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Empirical insights into knowledge-weaving processes in strategic environmental research

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ABSTRACT

Merging scientific and stakeholder knowledge plays a critical part in knowledge co-production processes, yet it is far from straightforward. We describe knowledge co-production processes by drawing on experiences from four strategic research cases that all sought to integrate scientific and stakeholder knowledge, while demonstrating the different settings and methodological choices for knowledge co-production in environmental research. To facilitate systematic analysis, we utilized the knowledge-weaving framework by Tengö et al. (2017) to examine co-production through the phases of knowledge mobilizing, translating, negotiating, synthesizing and applying. We also considered the inclusiveness of the weaving processes, where our results show that all of the study cases were able to engage participants across the four phases. Our analysis indicates that the framework is useful for unpacking the different phases of the knowledge-weaving process as well as the variety of activities that are used throughout the process. However, the results also emphasize the long-term nature of these processes, as knowledge-weaving activities were used predominantly in the mobilize and translate/negotiate phases and less at later phases of the process. This indicates that the benefits may be foreseen in similar future actions through the initiated learning and change processes.

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Co-production of knowledge; transdisciplinary; knowledge weaving

1. Introduction

The urgency of 'wicked' (Rittel & Webber, 1973) sustainability problems has called for new approaches to knowledge creation in both science and decision-making practice. Transdisciplinarity is one of the ways to describe the turn in science aiming to tackle complex societal problems using multiple types of knowledge. It refers to research that deals with real-life problems, involves a variety of actors from science and practice to account for the diversity of perspectives, and creates knowledge that is solution-oriented, socially robust, and transferable to both scientific and societal practice (Pohl & Hirsch Hadorn, 2007; Lang et al., 2012). In such processes, new ways of knowing can be integrated into decision-making through processes of knowledge co-production, which can be defined as 'processes that iteratively unite ways of knowing and acting – including ideas, norms, practices, and discourses – leading to mutual reinforcement and reciprocal transformation of

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societal outcomes' (Wyborn et al., 2019, 320). Understood in this way, co-production aims to involve multiple participants (scientists, policymakers, private sector, civil society, etc.) in producing multiple outcomes, including new knowledge, new ways of integrating knowledge into decision-making and action, and, most importantly, new outcomes in real-world practices (Miller & Wyborn, 2020; Stepanova et al., 2019).

Co-production approaches are becoming increasingly common, partly driven by research funders that require research to be policy-relevant and to have a strong societal impact (Arnott et al., 2020). Within international science and policy fora, there is a growing expectation that co-production will increase the impact of science, particularly on sustainable development challenges that are seen to require highly integrated approaches and close science-policy interaction (Norström et al., 2020; Lemos et al., 2018). In Finland, the Strategic Research Council at the Academy of Finland (SRC) provides funding for long-term research on major societal challenges and their solutions, and requires that research projects actively engage key stakeholders throughout the life cycle of the projects (SRC, 2020).

There is a growing body of literature on co-production processes, particularly in the sustainability context, that ranges from theoretical underpinnings (e.g. Berkes, 2009; Turnhout et al., 2020; Matuk et al., 2020) to methodological development (e.g. Norström et al., 2020; Simon et al., 2018) and empirical case studies. Empirical research on knowledge co-production has documented both successes and challenges in the attempts to make use of multiple ways of knowing (Godemann, 2008; Jagannathan et al., 2020; Turnhout et al., 2020; Vinke-de Kruijf et al., 2021). For example, Westberg and Polk (2016) observed that while transdisciplinary research projects supported learning and critical reflection on different perspectives, the learning outcomes were difficult to apply outside the temporary transdisciplinary practices.

In this paper, we contribute to the emerging body of literature by analyzing the co-production processes in four empirical research cases, all of which study sustainability challenges and their governance, but with differing thematic emphases. All four cases were funded by the SRC, and all include strong but differing approaches to knowledge co-production. To ensure a systematic approach and to facilitate comparison between the cases, we apply the knowledge-weaving framework by Tengö et al. (2017) to structure our analysis. We investigate what kind of knowledge was co-produced, how the various knowledge-weaving phases were applied in these cases, and how inclusive they were. We also assess the added value of such processes in generating solution-oriented and socially robust knowledge.

The paper is organized as follows: first, we briefly present the key concepts and frameworks used, followed by a description of the context and methods. After that, we outline our cases according to the knowledge types involved, and then present our findings on knowledge-weaving processes. We conclude our analysis with the lessons learnt.

2. Knowledge systems and co-production of knowledge

2.1 Key concepts: knowledge and knowledge co-production

Our analysis builds on two main concepts – knowledge and knowledge co-production. Building on Rydin (2007) and Stepanova et al. (2019), we regard knowledge as claims used in understanding causalities between action and impact. While knowledge claims may be partly composed of values and may entail experiences, they are not equal to either and can be assessed separately (Collins & Evans, 2002; Scholz and Steiner 2015). The concept of knowledge is closely linked to the concept of a knowledge system, which can generally be defined as 'the knowledge claims, values and standards, epistemologies, and structures that shape knowledge use' (Wyborn et al., 2019, 328). Moreover, a knowledge system can be seen as 'made up of agents, practices and institutions that organize the production, transfer and use of knowledge' (Cornell et al., 2013, 61).

