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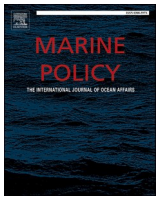

Full length article

Best bang for your buck: Considerations for cost-efficiency in knowledge co-production

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ABSTRACT

Knowledge co-production is a key strategy of collaborative engagement between research and management to achieve better outcomes. Whereas the principles of knowledge co-production in support of evidence-informed policy-making are increasingly understood, our understanding of its cost-efficiency - putting benefits in relation to its cost - is in its infancy. Here, we approach this gap by exploring the key considerations for ensuring that the benefits of co-production processes outweigh the significant direct and indirect costs they can incur. We conceptualise a relationship between the costs and benefits of co-production, consider preconditions that affect those costs and benefits, and outline options for improving the cost-benefit relationship. Specifically, we explore how to maximise co-production efficiency for key principles underpinning effective knowledge co-production (context-based, pluralistic, goal-oriented, interactive) and illustrate this with a hypothetical case study of co-production for the use and management of an emerging small-scale fishery. To this end, we conclude by providing a series of guiding questions that practitioners of co-production can use to help ensure that the benefits outweigh the costs. Our results provide researchers and practitioners with improved understanding of the costs and benefits of co-production and encourage the consideration of cost-efficiency in the planning of participatory research. Further, by considering the costs and benefits of co-production processes we provide critical insights into how to ensure effective and efficient science-policy engagement where expectations might exceed limited resources. This includes enabling more transparent and accountable funding and engagement decisions while engaging multiple context-specific streams of policy-relevant knowledge for evidence-informed policy.

1. Introduction

In a fast-changing world, commissioning, undertaking and disseminating policy-relevant research is critical and now commonly approached as a joint or participatory activity between researchers, funders and users (Hegger et al. 2012; Cvitanovic et al. 2019; Karcher et al. 2023). Knowledge co-production is the most commonly applied strategy in a spectrum of participatory science-policy knowledge exchange processes used in the environmental field (Karcher et al. 2021) and the marine field in particular (Karcher et al. 2024). It spans "*iterative and collaborative processes involving diverse types of expertise, knowledge and actors to produce context-specific knowledge*" (Norström et al. 2020, p.183) and can directly support the increasingly demanded paradigm of evidence-informed policy (Adams & Sandbrook, 2013; Cvitanovic et al. In Review). As such, co-production entails collaboration from the early stages of knowledge acquisition/creation (e.g., joint identification of research needs and formulation of research questions) throughout the entire research process (Hegger et al. 2012; Norström et al. 2020). We

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note that data collection refers to both sharing of existing knowledge between people (e.g., different types of knowledge) and the joint creation of new information. Like most science-policy strategies, co-production is highly context-specific and benefits from iterative processes among diverse actors (Lemos & Morehouse, 2005; Sarkki et al. 2015; Chambers et al. 2021, 2022; Zurba et al. 2022). For example, Reid and Chaytor (2022) described understanding policy needs/questions and forming trusted relationships as a key step. This is paramount as marine policy aspects often involve complex issues and actor constellations on different geographical scales with limited funding.

To achieve successful knowledge co-production and realise long-term benefits (e.g. the application of diverse knowledge types to socially equitable resource management), it is increasingly acknowledged that collaborative projects should be explicitly planned and maintained over a long time period (Mach et al. 2020; Karcher et al. 2022b). Instrumental modes of co-production with clear intended outcomes and a mediation that does not try to reshape participants' roles and identities ensure tangible outcomes under limited time and investment (Harvey et al. 2019). Other authors emphasise the role of co-leadership (Polk, 2015) and the contribution of multiple ways of knowing and acting (Wyborn et al. 2019; Cooke et al. 2021). This can provide the opportunity for co-production to span western and traditional or Indigenous knowledge systems through the notion of co-evolution of knowledge and empowerment through self-determined Indigenous research leadership (Chapman & Schott, 2020; Latulippe & Klenk, 2020; Muhl et al. 2023).

While benefits are clear, there are numerous challenges to the effective implementation of knowledge co-production (Addison et al. 2015; Cvitanovic et al. 2015a; Baker et al. 2020; Rölfer et al. 2022). One of the most commonly reported barriers are the costs which stem from the time and labour intensive nature of engagement, particularly related to the 'behind the scenes' work needed to form relationships founded upon trust and mutual respect (highlighted in Cvitanovic et al., 2019). Researchers, NGOs, government agencies, and funders are often asked to achieve, demonstrate, and judge the impact and added value of collaborative stakeholder engagement. Unfortunately, there is currently only limited understanding of how to plan, budget, and report on outcome-oriented co-production (Harvey et al. 2019). For example, marine researchers are very motivated to engage with policy and society but often lack the skills and experiences (Cvitanovic et al. 2015b). While there is growing conceptual advice on how to design a specific knowledge exchange strategy (Reed et al. 2014; Beier et al. 2017; Mach et al. 2020; Ferse et al. 2021), researchers, NGOs, funders, and government agencies have little guidance on what type and intensity of co-production is the most cost-efficient choice for a specific context and outcome.

Whether the co-production process is economical and worthwhile in a specific context is rarely asked. It is about more than money (Karcher et al. 2022b) and reflecting on the nature of investment in co-production for sustainability outcomes is a necessary task (Lemos et al. 2018). The absence of cost-efficiency guidance could lead to overlooking possible risks, resulting in sub-optimal engagement or inefficient resource use that compromises other activities. With limited resources and timelines, tools are needed to support cost-efficient plans and to justify a choice of strategy.

We approach this gap through a cost efficiency analysis and use conceptual counterfactuals to portray the alternative to a specific action. To effectively implement co-production we need to better understand "*which types of co-production practices are effective, and under which circumstances, and develop heuristics that can be used to guide instigators of co-production practices to determine which practices are appropriate for a given context or problem*" (Wyborn et al. 2019, p.340). Building on previous works outlining the significant costs and risks of co-production (e.g., Oliver et al. 2019; Karcher et al. 2022b), here we address the overarching question: How do we shift co-production towards higher cost-efficiency (i.e., value for investment, not only 'getting it done for less cost')? We take the following steps:

i) Conceptualising a relationship between the costs and benefits of practical co-production components to illustrate critical considerations when planning knowledge co-production;
ii) Considering preconditions that affect the possible costs and benefits of those components;
iii) Outlining options for improving the cost-benefit relationship (i.e. more, better, and quicker benefits and/or lower costs).

We address these goals through the lens of Norström et al.'s (2020) principles of knowledge co-production (i.e., context-based, pluralistic, goal-oriented, and interactive) as underlying theory, which we explore via a hypothetical fisheries management case study (*cf.* Moon et al. 2021). This provides some guidance to the planning process of knowledge co-production and improves the efficiency of resource allocation in co-production processes, which are often resource intensive. This helps build a more practical, evidence-based understanding of co-production return on investment, which is important as collaborative science-policy-society engagements become more standard. By exploring how to ensure cost-efficient knowledge co-production, we are providing guiding throughts for projects to succeed while keeping within budget and scope that supports the best possible allocation of effort and resources. We aim to provide actionable insights for the optimisation of collaborative stakeholder engagement and offer a tool as well as critical guiding questions to determine the best strategy from a full spectrum of types and intensities of science-policy-society engagements. This can help researchers, NGOs, and government agencies to identify the most efficient engagement strategy for attaining intended outcomes and secure required funding, and also for funders to understand and evaluate the full range of resources needed for knowledge co-production.

