strategicRESEARCH

A Climate-Neutral and Resource-Scarce Finland, PIHI (2015–2021)

Evaluation of the strategic research programme

ACADEMY OF FINLAND

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Executive Summary

The Finnish Government adopted the strategic research theme “A climate-neutral and resource-scarce society” on 18 December 2014. The research under the theme was expected to improve resource efficiency and the circular economy. This involves efficient recycling of renewable and nonrenewable natural resources, making full use of material and energy flows, and moving towards a climate-neutral and resource-scarce society as a result of changes in consumption, lifestyles and human activity. The theme also included seeking solutions with which to address identifiable obstacles to exports and competence-based growth. Based on this theme, the Strategic Research Council (SRC) launched the SRC programme ”A Climate-Neutral and Resource-Scarce Finland (PIHI)”. The PIHI programme started in May 2015 and ended in October 2021.

In December 2022, the Division of Strategic Research at the Academy of Finland invited an expert panel to assess the performance of the programme. The expert panel conducted this evaluation between January and April 2023. For the evaluation, the Academy staff provided comprehensive material on the background, plans and results of the programme. After analysing the material, the panel drew up initial conclusions and raised additional questions for the programme actors. Based on these, the panel conducted interviews with the project leaders and the programme director. The evaluation panel held a total of three meetings during the review process and prepared an evaluation report together.

The evaluation panel assessed the performance of the programme based on the following evaluation criteria:

1. promoting high-quality, multidisciplinary research on the problems and needs in the programme’s domain
2. creating concrete steps towards tackling those problems and needs in Finnish society
3. strengthening research & stakeholder communities in the programme’s domain

Based on its observations on the performance of the PIHI programme regarding items 1–3, the panel also drew lessons and suggestions for developing the strategic research programmes and their operations in the future.

As key findings of the evaluation for the first criterion, *promoting high-quality, multidisciplinary research on the problems and needs in the programme's domain,* the evaluation panel noted that the programme and the projects successfully reached most of the aims. The multi- and interdisciplinary set-up of the projects contributed to this. The problem and target settings were carefully done and sought to find answers to essential questions and challenges related to the systemic transition towards a carbon neutral resource scarce society. Altogether, the programme produced an impressive number of publications, awarded degrees, developed products, and start-ups. However, to reach the ambitious goals, more cooperation and coordination between the funded projects as a part of comprehensive well-orchestrated change

would have been desirable. Also, even while all projects funded under the PIHI programme were interdisciplinary in some way, several could have benefitted from a (larger) involvement of social sciences, including political and economic perspectives.

As key observations for the second criterion, *creating concrete steps towards tackling those problems and needs in Finnish society*, the review panel acknowledges that the programme covered stakeholders from all sectors of society. It is obvious that the PIHI programme has significantly affected the readiness of Finnish society to accelerate the transition by engaging relevant stakeholders and by bringing science-based knowledge and know-how about the challenges, opportunities, and solutions, as well as the tools – both technological and societal – needed in the transition. All projects funded under the PIHI programme clearly were able to create important knowledge and innovative insights related to the transition towards a carbon-neutral resource scarce society.

As key observations for the third criterion, *strengthening research and stakeholder communities*, the evaluation panel states that the PIHI programme provided versatile opportunities for dissemination and engagement aimed at solving grand societal challenges. The number of activities and events organised by the projects is very impressive. They helped the PIHI programme to contribute to the production of new and, in many cases, cutting-edge societally relevant knowledge, including publicly accessible data. However, the question of how to obtain and maintain stakeholder commitment is crucial.

Even if the panel acknowledges that the overall performance of the programme was very good, the review also identified lessons and recommendations to be considered for improving the design of future programmes.

- First, future funding strategies may want to strive for real interdisciplinarity and transdisciplinarity. Within the domain of the PIHI programme, several projects could have benefitted from a larger involvement of social sciences, including the political and economic perspectives. To that end, the panel recommends that the SRC consider relevant requirements for programme design, project proposals and resource allocation.
- Second, the SRC will have to consider programmes of narrower substantive focus to enhance opportunities for collaboration and synergy, thereby also providing a more powerful basis for dissemination and stakeholder commitment. Additional strategies to enhance stakeholder commitment and opportunities for the political, societal and economic uptake of programme results will also have to be developed.
- Third, the review panel points out that the SRC will have to make certain strategic decisions, for example, on the balance between scientific excellence reflected in scientific publications, and communication and engagement activities directed at the general public, relevant stakeholders and professional communities. In this context, the sustainability of science itself is also of relevance. Aspects to be considered include expectations regarding type, quantity and quality of

publications. However, the panel acknowledges the difficulty of setting targets across different disciplinary cultures.

- Finally, especially for programmes running for six years, it is recommendable to ask consortia to plan for “black swans”, i.e., to require them to do a more comprehensive risk assessment with different future scenarios including even unlikely scenarios. The COVID-19 pandemic at the beginning of the 2020s taught us that very large changes can occur quickly in the operating environment, the effects of which will impact also long-term research.

Tiivistelmä (Executive Summary in Finnish)

Valtioneuvosto päätti 18. joulukuuta 2014 strategisen tutkimuksen teemasta ”Ilmastoneutraali ja resurssiniukka yhteiskunta”. Teemassa rahoitettavan tutkimuksen odotettiin kohdistuvan resurssien käytön tehokkuuden parantamiseen ja kiertotalouteen, jossa uusiutuvat ja uusiutumattomat luonnonvarat kiertävät tehokkaasti ja materiaali- ja energiavirrat käytetään tarkasti, sekä siirtymiseen kohti ilmastoneutraalia ja resurssiniukkaa yhteiskuntaa kulutuksen, elämäntapojen ja muun inhimillisen toiminnan muutosten seurauksena. Teemassa tuli hakea ratkaisuja, joilla voidaan osaltaan vastata viennin ja osaamisperusteisen kasvun tunnistettaviin esteisiin. Strategisen tutkimuksen neuvosto (STN) teki tämän teeman perusteella päätöksen STN-ohjelmasta "Ilmastoneutraali ja resurssiniukka Suomi (PIHI)". PIHI-ohjelma alkoi toukokuussa 2015 ja päättyi lokakuussa 2021.