The second main concept, knowledge co-production, considers the ways through which knowledge claims are exchanged, integrated and used for planning and decision-making in collaborative settings (Polk, 2015; Westberg & Polk, 2016). While noting that knowledge co-production links to the diverse and dynamic linkages between science and society (Jasanoff 2004), we regard it in this analysis more normatively as a

deliberate collaboration between different actors to achieve common goals that link closely to the processes of knowledge integration (Polk, 2015; Norström et al., 2020).

Knowledge integration in the co-production processes entails several challenges that relate to the process itself, as well as to the participants and their relations. The recognized challenges may include a lack of understanding of each other's context; differences in values and worldviews; mismatches between expectations, supply and needs; stakeholder fatigue; conflicting interests; lack of methods and expertise supporting integration; lack of awareness about the crucial role of boundary workers; different perceptions of uncertainties in knowledge; and differences in institutional power (Djenontin & Meadow, 2018; Harvey et al., 2019; Godemann, 2008). However, encouraging examples of how to overcome some of the barriers also exist. Possible strategies for successful integration include creating a shared understanding of the problem, setting common research objectives, collaborative knowledge production processes, and the joint synthesis, implementation and communication of results (Lang et al., 2012; Polk, 2015). In general, trust and commitment between actors (individual as well as institutional) are seen as crucial for creating productive integration processes (Stepanova et al., 2019).

2.2 Frameworks used to analyze knowledge and knowledge co-production

To differentiate between the different types and levels of knowledge, we followed the framework by Stepanova et al. (2019), originally developed for conflict resolution related to natural resource management. The framework recognizes three analytical levels and the corresponding knowledge types, namely informal and formal (context level); local, managerial/professional and scientific (actors level); and system, target and transformative (practice level): together these different types can then lead to jointly co-produced knowledge (Figure 1).

While we considered all knowledge types, our analysis put particular emphasis on formal as well as managerial/professional and scientific knowledge due to the case studies' focus on predominantly formal planning and decision-making settings and the related strong engagement of public sector officials. Out of the three knowledge levels by Stepanova et al. (2019), we consider the level of practice particularly essential with following definitions for its three knowledge types: systems knowledge is seen as knowledge of the current status of the studies system; target knowledge as knowledge about a target to be reached; and transformation knowledge

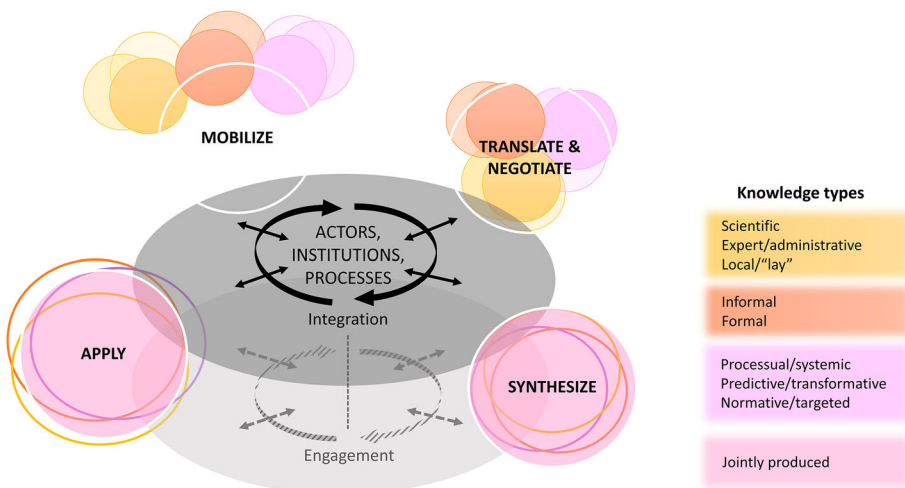

Figure 1. The framework used in this article for the knowledge-weaving process, combining four key phases of knowledge weaving (modified from Tengö et al., 2017) with different knowledge types (see Stepanova et al., 2019) and the two levels of inclusiveness (integration and engagement). Different knowledge systems are illustrated by bubbles of different colours in Mobilize and Translate & Negotiate phases, while 'Synthesize' phase is represented by rings with original colours from the bubbles and 'Apply' by rings spreading out from the realm of the common research context.

as knowledge about how to make the transition from the current to the target status (see also Pohl & Hirsch Hadorn, 2007).

To describe and analyze the processes of knowledge co-production, we applied the concept of *weaving* developed by Tengö et al. (2017). Knowledge weaving refers to 'collaboration that respects the integrity of each knowledge system', duly focussing more on interaction between different knowledge claims rather than their deep integration (see Figure 1). As interaction may take different forms during the knowledge co-production process, Tengö et al. (2017) divide the weaving process into five tasks (which we here modify slightly and call phases). Out of the five tasks, **mobilize** means to shape and articulate knowledge into a form that can be shared with others. **Translate** implies interactions between these knowledge systems to enable mutual comprehension of the shared knowledge. **Negotiate** means a joint assessment of convergence, divergence and conflicts across knowledge contributions. **Synthesize** concerns shaping broadly accepted common knowledge that maintains the integrity of each knowledge system, rather than 'integrating' into one knowledge system. **Apply** emphasizes knowledge usable for decision-making for all actors involved, at different scales, that can feed back into the respective knowledge system. For clarity, we regard the two phases (translate and negotiate) as one combined phase due to their close connection in our case projects: most of the strategies applied for translating the different knowledge systems in the studied projects happened in the context of *negotiation*.

