playgrounds – combinations of play equipment and elements of nature (e.g. sandy hills, live willow huts, green flowerbeds) – and open gardens – open to both kindergarten children and residents – in pre-schools. Policy officers from the city’s Project Coordination and Urban Regeneration Office organised operational co-production to involve stakeholder groups in the development, implementation and stewardship of open gardens and natural playgrounds. The open garden and natural playground in kindergarten no. 42 in the Wilda district was designed through workshops with architects, the police, ecologists, residents, kindergarten directors, teachers, parents, and children. Tactical co-production was put in place to develop partnerships with other kindergartens, the Department of Education as well as companies for replicating the nature-based solutions across the city. By now, 21 natural playgrounds have been installed.

3.2. Data collection and analysis

Between September 2017 and June 2021, researchers and policy officers from the three city governments worked closely together to iteratively design and implement co-production in the cities and derive lessons about what and how capacities for co-production were revealed, nurtured and developed. The collaborative research approach sought to co-develop the co-production processes that were undertaken by the policy officers in the cities, and to facilitate learning about opportunities encountered, challenges faced and lessons for implementing co-production. To these ends, four types of engagement and data collection activities were undertaken either between researchers and policy officers from one city, or between researchers and policy officers from all cities for peer-to-peer learning (Table 3, see Supplementary B for a detailed overview of engagement activities). In this engagement activities, the capacities for co-production were iteratively conceptualised, and used to facilitate and trace the learning of the policy officers in experimenting with co-production.

The interviews and engagement formats yielded rich data about how co-production was designed, implemented, and learned about in the cities, and in particular about opportunities and challenges faced and how these have been addressed (Frantzeskaki et al., 2020). This has generated in-depth knowledge about how capacities for co-production have been revealed and developed over time by the policy officers engaging with co-production and successively mobilising and developing knowledge, skills, support etc. vis-à-vis their governance contexts. The data also reflects particular insights and lessons about co-production during the COVID-19 pandemic, since the pandemic started amid the cities’ co-production processes.

Table 3  
Overview of engagement and data collection formats.

| Type of engagement / data collection          | Description                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                                 | Number of engagements                                                                       |
|-----------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------|
| <b>Semi-structured interviews</b>             | <i>What:</i> Semi-structured interviews with representatives across departments in the city governments<br><i>Insights:</i> Understanding the policy and administrative context within which nature-based solutions would be co-produced                                                                                                                                                                                                                                                                                                                                                                                                                                                                                    | Genk n = 12, Glasgow n = 13, Poznań n = 10                                                  |
| <b>Co-production workshops and webinars</b>   | <i>What:</i> Introducing policy officers to co-production and iteratively co-developing and reflecting on their co-production processes<br><i>Insights:</i> Understanding how policy officers adapt co-production and link it to their governance contexts, identification of lessons learned                                                                                                                                                                                                                                                                                                                                                                                                                               | Genk n = 4, Glasgow n = 4, Poznań n = 4, peer-to-peer n = 6                                 |
| <b>Reflexive monitoring learning sessions</b> | <i>What:</i> The cities applied reflexive monitoring to track their activities, decisions and progress regarding their co-production processes, formulate learning questions and follow-up actions (Lodder et al., 2022; Hölscher et al., 2022b; Xidous et al., 2021; van Mierlo et al. 2010). This was discussed during monthly (after 2020 bi-monthly) reflexive learning sessions between researchers and policy officers. Bi-annual learning experience webinars between researchers and policy officers from all cities facilitated peer-to-peer learning about co-production experiences.<br><i>Insights:</i> Identification of capacities, challenges faced, and how to mobilise opportunities and overcome barriers | Genk n = 18, Glasgow n = 24, Poznań n = 22, Peer-to-peer learning experience webinars n = 4 |
| <b>Knowledge hub sessions</b>                 | <i>What:</i> Knowledge hub sessions with all cities supported peer-to-peer learning about specific elements of co-production (e.g. stakeholder mapping) and how a particular city has addressed this.<br><i>Insights:</i> Identification of critical learnings across the cities, and how cities adopt co-production                                                                                                                                                                                                                                                                                                                                                                                                        | n = 4                                                                                       |

For each city, the collected data across all co-production processes was coded in reference to the co-production capacities: the conditions present in the processes, the activities by which the actors sought to mobilise or create them, and the challenges that were faced and reflect missing or weak capacities. The analysis was iterated with the cities during the above-mentioned workshops and webinars. Subsequently, the co-production capacities were compared across the three cities, with the aim to identify shared conditions, activities, and challenges (see Section 4, Tables 4–6). The findings were also translated into a ‘Co-production for cities guidebook’ (van der Have et al., 2022) that aims to help urban policymakers, planners and practitioners design, implement and reflect on co-production.