Suomen Akatemian strategisen tutkimuksen vastuualue kutsui joulukuussa 2022 asiantuntijapaneelin arvioimaan ohjelman toteutusta, tuloksia ja vaikuttavuutta. Asiantuntijapaneeli työskenteli tammikuun ja huhtikuun 2023 välisenä aikana. Strategisen tutkimuksen vastuualue toimitti arviointia varten kattavan aineiston ohjelman taustoista, suunnitelmista ja tuloksista. Aineistoon tutustuttuaan paneeli laati alustavat johtopäätökset ja esitti lisäkysymyksiä ohjelmassa rahoitettujen hankkeiden vetäjille, ohjelmajohtajalle sekä sidosryhmien edustajille. Paneeli piti arviointiprosessin aikana yhteensä kolme kokousta ja laati yhdessä arviointiraportin.

Asiantuntijapaneeli arvioi ohjelman saavutuksia seuraavien arviointikriteerien perusteella:

1. korkeatasoisen, monitieteisen tutkimuksen edistäminen ohjelman teema-alueen ongelmista ja tarpeista
2. konkreettisten toimien luominen näiden ongelmien ja tarpeiden ratkaisemiseksi suomalaisessa yhteiskunnassa
3. tutkimus- ja sidosryhmäyhteisöjen ja niiden välisten yhteyksien vahvistaminen ohjelman teema-alueella

Paneeli teki ohjelman saavutuksia koskevien arvioidensa perusteella myös johtopäätöksiä ja suosituksia STN-ohjelmien kehittämiseksi tulevaisuudessa.

Ensimmäisen arviointikriteerin osalta paneeli totesi, että PIHI-ohjelma ja siinä rahoitetut hankkeet saavuttivat onnistuneesti suurimman osan tavoitteistaan. Tähän vaikutti osaltaan hankkeiden monitieteinen ja poikkitieteellinen rakenne. Ongelmat ja tavoitteet asetettiin huolellisesti, ja niiden pohjalta pyrittiin löytämään vastauksia keskeisiin kysymyksiin ja haasteisiin, jotka liittyvät systeemiseen muutokseen kohti hiilineutraalia ja resurssiniukkaa yhteiskuntaa. Ohjelmassa tuotettiin vaikuttava määrä julkaisuja ja tutkintoja, kehitettiin tuotteita ja perustettiin uusia yrityksiä. Kunnianhimoisten tavoitteiden saavuttamiseksi olisi kuitenkin ollut toivottavaa, että rahoitettujen hankkeiden välistä yhteistyötä ja koordinaatiota olisi tuettu vahvemmin osana kattavaa ja hyvin organisoitua muutosta. Vaikka kaikki ohjelmassa rahoitetut hankkeet olivat jollakin tavalla monitieteisiä, useat niistä olisivat voineet hyötyä yhteiskuntatieteiden laajemmasta osallistumisesta ja erityisesti poliittisten ja taloudellisten näkökulmien vahvistamisesta.

Toisen arviointikriteerin osalta paneeli totesi, että PIHI-ohjelmaan osallistui sidosryhmiä kaikilta yhteiskunnan sektoreilta. On ilmeistä, että ohjelma on vaikuttanut merkittävästi suomalaisen yhteiskunnan valmiuteen vauhdittaa siirtymää ottamalla mukaan asiaankuuluvat sidosryhmät ja tuomalla käyttöön tutkimuspohjaista tietoa ja osaamista haasteista, mahdollisuuksista ja ratkaisuista sekä siirtymässä tarvittavista välineistä – niin teknologisista kuin yhteiskunnallisistakin. Kaikki ohjelmassa rahoitetut hankkeet pystyivät selvästi luomaan tärkeää tietoa ja innovatiivisia näkemyksiä siirtymisestä kohti hiilineutraalia ja resurssiniukkaa yhteiskuntaa.

Kolmannen arviointikriteerin osalta paneeli totesi, että PIHI-ohjelma tarjosi monipuolisia mahdollisuuksia levittää ja juurruttaa tutkimustietoa ja -osaamista suurten yhteiskunnallisten haasteiden ratkaisemiseksi. Hankkeiden järjestämän toiminnan ja tapahtumien määrä on erittäin vaikuttava. Monipuolinen toiminta auttoi hankkeita tuottamaan uutta yhteiskunnallisesti merkityksellistä ja julkisesti saatavilla olevaa, usein huippuluokan tietoa. Ratkaisevaa on kuitenkin se, miten sidosryhmien sitoutuminen varmistetaan ja ylläpidetään.

Vaikka PIHI-ohjelman kokonaistulos oli paneelin arvion mukaan erittäin hyvä, arviointi nosti esiin myös opittavaa sekä suosituksia, joita on syytä harkita tulevien ohjelmien toimeenpanossa.

- Tulevissa rahoituksissa voitaisiin pyrkiä aitoon tieteidenvälisyyteen ja poikkitieteellisyyteen. PIHI-ohjelman teema-alueen hankkeissa olisi ollut hyödyllistä, jos yhteiskuntatieteet, mukaan lukien poliittiset ja taloudelliset näkökulmat, olisivat olleet laajemmin mukana. Paneeli suosittelee, että STN harkitsee tähän liittyviä vaatimuksia ohjelmille, hankkeille ja niiden resurssien käytölle.
- STN:n kannattaisi tavoitella sisällöltään suppeampia ohjelmia, jotta parannetaan mahdollisuuksia yhteistyöhön ja synergiaan ja luodaan näin myös tehokkaampi perusta tulosten levittämiselle ja sidosryhmien sitoutumiselle. Lisäksi on kehitettävä uusia strategioita, joilla lisätään sidosryhmien sitoutumista ja mahdollisuuksia ohjelmien tulosten poliittiseen, yhteiskunnalliseen ja taloudelliseen hyödyntämiseen.
- Asiantuntijapaneeli ehdottaa, että STN tekisi joitakin strategisia linjauksia siitä, miten tasapainotetaan yhtäältä tieteellisinä julkaisuina ilmenevä korkeatasoinen

tutkimus ja toisaalta suurelle yleisölle, asianomaisille sidosryhmille ja ammattiyhteisöille suunnatut viestintä- ja sitouttamistoimet. Tässä yhteydessä myös itse tieteen kestävyys on tärkeää. Huomioon otettavia näkökohtia ovat muun muassa julkaisujen tyyppiä, määrää ja laatua koskevat odotukset. Paneeli kuitenkin myöntää, että tavoitteiden asettaminen eri tieteenalakulttuurien välimaastossa on vaikeaa.