In order to obtain a more nuanced view of different knowledge-weaving phases, we also considered the inclusiveness of the knowledge-weaving process, using two levels of inclusiveness, namely *integration* and *engagement*. The weaving activities can be regarded as particularly inclusive (see e.g. Arnstein, 2007) when the co-production participants are equally involved in the process: we refer to this as weaving with integration. The other level, weaving with engagement, refers to the process where the inclusion of co-production participants is less intense. We will demonstrate in our analysis the differences in inclusiveness of the process, manifested as a diversity of the weaving activities.

3. Materials and methods

3.1 Research context: SRC and the four case studies

The Strategic Research Council (SRC), established in 2015 and coordinated by the Academy of Finland (SRC, 2020), is one of the forerunners in the field of transdisciplinary research funding. The council runs about 20 thematic programmes, each consisting of 3–6 research consortia. Programme themes are defined through a consultative process whereby researchers and other societal actors highlight urgent and future challenges where more research is needed. The Finnish government confirms the strategic need for the proposed topics. The specific feature of SRC research is its direct linkage to national-level policymaking and the related strong engagement of public sector officials in knowledge co-production (Hjelt et al., 2021). This distinguishes SRC research from many other co-production projects, which tend to focus on more local-level actions and/or lay knowledge, instead of more administrative or professional types of knowledge (Stepanova et al., 2019).

As stated by the SRC (2020), an 'important element of such research is active collaboration between those who produce new knowledge and those who use it'. The SRC-funded projects are required to have a separate interaction plan in which these activities should be aligned with research objectives, and stakeholders are expected to be involved in the research throughout the project. The analysis in this paper focuses on four SRC-funded research projects, introduced briefly below and more thoroughly in the supplementary material. All of the authors are involved in at least one of the projects in different roles (such as a programme director or as a project staff).

The SOMPA research project (**the Peatland Case**) focuses on novel soil management practices in Finnish peatlands that are in agricultural or forestry use, namely cropland and forest peat soils (https://www.luke.fi/sompa/en/). The research aim is to develop understanding of novel and widely applicable management practices that support economic and ecological sustainability and climate mitigation in Finland and beyond.

The IBC-Carbon project (**the Forest Case**) denotes Integrated Biodiversity Conservation and Carbon Sequestration in the Changing Environment (http://www.ibccarbon.fi/en-US). The project tackles the wicked problem of simultaneously securing forest biodiversity, forest-based ecosystem services and the sustainable commercial use of Finnish boreal forests.

The CORE project focuses on collaborative environmental management, and experiments with knowledge co-production in several cases (www.collaboration.fi). In this article, the focus is on the **Citizens' Energy Case**, which aims to develop a shared understanding among relevant policy actors of the potential of on-site renewable energy production in apartment buildings in low-carbon energy transition.

The Winland project (**the Sustainable Security Case**) is the only project among the four that has already been completed, running between 2016 and 2019 (https://winlandtutkimus.fi/english). Winland set out to explore how pressures and shocks and political decision-making related to energy, food and water security may affect Finnish comprehensive security and resilience.

3.2 Research methods and data

We employed a case study method (see e.g. Yin, 2014) to conduct a cross-case synthesis among four research projects that employ a knowledge co-production approach. Rather than discussing each case separately, we aimed to integrate the empirical evidence from all four cases and to identify common themes with the help of the selected frameworks by Stepanova et al. (2019) and Tengö et al. (2017). Furthermore, we grouped the findings according to the level of inclusiveness (e.g. Arnstein, 2007) with the help of two basic levels for each weaving phase, namely integration and engagement. Figure 1 visualizes the linkages between the two frameworks and the levels of inclusiveness.

The selected cases are thematically close (addressing sustainability challenges), while illustrating different strategies and settings for knowledge co-production (see Table 1 and Appendix).

The empirical research data for the four cases was collected in two main ways: through a questionnaire (survey) and through collaborative analysis and reflection during the actual writing of the article, structured according to Figure 1. Using the Tengö et al. (2017) framework as a basis, the questionnaire on co-production activities was prepared by the first author, with answers provided during 2019 by the selected project participants, who are all actively involved in co-production activities (Table 1). The questionnaire was complemented by collaborative analysis and reflection by the authors during the actual writing process (which included altogether 4 workshops and 14 online meetings), using the analytical frameworks as well as summary tables to provide a structure for the analysis and to enhance consistency across the cases.

Both the survey results and the project-specific analysis and reflection made use of participatory observation and documentation (e.g. reports, meeting notes, recordings) of the project activities (e.g. workshops, meetings, surveys, scenario processes). Table 1 provides the key characteristics of these in all four case projects.

In the discussion section, we also reflect our project-specific findings against the information from the external evaluation report on the societal impact of the SRC programmes 2016–19 (Hjelt et al., 2021) and related self-evaluation report (Suomen Akatemia, 2021). This allows us to consider our findings against the related findings from 13 different SRC projects (including one of our case projects i.e. Winland) in four thematic SRC programmes (Hjelt et al., 2021).