First, we briefly introduce the theoretical grounding in the four principles of knowledge co-production (Section 2). Then, we outline overarching costs, benefits and cost-benefit analysis for co-production (Section 3) and discuss efficiency related pre-conditions and enablers (Section 4), before we apply them practically in a hypothetical case study (Section 5). Finally, we discuss the given cost-benefit considerations and provide guiding questions for practitioners and planners (Section 6). Overall, we seek to provide researchers and practitioners planning a co-production project to proceed with a better understanding of cost-efficiency in participatory research.

2. Theoretical background – the four principles of knowledge co-production

As the implementation of co-production has accelerated, an emerging body of research has examined how improve our understanding of co-production in practice (Djenontin & Meadow, 2018; Chambers et al. 2021; Partelow et al. 2025). A seminal paper from Norström et al. (2020) draws on the collective experiences of a range of co-production practitioners to identify the key principles needed for successful knowledge co-production. Those principles outline that the process should be i) context-based, ii) pluralistic, iii) goal-oriented, and iv) interactive as a package of holistic co-production (Norström et al. 2020).

2.1. *Context-based*

Any participatory research, including knowledge co-production is situated in a specific context that it needs to consider and that vice versa affect its practice (Norström et al. 2020; Ison et al. 2024). This means working in the context of the issue and circumstances of the broader social-ecological system is key. Those circumstances span, among others, institutional, cultural, and logistic factors (Djenontin & Meadow, 2018). A critical starting point to this can be horizon scanning and analysis of history, governance, socio-economics, as well as building the right team for the context (e.g., topical and local experts, social capital,

knowledge brokers, teaming up with local champions or local organisations etc.) (Karcher et al. 2022a). This principle contributes to situating knowledge needs and identifying the situational space of co-production (Reed et al. 2014; Norström et al. 2020; Cooke et al. 2021; Karcher et al. 2022b; Zurba et al. 2022).

2.2. Pluralistic

Pluralistic refers to "*bringing together academics (from different disciplines) and people from other sectors (from for example, government, business, civil society, local and indigenous communities) to generate knowledge and catalyse change*" (Norström et al. 2020, p.186). This includes deliberately building and managing trust, engaging diverse stakeholders, forming equitable relationships under shared power, and respectfully including Indigenous, traditional and local knowledge (e.g., Reed, 2008; Hegger et al. 2012; Polk, 2015; Wyborn et al. 2019; Latulippe & Klenk, 2020; Mach et al. 2020; Steger et al. 2021; Zurba et al. 2022). Meaningful engagement of different actors and their experiential, local or traditional knowledge can empower marginalised communities, broadens the available evidence base, and is important for knowledge use in decision-making and -quality (Raymond et al. 2010; Cook et al. 2012; McKenzie et al. 2014; Bremer et al. 2019; Buschman, 2022).

2.3. Goal-oriented

For the co-production process to be goal-oriented, it needs "*clearly defined, shared and meaningful goals that are related to the challenge at hand*" (Norström et al. 2020, p.184). Goal orientation in co-production starts with co-identification of needs, co-design of goals and research, and clear co-production governance from the start (Wyborn et al. 2019; Cooke et al. 2021; Steger et al. 2021; Karcher et al. 2023). This co-identification of research questions, goals and challenges is widely acknowledged to be important for meeting collective needs (Moser, 2016; Beier et al. 2017; Kumar et al. 2018; Thompson et al. 2019). Finally, also the prompt communication of findings (both intermediary and final) and the right format are critical to deliver on goals (Reed et al. 2014; Karcher et al. 2023).

2.4. Interactive

Co-production also needs to be interactive. Norström et al. (2020, p.186) state that "*co-production requires frequent interactions among participants to occur throughout the process, extending from collaboratively framing and designing the research agenda, to conducting the research, and jointly using and disseminating the knowledge generated*". Interactivity includes regular, substantive, equitable, and sustainable engagement (Lemos & Morehouse, 2005; Mach et al. 2020; Zurba et al. 2022). Thereby, interactions are often appreciated as face-to-face engagement, for example through formal and informal meetings, events (e.g. conferences), or field visits. Interaction also includes sharing resources, using or co-producing boundary objects (e.g., maps, tools, metaphors), and feedback loops for a final product. This is emphasised through the practical notion of iterativity within this principle (Sarkki et al. 2015; Carrick et al. 2022; Karcher et al. 2023).

3. Costs and benefits of knowledge co-production

3.1. Costs of co-production

Participatory research such as knowledge co-production is more complex and therefore 'costlier' than single entity knowledge production. A wide range of costs (direct/indirect and monetary/non-monetary costs) can be encountered before, during and after co-production processes (Karcher et al. 2022b). For example, the early phases of co-production (i.e. before the research commences) require investments in horizon scanning and stakeholder mapping/analysis, as well as significant energy, time and emotional effort to meet and link multiple diverse actors, understand disciplinary cultures or languages, and develop contextually appropriate ways of working together (Thompson et al. 2019; Karcher et al. 2022b). Such engagement and inputs are crucial before the formal (i.e., as part of a research project) co-production process can start and require joint effort to identify the research question and scope of the project (Djenontin & Meadow, 2018; Steger et al. 2021). Other costs include, for example, administration, training, networking, facilitation, and communication (Hoeft et al., 2014; Meadow et al., 2015; Cvitanovic et al., 2019; Kolstad et al., 2019). These high costs to maintain social networks even beyond the project component refer to the investment of time and energy to build and maintain a common understanding and trust required to work effectively in deep collaboration within a research team and even more so with societal actors. Also the costs for product development and project impact should not be underestimated and require funding during and beyond the lifetime of the research component (Reed et al. 2014; Cvitanovic et al. 2016; Posner et al. 2020).

3.2. Benefits of co-production

Some issues cannot be undertaken by one entity alone and therefore they require knowledge co-production for any legitimate relevant outcome. Benefits from co-production are project-specific and often best defined by those involved and should measure the success towards co-designed goals (Mach et al. 2020; Le Heron et al. 2021). What are the units of measurement for the benefits? Some funding schemes use income of universities (i.e. how much external organisations pay for co-produced or exchanged knowledge by universities or other institutions) as a proxy for demand and quality (Ulrichsen, 2016). However, financial returns and organisational revenue are not necessarily well equipped for the diverse, often non-tangible, range of successes from knowledge exchange (Cooke et al. 2020; Cvitanovic et al. 2021a; Karcher et al. 2021, 2022b). Particularly from a decision-maker point of view, not only instrumental but also conceptual (e.g., change of thinking, understanding, or ideas) and connectivity impacts (e.g., relationships, networks, access) are the most common and highly appreciated impact types (Amara et al. 2004; Edwards & Meagher, 2020; Edler et al. 2022; Reid & Chaytor, 2022; Gerlak et al. 2023; Karcher et al. 2023). Similarly, from a participant's perspective, there is an opportunity to contribute to development of a research approach, to change the discourse in research and to share in developing results (e.g., Thompson et al. 2019). Yet, the focus on macro impacts in evaluation can come at the expense of those relevant micro impacts like interactions or conceptual impacts (Budtz Pedersen & Hvidtfeldt, 2023). This calls for better appreciation and explicit planning for diverse impact types beyond direct, hard to attribute, instrumental change (Meagher & Martin, 2017; Karcher et al. 2021; Meadow & Owen, 2021). The "*increasing recognition that we need better ways to account for the social, economic and environmental value that results from our activities*" has led to the more holistic notion of *social* return on investment (Nicholls et al., 2012, p.6). This development also relates to increasing requirements in research grants to include some reference to societal impacts (i.e., research impact). An example of this is the UK's Research Excellence Framework. Intangible costs and benefits, including social returns, require active consideration in efficiency planning and evaluation. While there is increasing guidance on how to perform participatory research that produces societal impacts (Meadow & Owen, 2021) and a range of frameworks exist for their evaluation (Wall et al. 2017; Pedersen et al. 2020; Louder et al. 2021), finding metrics for societal impacts is an ongoing challenge for co-production projects (Gerlak et al. 2023), calling for more specific evaluation frameworks for the value-addition of science-policy boundary spanning (Karcher et al. 2025).