- Erityisesti kuuden vuoden mittaisten ohjelmien osalta on suositeltavaa pyytää konsortioita varautumaan "mustiin joutseniin" eli vaatia niitä tekemään kattavampi riskinarviointi erilaisista, myös epätodennäköisemmistä tulevaisuuden skenaarioista. COVID-19-pandemia 2020-luvun alussa opetti, että toimintaympäristössä voi tapahtua nopeasti hyvin suuria muutoksia, joilla on vaikutusta myös pitkäkestoiseen tutkimukseen.

Foreword

The Strategic Research Council (SRC) established within the Academy of Finland funds thematic research programmes aiming at high scientific quality, great societal relevance and distinguishable impact. SRC-funded research seeks solutions to grand challenges that require multidisciplinary approaches. An important element of the research is active and ongoing collaboration between knowledge producers and knowledge users.

The SRC is responsible for monitoring and evaluating the impact of the research it has funded. However, it is not always feasible to provide conclusive evidence of impact. The societal impact of research can also manifest itself years after the completion of the work.

Evaluating social impact in the context of research funding requires a distinctive method. The evaluation of SRC programmes does not merely rely on performance indicators but looks at the effectiveness of interaction, its consequences, and potential future impact. Understanding the operations and outcomes of each programme necessitates considering its specific framework, rather than comparing the success of different programmes with each other. The challenges and prospects of finding solutions to specific societal challenges differ, as do the roles that various fields of research play in society.

Four SRC-funded programmes were completed in 2021, and their ex-post evaluation was carried out in 2022–2023. This report presents the results of the ex-post evaluation of the programme A Climate-Neutral and Resource-Scarce Finland, PIHI (2015–2021).

The SRC wants to thank the panel members for their indispensable contribution to the programme evaluation. The results of their work, as presented in this report, are of substantial value for the SRC in building the overall picture of the impact and development prospects of its programme funding. In addition, the SRC wants to thank the PIHI programme director, consortium members, and stakeholder representatives who participated in the interviews or surveys conducted as part of this evaluation.

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1 Introduction

1.1 Strategic research programmes

The goal of the strategic research funding, established in 2014, has been to strengthen the impact of research in Finland by producing knowledge that helps develop the functions of different sectors of society. To pursue this goal, the Strategic Research Council (SRC) established within the Academy of Finland is tasked with funding high-quality, long-term, and programme-based research that aims at finding solutions to the major challenges facing Finnish society. Each year, the SRC prepares a proposal on key strategic research themes to be approved by the Finnish Government. The Government decides the final themes, which the SRC formulates into research programmes. The programme funding is intended for extensive, multidisciplinary research consortia that carry out research that is relevant for the programme theme, with an emphasis on active interaction and engagement with knowledge users.

The consortia funded under SRC programmes receive funding for 3–6 years. The consortium's funding plan may also include the full-time salaries of the principal investigator (PI), the subproject PIs and the work package leaders. A part-time programme director employed by their own background organisation, such as a university or research institute, is selected for each SRC programme. The programme directors are responsible for programme-level development of interaction and cross-programme cooperation, and they promote the societal impact of strategic research. For further information on strategic research funding, see the current funding principles.[1]

The SRC is responsible for monitoring and evaluating the impact of the research it has funded, both during and after the funding period. According to the funding principles, the ex-post evaluation is implemented at the programme level. The aim of the evaluation is to assess the current or prospective scientific and societal impact of the completed programme and to produce knowledge to support the development of strategic research programmes. The evaluation focuses on the targeting, processes, outputs and outcomes of the research and interaction activities funded under each programme, as well as their observed or anticipated effects. A particular focus is on the results of multidisciplinary work and the ability to promote scientific renewal. Special characteristics of each programme and project, as well as different societal roles of science, are all considered in the impact review. The evaluation follows the principles of open and responsible science.

1.2 Evaluation of strategic research programmes 2015–2021

This report presents the outcomes of the ex-post evaluation of one of the very first SRC programmes, A Climate-Neutral and Resource-Scarce Finland. The evaluation was conducted in 2022–2023, simultaneously with the evaluation of three other

[1] Funding principles of the Strategic Research Council, 13 March 2023: https://www.aka.fi/en/strategic-research/for-applicants-and-projects/for-applicants/funding-principles/ [referred to 12 May 2023]

programmes that ended in 2021, and the evaluation of all four programmes followed the same design, methods, and protocol.

This round of ex-post evaluations was the second time SRC programmes have been evaluated after their completion. The first round of ex-post evaluations was conducted in 2020–2021, and the target of that evaluation was four smaller and shorter programmes which had run between 2016–2019. One of the key findings was that the three-year funding period was too short to enable the programmes to fully realise their ambitious goals.[2]

In 2021–2022, the strategic research funding scheme as a whole was evaluated by an external research group. The evaluation was part of the implementation of the Government Plan for Analysis, Assessment and Research (VN TEAS). The external group examined if and to what extent the goals set for the SRC funding have been realized during its first years of implementation (2014–2020). Overall, the results were very positive.[3]

The present round of ex-post evaluation focused on the following programmes:

- A Climate-Neutral and Resource-Scarce Finland, PIHI (2015–2021)
- Equality in Society, EQUA (2015–2021)
- Disruptive Technologies and Changing Institutions, TECH (2015–2021)
- Changing Society and Active Citizenship, CITIZEN (2017–2021)

The evaluation of each of the four programmes was conducted by a panel of 4–6 invited foreign and Finnish experts, who had strong experience in the programme's themes within and/or beyond academia (Appendix 1). At least one member of each panel had also participated in the review of research proposals submitted to the original SRC programme call.

The evaluation panels worked independently, without interaction with the other panels. The scope of each evaluation was the given SRC programme as a whole, including: the performance of the projects funded in the programme; the performance of the programme-level work, coordinated by the programme director; and possible added value emerging from the programme.