4. Findings

4.1 Knowledge types of the cases

First, we categorized the main knowledge types in the four cases according to the frame by Stepanova et al. (2019) (see Table 2). While the general context for all four cases was mostly formal and many of the key

Table 1. Summary table of the key characteristics related to the stakeholders, events and participatory observation processes in the four case projects.

	Peatland Case	Forest Case	Citizens' energy Case	Sustainable security Case
Project duration and no. of researchers involved in co-production activities	2018–present; 38 researchers	2018–present; 34 researchers	2018–2020; 11 researchers	2016–2019; 30 researchers
Number of stakeholder organizations in co-production processes	14 stakeholder organizations	16 stakeholder organizations	16 stakeholder organizations	25 stakeholder organizations
Number of stakeholder workshops	Nine stakeholder workshops; 176 participants	Four stakeholder workshops; around 100 participants	Four workshops; around 30 participants each	Four project workshops + three thematic scenario workshops; around 250 participants
Participatory observation: key process and documentation	Through written notes from the stakeholder workshops and meetings; notes taken by several researchers and interaction experts, and compared with each other. The observation followed a pre-set workshop plan that included participatory tasks and related documentation (structured discussion, shared notes and mind-maps).	Through joint documentation and written notes on workshop activities, including structured discussions, shared vision boards, action methods and psychodrama. The written notes were taken by at least one researcher and the interaction leader.	Through written notes from meetings, complemented by workshop outputs (incl. one Mentimeter survey) and interview transcripts. The workshops were audio recorded and two small group sessions per workshop were also video recorded.	Through personal written notes and recordings of workshops and meetings; notes taken by several researchers and interaction experts, and compared with each other. The notes were complemented by workshop and meeting material such as posters, ranking tables, feedback reports and online survey results.
Number of survey respondents and their role in the project for the background questionnaire 2019	Five respondents: consortium leader, coordinator, principal social interaction expert and principal researchers of two working packages	Three respondents: the interaction leader, professional facilitator and one principal researcher	Three respondents: vice-consortium leader; interaction WP leader, and one principal researcher	Three respondents: project director, coordinator and co-creation lead

stakeholders were public sector officials, the projects involved actors across different levels, from local and managerial to scientific level.

4.2 How was the knowledge mobilized?

Following four sections discuss the key findings according to the four phases of knowledge weaving considering the different methods, actions and concepts used in each phase as well as their level of inclusiveness (integration / engagement).

The first phase, **mobilizing** entails drawing out and articulating knowledge into a form that can be shared with others (Tengö et al., 2017). When considering the inclusiveness of mobilizing activities, two types of activities were used for the most part: i) interactive mobilization – project-led interactive workshops where participants were included in the process (integration), and ii) informal meetings and discussions with key stakeholders, complemented with surveys and document analysis (engagement).

Mobilizing as integration. The most common methods for mobilizing the knowledge in an integrative way involved participatory workshops that were typically organized at the beginning of the project. For example, the Forest Case organized a full-day workshop for researchers and forest professionals to tap into their expertise on different forest management methods, and on how these methods contribute to climate change mitigation, enhance adaptation to climate change, or secure forest biodiversity. Participatory activities used to draw

Table 2. Description of knowledge types by case (according to Stepanova et al., 2019).

Case	Context (informal/formal)	Actors (local/managerial/scientific)	Practice (system/transformative/target)
Peatland	Informal knowledge about the current farming and forestry practices ('good examples' of what works, perceived barriers to changing current practices) on the one hand, and about the current policy processes and practices (enabling and preventing processes for climate smart practices) on the other hand informs the process of building formal knowledge about novel peatland farming and forestry practices (e.g. controlled drainage, continuous cover forestry) and policies (e.g. sustainable forestry subsidies).	The key actors represent the local/lay and expert knowledge (landowners, farmers, extension officials), managerial/administrative knowledge (policymakers, administrative personnel, producers/industry), and scientific knowledge (researchers).	Scientific knowledge-based system and process *descriptions* that can be used to *predict* future changes (in the respective variables i.e. peatland forestry and farming greenhouse- gas emissions, and production capacity) and thus *normatively* guide the current management practices and related policies.
Forest	Formal knowledge (statistics on forest resources, datasets, scientific publications) and informal or experiential knowledge of forest researchers and forest professionals about e.g. practical forest management and restoration solutions.	Local (lay) knowledge: forest professionals and forest owners. Managerial knowledge: ministries, national forest agencies, state enterprise managing Finland's national forest resources. Scientific knowledge: the Finnish national IPBES panel and the Finnish Climate Change panel.	Formal knowledge of current processes, data on carbon sequestration potential of old forests or their biodiversity features; transformed via jointly produced scenarios into predictive and transformative knowledge through state-of-the-art modelling; influence on practical forestry level through e.g. identifying forest stands that might be optimal conservation targets, and developing a properly functional and accepted compensation mechanism in cooperation with stakeholders.
Citizens' energy	While mainly formal knowledge (scientific articles, statistics, etc.) was utilized for the background work, during the transition visioning workshops much informal knowledge was also shared among the participants and utilized for developing different transition pathways.	Researchers, public sector managers, small and medium-size enterprises, energy companies, municipalities, non-governmental organizations, neighbourhood associations, local activists, technical experts.	Knowledge was produced on all three practice-related knowledge types: the participants addressed the current situation and drivers of change (systemic), future targets (normative) and built transition paths to reach the targets (transformative).
Sustainable security	While the general research context is largely formal, the actual interactions and practices took place in complex networks that combine formal and informal knowledge. For example, foresight discussions around the concept of comprehensive security happened mainly through a series of foresight workshops organized by the Security Committee but attended by a variety of different actors.	The key actors consisted of administrative and professional communities as well as representatives from research institutes, private sector and civil society, with the focus on the national scale.	Making use of all three practice-related knowledge types: while the main focus of the research and co-creation process was systemic, the project maintained a predictive and even transformative view of knowledge co-production, and had the increased resilience of Finnish society as a normative target.