3.3. Cost-benefit analysis for co-production

While the scholarship has increasingly contributed to improving the techniques of co-production, considerations on its cost-efficiency, putting its value/benefits in relation to its cost, are rare. Becoming aware of factors that may increase or decrease co-production efficiency to achieve an intended outcome is a crucial step for planning and participating in co-production processes to generate the most desirable outcomes in a given situation. This is important because policy-relevant knowledge needs to consider multiple types of evidence but with limited resources and often challengingly short timelines. How much benefit is possible, does it achieve this benefit, how much investment is needed to achieve a level of benefit, and how quickly are benefits achieved? Cost (C) - benefit (B) analysis (CBA) is one way to explore this problem (Florio, 2019). It approaches efficiency through the identification and measurement of costs and benefits and the assessment of those costs and benefits over the timespan of an investment (Nas, 2016). Consideration and comparison of the B:C ratio between different investments in co-production might help select the approach that promises the best outcomes of a given investment or achieving a given outcome faster or with less investment. CBA assumes "*that the socioeconomic impact of a project is represented by the difference over time in the benefits to different agents and the costs of producing such benefits*" (Florio, 2019, p.30). A B:C ratio that is greater than one (1) will mean that the benefits will outweigh the costs over a given time period. For example, investment in co-production through face-to-face meetings during and after the project may result in benefits that outweigh the costs (i.e. B:C >1). But higher investment early in the project (rather than delaying) may result in more and earlier benefits which increase the B:C ratio. It is key to consider how the magnitude (total amount invested), time (when the investment takes place, i.e., early or late in the project), and quality of achievements through co-production (e.g., size and diversity of the benefits relative to goals) impact the B:C ratio.

In knowledge co-production, external pre-conditions can constrain what a project might achieve, how quickly, and at what cost. Outcomes may be achieved cumulatively with investment or only towards the end of a project/only after high investment, which can be visualised as linear or curved B:C relationships (Fig. 1). This framing can help explore questions such as: Can benefits realistically increase quickly with investment? Do external factors and pre-existing conflicts limit the potential benefits? There are also factors that can help co-production projects to move faster, cheaper, or achieve more benefits. Some of those might already be in place as pre-conditions (e.g. existing relationships, inclusive governance structure, legacy of engagement), others can be actively implemented by the co-production project. The latter can be seen as enablers of co-production and offer the chance for a project team to actively shift the cost-benefit relationship towards higher efficiency. Those factors can be related to the process of engagement, but also the selection of participants, quality of facilitation and power sharing.

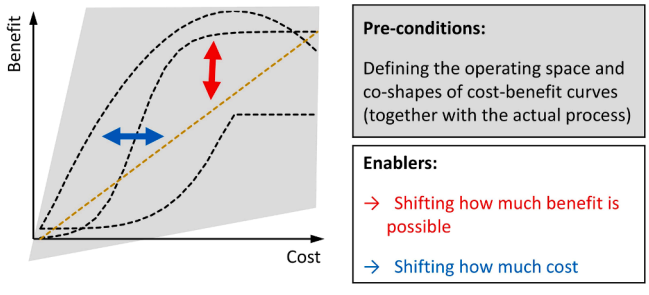


Fig. 1. Conceptual illustration of a range of potential cost-benefit relations (non-exhaustive; dotted lines) that are possible within a co-production context (grey area) and can be shifted by certain enablers to be more efficient (e.g., cheaper, more beneficial; arrows). Shape of grey area indicates the assumptions that minimal investment cannot lead to the best possible outcome, that minimal investment can even have a negative outcome (doing more harm than good, below x-axis), and that maximum investment is likely to generate at least some form of benefit. A linear C:B line of 1:1 is marked in gold. This illustration is adapted from previous work in conservation cost-utility analyses and governance costs (Cullen et al. 2005; Laycock et al. 2011; Cvitanovic et al. 2018).

The possible cost-benefit relations exist within the margins of the specific pre-conditions (the operating space). This context-specific operating space is highlighted by the grey shaded area in Fig. 1. It outlines the boundaries of realistic cost-benefit scenarios for a co-production project. For example, zero investment will not lead to much benefit. On the other hand, even high investment could lead to minimal benefits under unfortunate pre-conditions and poorly designed co-production processes. In this conceptualisation, the C:B relations can have different forms (depending on the pre-conditions and process settings). For example, if there is a lag phase before trust is built, there might be an initially slow increase of benefits with investment but a strong increase once trusted working relationships are established. Building on existing networks can provide benefits faster while regular face-to-face engagement and skilled facilitation require more investment but raise the potential benefit.

For co-production efficiency, it can also be important to assess how quickly a certain benefit is achieved. In this paper, we only touch on the development of timelines for co-production and the goal of achieving faster benefits. However, the enablers we identify can not only affect how much benefit is possible and how much investment is needed to achieve a level of benefit, but also how quickly benefits can be achieved.

4. Cost-benefit considerations of knowledge co-production principles

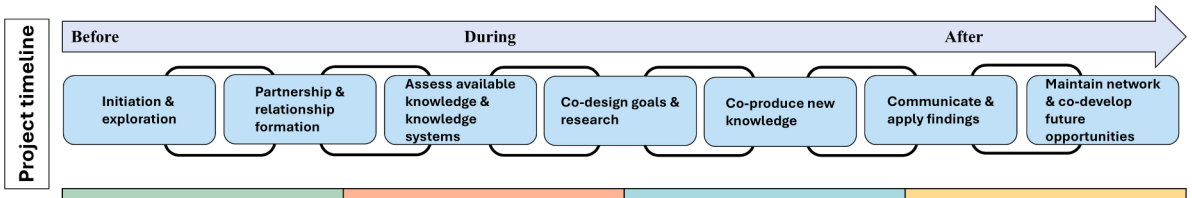
Using the principles outlined by Norström et al. (2020) as a starting point (Section 2), we undertook a review of recent literature, and compiled a range of common components of environmental knowledge co-production (Fig. 2). In the following sections, we use the four principles of co-production to describe the pre-conditions shaping their operating space, and enabling factors that can shift the B:C curve (i.e., greater and earlier benefits and/or lower costs). The application of all four principles (most if not all, depending on context and goal) is expected to contribute to co-production effectiveness (Norström et al. 2020). Even though we visually show the four principles along a project timeline (Fig. 2) we do not imply that they only occur at a specific phase of the co-production process rather throughout (*cf.* Cooke et al. 2021; Steger et al. 2021).