The panels were tasked with evaluating the performance of the programme in relation to the key goals of SRC funding:

1. promoting high-quality, multidisciplinary research on the problems and needs in the programme's domain
2. creating concrete steps towards tackling those problems and needs in Finnish society (and even beyond)

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[2] Strategic research programme evaluation: https://www.aka.fi/en/strategic-research/strategic-research/strategic-research-in-a-nutshell/programme-evaluation2/ [referred to 12 May 2023]

[3] Kivistö, J., Kohtamäki, V., Lilja, E., Lyytinen, A., Tirronen, J., Holmberg, K., Teräsahde, S. (2022). Strategisen tutkimuksen rahoitusinstrumentin arviointi. Valtioneuvoston selvitys- ja tutkimustoiminnan julkaisusarja 2022:60, Valtioneuvoston kanslia. http://urn.fi/URN:ISBN:978-952-383-487-3

3. strengthening research and stakeholder communities in the programme's domain (even beyond the programme's life span)

The panels were instructed to focus on the input, activities, outputs and outcomes of the research and interaction activities funded in the programme, as well as their observed or anticipated effects (Appendix 2). In addition, the panels were asked to draw lessons and recommendations for developing the strategic research programmes and their operations in the future.

The panels worked between January and April 2023. The evaluation work contained the review of a substantial body of evaluation material (Appendix 3), interviews with key programme actors, participation in three online meetings with the other panel members, compiling the results of the evaluation into this report, and presenting and discussing the key findings with the SRC.

A major part of the quantitative and qualitative evaluation material was assembled from the project's funding applications and various reports from the duration and completion of the programme. In addition, the material included the results of two separate surveys, conducted after the ending of the programme: a self-evaluation questionnaire for consortium members, and a survey for the projects' and the programme's key stakeholders. An important part of the evaluation material were also the interviews with the consortium representatives and the programme director in March 2023.

The evaluation panels were supported by the Academy of Finland staff at the Division of Strategic Research. The staff collected and processed the evaluation materials, designed the evaluation framework and criteria, prepared and attended the panel meetings, organized and documented the interviews, and finalised the evaluation reports.

1.3 Structure of the report

The report is composed of four sections plus several appendices. After this introduction (Section 1), we present an overview of the programme. The overview includes the programme description as it appeared in the programme funding call in 2015, a short, non-technical description of each of the five consortia and the programme director funded in this programme, as well as summary tables on the programme's composition and resources (Section 2).

Sections 3 and 4 were written by the evaluation panel and they constitute the crux of this report. Section 3 focuses on the performance of the programme in relation to the three key goals of SRC funding, and the structure of the section loosely follows the criteria defined in the evaluation framework (Appendix 2). Section 4 presents the conclusions, lessons, and recommendations of the panel, based on their observations and key findings evidenced by the evaluation material.

In addition, the report includes several appendices, which offer more detailed information on the evaluation protocol (Appendices 2–4), as well as on the input, activities, output and outcomes of the projects and the programme that are the focus of the evaluation (Appendices 5–13). The latter include personnel key figures, list of

projects' collaborators, publication lists and analyses, lists of other research output, new research funding, titles of impact stories, and methods and results of the two surveys conducted for the purpose of this evaluation.

2 Overview of the programme

The Finnish Government adopted the strategic research theme “A climate-neutral and resource-scarce society” on 18 December 2014. Based on this theme, the SRC launched the programme “A Climate-Neutral and Resource-Scarce Finland (PIHI)”. The programme started on 1 May 2015 and ended on 30 April 2021, but due to the COVID-19 pandemic, the funding period was extended to 31 October 2021.

Under the PIHI programme, five research consortia and a part-time programme director were granted funding. One of the five research consortia, CloseLoop (see below), was funded on the basis of a supplementary call, and its duration was only 3,4 years, whereas the other projects lasted 6 years.

2.1 Programme description in the funding call

The Academy of Finland April 2015 call included the following description of the SRC programme PIHI:

The research under the theme focuses on improving resource efficiency and on the circular economy. This involves efficient recycling of renewable and non-renewable natural resources, making full use of material and energy flows, and moving towards a climate-neutral and resource-scarce society as a result of changes in consumption, lifestyles and human activity. The theme involves seeking solutions with which to address identifiable obstacles to exports and competence-based growth.

The focus areas are transition and risk management, resilience and sustainable growth. In these areas, key consideration should be given to a well-managed transition to a climate-neutral and resource-scarce society, and to responding to those obstacles that lead to an adherence to existing manufacturing methods and technologies and that inhibit the adoption of new solutions. In addition, the focus areas will involve analysing climate change and self-sufficiency in resources and energy especially from the perspective of safety and supply security. Solutions and skills that support climate neutrality and resource efficiency form the basis for sustainable growth.

Based on this thematic framework, the Strategic Research Council adopted the SRC programme A Climate-Neutral and Resource-Scarce Finland on 9 February 2015.

The sustainable use of natural resources and the mitigation of climate change require a climate-neutral and resource-scarce society. We must decrease our use of resources and improve efficiency in manufacturing, as we are moving towards increasingly sustainable consumer habits and lifestyles. A circular economy involves efficient recycling of renewable and non-renewable natural resources and making full use of material and energy flows. The circular economy also improves national-level self-sufficiency and is therefore essential in terms of safety and supply security. A sustainable bioeconomy, which uses renewable natural resources in the production of food, energy, products and services, is an essential part of a climate-neutral and

resource-scarce society. The climate is changing and will continue to do so. This will require a particular focus on resilience and risk management.

Programmatic questions

In its research plan, the consortium must address questions A and B, and can choose to address either or both of questions C and D.

Under each question, there are a number of examples of possible perspectives on and approaches to the research.

A. How can we improve resource efficiency and support the move towards a circular economy, which will serve to boost exports and competence-based growth in Finland?

Possible premises: What kinds of combinations of technology and business models can help in moving towards an economy where renewable and non-renewable natural resources are recycled efficiently and where value is retained and cumulative? How can we make full use of material and energy flows by renewing existing systems and creating new operational models? What kinds of services and new applications for the general public, businesses and policy-makers will the circular economy require? What obstacles are there to exports, competence-based growth and innovative domestic markets, and how should these obstacles be addressed? How will disruptive technologies influence the environment, natural resources and carbon sinks, that is, enable a climate-neutral society?