4. Results: capacities for co-producing nature-based solutions in Genk, Glasgow, and Poznań

This section presents the findings on how policy officers in Genk, Glasgow, and Poznań have materialised and developed capacities for co-production. Specifically, it identifies how the policy officers have

**Table 4**

Capacity to create institutional space for co-production in Genk, Glasgow and Poznań: enabling conditions and activities.

| Enabling conditions                                                            | Activities                                                                                                           | Examples                                                                                                                                                                                                                                                                                              |
|--------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Awareness about (benefits of) co-production</b>                             | Communicate (benefits of) co-production to high political levels, use momentum and timing                            | Glasgow used COP26 in Glasgow to raise the political profile for nature-based solutions and co-production.                                                                                                                                                                                            |
|                                                                                | (Informally) reach out to and develop personal relations with colleagues (at different hierarchical levels)          | Poznań developed good personal relationships with individuals in the Department of Education, which helped to obtain their support and collaborate with them on co-production.                                                                                                                        |
| <b>Goals and procedures for co-production in policy and planning processes</b> | Illustrate to colleagues how co-production is beneficial to them                                                     | Poznań ran eye opener workshops to illustrate nature-based solutions' co-production to other city departments.                                                                                                                                                                                        |
|                                                                                | Link co-production to existing priorities and mandates                                                               | Glasgow used the OSS as statutory planning requirement and the Community Empowerment Act by the Scottish government to lobby for co-production.                                                                                                                                                       |
|                                                                                | Integrate co-production into project structure (Genk)                                                                | Genk integrated co-production as a principle into every aspect of delivering the Stiemer Programme.                                                                                                                                                                                                   |
|                                                                                | Establish cross-departmental team for co-production in city government (Genk)                                        | Genk established a participatory steering group made up of several city departments to scale up participatory processes.                                                                                                                                                                              |
| <b>Resources (funding, infrastructure)</b>                                     | Integrate co-production into tenders (Genk)                                                                          | Genk seeks to add a section on co-production as a process design element next to the technical design aspects.                                                                                                                                                                                        |
|                                                                                | Identify funding sources for co-production (e.g. EU grants)                                                          | Poznań sought an opportunity to apply together with a school director for "citizens' budget" to develop the Green Classroom.                                                                                                                                                                          |
|                                                                                | Choose venue according to engagement aims and provide time to ensure adequate technological infrastructure (Glasgow) | In Glasgow, adequate technological infrastructure was needed to facilitate citizen science and open space mapping workshops. This influenced the choice of location for a workshop due to the need for well-functioning Wi-Fi, and required a high amount of time to get many computers ready-to-use. |
|                                                                                | Create accessible physical spaces for informal connections                                                           | In Genk, as part of a continuous co-production infrastructure, accessible physical spaces have been created that support informal connections with colleagues from other departments or the wider public for partnership-building.                                                                    |

**Table 5**

Capacity to safeguard inclusive and legitimate co-production in Genk, Glasgow and Poznań: enabling conditions and activities.

| Enabling conditions                                                                          | Activities                                                                                              | Examples                                                                                                                                                                                                                                |
|----------------------------------------------------------------------------------------------|---------------------------------------------------------------------------------------------------------|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Skills for design, organisation and facilitation</b>                                      | Involve / hire actors connected with context and communities to identify actors                         | The partnership with Greenspace Scotland helped Glasgow to identify and engage local and national actors, and mobilise necessary communication and facilitation skills.                                                                 |
|                                                                                              | Identify people with co-production skills in city government                                            | Genk could link up to neighbourhood managers to identify and engage communities in the pilot projects.                                                                                                                                  |
|                                                                                              | Establish internal co-production position (Genk)                                                        | A social innovation officer was hired in Genk with expertise in co-production to lead all co-production processes in the Stiemer programme.                                                                                             |
|                                                                                              | Involve facilitation experts                                                                            | In Genk, the Junior Team idea generation was designed together with LUCA School of Arts and the Youth Department with experiences in organising workshops for children.                                                                 |
| <b>Procedures and methods for inclusive and transparent process designs and facilitation</b> | Promote skills to mediate conflicts and concerns                                                        | In Poznań, when parents were concerns about bees in the garden, first teachers were educated about the ecology of the garden and then the parents by the teachers (e.g. about importance of bees).                                      |
|                                                                                              | Identify selection criteria and identify actors through stakeholder mapping, snowballing and events     | Poznań identified stakeholders based on needed knowledge (e.g. legal knowledge from police, expert knowledge on ecology). The Conference on Natural Playgrounds for Youth Education helped to identify interested relevant actors.      |
|                                                                                              | Tailor engagement aims / steps, formats and tools according to specific target group and availabilities | When organising workshops, Glasgow considers the time people have for participating and whether the venue is accessible by public transport. Glasgow used mixed methods approaches in workshops to cater to different groups of people. |
|                                                                                              | Explicitly define the responsibilities of everyone involved                                             | In Genk, responsibilities and roles are discussed and reflected upon during learning sessions for individual projects, e.g. SUDS & SODA.                                                                                                |
| <b>Adaptability</b>                                                                          | Manage expectations                                                                                     | Glasgow emphasises the importance to be honest – aspirational but realistic – when communicating goals to avoid participation fatigue.                                                                                                  |
|                                                                                              | Nurture reflexivity and learning to identify                                                            | Poznań identified why the Green Classroom failed in the past and took this into                                                                                                                                                         |