4.1. Context-based

4.1.1. Pre-conditions to context-based co-production

The operating space is strongly dependent on the legacy of engagement (i.e., the sum of pre-existing connections, experiences, and social capital built within the local context). Collaboration and existing relationships (including personal relationships or networks, work experiences, social capital, and trust) also play a key role (Schuttenberg & Guth, 2015; Cvitanovic & Hobday, 2018; Hakkarainen et al. 2020; Karcher et al. 2022a). Considering context-based pre-conditions first means looking back at the positionality of the research team and the social context, what has been done before, how that went, and what can be built on.

Ensuring context is adequately considered further requires assessment of actors and factors that may affect co-production or be influenced by it (Norström et al. 2020). Actor accessibility, heterogeneity of stakeholder interests, values, socioeconomic background, and conflict potential require consideration while planning co-production (Reed et al. 2018b). It is also useful to identify sensitivities and potential points of conflict and look at how conflict has been avoided, managed, or resolved in the past. Wyborn et al. (2019, p.334) suggest particular attention to



	Context-based	Pluralistic	Goal-oriented	Interactive
Components	▪ Situate context ▪ Understand knowledge needs ▪ Right project team & expertise	▪ Engage diverse stakeholders ▪ Equitable relationships ▪ Respectfully include non-academic knowledge systems (e.g. Indigenous & local knowledge) ▪ Transformative thinking	▪ Co-identify needs ▪ Co-design goals & research ▪ Clear governance ▪ Communicate & evaluate findings	▪ Regular, substantive & sustainable interactions ▪ Iterative process ▪ Use boundary objects
Pre-conditions	▪ Problem complexity ▪ Political & social background ▪ Institutional framework ▪ Previous experience & networks ▪ Conflict potential	▪ Existing relationships ▪ Stakeholder community ▪ Governance structure ▪ Decision-context ▪ Power relations	▪ Existence of clear need ▪ Resources (timing & amount) ▪ Formalised pathways ▪ Governance system	▪ Availability of resources ▪ Accessibility of actors ▪ Motivation & incentives ▪ Professional/ institutional support
Enablers	▪ Training ▪ Contracting additional expertise ▪ Stakeholder mapping ▪ Plan for relationship building ▪ Legacy of engagement	▪ Systematic representation ▪ Trust, openness, transparency ▪ Equal opportunities ▪ Power sharing ▪ Explicit discussions & needs	▪ Openness & transparency ▪ Flexible- and/or co-funding ▪ Joint prioritization ▪ Timeframe of impacts ▪ Monitoring engagement	▪ Matching scales ▪ Early & regular engagement ▪ Face-to-face ▪ Skilled facilitation ▪ Make engaging easy & rewarding

Fig. 2. Common steps (i.e., project timeline) in co-production (Cooke et al. 2021; Steger et al. 2021) along with: (i) practical components of co-production (that can be planned and budgeted), (ii) pre-conditions that shape the operating space for possible benefits per investment, and (iii) enablers that can shift towards more efficiency. All are based on a narrative review of the literature (for more detail see Supplementary Material) and grouped under the four co-production principles by Norström et al. (2020).

> "how social and cultural norms, existing policy and institutions, and past relationships between communities, stakeholder groups, and organisations shape the interactions between individuals participating in the process".

Political appetite/receptiveness and culture will also influence co-production and research uptake in policy-making (Court & Young, 2003; Goldman & Pabari, 2021). It is important to check what previous experiences all actors have had when engaging with research or decision-making, how have they been affected (Dilling et al. 2021)? What are the sensitivities and conflicts? What knowledge needs to be co-created (to only co-produce where additional knowledge is needed (Sutherland et al. 2017))?

Depending on the context and actor positionality, knowledge co-production requires particular attention to counter neo-colonialism and parachute science (de Vos, 2020; Yeager, 2021; de Vos & Schwartz, 2022). Such parachute science occurs

> "when scientists and/or NGOs from the Global North venture to the Global South to conduct research or deploy programs and fail to invest in, fully partner with, or recognise local governance, capacity, expertise, and social structures" (de Vos & Schwartz, 2022, p.1).

Colonialism and Indigenous dispossession have placed severe environmental injustices around the world and caused continuous misrepresentation and unethical discontinuation of 'customary' resource use and rights (Wilson, 2021; Bennett et al. 2023).

4.1.2. *Enablers for context-based co-production*

Karcher et al. (2022b) and Bamzai-Dodson et al. (2021) provide recommendations on how to consider the context in question through guiding questions around problem complexity, existing knowledge, engagement needs, local context (social, political, economic), decision context (e.g., power, governance system), and leadership or institutional support. For co-production success it is key to get the timing right and to collaboratively choose a topic which is of demand/significance to policymakers, local communities, and/or other non-academic actors (e.g. a topic or problem which has media attention), or a window of opportunity (e.g. a policy window; Rose et al. 2020; Karcher et al. 2022a). It is also important that temporal, spatial and governance scales are aligned (Newig et al. 2016; Reed et al. 2018b). High levels of context knowledge can increase the likelihood of overall co-production success (Ferguson et al. 2022).

4.2. *Pluralistic*

4.2.1. *Pre-conditions to pluralistic co-production*

Characteristics of the stakeholder community (who, how many, how diverse, who is interested, who has influence) and their needs and ambitions are key considerations for ensuring a pluralistic co-production process (Reed et al. 2014, 2018b, 2018a; Beier et al. 2017; Kumar et al. 2018; Ferse et al. 2021; Nyboer et al. 2021; Karcher et al. 2022b). Additionally, the decision-context affects the pre-conditions to pluralistic engagement. For example, the opportunity for meaningful engagement of scientific, western and traditional, local or Indigenous knowledge (where applicable) and equitable roles and empowerment (e.g., Chapman & Schott, 2020; Latulippe & Klenk, 2020) requires such willingness and institutional support (e.g., funding) by research and governance systems.

Unequal power relations are a critical challenge for societal transformation through co-production and the effectiveness of engagement (Reed et al. 2018b; Turnhout et al. 2020; Ferse et al. 2021). For that reason it is important to consider what everyone is bringing to the table

and what is most needed for what purpose (Oliver et al. 2019). How can different voices and perspectives be heard and included meaningfully, beyond tokenistic gestures (e.g., Hickey et al. 2018)? What would be a positive outcome for everyone? This needs to consider the different motivations of actors to participate in co-production and how co-production is inevitably shaped by the different identities and positionalities of participants (Muhl et al. 2023). How can contestation of views and interests be coordinated to be equitable, legitimate, and impact-oriented (*cf.* Turnhout et al. 2020)?

Within the pluralism principle, there is the clear need to ensure that there is meaningful representation and involvement of minority groups. However, engaging underrepresented or minoritised groups in researchers and societal partners requires active and deliberate steps (Johri et al. 2021; Shellock et al. 2022; Kaikkonen et al. 2024). In order to improve equity, diversity, and inclusion and counter parachute science, co-production not only needs to respect and include diverse perspectives, but also enable participation in decisions, support local leadership and co-create local benefits, for example through long-term collaboration with local researchers, institutions and funding bodies (Bennett et al. 2021; Stefanoudis et al. 2021).