B. What are the requirements for climate neutrality and resource efficiency in society?

Possible premises: What changes in consumption, lifestyles, education and other human activity are needed in order to transition to a climate-neutral and resource-scarce society? How can we further support these changes? Which institutional factors prevent us from moving towards a climate-neutral and resource-scarce society, and how should these obstacles be addressed? What obstacles related to manufacturing and the competence base, for instance, will lead to an adherence to existing manufacturing methods and technologies, and inhibit the adoption of new solutions? What kinds of skills are needed to support the implementation of climate neutrality and resource efficiency in society? What alternatives are there for energy production, and what are the risks in terms of, for instance, health, the climate, biodiversity and the economy?

C. In what ways can the public sector best support the overall transition so as to maintain a well-managed move towards a climate-neutral and resource-scarce society?

Such ways can include innovative experimentation, such as pilot projects, demos, learning by experimentation and institutional change. Are there any particular risks involved in this transition, and how can they be anticipated and managed? How will the risks, investments, costs and benefits resulting from the transition be distributed between businesses, the public and private sectors and different countries? In the

transition, how do we ensure self-sufficiency in resources and energy production, especially in terms of supply security and safety? What kinds of information structures and new information interfaces will the management, follow-up and evaluation of the transition processes require?

D. How can we ensure that businesses, employees, the public sector and consumers possess the resources and skills that best promote adaptation to climate change and the transition to a climate-neutral and resource-scarce society?

2.2 Public descriptions of the funded projects and their results

In their final reports, submitted in January 2022, the funded projects and the programme director summarized their work as follows:

Closing the Loop for High-Added-Value Materials (CloseLoop)

Using the principles of circular economy is one way to exploit limited resources more efficiently. The CloseLoop project looked at the potential of circular economy in Finland, both at a systemic level and in terms of technology development, focusing on high-value-added metals. The transition to a circular economy is a systemic change, with changes in production structures, business models, products and consumption practices. Cooperation, knowledge, and education play a key role. Co-operation of key actors is needed for the achievement of circular economy objectives. Circular economy development requires new tools and policies for communication between businesses and the public sector. The CloseLoop project has developed a new version of Lifecycle Analysis (LCA), which allows multi-operator concurrent LCA assessment. There are plenty of different technologies behind the realisation of the circular economy vision. The project explored and developed new recycling processes, utilization of industrial residues, substitution of critical materials and further use of the recovered raw materials.

Transition to a Resource-Efficient and Climate Neutral Electricity System (EL-TRAN)

The EL-TRAN consortium explored how Finland's electric energy system can transition to a more climate neutral and resource effective one including electricity generation, distribution and consumption. Interdisciplinary research extended from technological solutions to energy policy, views of experts and the public, and to the international context of energy transitions especially in the Nordic and EU regions. The consortium found significant support for the transition, examined policy instruments for accelerating the electrification of road transport and transition of heavy-duty road transport to biogas, and analysed prospects of better managing peak electricity demand situations by means of energy solutions in buildings, and the use of microgrids and power-based tariffs, as well as the future electric energy system of 2030/2050 including the role of bioenergy. The consortium stressed acknowledging the various societal interests for the transition to be realistic.

Sustainable, Climate-Neutral and Resource-Efficient Forest-Based Bioeconomy (FORBIO)

The FORBIO project aimed to create new know-how, means, and solutions which could provide preconditions for the sustainable, resource-efficient, and climate-neutral management and utilization of forests, and for proper adaptation to the changing operative environment (e.g., the changing climate, and the demands of forest-based bioeconomy and society). The project has provided for the key stakeholders smart know-how, means and solutions for better risk management and for enhancing in a sustainable way the climate-neutrality and resource-efficiency of forest biomass production, feedstock supply for bio-based symbioses, and the production and use of forest biomass-based products. It has also provided for decision making holistic know-how which can significantly improve the development opportunities of climate neutral (low-carbon), resource-efficient and sustainable forest-based bioeconomy and society, in Finland and, also in the whole European Union.

Novel Protein Sources for Food Security and Climate (ScenoProt)

ScenoProt aimed to diversify protein sources and improve protein self-sufficiency. Scenarios showed that the technical readiness for a change already exists. The diversification of the food system increases resilience in a changing world. Based on cultivation experiments, faba beans, hemp and quinoa have yield and carbon sequestration potential. They are also good in nutritional value. We developed new product concepts and processing methods for faba bean and hemp products. In addition, research on feed, fish, fungi and insects produced information on new sources of protein. During the studies in Central Finland, new business was created in the region. The market and consumer attitudes have become more favourable to plant-based products in recent years. A clinical intervention showed that switching from animal to plant-based dietary protein sources has both health and environmental benefits. The best diet is likely to be found between the extremes.

Gulf of Bothnia as Resource for Sustainable Growth (SmartSea)

An overall objective of the SmartSea project was to provide science-based guidance for decision making and sustainable utilisation of the marine resources in the Gulf of Bothnia. In this project, key areas of natural resources and ecosystem were located; physical, biogeochemical and human activity changes were estimated; impacts, risks and opportunities of climate change were assessed; and solutions to enhance energy and food production were provided. The project has also interacted with MSP planners, industry, local authorities and policy makers. The proposed solution for a sustainable development of the Gulf of Bothnia aims to protect at least 30% of its marine areas by 2030, concentrate wind energy production outside the coastal regions, integrate offshore activities, develop automated environmental monitoring and modelling systems and apply an ecosystem approach to maritime spatial planning.