out the informal and formal knowledge in the workshop included action methods and psychodrama, warming-action-sharing deliberation, picture cards, lines, symbols, pair and group discussions, and facilitated workshop methods such as learning cafés. All knowledge was collated into a memo and presented to the participants for comments before being implemented further in forest-scenario modelling. The Citizens' Energy case used the transition arena method (Hyysalo et al. 2019) to mobilize a broad range of relevant knowledge on the possible pathways to increase citizens' energy production by 2030. These forms of knowledge covered public authorities' knowledge of the legislative framework, researchers' and front-runner companies' knowledge of the feasibility of new renewable energy technologies, as well as local activists' practice-

based knowledge of the types of concrete problems that housing cooperatives encounter when considering solar panels or ground energy solutions in housing cooperatives in urban areas.

Mobilizing as engagement. Along with the integrative participatory workshops, various kinds of activities with key stakeholders were organized in order to mobilize the knowledge through engagement. For example, in the Peatland Case, the committed stakeholders and their interest and role in the project were assessed in the planning phase by introducing the research objectives and scientific background, and asking the stakeholders what reflections these elicited (identified through preliminary stakeholder analysis). This phase involved informal discussions with the stakeholders that helped in identifying their existing knowledge base regarding needs and supporting factors for climate-smart practices and perceived knowledge gaps preventing their implementation.

The multiple means of interaction with the stakeholders also conducted during the later phases of the project provided a spectrum of individual perspectives as well as a representative take on the stakeholder groups' perspectives. This revealed good examples of existing climate-smart practices, as well as knowledge gaps in wider application (practical implementation of different field and farm types) and outcomes (economic viability), and in the role of gaps in scientific knowledge in decision-making (greenhouse gas mitigation of the different practices in different contexts e.g. continuous forestry harvesting methods and cycles). Furthermore, as a 'legacy effect', the researchers in this case were able to draw on the stakeholder knowledge from their previous studies and projects to guide the common agenda and mission-setting in the planning phase of the project in particular.

4.3 How was the knowledge translated and negotiated?

Following Tengö et al. (2017), **translating** implies interactions between knowledge systems to **enable mutual comprehension** of the shared knowledge, while **negotiating** means the joint assessment of convergence, divergence and conflicts across knowledge contributions. In these processes, the projects actively apply different integrative elements (Huutoniemi, 2014) to adapt knowledge products to enable mutual comprehension (translate) and to interact among different knowledge systems to develop mutually respectful and useful representations of knowledge (negotiate). These integrative elements were used as boundary objects, being mainly integrative concepts and figures, methods and contexts. Regarding inclusiveness, we consider here the use of integrative participatory methods as ways of translating and negotiating with an *integrative* approach, while translating and negotiation as *engagement* refers to the activities where participants engage with the help of an integrative concept.

Translating and negotiating as integration. Different kinds of integrative methods such as scenarios or models were used in a participatory way in several case projects. For example, the Sustainable Security Case made use of a participatory scenario process that aimed to both spell out and synthesize the stakeholders' diverse views and knowledge of the key research themes (energy, food, water) with the help of joint storylines and analyses. In this way, the scenario process provided a means of interacting among different, partly contested knowledge systems, also contributing to the joint assessment of their convergence and/or divergence. This process likewise contributed to the foresight model for sustainable security that was developed within the project (Minkkinen et al., 2018; Minkkinen, 2019).

In the Citizens' Energy Case, the visual game board on which the participants constructed the citizens' energy pathways in small group settings facilitated interaction between the different actors and helped them to create a shared understanding of the necessary actions towards increasing citizens' energy production by 70% by the year 2035. The public sector authorities and experts came to better understand the practical obstacles faced by active housing cooperatives, while the citizens and NGOs developed a better understanding of the current legislative framework and technical solutions to scale up local initiatives. In groups with NGO and/or citizen activists and energy company representatives, the participants also had to negotiate the meaning of citizens' energy as energy companies emphasized the possibility of off-site renewable energy production by enterprises. The differences were negotiated by including off-site renewable

energy production as one path towards carbon neutrality, allowing housing companies more options to use renewable energy.