4.2.2. Enablers for pluralistic co-production

Trust is a key enabler of fruitful collaboration and use of knowledge in decision-making (Reed et al. 2014; Tinch et al. 2018; Newig et al. 2019; Cvitanovic et al. 2021b, 2024). High-quality interpersonal relationships where actors understand and respect each other's ambitions and restrictions, as well as an overall transparent process are success factors and therefore increase possible benefits (Karcher et al. 2022a, 2023). Related to the *context-based* principle, it is important to build on legacies of positive engagement among actors as this can be an enabler for pluralistic collaboration (i.e. it can contribute to more and earlier benefits). Ethical engagement and research partnerships with pluralistic actors is enabled by, for example, systematic representation, self-determination, and reciprocity (Wilmer et al. 2021).

4.3. Goal-oriented

4.3.1. Pre-conditions to goal-oriented co-production

Time and resources required for co-designing goals and collaboration can depend on levels of pre-existing trust (or conflicts) and the complexity of the problem at hand. The presence and nature of institutionalised or otherwise formalised pathways of collaboration between, for example researchers and decision-makers, set the playing field. A starting point should be to ask what outcomes would be most valuable to whom (Dilling et al. 2021). The nuances of goal-oriented engagement will depend, among others, on the governance system, institutional frameworks, and the question how much legitimacy a certain outcome requires (Bamzai-Dodson et al. 2021). Community-driven, locally initiated projects, and those following policy demand (Karcher et al. 2022a) may have higher chances for positive outcomes compared to top-down research initiatives. This may be due to local knowledge and bottom-up momentum that may favour the cost-benefit ratio for similar investment. However, they still face social risks, for example regarding power dynamics and expectation setting.

4.3.2. Enablers for goal-oriented co-production

To achieve a shared goal, it is important that all actors approach the collaboration with a high degree of openness without too many preconceived ideas or finalised decisions (Karcher et al. 2022a). The ability to develop a mutual goal from inception may seem like an unnecessarily time-consuming step but it is likely to contribute to a shared goal and buy-in and supports quality (e.g., relevance and legitimacy) of produced knowledge, while preventing delays by individuals who may push a preconceived idea. It also helps actors view the process and possible outcomes as relevant and the group as legitimate (Emery et al. 2015). Therefore, the transparency of both the co-production and management processes is relevant (Sterling et al. 2017; Gerlak et al. 2023). It might be helpful to not only co-identify goals but also co-define explicit outcomes, when outcomes are expected to occur, and if there are intermediary outcomes that can be shared (Karcher et al. 2022b). From there, participants can discuss what is needed to achieve these outcomes, how much engagement is required and if/how tasks can be divided and delegated across the group (Smith et al. 2023). Recommendations include applying a theory of change with explicitly articulated goals to support goal orientation given the otherwise hard to evaluate nature of participatory knowledge generation and translation (Oliver, 2023). It is also beneficial to pursue flexibility in funding and priorities (Beier et al. 2017; Cvitanovic et al. 2021c; Nyboer et al. 2021; Karcher et al. 2022b). An engaged funder can contribute to goal-oriented co-production, for example by coordinating collaboration, monitoring engagement, orchestrating connections, and providing clear structures and priority-setting workshops (Karcher et al. 2023).

4.4. Interactive

4.4.1. Pre-conditions to interactive co-production

An obvious pre-condition affecting investment in interactive co-production is the availability of resources for such intensive modes of engagement (Bamzai-Dodson et al. 2021; Karcher et al. 2022b). The accessibility of actors shapes collaboration over time including the direct costs that apply through travel and other expenses (Meadow et al. 2015). Again, the level of trust among actors will determine the benefits and investments needed for interaction. For high levels of interaction, intrinsic motivation of all actors might need to move beyond their daily business and comfort zone (Karcher et al. 2022b), and incentives, professional support and reward structures for engagement of professional roles (e.g., researcher, policy-maker) may be needed. Ultimately, also the complexity of the problem including possible sensitivities/contestations around it determine the intensity of needed interaction. It is important to "*match the length and frequency of engagement to the goals of the process*" (Reed et al. 2018b, p.S15).

4.4.2. Enablers for interactive co-production

One way to generate more benefits of co-production is investing in early and regular engagement that is well facilitated and matches the temporal and spatial scale of what is needed (Reed et al. 2018b; Karcher et al. 2023). Strong communication, coordination, and facilitation are among the most common enablers of knowledge co-production (Gerlak et al. 2023) and enable evidence use through high quality collaboration and relationships (Oliver et al. 2014). Also the core qualities of the actor group, their devotion and motivation play an important role towards more benefits (Karcher et al. 2022a). The responsiveness, and mutual respect of co-production partners are additional enablers of co-production success (Karcher et al. 2023). While it can be challenging to maintain actors' motivation over a long time, planning for intermediary outcomes and the communication and celebration of achievements can support this. It can help to adjust the location and format of interaction to the participants' needs and make engaging easy, fun, and rewarding for everyone (de Vente et al. 2016; Cooke et al. 2021). Depending on the actors involved (e.g., industry), structured facilitation and development of Memorandum of Understandings (MOUs; agreements on expectations, contributions, behaviours) can also be beneficial (Thompson et al. 2019).

5. A hypothetical case study to show cost-benefit considerations of co-production

To allow for a detailed exploration of co-production efficiency, we use a hypothetical case study, following the approach taken by Moon et al. (2021). The hypothetical is designed to demonstrate the practical application of the conceptual considerations, to show how co-production principles translate into real-world scenarios and simplify

the abstract concept of cost-benefit relationships. The hypothetical illustrates a scenario for the potential costs and benefits of co-production in action. It attempts to showcase an example relevant to the broad readership yet specific enough to draw explicit links to the cost-benefit dimension of co-production by raising counterfactuals ('what if') for not investing in each of the four principles, comparable to a scenario-based approach to project planning and implementation (Stephenson & Hobday, 2024). To align with the expertise of the author group, our case study is centred on fisheries management within the context of an emerging marine resource. Across the author group, we have experience as researchers of marine resources and science-policy-society collaboration (AJH, CC, DBK, IvP, RLS, RS), research managers (AJH, CC, IvP, RLS, RS), research funders (CC, IvP) and in government agencies (CC, DBK, IvP). As a group, we also have experience applying and analysing co-production processes that we draw from here. Rather than referring to a specific location, we discuss specific cost-benefit considerations for the management of a hypothetical and emerging small-scale fishery that could be located in a range of countries.

5.1. The hypothetical case study setting

We consider a hypothetical project that seeks to establish how climate-smart fisheries management may relate to the establishment of new domestic fisheries – to enable a shift to species that are likely to respond better to changing climate (or simply change distribution into the region in response to climate change). Fishing resources are major contributors to regional economies, nutrition and food security. With climate change being a key threat concurrent with other anthropogenic pressures such as international fishing and pollution, climate-adaptive fisheries management is needed to support food security (Teneva et al. 2023). In scoping options for a new fishery, it is critical to understand the value and importance of different species, the knowledge of local fishers about the new stock (e.g., their location and the gear/methods needed to catch them) and the value chain for taking fish from the water to table. As such, scoping for the new fishery must move beyond simple economic evaluations, and must include consideration of broader social and cultural values, for example via 'full spectrum sustainability' (e.g., Young et al. 2016; Foley et al. 2020). Within the context of fisheries management, the engagement and application of local or traditional knowledge is important alongside scientific knowledge (Johannes, 2002; Friedlander et al. 2013; Stephenson et al. 2016).