Programme director's project

The overall objective of the PIHI programme was to advance the transformation towards a climate-neutral and resource-scarce (or rather resource-efficient) society

and to strengthen adaptation to climate change. The programme activity aimed at advancing societal impact and making the results of the five projects and other related SRC projects known. The projects of the PIHI programme covered the sustainable use of forests, the energy transition, protein self-sufficiency, the sustainable use of the Gulf of Bothnia and the circular economy of critical minerals. In practice, the work in the programme was about supporting the projects within their own focus areas, developing joint results and events, disseminating key findings in events and encouraging dialogue between the projects and other SRC programmes. A challenge for the PIHI programme was the wide scope of the programme and the different focal areas of the projects. All projects made significant contributions within their own fields contributing to the transformation towards a climate-neutral and resource-scarce society, but in concrete issues, the connection between the projects remained rather thin. Therefore, it was not meaningful to provide strong societal messages at the programme level by only relying on the projects of the PIHI programme. By joining the findings of projects from other SRC programmes with those of the PIHI projects, it was possible to develop stronger science-based societal messages across the SRC programmes.

The importance of the cross-programme co-operation is particularly visible in the analyses of the energy systems, which became a joint effort of the PIHI and TECH (Disruptive Technologies and Changing Institutions) programmes. The projects that focused on energy issues formed a coherent set, highlighting different aspects of the energy system. The projects examining the circular economy of critical materials and the conditions for developing offshore wind energy in the Gulf of Bothnia contributed to that theme. By joining the analyses of the different projects, it was possible to highlight the challenges of the energy transition and its practical implementation. The joint efforts were visible in a diversity of activities, including a joint art project with the Finnish Clean Energy Association in the form of the first energy opera, joint policy briefs that influenced the current Government's programme document, joint events under the SRC, and the 'solution cards'. The key joint message is that the energy transition needs to be advanced using policy mixes, which are coherent across societal sectors. The energy transition requires technological and social innovations, more advanced policy instruments as well as processes that are capable of changing the societal structures and practices.

Similar joint actions between PIHI and the other programmes demonstrated that protein self-sufficiency is not just a question of agriculture but has important connections to healthy food and the diversity of the food system. The sustainable use of forests explored by the FORBIO project demonstrated, together with other forestry-oriented projects, to MEPs that the use of forests needs to be examined from multiple angles and not only as an issue of forest biomass. Under the leadership of the PIHI programme, the assessment of the national strategic programme to promote circular economy was conducted (2021). A key finding was that although the programme provides incentives to advance a circular economy, it includes few measures that would discourage actions that are problematic for developing a circular economy or that would put a price on externalities a circular economy could reduce.

In summary, the PIHI programme highlighted several important pathways towards a climate neutral and resource-efficient society. The programme has encouraged the projects to initiate new projects that continue the work and translate the findings into policy statements and emerging innovations.

2.3 Composition of the programme

The total funding awarded to the PIHI programme was 29,3 million euros. Four out of the five consortium projects were composed of two funding periods (3 + 3 years) and awarded 6–6,5 million euros each. One project (CloseLoop) was composed of one funding period only, being substantially smaller than the others. The part-time programme director was awarded slightly over 600 000 euros (Table 1).

Overall, 16 organisations received funding from the PIHI programme. These mostly include Finnish universities, state research institutes, and international/foreign research organisations (Table 2).

The self-reported key research fields represented by the projects (five per project) cover a total of 22 fields, including several fields of natural sciences and engineering, biosciences and the environment, as well as social sciences and humanities (Table 3).

Table 1. Funding awarded under the PIHI programme

Project	Applicant	Funding, €		
		1. period	**2. period**	**Both periods**
CloseLoop	Karppinen, Maarit	3 615 402		3 615 402
EL-TRAN	Aalto, Pami	3 220 000	2 808 090	6 028 090
FORBIO	Peltola, Heli	3 220 000	2 878 720	6 098 720
ScenoProt	Pihlanto, Anne	3 550 000	2 941 630	6 491 630
SmartSea	Haapala, Jari	3 660 000	2 782 740	6 442 740
Programme director	Hildén, Mikael	259 130	366 531	625 661
PIHI programme				**29 302 243**

Table 2. Organisations involved in the PIHI programme

Situation at the latter half of the programme. The darkest colour indicates the organisation that led the consortium.

Organisation type	Organisation	Close-Loop	EL-TRAN	FORBIO	Sceno-Prot	Smart-Sea	Prog. director
University	University of Helsinki						
	University of Turku						
	University of Eastern Finland						
	Tampere University						
	Aalto University						
	University of Jyväskylä						
State research institute	Natural Resources Institute Finland (LUKE)						
	VTT Technical Research Centre of Finland						
	Finnish Environment Institute (SYKE)						
	Finnish Meteorological Institute (FMI)						
	Geological Survey of Finland (GTK)						
Other domestic	Makery Oy						
Foreign/inter-national	European Forest Institute (EFI)						
	Norwegian University of Life Sciences (NMBU)						
	Swedish Meteorological and Hydrological Institute (SMHI)						
	The Netherlands Organisation for Applied Scientific Research (TNO)						

Table 3. The five most important research fields of the PIHI research projects

The heatmap shows the top 5 research fields of the five PIHI projects. The research fields are selected by the projects from the Academy of Finland's research field classification[4]. The tone of the colour indicates the importance of the research field for the project, the darkest colour referring to the most important research field etc. Research fields that were not mentioned by any of the projects are excluded from the heatmap.

Category	Research field	CloseLoop	EL-TRAN	FORBIO	ScenoProt	SmartSea
Natural sciences and engineering	Chemistry			3		
	Inorganic chemistry	1				
	Particle and nuclear physics		3			
	Geology					2
	Meteorology and atmospheric sciences, climate research			2		1
	Functional materials, semiconductors	2				
	Metals	3				
	Construction and municipal engineering		4			
	Energy engineering		2			
	Environmental engineering					
	Marine technology					4
	Industrial management			5		
Biosciences and the environment	Forest sciences			1		
	Food sciences				1	
	Agricultural sciences				2	5
	Nutrition				3	
	Environmental science				5	
	Environmental research					3
Social sciences and humanities	Business administration	4		4		
	Politology		1			
	Social sciences	5			4	
	Law		5			

[4] Academy of Finland's research field classification: https://www.aka.fi/en/research-funding/apply-for-funding/how-to-apply-for-funding/az-index-of-application-guidelines2/research-field-classification/ [referred to 12 May 2023]

3 Performance of the programme

3.1 Promoting high-quality, multidisciplinary research on the problems and needs in the programme's domain

Multidisciplinary competence of research teams

The funded projects consisted of multidisciplinary consortia from strong research institutes, with internationally renowned researchers, and sometimes in collaboration with industrial and public partners. The projects addressed in scale, longevity and focus problems of important sustainability challenges for Finnish industry and society and required a multidisciplinary setting right from the outset. The multiple disciplines present in the consortia covered the necessary competencies to comprehensively address the underlying problems. Thus, e.g., EL-TRAN followed a holistic approach to energy transition that included the formulation of requirements for Finnish energy policy actors to implement the energy transition and the development of a roadmap for public sector actors to support this process. Another example is the project SmartSea, where for the Gulf of Bothnia different interests, such as leisure activities, tourism, offshore wind power, and fish farming had to be brought together and harmonized in a sustainable way.