(continued on next page)

**Table 5** (continued)

| Enabling conditions | Activities                                                       | Examples                                                                                                                                   |
|---------------------|------------------------------------------------------------------|--------------------------------------------------------------------------------------------------------------------------------------------|
|                     | lessons from previous experiences                                | consideration for future co-production processes.                                                                                          |
|                     | Employ tools for reflexive monitoring                            | All cities employ reflexive monitoring to regularly reflect on progress, identify opportunities, barriers and next steps.                  |
|                     | Provide shared spaces and allocate dedicated time for reflection | Genk established the Stiemer conclave that takes place every six months for two full days to reflect on progress on the Stiemer programme. |

mobilised or created enabling conditions for co-production, and what challenges they faced in doing so. Thus, the analysis illustrates the various activities by which policy officers in the three cities have interacted with and changed their incumbent governance contexts in order to engage with co-production and embed it into urban governance for nature-based solutions planning, delivery and stewardship.

#### 4.1. Capacity to create institutional space for co-production

A starting difference between the cities was that the policy officers in Genk could draw on extensive experience with co-production, while the ones from Glasgow and Poznań needed more time to familiarise themselves with co-production and garner support from political leaders and colleagues. Despite this, all cities were able to create space for co-production by mobilising the resources and support they needed for their various co-production processes (Table 4). The creation of space for co-production enabled the policy officers to conduct various co-production processes and laid the foundation for sustaining co-production efforts beyond individual processes and nature-based solution projects. However, the policy officers also struggled to operationalise co-production within existing project structures and working processes that asked for quick and narrowly defined projects.

In order to leverage institutional support, the cities' policy officers undertook various activities to raise awareness about co-production and its benefits. In Glasgow, political opportunities such as COP26 and the Community Empowerment Act by the Scottish Government were used to convince politicians and policymakers at the higher level of the value of co-production. While the officers in Poznań could build on good personal relationships with other departments to get their support for co-production, they struggled to increase awareness at the top level. The policy officers from all cities stated that they needed more systematic evidence about the benefits of co-production, because most colleagues view co-production as extra work without providing a clear value and prefer to adhere to their very specific roles and practices for delivering quick, pre-defined results.

A considerable success in the cities was to make co-production a standard approach for all activities of the respective nature-based solution programmes. The five-year Action Programme for the implementation of the OSS identified community engagement as a key procedural requirement to combine nature-based solutions with empowerment. In Poznań, the co-production of open garden and nature-oriented playgrounds was integrated into the Department of Education's kindergarten upgrading agenda, thus embedding co-production in the further roll-out of nature-based solutions. Building on the high level support in Genk, the policy officers made co-production a principle in all nature-based solution developments of the Stiemer programme in connection with the goal to share ownership over the Stiemer valley.

The policy officers were able to mobilise the resources needed to ensure preparation and implementation of their co-production processes – for instance, by identifying funding streams with dedicated co-production requirements. In Poznań, a grant provided by the

**Table 6**

Capacity to link co-production process and results to contexts in Genk, Glasgow and Poznań: enabling conditions and activities.

| Enabling conditions                                                       | Activities                                                                                                                                                                             | Examples                                                                                                                                                                                                                                                                                                                                                                                                                                  |
|---------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
| <b>Relations with diverse urban communities</b>                           | Conduct site visits to understand the local context and build relations with local communities                                                                                         | In Glasgow, site visits to Bellahouston and Drumchapel generated understanding about complex local needs to make the process relevant and build trust with local communities.                                                                                                                                                                                                                                                             |
|                                                                           | Use intermediaries to connect communities and city government                                                                                                                          | In Glasgow, the Thriving Places Initiative acts as a medium to communicate the results of workshops back to the wider local community.                                                                                                                                                                                                                                                                                                    |
|                                                                           | Identify ongoing processes and strategies in policy, business and local communities and how the co-production process could feed into those                                            | Upon realising that the Gardens of Waterschei pilot project closely links to the upgrading of the nearby trading street Stalenstrat, led by the Economic Department, the Genk team developed a joint, integrated plan that connects both areas better.                                                                                                                                                                                    |
|                                                                           | Align process and results with institutional regulations, rules and processes                                                                                                          | Glasgow needed to get permission in place to use the open space and get support from council to clear site.                                                                                                                                                                                                                                                                                                                               |
| <b>(Continued) societal support for co-production process and results</b> | Develop communication brand/strategy to showcase and disseminate relevance of co-production process and results to different target audiences (e.g. PR campaigns, site visits, events) | Together with communication experts and through a structural cooperation between the Department of Communication and Stiemer promotion team, Genk created a Stiemer brand and professional communication strategy with recognisable identity. The Genk Stiemer programme organises various activities connected to the Stiemer valley (e.g. exhibition of a local artist who works in the valley, taste the valley event, photo contest). |
|                                                                           | Develop dedicated information toolkits (Glasgow, Poznań)                                                                                                                               | Poznań created a nature-based solution catalogue as a guidebook of good practices for the creation of open gardens and natural playgrounds, verified by scientific experts.                                                                                                                                                                                                                                                               |
|                                                                           | Organise continuous and diverse engagement activities in local contexts tailored to reach and engage target audiences                                                                  | Poznań organised consultation meetings, workshops and a conference for those interested in co-producing open gardens and natural playgrounds.                                                                                                                                                                                                                                                                                             |
| <b>Partnerships for (lasting) place-based engagement</b>                  | Collaborate and engage diverse actors (e.g. NGOs, citizen organisations) in organisation of activities                                                                                 | In Poznań, the continuous activities in the open garden of the kindergarten in Wilda, involve NGOs that organised workshops.                                                                                                                                                                                                                                                                                                              |
|                                                                           | (Co-)define individual goals, roles and responsibilities in alignment with overall goals for long-term                                                                                 | Genk established a novel governance structure that identifies dedicated roles and tasks linking top-down and bottom-up for each                                                                                                                                                                                                                                                                                                           |