In the following sections, we consider knowledge co-production to support the management of a newly emerging national fishery. Despite embedded in a local context of tensions among different marine users, we assume that a knowledge co-production project commences with a hypothetical project timeline of around four years. The co-production project goal is to contribute to sustainable, legitimate, evidence-informed use and management of the emerging fishery. Building on the review of literature (Section 4), the following section compiles our experience-based considerations with regard to a hypothetical case study, and touches aspects of costs and benefits in the narrative.

5.2. Context-based efficiency in hypothetical case study

To ensure the knowledge co-production is context-specific, the hypothetical project will need to situate itself in the local historical, social, and political context. Given the short timeframe, the project needs to pay careful attention to getting the context right at the start. Getting the contextual foundation wrong could harm the project, local communities, and the sum of possible benefits. Here, a critical issue is the distribution of access and benefit. Who would get to access the new resource? Research with one group could provide them with advantages over other communities. Context-based considerations for co-production investment in the new fishery may comprise three main tasks and each of these tasks has relevant cost considerations: 1) identifying perspectives and knowledge systems, 2) careful stakeholder engagement planning to ensure local social system and history is well understood and considered, and 3) ensuring the right team capacities are in place to tackle the first two tasks and the co-production project as a whole.

1. As a newly emerging fishery, there is likely to be little formal scientific data on the specie, but local knowledge may be expansive, for example regarding the abundance, harvest, and sustainable management opportunities. With this lack of context-specific scientific knowledge and potentially complex social-ecological system, co-production of a shared understanding is key. This may mean investment in multiple and early learning opportunities (workshops/fieldtrips etc.) with a cross section of interested participants is needed. Early investment in developing shared context-based learning will benefit the generation of management opportunities. Where management decisions are not pre-determined and outcomes of resource use and management are required to be legitimate and publicly accepted, there is a better chance for well-informed management through co-production (and benefits are more likely to outweigh costs).
2. We need to invest in collaborating with local experts and knowledge systems to assess local custom, use of marine resources and historical cultural power dynamics prior to bringing different groups together to avoid causing harm. Pre-existing local conflicts, for example, about resource use, as well as colonial history and mindsets (where applicable) can put systemic burdens on different actors. Their societal position requires careful and culturally sensitive consideration and local collaborators for equitable collaboration and distribution of benefit.
3. As the coordinating team for the hypothetical co-production effort, we need assistance and situationally embedded collaborators to ensure efficient and ethical procedures (particularly if we are not embedded in this social-ecological system). To do so meaningfully, we need to create co-leadership opportunities with locally embedded experts (including knowledge brokers) and local groups (e.g., grassroot organisations, local action groups) that understand the specific context, history, stakeholder diversity and knowledge systems. Well-researched and upfront social system assessments will mean that existing relationships can be used to progress co-production. Well-established relationships with key actors can enable quicker and more beneficial outcomes, while disappointing experiences in the past (e.g., for communities engaging with science and government) can cause mistrust and require careful deliberate trust building and transparency. Meaningfully collaborating with well-connected and knowledgeable local champions can decrease the time and resources needed (i.e. reduce costs) for achieving co-production benefits.

5.2.1. Counterfactual in hypothetical case study – what if not investing in the context-based principle

Not investing in getting the context-based principle right in our case study could result in an inappropriately staffed research team. It can maintain biases and norms, which impedes diversity, equity and inclusion in the field. In addition, it could impede the building of trusted relations, risk overlooking local actors or conflicts, and imposing everyone to ivory tower parachute science while risking relevant local benefits. Not understanding existing connections and actors could lead to conflicts, delays, lost legitimacy and knowledge outcomes that are not relevant to the emerging fishery. It is also important to adhere to the rule of "do no harm" and minimise disruption to local culture and dynamics. Further, not investing in participatory context-based learning could lead to flawed assumptions about the resource and less beneficial outcomes. Overall, an unsuitable approach for a specific context could compromise positive outcomes and have deleterious impacts for local communities and stakeholders.

5.3. Pluralistic efficiency in hypothetical case study

Our hypothetical case study requires legitimate engagement of an appropriate range of actors and sectors to provide a diversity of insights, perspectives, and knowledge types. Given our positionality, this means having locals on the project as early as possible (if working in a region where we do not originate from or live). Cost-benefit considerations for pluralistic co-production of knowledge for the management of the emerging fishery include: 1) ensuring the right group of diverse actors is engaged ethically to ensure greater benefits and legitimacy, 2) deliberately building trust among all actors, and 3) supporting their smooth and constructive interaction to attain and share benefits promptly.

1. Pluralistic knowledge creation requires accurate stakeholder identification. Getting this right in a local context where we might not reside requires meaningful co-leadership with local researchers, experts, and facilitators because it exceeds our experience. We need to consider actors like local community-based fishing, domestic and international offshore fishing, tourism, traditional resource use and custom, as well as local and national governments. Engaging representative and well-respected actors for a shared cause (see *goal-oriented*) decreases time and cost of convening while building trust increases the likelihood of collaborative interaction and inclusion of diverse voices. Pluralism also requires special attention to incorporating different types of knowledge and engaging often disadvantaged groups in environmental management, particularly those with multiple disadvantaged statuses (i.e., considering intersectionality; Crenshaw, 1989), for example, based on gender, race, religion, social status, economic sector, sexual orientation and ability. This requires careful stakeholder mapping, power analysis and contextual awareness led by local experts (see *context-based*).
2. Given the diversity of actors involved, the role of the research team, and the expected tensions around resource use, it is critical to deliberately build trusted relationships. We would add local researchers to the project team during the development of the proposals and ask them to let their colleagues and networks know about the project. Led by the local project members, we would visit sites where activities take place to see what local practices are. We would share experiences working in other regions that are coping with similar challenges. We would take time to jointly plan preliminary goals, results, and explain how feedback and input can be made.
3. Where power imbalances exist between, for example, small-scale fishing communities and the government, and scientific knowledge is regarded as the only valid source of information, other types of knowledge are easily discouraged or underappreciated. Hence, we need investment in time and space for open discussions and equal opportunities. We need to assign resources to an informal locally-led assessment of cultural aspects to better understand the local customs and to observe them in terms of engaging different actors (e.g., giving everyone a voice and treating everyone equally can also be inappropriate in some communities/contexts if only chiefs/elders/leaders should speak on certain issues). Additionally, politically (e.g., post-colonially) disempowered actors may come to the table with limited trust and buy-in. We need to recognise that diverse actors have different values, resources, power, and vulnerabilities whose contestation or empowerment takes place in an intrinsically politicised context and process (Turnhout et al. 2020). As such, co-ownership or power sharing might be needed which takes more time than a top-down approach but enables more accepted outcomes.