However, the combination of natural and engineering sciences on the one hand and the social sciences on the other was sometimes rather natural science / technology driven and could have been better balanced. Thus, the political and societal dimensions of the tackled sustainability challenges and the developed solutions could have been addressed in a broader manner. One example for this is FORBIO. Here the focus was on the early stages of the value chain where valuable results had been elaborated. However, downstream processes and the transition of the whole sector and the underlying business models would have been important areas of work as well. Also, in the case of ScenoProt, for instance, it would have been interesting to see a more detailed analysis of the reasons for the transformation of the food system being so difficult and potential solutions to accelerate and implement solutions.

This is not only a function of disciplines, but also of time and resources. In general, a better balance between natural and social sciences would have been preferable. The projects funded by the PIHI programme tended to be driven by the natural science / technological side, comprising valuable "add-ons" from other fields. This, however, meant that in some of the projects, the focus on business and society in both results and publications lagged behind what was promised in the proposals. The latter may have suffered particularly from cuts in funding in the second period. Due to these limited resources provided to the social science parts, they produced considerably less output in terms of visibility and publications.

Relevance and synergy of research plans

The projects fit in an excellent way to the scope of the PIHI programme for "A climate-neutral and resource-scarce society". The programme aimed at four programmatic questions regarding (A) a resource-efficient and circular economy, (B)

requirements for climate neutrality and resource efficiency, (C) public sector support to sustainability transitions, and (D) adaptation to climate change as well as the transition to a climate-neutral and resource-scarce society by businesses, employees, the public sector, and consumers. Thereby, the projects focused on questions of high relevance to climate change and Finnish interests:

- CloseLoop: Lithium batteries were considered as examples of sources of precious metals in circular economy. The design of sustainable circles was considered as well as opportunities for the regional promotion of circular economy.
- EL-TRAN: The focus of this project was the distribution of energy supply and how to manage an ever more decentralized and complex electricity grid.
- FORBIO: The project aimed at reaching a holistic understanding of a sustainable, climate-neutral and resource-efficient forest-based bioeconomy. In the center of the research carried out were climate risks and forest management and use.
- SmartSea: This project aimed at scientific decision support for the utilisation of marine resources in the Gulf of Bothnia. This area shows high growth potential while representing vulnerable ecosystems and being especially exposed to impacts of climate change.
- ScenoProt: A carbon-neutral and resource-efficient protein system supporting climate goals was the aim of ScenoProt. A diversified food system is part of public health, and a self-sufficient and diverse protein system supports crisis resilience and security of supply.

The consortia's research plans and approaches were chosen appropriately for the selected topics. Again, individual projects could have been more relevant regarding societal and sustainability impacts by taking a somewhat broader approach. The chosen approaches led to a somewhat smaller coverage of the programmatic questions C and D through the projects as well. Others, such as EL-TRAN and FORBIO, were very broad from the start and needed to focus on specific aspects over the course of the project.

Regarding synergies between the projects, one has to emphasize that, first, due to the overarching topic of a climate-neutral and resource-scarce society, the topics of the projects were quite diverse, as shown above. Naturally, this creates problems for creating synergies across the program. Nevertheless, the projects showed some synergies, e.g., regarding wind power. Second, synergies with other national and international programs such as the EIT Raw Materials were identified and used very well. However, given the general focus on climate change, more joint efforts within this programme would have been conceivable to create public and political awareness for exactly the breadth of the issues.

Resources for managing multidisciplinary collaboration

The successful achievement of the intended goals of the programme largely depends on the given resources. In general, the overall budget of 29,3 M€ and the individual budgets for the projects (Table 1) seem to provide reasonable funding both for the targets and the achieved results and impacts (see later sections). For

multidisciplinary collaboration to succeed, time is a second necessary resource. Over both funding periods, a duration of funding of 6 years for most of the projects gave a lot of time for the projects to develop, i.e., carry out joint work on core concepts and methods, interact between work packages and satisfy their inquiries, to provide insights, as well as to jointly interpret and derive general conclusions. Developing synergies and disseminating results as well as co-creating with different stakeholders are, however, even more demanding in terms of time and resources while at the same time improving the exploitation of research results.

It is difficult to assess whether enough of the resources were invested in efforts to support the collaboration across disciplines. Anyway, more focus on appropriate tools and activities and larger shares of resources dedicated to such purposes can be required from proposals in future programs.

Methods and practices of multidisciplinary research

In general, the projects used appropriate, state-of-the-art, and cutting-edge methods and practices to carry out their research. This also included a wide range of activities for joint research and collaboration amongst the researchers, and for communication and dissemination, if not collaboration, with stakeholders. The multi- and transdisciplinary aspects covered seminars, local, regional and national workshops with stakeholders, field events for business and media, workshops for school children, futures workshops, interaction panels and policy analyses, surveys of particular interest to relevant stakeholders, market analyses, (social) media publications, websites and blogs, pilot trials, demo material packages, platforms created with simulation models available to different user groups, and participation in consultative meetings at ministries and EU bodies. This is a diverse and impressive list.

The projects proposed a wide range and long list of mutual international research exchanges and networking to collaborate with the best international researchers and institutions from the field, to keep up with the state of the art and disseminate their own findings. In the implementation, considerable levels of international networking were demonstrated by the projects overall, with very few exceptions of individual projects. Noteworthy here was also the visibility the projects had on the EU and UN levels. For example, Finland was invited to coordinate the battery recycling research of the European Strategic Energy Technology Plan.