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Table 6 (continued)

| Enabling conditions | Activities                                                                                                             | Examples                                                                                                                                                                                                 |
|---------------------|------------------------------------------------------------------------------------------------------------------------|----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|
|                     | management and maintenance                                                                                             | element of the Stiemer programme.                                                                                                                                                                        |
|                     | Facilitate continuous informal interaction through physical spaces and platforms                                       | Genk created physical spaces for informal connection with colleagues from other departments (Stiemerloft) or the wider public (Stiemer Lab, Stiemer Hub).                                                |
|                     | Designate one coordinator / coordinating group who is in charge of the process and ensures it keeps in line with goals | In Genk, steering committees have been instigated for each pilot project, also including community representatives, as an effective foundation for facilitating the co-production processes.             |
|                     | Strengthen community capacities                                                                                        | Glasgow developed capacity building toolkits to local communities to help and motivate them to take ownership over projects, including collation of information on funding sources for community groups. |

European Environmental Agency (EEA) created new opportunities to collaborate with the Department of Education and schools. It was important to make physical spaces and technological infrastructure available. In Glasgow, the choice of location for a workshop depended on adequate technological infrastructure, including well-functioning Wi-Fi, to facilitate citizen science and open space mapping workshops. In Genk, accessible physical spaces have been created for continuous, informal engagement and relationship-building. The Stiemer Loft is a creative workspace in Genk city hall, where the walls feature Information about the Stiemer programme (e.g. maps, process charts), with the aim to prompt informal connections with colleagues from other departments. The Stiemer Hub provides an experimental environment for discussion and engagement with citizens.

Main barriers reveal the challenge to embed co-production in existing funding structures and work processes of the city governments. Despite leveraging individual funding streams, structural financial support for co-production was limited because the short timeframes of project funding contrast with the time needed co-production. In Genk, for instance, it was difficult to include requirements for co-production into tenders, because the latter ask for concreteness while the former is very vague in terms of results. This links to the need to create awareness about (benefits of) co-production that also convinces colleagues of its value and enhance flexibility to experiment with a novel, more open-ended approach.

#### 4.2. Capacity to safeguard inclusive and legitimate co-production

Despite best intentions, the policy officers in the cities have struggled most with engaging a diverse representation of citizens, as well as addressing conflicts of opinions and interests. The capacity to safeguard inclusive and legitimate co-production is still visible in the learning processes the policy officers underwent in developing and leveraging the necessary skills, as well as procedures to prepare, design and adapt co-production processes tailored to different aims and needs (Table 5).

The policy officers identified the need to mobilise various skills needed for co-production, particularly as most of them did not have prior experience with it. The participation in the Connecting Nature project and associated learning webinars and workshops as well as peer-to-peer learning activities supported them in getting acquainted with co-

production principles and methods. Additionally, they collaborated with colleagues from other departments or external actors, who had experience with co-production. In Genk, the Junior Team idea generation was specifically designed, together with LUCA School of Arts and the Youth Department with experiences in organising workshops for this audience, to involve children in the development of the Stiemer valley. Poznań hired a facilitator who helped prepare online workshops that had become necessary during the COVID-19 pandemic. The officers in all cities stated that by doing co-production, they had gained confidence in their own skills to organise and facilitate co-production.

Collaborating with key actors embedded in local contexts has been particularly important to enhance inclusivity by supporting the mapping and activation of relevant actors. Genk and Glasgow could turn to existing neighbourhood managers and community engagement officers, respectively, to support actor identification and mapping, connect with local residents and support workshop facilitation. This was also valuable for maintaining long-term engagement and relationships with regards to specific nature-based solutions: the neighbourhood manager in Genk is still involved in the allotment gardens in Schansbroek park. However, all cities struggled to reach residents, especially citizens of immigrant origin and low-income groups. The policy officers in Genk started to collaborate with a colleague with a social work education because they realised this person was able to reach more people because of different ways of communicating.