5.3.1. Counterfactual in hypothetical case study – what if not investing in the pluralistic principle

Without pluralistic engagement, the hypothetical case study would lack legitimacy of produced knowledge. Given the emerging fishery is supposed to benefit local fishers, their input and practical local knowledge is a critical factor, enabling the achievement of better and more diverse objectives through a changed scope of discourse giving attention to the potential trade-offs across social, economic and governance aspects. Without pluralistic knowledge co-production there is a high probability of 'status quo' thinking and acting which in many places means that big (i.e., power, resources) players might promote their objectives and thwart transformative change. Failing to navigate pluralism in co-production might inhibit benefits by missing relevant knowledge (e.g., of fishing grounds and traditional fishing practices or tourism priorities), limiting buy-in and motivation, and creating new conflicts leading to mistrust, anger, and non-ideal management decisions. To decrease the likelihood of risking such non-ideal outcomes, we have to invest more resources in engaging with local and Indigenous knowledge systems (as applicable) which requires tangible and intangible investment. Excluding actors as well as not managing expectations and power relations could lead to further marginalisation of already marginalised groups.

5.4. Goal-oriented efficiency in hypothetical case study

To achieve the principle of goal-orientation in our hypothetical case study, investment needs to: 1) unite all actors in a shared, feasible, and relevant goal, and 2) support the attainment of that goal with mutual benefits and an agreed timeframe.

1. Building shared goals takes time, transparency, and compromise because different actors are likely to have different goals, expectations, and limitations. Governments might struggle to identify and articulate clear needs for information, which can inhibit the collaboration's chance to co-produce decision-relevant knowledge. Hence, time and resources for co-identification of needs and priorities are needed. We address this, for example, by a field visit with in-kind support from a government agency (e.g., vessel) to explore where these new fish are and how they can be caught. Informal (e.g. lunch, field visits) and formal (e.g. priority setting workshops) forms of engagement are used as a starting point to discuss the goals of managing and using the new fishery in the future. Starting with a blank sheet of paper participants can collate high-level goals/ valuable outcomes. The process of discussion will make differences and communalities apparent and identify project priorities (including intended outcomes and formats). In further discussions, timelines, contributions, and project milestones can be discussed.
2. Focusing on jointly prioritised, realistic short- and medium-term benefits with clearly defined outcomes for each party helps expectation setting and counteracts disappointment and demotivation. For example, it can be more realistic to aim for testing one harvesting strategy and identify management priorities than changing user rights in federal law. Furthermore, we need to be aware that goals can change, for example, if governments, public opinion, or fish stocks change. Not being able to respond to changes may impact the expected benefits (i.e., relevance) of co-production. Through co-funding arrangements with the respective management agency and buy-in, we can secure space for emerging priorities in the project. To be able to adjust, we need to conduct monitoring and re-evaluation of goals and progress. For example, we may incorporate several contact-points with the actors to monitor if the co-developed priorities remain accurate, to share intermediary progress, and nurture interpersonal relationships.

5.4.1. Counterfactual in hypothetical case study – what if not investing in the goal-oriented principle

Not investing in the identification and prioritisation of a clear and realistic shared goal could put at risk the benefits of co-production. If it is not clear what the ambition of the engagement is, it is hard to achieve it

or even evaluate it. Failing the goal-orientation principle could lead to participants feeling like their efforts are not leading anywhere, for example sharing knowledge and needs about the use of marine spaces might not lead to valuable insights into how to use the emerging fishery. This could substantially limit the relevance of resulting knowledge if its purpose was never agreed on. Missing out on targeted engagement and goal-based planning and evaluation may limit the ability to demonstrate success given this may mean different outcomes to different actors. Therefore, investment in this principle is needed for goals to be jointly developed and mutually beneficial.

5.5. Interactive efficiency in hypothetical case study

To some extent, the efficiency of interactivity depends on a compromise between high pluralism and a narrow goal orientation. Aiming for cost-efficient interactivity in our hypothetical case study, it is key to consider 1) where, 2) when, and 3) how interactions can take place to lead to the highest benefits in the shortest investment timeframe.

1. In our hypothetical emerging fishery relevant actors may be spread across the region. Hence, accommodating for regular, interactive exchange may disproportionately burden remote actors (e.g., fishing communities). If reliable bandwidth for online engagement is not available in remote regions, we need resources for travelling and accommodation. We also need to consider whether research and management actors might find it easier to travel and get such travel funded than local fishers and tourism operators.
2. Shifting the timeline of investment towards starting interaction early in a research and decision process may support efficiency of interactions and prevent heading in the wrong direction (*goal-oriented*). Additionally, for the use and management of an emerging fishery, we need to invest in practical iterative steps, for example to jointly test new fishing gear or locate fish abundance. A mutually designed harvesting strategy could be a tangible boundary object to help unite discussions and expertise that everyone can relate to from their own perspective.
3. Considering the individual burdens of co-production engagement, we need to ensure that all actors stay motivated and get something out of the process. If actors do not see any tangible or intangible value in engaging, they will drop out, risking a range of benefits. Informal social events could help maintain motivation and trusted relationships that will contribute to the magnitude of possible benefits. Given the high diversity of actors involved, frequent engagement comes with challenges to make all voices heard and keep them engaged over time. Therefore, we need to invest in professional, outcome-driven, and locally respected facilitation.

5.5.1. Counterfactual in hypothetical case study – what if not investing in the interactive principle

Without interaction, there is very limited opportunity for social learning and actors improving their mutual understanding. A one-off and one-way input of management perspectives for the emerging fishery might miss the mark, for example because it limits cross-fertilisation and the adjustment of goals and outcomes. Not allowing for iteratively developing knowledge among actors (including feedback loops) could lead to misunderstandings and risk the credibility and relevance of outcomes. Practically, not investing in interaction would leave out many remote actors (fishers, tourism operators, Indigenous groups, etc.) that are spread over the region. This could indirectly lead to only the nearby actors and those having sufficient resources to travel, or those with sufficient internet bandwidth being heard. Therefore, interactivity requires significant financial investment, as well as the intangible investment to actively engage, reassess, and synthesise a shared benefit. Besides, the application of co-produced knowledge (i.e., the sustainable harvest) will lack in quality and applicability without co-learning the harvesting strategy.

6. Discussion

6.1. An alternative view to the maxim of intensive knowledge co-production

While every co-production principle has its own cost-benefit ratio and counterfactual if not investing in it (*above*), so does co-production as a whole, combining the four principles to achieve more than the sum of their pieces. Here we present the overarching efficiency consideration (including diverse forms of costs and benefits) that highly participatory forms of research need to recognise their pre-conditions and that high participation might not always be the most efficient choice. In the hypothetical fisheries case this could be seen as the best and most sustainable catch per unit effort. Considering different intensities of participation and their associated cost is important, because similar levels of investment might lead to different outcomes in different contexts and therefore have different efficiencies (following e.g., Laycock et al., 2011). Such considerations (in shared responsibility of all involved actors, including funders) was suggested previously in health research to first identify the likelihood whether co-production actually helps in meeting its goals, or whether other approaches are at least similarly likely to do so (Oliver et al. 2019). While running the risk of falling short on legitimacy and relevance (e.g., Cash et al. 2006; Roux et al. 2006), linear pathways of knowledge (e.g., knowledge transfer, advice bodies) continue to play a role, particularly when initiated or demanded by government entities (Steger et al. 2021; Karcher et al. 2022a; Maas et al. 2022). Governance costs vary across management situations, governance structures and complexities (Birner & Wittmer, 2004; Cvitanovic et al. 2018). Likewise, co-production strategies and roles vary between problem types, and are therefore context-specific (Turnhout et al. 2007; Hage et al. 2010; Bamzai-Dodson et al. 2021). Sometimes, less intensive modes of engagement are ok, less complex problems and actor constellations may allow for less complex solutions, otherwise causing high governance costs (Cvitanovic et al. 2018).