Translating and negotiating as engagement. Various integrative concepts, such as figures and maps were used in the integration process. The Forest Case produced a figure to articulate how the different work packages (from different research disciplines) produce knowledge and how they interact in the project. The figure also summarizes the project workflow and shows how knowledge production is ultimately an iterative process needing constant feedback and reformulation together with the stakeholders. This and other visualizations have served as boundary objects both among researchers from different disciplines and between researchers and stakeholders in clarifying their roles and communication.

4.4 How was the knowledge synthesized?

Synthesize entails shaping a broadly accepted common knowledge base that maintains the integrity of each knowledge system (Tengö et al., 2017). Here, we emphasize the knowledge integration towards scientific inquiry. Regarding the inclusiveness of synthesizing, we see the activity as integration when non-academic knowledge is woven into scientific inquiry as an iterative process. Synthesizing as engagement means that non-scientific information is only partly integrated.

Synthesization as integration was identified when the non-academic knowledge was iteratively integrated into the process of scientific inquiry. The Forest Case integrated the non-academic knowledge in the forest management scenarios and the modelling of forest owner behaviour. In designing functional monetary compensation for private forest owners, their opinions, attitudes and knowledge shape the preconditions of the proposed system where both biodiversity and carbon sinks would determine the value of a forest site in a voluntary forest protection programme. The operational constraints and circumstances of forest professionals were acknowledged by meeting with forest owners who wish to protect part of their forest for climatic and ecological reasons by making a conservation contract.

In the Citizens' Energy Case, the different forms of knowledge were integrated into transition paths towards increased citizens' energy production. The paths were developed in small groups with mixed expertise to ensure cross-fertilization of ideas. Further integration was sought by asking each group to present their path to the others, after which the groups had a chance to modify their own path and select elements from the other paths. The final paths were quite similar but they were reported separately to maintain the richness of detail and to allow for a diversity of views.

Synthesizing as engagement. In the Forest and Peatland Cases, there is an ongoing check-up mechanism to ensure that the project is focussed on relevant issues from the perspective of the key knowledge users. For this purpose, there are regular meetings with the 'steering group', which has representatives from all key stakeholders. Case researchers inform the stakeholders on the progress of the project, and stakeholders give their opinions and share information on their own processes, which could make use of the project's results. Although the knowledge shared is often in both ways 'one-way', it opens up possibilities for changes in the focus, weighting or timing of tasks both in the case and in the stakeholder's own work.

4.5 How was the knowledge applied?

In keeping with Tengö et al. (2017), **apply** means the use of the common knowledge base to make decisions and/or take actions, and to reinforce and feed back into the knowledge systems. Here, we particularly focus on applying knowledge towards the policy and planning process, in contrast to synthesizing, where the focus was on scientific inquiry. In regard to inclusiveness, applying as *integration* considered the projects' direct involvement in an ongoing policy or planning process where the co-produced knowledge was directly used/integrated into a real-world case having an impact on the process, while applying as *engagement* co-production activities touch upon topical real-world issues. However, the co-production process itself is not directly linked to an ongoing policy process.

Applying as integration often took place by direct involvement in policy or planning processes. These could be sudden windows of opportunity, such as non-planned opportunities to apply information, which was partially 'ready' and co-produced. Importantly, these processes were usually not in the hands of researchers, but emerged from ongoing stakeholder processes. For example, the policy relevance of the Peatland Case research increased somewhat unexpectedly during the initial years of the project as the carbon storage/accounting issue and EU climate policy entered the public debate. The Peatland Case researchers were invited to advise policymakers planning the government programme in 2019 and they contributed to drafting recommendations for the government, for example on the future research needs regarding the agricultural sector. Most importantly, some of the key messages of the project have been integrated into the current government programme and its climate goals in Finland, and the researchers have given practical recommendations on how to implement these.

Applying as engagement was identified as active involvement in pushing a policy or planning process, and contributing to its content throughout the process. In the Citizens' Energy Case, the citizens' transition arena is an example of a process whereby research is tightly engaged in an ongoing real-world process. In the first session, the results of the discussions on drivers of and barriers to citizens' energy were applied as the participants were asked to think about a worthwhile transition target and timeframe using the understanding gained in these discussions. The methodology used pushes the participants to think through the steps, and the actions that the stakeholders must take. This entails working towards a concrete plan with regard to who needs to do what and when so that they do not slow down the transition.

Similarly, the transition arena methodology was applied in a joint effort with the Forest Case and the Ministry of the Environment to take further action in forest and mire conservation and restoration in Finland. Researchers on the forest case produced a background memo including preliminary targets for the conservation and restoration, while in the transition arena session researchers and stakeholders, including the key ministry officials, refined the targets and negotiated the steps needed to reach them. Forest Case researchers were again involved in delineating the conclusions in the form of a 'transition pathway'. The process played an important role in the launching of a new national habitats programme.

"Weaving" task/phase / Inclusiveness of weaving process	**Mobilize**	**Translate and negotiate**	**Synthesize** (towards scientific inquiry)	**Apply** (towards planning and policy processes)
Integration	Interactive mobilization e.g. workshops	Integrative methods (e.g. scenarios or models)	Iterative integration of the non-academic knowledge into the process of scientific inquiry	Direct involvement in policy/planning process
Engagement	Informal stakeholder meetings and surveys, and document analysis	Integrative concepts (including visualizations and figures)	Regular exchange of knowledge (non-academic, academic) as a "check-up mechanism" (steering group)	Knowledge outcomes directly adapted by policymakers and practitioners

Figure 2. The key activities facilitating knowledge co-production across the four phases of knowledge weaving (horizontal axis) in the four case projects, categorized according to their level of inclusiveness (vertical axis). The colours of the cells indicate the prevalence of the activities in the case projects: the darker the colour, the fewer such activities.