A key learning about procedures and approaches was to first define the specific goal and context of a co-production process and then the target audience and methods. In Poznań, the target audience was defined and subsequently actors were systematically mapped based on needed knowledge: including children's knowledge about their needs for a nature-oriented playground and legal knowledge from police to address questions of safety when opening the kindergarten to the public. The choice of instrument and engagement method depended on specific objectives and target groups, as well as actors' capabilities to participate, including issues such as a venue's accessibility (e.g., by public transport). In Glasgow, a hybrid method was employed to tend to different availabilities and digital skills: participants could fill in a web form with various questions about data prior to the workshop, or use provided laptops or worksheets, if uncomfortable with using laptops, at the workshop.

Bringing actors with divergent needs, experiences and interests also unravelled conflicts. All cities noted conflicts between experts and citizens as the most difficult ones to solve. In Glasgow, ecologists have been reluctant to consider local community needs and knowledge in relation to the maintenance of open spaces, because they believed their solution was the most effective. On the other hand, locals have been less open to these solutions as they felt their needs have not been incorporated. For addressing conflicts in Poznań, the teachers in the Wilda kindergarten were employed as mediators to educate parents, who were opposing insect houses in the open garden due to fears of bee stings, about the importance of bees.

All cities have shown adaptability in their processes to accommodate new insights and needs. The reflexive monitoring method, introduced to all cities as part of the Connecting Nature project (Table 3), has provided the policy officers with a process tool to step away from day-to-day activities and demands and evaluate ongoing decisions and progress in view of long-term ambitions. The cities established dedicated reflexive monitoring teams with regular meetings to identify and act upon opportunities and barriers when implementing co-production. This also supported reflection about and strategically strengthening co-production capacities. Genk has further institutionalised the approach by setting up the Stiemer Conclave for two full days every six months, which involves diverse actors involved in the Stiemer programme implementation.

#### 4.3. Capacity to link co-production process and results to contexts

The policy officers in all cities undertook considerable efforts to link the co-production processes and results to their incumbent contexts by communicating about their processes and results to wider audiences, linking them to existing processes and strategies and investing in partnerships and collaborations for trust-building and continuous engagement (Table 6). This contributed to generating and sustaining enthusiasm and engagement, although many efforts remained limited to specific actor groups (Section 4.2). Additionally, enthusiasm and engagement remained dependent on support and coordination provided by the city governments.

The policy officers deeply engaged with the various contexts of the co-production processes to position them within the needs and wishes of local communities, and build relations for engagement. They developed comprehensive knowledge about the contexts and communities, for instance through site visits, including existing goals, ongoing processes and local needs. In some instances, they could build on pre-existing work in a specific area. Intermediaries, such as the Thriving Places Initiative in Glasgow helped establishing links and building trust between the city government and citizens and enhance understanding of the specific local contexts. In Genk, the Friends of the Stiemer, a group of engaged citizens in the Stiemer valley, help the policy officers keep track of and connect with relevant community developments.

Seeking relations with the local contexts also meant connecting with ongoing policy and planning processes and existing formal rules and regulations. The policy officers could draw on their working knowledge at the city government or existing collaboration and informal connections with colleagues from other departments, to integrate different planning processes by pursuing shared goals and pooling funding. Upon realising that the Gardens of Waterschei pilot project closely links to the upgrading of the nearby trading street Stalenstrat, led by the Economic Department, the Genk officers sought to develop a joint plan that would involve the shop owners in the co-production of the project. Additionally, the policy officers needed to align new approaches and concepts from the co-production of nature-based solutions with formal rules and regulations to enable implementation. New safety rules were necessary for the open garden at the kindergarten in Wilda in Poznań, because there have not been legally binding instruments for giving residents access to open gardens in kindergartens.

The cities conducted diverse communication and engagement activities to make the co-production processes and results visible, increase social relevance, sustain momentum and commitment, and activate actors. Together with the Department of Communication and the Stiemer promotion team, Genk developed a communication strategy with a recognisable visual identity. The Genk Stiemert programme organised various activities connected to the Stiemer valley (e.g. exhibition of a local artist who works in the valley, taste the valley event, photo contest), together with diverse actors. In Poznań, continuous activities such as workshops were organised in the open garden of the kindergarten in Wilda in collaboration with NGOs.

New partnerships and collaborations – both across city departments and between the city government and other groups of stakeholders – emerged throughout the co-production processes in the cities. These partnerships were important to implement the results, and facilitate long-term stewardship of the nature-based solutions. Main conditions to facilitate partnerships were trust-building based on personal relations developed through co-production and the (re-)definition of roles and responsibilities. In Poznań, while the local government is a crucial initiator of new projects, kindergarten management will be responsible for maintaining the gardens. Genk initiated ‘Stiemer Deals’ to promote social innovation initiatives, which clearly define the role and task distribution between city and stakeholders, custom-designed depending on the deal. The creation of accessible physical spaces in Genk, like the Stiemerloft and the Stiemer Hub (Section 4.1), provided further space to foster informal connection and exchange.