Considering situations where co-production may not be the most cost-efficient choice is necessary for research, policy and funding decisions, particularly when comparing different intensities of co-production with other engagement strategies that may be less resource intensive. Knowledge co-production might not be required for all issues and objectives but there is an increasing number of complex social-ecological issues for which it is required and then should be undertaken deliberatively and thoroughly to get the best outcome for the available investment of resources. Co-production, especially in marine and other complex fields, often involves substantial direct and indirect costs—time, resources, and efforts in relationship-building and stakeholder management. These costs may sometimes exceed the potential benefits, especially in cases where alternative research methods or less intensive engagement strategies could yield similar results quicker or cheaper. Some problems might require technical expertise that does not necessitate broad stakeholder engagement, others may have predefined methods and inputs limiting the potential for co-design. For example, when the low complexity of the research problem does not justify extensive stakeholder engagement, when the time required for relationship-building might delay urgent undisputed policy decisions, or the funding for another in-person workshop would better be used to hire a graphic designer to illustrate outcomes.

Considering this possibility and identifying the most cost-efficient strategy to achieve good outcomes helps researchers, NGOs, government agencies, and funders to take informed decisions when planning, justifying, and evaluating co-production engagement. Being transparent about the strengths and trade-offs of co-production increases the credibility, the scholarly discussion and the argument to systematically identify cost-efficient solutions. This is also relevant to policy-making

and can help guide science-policy-society engagement and consultation planning in context-specific evidence-informed policy processes. Considering the costs and benefits of co-production is important for ensuring effective and efficient science-policy relations in situations where high urgency and expectations might exceed limited resources. Such consideration can enable more transparent and strategic engagement planning (e.g. intensity of engagement) while engaging multiple streams of knowledge in evidence-informed policy. Research and policy development often require prioritising based on their cost-effectiveness and ability to meet objectives. By demonstrating that co-production can be designed under similar, business-case, principles, we hope to empower different actors in research and management to make and defend better strategic decisions regarding the use of collaborative engagement method and intensity. Identifying the most suitable and efficient engagement strategy early on saves money, time, and unnecessary stress.

Building on the idea of cost-benefit curves for co-production (see Fig. 1), we propose a conceptual approach to overall efficiency of interactive knowledge co-production as the mean increase of benefits per unit investment. The extent of interactive co-production at points of maximal efficiency could be seen as optimal engagement. Co-production principles may have different contributions to overall success, they might therefore require different considerations depending on the context, and their cost-benefit relations affect the overall efficiency of the knowledge co-production. An additional concluding remark is for the consideration of time in cost-benefit planning of co-production. Different investment points may occur and benefits may be delayed both due to internal and external reasons. Acknowledging a longer project timeline (i.e., low-cost maintenance in the back end) can capture more slowly emerging impacts and hence increase the B:C ratio.

6.2. *Guiding questions on cost-benefit implications*

Distiling the narrative literature review and illustration of the hypothetical case study, we would like to collate some guiding questions towards considering cost-efficiency for researchers and practitioners planning to conduct co-production:

- Does relevant knowledge already exist in accessible form or can be gained by one or two parties without the effort of knowledge co-production (evidence synthesis, consultation)?
- Is co-production required or beneficial, to whom, and why (e.g. unique knowledge, complex or conflicted resource use, etc.)?
- Is 'beyond status quo' thinking needed and appreciated to solve the issue?
- Could co-production be non-beneficial for some people/groups and why?
- What are the strengths and unique features of potential contributions of different actors?
- What type(s) of co-production are best suited to the question/problem?
- Is there another activity that might achieve a better C:B ratio when considering intangible costs and benefits (value for investment)?
- What pre-conditions could affect the efficiency of co-production in the given context?
- Which of the four necessary co-production principles (context-based, pluralistic, goal-oriented, interactive) will be the hardest and most expensive to achieve and what would happen if it would not be achieved?
- What enabling factors could be planned for to support co-production efficiency?
- Can the benefits be measured and/or be easily observed (and how soon)?
- How can intangible, conceptual, relational, and societal benefits be planned and measured?
- Is the level of investment in a co-production activity high enough to result in predicted benefits?
- Can the benefits be generated quicker and last longer for the same investment?
- Is it possible to determine when optimal engagement has been reached?

7. Conclusion and future research

Many have expressed visions for science-policy collaboration to become more mainstream and "*no longer a specialist or additional activity, but something which is valued and rewarded by institutions, resourced by funders and an established part of the policy process*" (Karcher et al. 2022a; Reid & Chaytor, 2022, p.26). However, little evidence is available that weighs both costs and benefits of co-production. In the hope of providing a starting point for researchers, organisations, and funders, we have outlined a few high-level factors that could help shift co-production efficiency towards more, better value and quicker benefits. Through this narrative review with our perspective illustrated in the hypothetical case study, we gave considerations to tackle co-production efficiency, for example through the improvement of benefits (i.e., increasing value for given investment) which is relevant when a fixed research budget is given. In conclusion, we need to think more strategically and explicitly about co-production efficiency and get better at considering the full range of intangible costs and benefits in our planning and evaluation. Like this, we hope to have provided some guidance for researchers, NGOs and management entities planning participatory research, suggesting two key steps in the start of engagement planning: Understanding whether complex, costly co-production is needed for their issue (alternatives), and if so, planning it in the most rigorous, thorough, and cost-efficient way possible for best outcomes per investment (through counterfactuals, i.e., not doing so).

Empirical research is needed to examine the conceptual ideas developed in this paper. For example, whether a (context-specific) optimal engagement is borne out in the relationship between co-production investment and relative increase of benefits. It is important to gain a more comparative understanding of which strategies are most efficient in which situation, and how pre-conditions may support or compromise success (Wyborn et al. 2019; Karcher et al. 2022b). Such work should build on Bamzai-Dodson et al. (2021) who give guidance depending on the ambition of co-production to inform, consult, participate, or empower, and Meadow et al. (2015) who outline modes of stakeholder engagement in relation to the question focus. A key research need is whether using a different knowledge exchange strategy would result in more, earlier, or better value outcomes. Therefore, it is key to match the strategy to the specific context, goals, and complexities, clearly name and plan for intangible costs and benefits, and gather more guidance deciding on the right strategy and intensity of engagement in a specific circumstance.

CRediT authorship contribution statement

Alistair J. Hobday: Writing – review & editing, Investigation, Conceptualization. **Robert L. Stephenson:** Writing – review & editing, Investigation, Conceptualization. **Rebecca Shellock:** Writing – original draft, Investigation, Conceptualization. **Ingrid van Putten:** Writing – review & editing, Writing – original draft, Supervision, Methodology, Investigation, Conceptualization. **Christopher Cvitanovic:** Writing – review & editing, Writing – original draft, Supervision, Methodology, Investigation, Conceptualization. **Denis B. Karcher:** Writing – review & editing, Writing – original draft, Visualization, Project administration, Methodology, Investigation, Conceptualization.

Declaration of Competing Interest

The authors declare that they have no known competing interests or

personal relationships that could have appeared to influence the work reported in this paper.

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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.marpol.2025.106769.

Data availability

No data was used for the research described in the article.

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