Table 3. Added value of knowledge-weaving process for knowledge produced in the case.

Case	Key knowledge types integrated	Added value of the weaving process	Most significant challenges
Peatland	Local and expert knowledge with scientific knowledge	Societal impact (increased reaction readiness in the event of windows of opportunity opening): informing policy processes with scientific knowledge *and* with understanding of the 'state of the field'. Landowners informed the planning of the stakeholder workshops, which further informed the defining of the research questions. Societal impact: a network of engaged stakeholders who are motivated to learn from the scientists and to share their local/ managerial expertise.	Boundary work of the societal interaction experts in the project is time-consuming; difficult to plan in advance when and where this work is needed most. Challenges in engaging researchers who are not familiar with knowledge integration methods.
Forest	Integrated scientific knowledge complemented with managerial and administrative knowledge and with local knowledge.	Development of more realistic and acceptable scenarios, models and model outcomes. Enhancing understanding and acceptance of the voluntary compensation system, agreed with administration, among forest owners and decision-makers. Co-production processes enhance commitment and build trust among stakeholders to pursue steps towards more sustainable solutions.	Diversity of viewpoints: appreciated and heard, but a relatively simple scenario or model setting does not allow for including all details. These constraints involved in this scientific process need to be clearly communicated to the stakeholders. Power relations and 'fixed' stakeholder positions are hard to address in a relatively short research project. Long-term 'stakeholder ownership' of the results is uncertain.
Citizens' Energy	Citizen/local, managerial/ administrative, technical, scientific knowledge	Creating and enhancing key stakeholders' commitment to a transition towards increased production of on-site renewable energy. Better understanding of the diverse roles and capabilities of different actors in energy transitions; what actions are needed from legislators, national- level authorities, municipalities, companies, knowledge extension services and citizens to promote on-site renewable energy production.	Limited opportunities to address possible differing interpretations of the actions the groups chose for their change paths. For example, 'enhancing on-site citizens' energy solutions' gave rise to the question of whether this can rely on solutions provided by energy companies, or whether citizens' energy only refers to decentralized energy production by housing companies. Lack of a clear topical policy process that would have used the outcomes of the process directly.
Sustainable Security	Managerial/ administrative knowledge with scientific knowledge	Enhancing key stakeholders' commitment and motivation in the co-production process. Enhanced understanding of current policy challenges in the research theme, as guidance for research. Joint assessment of differences and similarities across knowledge types.	Diversity of stakeholders and knowledge types involved, due to the open engagement process. Sporadic engagement by the most important stakeholders (gatekeepers). Limited possibility to address the power relations and asymmetries between the different stakeholders.

4.6 Summarizing the key characteristics of knowledge weaving

Above, we have analyzed how the four different phases of knowledge weaving (mobilize; translate & negotiate; synthesize; apply) contributed to the knowledge co-production processes in the four case projects. However, each case naturally has its own characteristics, and a comparative analysis may thus help to understand the potential added value as well as the challenges related to knowledge weaving. Table 3 summarizes the key knowledge types as well as the most important added value and challenges for each of the four cases. While all four cases share many similarities, some interesting differences were also observed. For instance, some projects were able to work closely with related ongoing policy processes, while others lacked this opportunity.

Figure 2 synthesizes the key activities across the four phases (horizontal axis) and their level of inclusiveness (vertical axis) in the four case projects. While the case projects included some activities in all phases and at both levels, the activities had a stronger emphasis on earlier phases (indicated by the different cell colours in Figure 2; the darker the colour, the fewer activities in total across the four case projects). In addition, the level of inclusiveness was somewhat lower in the latter two phases, with only part of the projects reporting activities under integration for the Synthesize phase, and particularly for the Apply phase. This emphasizes the importance of considering the different knowledge co-production activities also according to their level of inclusiveness, as it ultimately defines the depth of the knowledge co-production.

The different activities thus seem to serve partly different purposes across the four phases. Such a finding is supported by the SRC evaluation report (Hjelt et al., 2021) and the related self-evaluation report (Suomen Akatemia, 2021). The survey conducted by Hjelt et al. (ibid.) included a question about the usefulness of different interaction activities in facilitating societal impact (n = 90). Among the 10 listed activities, the respondents clearly found stakeholder workshops and events the most useful (87% finding them very useful or useful), followed by having an expert role in working groups or panels (69%), and the publication of policy recommendations (64%). Another question concerned the main ways in which SRC projects lead to societal impact, with respondents (n = 70) indicating general knowledge production on the relevant research themes, advancement of multisectoral collaboration, and new openings in societal debate as the three most important ones.