The main limitation in all cities concerns the challenge to sustain long-term enthusiasm. The cities noted the risk that not clearly visible and tangible results frustrate participants and discourage them from participating in future co-production. This has occurred when there were large time-lags between engagement activities, such as visioning and implementation, or when the city government has stopped being involved without follow-up. It was, therefore important for the policy officers to remain the designated coordinator, or coordinating group, in charge of the collaborations to ensure they continue and keep in line with the overarching goals. To enable actors to take up roles and to self-organise activities, the cities provided support and facilitated capacity-building. Glasgow recognised capacity gaps in community organisations to develop and maintain projects and, in collaboration with the Neighbourhoods and Sustainability Department, developed toolkits for community capacity building and guidance on nature-based solutions.

#### 5. Discussion: lessons for embedding co-production as a mode of collaborative urban governance for nature-based solutions

The following discusses lessons for embedding co-production as a collaborative governance practice, and provides reflections on the implications of the COVID-19 pandemic on the cities’ co-production processes. The findings contribute to a process-based understanding of embedding co-production into existing governance arrangements by materialising and developing co-production capacities. The results demonstrate how policy officers in the three cities have revealed, nurtured and build-up knowledge and skills, relations and institutional procedures and processes needed for co-production, while engaging in diverse processes to co-produce nature-based solutions. The policy officers stated that these changes enabled them to engage in co-production and thus make nature-based solutions something much more valuable to the local communities.

The following discusses three lessons for embedding co-production in governance capacities. The lessons highlight key conditions for co-production, and the barriers and ways forward for developing these conditions vis-à-vis existing governance arrangements. The policy officers’ efforts and experiences underscore that engaging with and embedding co-production requires continuous learning and addressing tensions that arise with existing urban governance. While they were able to make co-production a key process consideration for all nature-based solutions in their cities, many institutional barriers for sustaining co-production prevailed. As the officers themselves recognised these shortcomings, they searched for ways to address them.

A limitation of the study is that the results are based on interactions between researchers and policy officers, and does not explicitly consider how participants have perceived the processes and whether the co-production capacities would be different for actors other than city governments. The strength of the research approach is the in-depth knowledge gained about the experiences and learning processes of policy officers in materialising co-production capacities.

##### 5.1. Embedding a tailor-made approach for inclusive and place-based co-production

The diversity of co-production processes in the cities shows the versatility of co-production as a mode of collaborative nature-based solutions governance that engages different (groups of) actors in different settings and for different purposes but under a shared umbrella of nature-based solutions planning, delivery and stewardship. The challenge for policy officers is tailoring the co-production processes to the specific contexts, goals and target audiences. There is a risk that co-production efforts are wasted when the process and results are not connected with the institutional, ecological, cultural etc. contexts or the right actors, rendering results unused, cherry-picked or disempowering for local communities (Ferlie et al., 2019; Mahmoud and Morello, 2021; Dorst et al., 2022).

Tailoring co-production requires more research about and investment in conditions that enable policy officers identify who should be involved in specific processes, and mobilise them accordingly. Generally, what counted as inclusive participation in the three cities depended on the specific goal and context of a co-production process. The policy officers acknowledged that not all processes needed to involve extensive citizen engagement. This resonates findings by Zingraff-Hamed et al. (2020): “[w]hile the quantity of stakeholders to be involved is of importance, it seems more relevant to involve the ‘right’ stakeholders”. However, without providing clarity on who the right stakeholders are in relation to specific co-production processes risks deflating co-production by avoiding to share decisions with the public (Cousin, 2021). To identify the ‘right’ stakeholders, the policy officers identified selection criteria, developed mapping procedures, conducted site visits and collaborated with actors embedded in specific contexts. However, the selection criteria were not strategically defined for different types of co-production processes leading to blind spots regarding, for instance, the explicit inclusion of disadvantaged groups in strategic and tactical co-production. Co-production should always aim to include disadvantaged groups to avoid reinforcing inequality of outcomes (Sorrentino et al., 2018; Anguelovski et al., 2019), and, in the context of nature-based solutions, nature as ‘voiceless actor’ through e.g. park rangers, community groups and volunteers that are affected by degraded urban ecosystems or in direct interaction with urban nature (Pineda Pinto et al., 2022). Additionally, more knowledge is needed about how a specific type of nature-based solution influences inclusivity to support actor mapping: some can include citizens from ideation to construction and co-management, others only in the early design stages and later in maintenance (Mahmoud and Morello, 2021; Midgley et al., 2021).