5. Discussion

Our analysis examined the processes of knowledge co-production as a means of integrating different knowledge types within four different strategic research projects with a strong societal impact dimension. We carried out a systematic comparison of four case projects, building on the concepts of different knowledge types (Stepanova et al., 2019), knowledge weaving (Tengö et al., 2017), and levels of inclusiveness (e.g. Arnstein, 2007).

All four cases reported added value of a knowledge co-production process both for research and societal impact. In particular, the co-production processes helped to elicit and concretize the various ways of knowing and hence align with the views of knowledge co-production as pluralistic recognition of multiple ways of knowing (e.g. Norström et al., 2020). While the knowledge-weaving framework by Tengö et al. (2017) emphasises the role of indigenous and local knowledge, it was also applicable to our study where managerial, administrative and official knowledge played an important role. Our analysis shows that the frame is also useful in this context for unpacking the different phases of the knowledge weaving process and the related activities and methods.

A key observation following from our analysis is that there are several ways to mobilize, translate and negotiate, synthesize and apply knowledge in co-production processes. By adding the aspect of inclusiveness to the analysis of knowledge weaving, we were able to highlight the nuances and the variety of ways how the weaving activities were implemented. It was shown that in different phases of co-production, the strategies can be less or more inclusive, depending on the aims and needs of both the project and its key stakeholders. We also noticed that knowledge-weaving activities with lower levels of inclusiveness in the beginning of the process tend to feed into higher levels of inclusiveness in the latter knowledge-weaving phases (synthesize and apply), emphasizing their connections.

In the ***mobilise*** phase, most of the studied processes started with the aim of creating a shared goal (Norström et al., 2020). Yet, the experience from the later phases of our cases indicates that it is not always possible (or even necessary) to have clearly defined shared goals. Instead, goals for the co-production process may actually be 'plural' and diverse, with different stakeholders having differing expectations and motives for their engagement. In such situations, it is important to maintain a shared point of interest that is both scientifically interesting and societally relevant. At the same time, it is useful to make this diversity of goals more visible, and preferably also to find ways to connect them.

Our results indicate that for these kinds of science-policy-practice interaction contexts, the ***translate*** and ***negotiate*** phases (which are separate phases in Tengö et al., 2017) were very much entangled and essentially formed just one co-production phase. As observed in two of our cases, this may be explained in part by the contexts of the case projects and the fact that several key stakeholders were public sector officials which had

relatively similar backgrounds and conceptual understanding as the project researchers had. Therefore, translation as phase was less obviously present, and intertwined with the negotiation phase where unclarities when noticed were tackled.

Our study highlights the context and actor specificity of the required translation. That is, we see context-specific ontologies whereby similar 'facts' are taken as the starting point, but these facts acquire a different meaning depending on the perspective taken. This has an important implication for those facilitating knowledge co-production to ensure that participants, even with similar backgrounds, do not just assume that they view the world and attach meanings to concepts in similar ways – or have a similar position in power.

In the ***synthesizing*** phase, towards the end of the process, when the participants are involved in the iterative integration of non-academic knowledge into the scientific inquiry, the outcome may be different from that with less inclusive regular check-up mechanisms, such as steering committees. Yet they can both be labelled as synthesizing in co-production (se figure 2).

Previous studies highlight the continuous interaction in co-production settings that allows ongoing learning by the participants (see e.g. Norström et al., 2020; Wyborn et al., 2019), which was also confirmed in our cases. However, the co-production processes tend to be project-based, which means that single interaction processes are temporary. According to our findings, the benefits from the current co-production processes may often only be attained in similar activities in the future, and not that much in the outputs of the current research. In our cases, knowledge-weaving activities were mainly used in the mobilize and translate/negotiate phases, rather than at the end of the process. Positive experiences may accumulate, however, as stakeholder trust and motivation towards co-production activities gradually increase.

Although not explicit in the framework of this study, politics and power in knowledge co-production have been recognized as crucial elements to be accounted for in co-production settings (e.g. Turnhout et al., 2020; Vincent et al., 2020; Montana, 2019). Questions about whose voices are heard, and whose are not, and who has the right or ability to participate are essential, particularly when the aim is to ensure the integration of a range of different knowledges. In our cases, it was recognized that it is not always possible to coordinate participation and ensure that all relevant actors are engaged due to an open engagement process. This may lead to a limited opportunity to address the power relations and asymmetries between the different stakeholders (see also Table 3).

6. Conclusions

To conclude, the added value of knowledge co-production lies in understanding the complexity of the knowledge-weaving processes, and enabling the creation of actionable knowledge in the context where it was produced. In terms of the inclusiveness of knowledge weaving, all four projects were able to engage across four phases, while deeper inclusion in the form of integration was less visible particularly towards the latter phases. At the same time, however, knowledge-weaving activities with lower levels of inclusiveness were seen to feed into higher levels of inclusiveness in the apply and synthesize phases. Therefore, even if the actual implementation of the knowledge co-production takes place in short-term projects, the long-term nature of these processes needs to be recognized, and the benefits of one co-production process may become visible also (or even primarily) in similar future projects and processes. Moreover, learning among the participants can also be seen as a valuable outcome as such. Knowledge co-production connects multiple different perspectives that might complement but also contradict each other, and the related discussions might even initiate transformative learning processes in the long run. This also means that the development of a systematic approach to assess the transformativeness of knowledge co-production activities merits further research.

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