Despite best intentions to achieve diverse and inclusive sets of participants in the cities, reaching out to and motivating diverse stakeholders has been a major shortcoming in all cities. Scholars outline various strategies to actively reach out to actors and raise motivation to participate, including spending time with communities, employing tailored communication formats and providing incentives (e.g. financial support, training, social recognition) (Vanleene et al. 2019; Bussu and Galanti, 2018; Campbell et al., 2016). In the three cities, especially the collaboration with street-level professionals and intermediaries embedded in specific localities, as well as paying attention to availability profiles and accessible venues marked pivotal conditions for enabling wider engagement. Still, existing knowledge is limited about how to involve hard-to-reach actors. A key learning in Genk was to invest in social skills, which further underscores the need to identify and embed new skills and working relations with communities when aiming for inclusive co-production.

Additionally, a tailoring approach extends to the results of co-production, which at times conflicted with administrative and legal requirements. Other scholars similarly found that co-produced results might conflict with existing regulations and norms (e.g. safety inspections, financial reporting), yet those are also necessary and non-negotiable because city governments are held accountable (Torrens and von Wirth, 2021; Jaspers and Steen, 2019). The policy officers could mitigate (some) rigid bureaucratic processes by strategically selecting sites for the nature-based solutions to avoid problems of land ownership or politicisation, or by involving relevant actors – such as the police in the design of the open kindergarten in Poznań. Some scholars call for further changes that designate experimental zones in which co-production takes place with lenient planning rules that allow organic development and innovation (Bisschops and Beunen, 2019; Cousin, 2021).

## 5.2. Embedding open-ended co-production with long-term benefits

The learnings of the policy officers signify the need to create conditions for enabling co-production as a more open-ended governance approach so as to encourage new knowledge, problem definitions and

solutions to emerge. Literature on co-production has well-documented the tensions resulting from, on the one hand, letting go of some level of control and embracing uncertainty and contestation and, on the other hand, existing ways of working that pre-define solutions and ask for quick action (Dorst et al., 2021; Sarabi et al., 2021).

A main challenge in the cities was to embed co-production in institutional structures, public funding and tendering procedures to take into consideration the characteristics of co-production, including the high amount of time needed for the preparation, collating and communicating results and sustaining co-production efforts in the long-term. Even if co-production is accounted for in the design phase, funding and human resource provision often does not cover ongoing involvement for the later stages after the design plans have been delivered (Boros and Mahmoud, 2021; Jaspers and Steen, 2019; Hölscher, 2018). In the cities, this has led to disappointment among communities in the past when they felt left alone after a co-production process ended.

The co-production capacities mark important steps forward for overcoming these barriers – for instance, by institutionalising co-production as an important principle for the cities’ nature-based solutions programmes, establishing dedicated positions, and identifying alternative funding sources for co-production. Still, the capacities remain largely limited to small groups of policy officers and those they have collaborated with, and many barriers such as limited funding, rigid tendering procedures and scepticism from colleagues prevailed. In their efforts to garner support for co-production, the policy officers struggled to clearly communicate the benefits of the approach. This asks research to support monitoring and evaluating progress and success of co-production, paying attention to qualitative outcomes such as new narratives, collaborations, and empowerment next to quantitative performance indicators (Wendling et al., 2021).

The policy officers valued reflexive monitoring as a powerful method to monitor and evaluate co-production in real-time. On the one hand, reflexive monitoring helped steering the processes, identifying new actors, and addressing barriers and opportunities. This allowed the officers to both be agile and proactive in a way that fits the dynamic and open-ended nature of co-production, and to navigate their incumbent contexts and embed co-production. On the other hand, the method also generated insights about emergent results to be taken up in communication and awareness raising activities. Next steps are further nurturing spaces for reflexivity so that it does not get compromised by having to deal with day-to-day demands. Genk has been exemplary in this, installing the bi-annual, two-day Stiemer Conclave involving actors from different city departments and other urban actors engaged in the Stiemer valley.

## 5.3. Embedding new relations and roles to sustain co-production

The cities’ co-production processes spurred new relations between actors, in form of cross-departmental collaborations (e.g. with the Department of Education in Poznań), public-private partnerships (e.g. with Greenspace Scotland in Glasgow to help design and implement co-production itself) and community groups with links to the city government (e.g. Friends of the Stiemer in Genk). While supporting sustained co-production of nature-based solutions, the new relations raised questions about changing roles of actors, and how to embed these in formal and informal governance models and partnerships. Changing entrenched roles bears risks of disempowerment, especially when citizenship is positioned as ‘gap-filling’, or when powerful actors are able to shape co-production according to their interests (Turnhout et al., 2020; Torfing et al., 2019; Bussu and Galanti, 2018).

The new relations and roles in the cities take both formal and informal forms. For example, Genk has developed a new governance model that defines advisory roles of the Friends of the Stiemer. The Stiemer Deals in Genk provide an innovative example of tailor-made agreements between any stakeholder and the city government to stimulate social innovation initiatives that also realise goals of the Stiemer programme. Scholars highlight the role of informality to support

breaking down boundaries and resolve conflicts, thus providing opportunities for new relations, roles and empowerment to emerge (Chatterton et al., 2018; Stepanova et al., 2015). Campbell et al. (2016) suggest providing ‘hanging out’ opportunities for stakeholders during and after a co-production process, resembling the informal spaces created in Genk (e.g. Stiemer Loft). Informality can also be introduced through various methodologies, including art-based or creative placemaking that connects people, and instils creativity (Boros and Mahmoud, 2021; Basnou et al., 2020).

A central question the policy officers faced concerned their own roles when shifting from being service providers to taking on an enabling role in which the city government facilitates the co-production of services while still exercising legal authority (Brandesen and Honingh, 2018; Torfing et al., 2019). While the formalisation of roles provided clarity about mutual expectations, a main lesson was for the policy officers to remain the designated coordinator to initiate, keep track of and communicate about the processes, ensure that results would happen. Other scholars confirm that, in practice, coordinators tend to be from public authorities to ensure the legitimacy as well as availability of resources for taking on the necessary tasks (Zingraff-Hamed et al., 2020; Jaspers and Steen, 2019). It was however not always easy for the policy officers to take up coordinating roles, particularly when needing to mediate conflicts between colleagues from the city government, experts and local communities. Collaborations with external actors that had experience with facilitation helped, yet the struggles call for further clarity on the roles of policy officers working at the interface of diverse actors and corresponding interests.

Furthermore, the policy officers realised that sustaining new roles and relations required continuous nurturing and supporting those actors who are expected to participate in the joint production of nature-based solutions. While participating in co-production can enhance the abilities of community actors, for example, to find their way more effectively to administrative support or by learning about nature (Basnou et al., 2020; Jaspers and Steen, 2019), this does not ensure the ability to develop and maintain projects. Upon realising this, the policy officers in Glasgow started to collaborate with colleagues from the Neighbourhoods and Sustainability Department to facilitate community capacity building. This provided further clarity on how capacities for co-production manifest in new roles of city governments as facilitators and coordinators.

#### 5.4. Co-production during the COVID-19 pandemic

The COVID-19 pandemic hit amid the cities’ co-production processes. At first glance, the pandemic has had predominantly negative impacts: Apart from putting additional strains on the cities’ budgets, strict lockdowns and social distancing led to many co-production events being cancelled or postponed and public gardens closed. It became more challenging to achieve inclusivity and approach vulnerable groups.

Nonetheless, COVID-19 has also highlighted opportunities for co-production. In general, the lock-down experience underscored the benefits of green and open spaces for mental and physical health and wellbeing (Fisher and Grima, 2020; Venter et al., 2020). The pandemic also boosted community self-organisation activities, such as mushrooming ‘Friends of Parks’ groups in Glasgow, providing opportunities for the city governments to work collaboratively (see also Steen and Brandesen, 2020). At the same time, the cities experimented with new online formats to continue collaboration in virtual or hybrid ways. Glasgow created videos to support capacity building with a different legacy compared to one-off workshops and sometimes achieving greater engagement.

## 6. Conclusion

The exemplar research in, and with the cities provides insights into how co-production can be developed and supported, what co-production offers to urban governance in practice, and what urban

governance with co-production may look like as nature-based solutions continue to be mainstreamed and scaled outwards. The policy officers in the three cities recognised co-production as an opportunity to plan and deliver more contextualised and inclusive nature-based solutions and to establish lasting partnerships for stewardship once nature-based solutions are implemented. Their co-production experiences illustrate their learning while engaging with co-production, in terms of how processes can be designed and implemented and how to create enabling conditions for doing so.

A remaining challenge for embedding co-production in urban governance concerns the discrepancy between co-production and existing formal governance settings and processes. For the policy officers in the cities, engaging in co-production meant grappling with the diversity and messiness of co-production, while continuously having had to find time, mobilise skills and garner support for co-production. Further embedding co-production demands attention to sustaining co-production beyond individual interventions by investing in long-term relationships and providing continued support to engagement activities and local communities. Without this long-term view, co-production will always be at risk to cause detrimental results like disempowerment, participation fatigue and eroding trust between city governments and urban communities.

The capacities’ lens permitted the cities to reflect on what conditions are in place, which ones are needed, and how they can be developed. Building co-production capacities requires starting from existing contexts and conditions. The research also showed, however, that without being able to clearly articulate the benefits of co-production for specific contexts and target audiences, it will remain challenging to mobilise the necessary support to embed co-production.

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## Author statement

All authors contributed to writing and reviewing the manuscript. KH led the development of the conceptual framework and interpretation of data. GD, AD, AO, MQ, SS and KVDS led the development and implementation of co-production in the cities, supported by KH, NF, DK, MC, ML and CvdH.

## Declaration of Competing Interest

The authors have no conflict of interest.

## Data Availability

The data that has been used is confidential.

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## Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at [doi:10.1016/j.envsci.2023.103652](https://doi.org/10.1016/j.envsci.2023.103652).

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