It is certainly at least partly due to the COVID-19 pandemic that the projects lagged a bit behind their original plans in terms of international exchanges. Even for the projects with little international exchange, however, the success in international visibility through publications and subsequent extensive international collaborations in EU projects has to be acknowledged.

Training, supervision, and career development

The programme yielded a large number of degrees. In total two Bachelor's degrees, 48 Master's degrees and 33 PhDs were reported by the projects (Table 13 in Appendix 10). Analysing these figures further shows quite a bit of a difference in distribution amongst the different degrees between the projects. This may be influenced by

disciplinary traditions in terms of PhDs, for instance, and a function of levels of advancement of researchers working in the projects, of course. Regarding the career levels (Figure 1 in Appendix 5), most involved research personnel were on a mid-level (275, stage III). The figures of 53 and 56 for stage I and stage II seem to be comparably smaller than expected. The asymmetry in resources provided to natural and engineering sciences on the one and social sciences on the other hand in several of the projects was mirrored also in terms of the completion of degrees.

The programme contributed comprehensively to academic careers through the awarded degrees on the bachelor's, master's, and PhD level. Some of the projects contributed to new training and academic programs at participating universities. However, academic careers are still made mostly within a discipline. For the coverage of a career, the funding duration of 6 years is also too short, and no records are provided whether researchers changed from one discipline to another. It would also be interesting to see if the researchers from the multidisciplinary consortia were recruited by relevant business stakeholders and how their qualification was appreciated.

Productivity

The project produced, in general, a very substantial output in terms of publications. In total, 709 publications were reported. Most of the publications were in English, facilitating a broad reception in the international research community. This can also be seen from the fact that most publications were international ones, often together with international co-authors. The publications also demonstrate collaboration between disciplines. (Appendix 8.)

There were huge differences between projects in terms of share of scientific and professional, peer reviewed and non-peer reviewed publications and rank of journals. E.g., CloseLoop had a share of more than 80% of the reported publications in peer reviewed scientific journals. This share was only around 25% for ScenoProt. ScenoProt, in turn, reported more than 35% publications for professional communities, while this category is missing for CloseLoop (Appendix 8, Figure 5). Regarding the quality level also differences can be observed. On the JUFO scale, FORBIO, for example, reported 15% category 3 publications and an additional 25% in category 2. The share of publications in these highest categories is more than 20% across all projects. In Finnish universities and state research institutes in general, however, this share is above 30% (Appendix 9, Figure 11). Thus, questions of quantity versus quality of publications arise (see also below).

Dissemination, visibility, and accessibility of outputs

As pointed out above, the projects achieved a substantial publication output. On a yearly basis, this peaked already in years 3 and 4 and stretched over the period of 7 years (Appendix 8, Figure 4). As described as well, the projects showed different individual patterns regarding the publication media (between peer reviewed scientific works, publications for professionals and the public). Here, it is of course debatable what the share of the different categories should be. The overall substantial output also exists in respect to international co-authoring and the share of Open Access

publications, where the PIHI programme performs similar to Finnish universities and state research institutes (Appendix 9, Figures 9-10). While individual figures vary from project to project and the SRC may want to consider targets in terms of shares of each category, the overall numbers seem more than enough for the programme.

Additional outputs that should be mentioned are the projects' contributions in terms of publicly accessible data, which include the Open Access data base on climate risks from FORBIO, the contributions of ScenoProt to the Finnish Food Composition Database and the collaborative Life Cycle Engineering environment of CloseLoop (Appendix 10, Table 12).

Significance, novelty, and innovation of results

Each of the projects achieved significant, novel, and innovative scientific leaps and thus contributed to achieving the overall scientific goals of the program:

- CloseLoop elaborated solutions, i.e., approaches and processes, for closing material cycles of electronic devices and elaborated a collaborative life cycle engineering platform.
- EL-TRAN provided insights on the electricity system which are now generally accepted truths (also from other projects), and generated attention on Nordic examples. In addition, it developed a concept for combining solar panels and electricity storage in apartment buildings with the necessary proposals for measures to be taken by different stakeholders.
- FORBIO came up with contributions to holistic understanding of sustainability of a forest-based bioeconomy covering climate-neutrality and resource efficiency. This includes solution models to better manage risks in forest management. Through interactions with stakeholders and case studies on changing operations of companies it was also possible to provide new knowledge and best practices.
- ScenoProt developed prototypes of new protein crops, and new practices in crop rotation or cultivation methods for protein plants such as fungi.
- SmartSea developed the first underwater nature value map covering the entire Finnish maritime area and discovered that the majority of the best underwater nature values are located outside maritime areas controlled by the state.

However, the results of projects strongly depend on the information and methodologies used in research, such as modelling and data selection. Understandably, within the framework of financial resources, the research teams had to make some choices and exclusions in terms of the models and scenarios used. The potential effects of these choices should be considered in a clear manner when interpreting the research results. For example, the SmartSea project was able to use only two of three relevant climate scenarios in its modelling due to lack of sufficient economic resources. For interpreting the research results, it would have been useful to obtain information on whether this limitation possibly affected the results of the research.

Conclusion

To conclude, we find that the multi- and interdisciplinary set-up of the projects seems to have worked quite well. Thus, the projects were able to successfully pursue their research questions and reach most of their goals. Together, the projects were successful in reaching the majority of the PIHI programme's aims. Moreover, the PIHI programme built an effective foundation for further relevant research. Themes such as the security and resilience of the electricity system, biodiversity as one objective of forest management, the diversity of the food system and political and societal support of its transformation can be and are being followed by new research by the consortia and others.

However, more balance in disciplinary collaboration would have been desirable. In particular, more attention to social sciences, including economic and political/policy perspectives, is necessary to allow addressing of competing stakeholder visions and interests, political barriers to as well as enablers of successful implementation, societal and economic dissemination, and the necessary sustainability transition.

Though within a consistent frame to achieve a climate-neutral and resource scarce Finland, a substantive distance between the projects existed. This was a challenge for synergies in the programme. A continuation of project themes in subsequent programmes helped to leverage synergies with other projects and funding schemes in Finland and on the international level. However, identifying and creating even more synergies would have been desirable and possible.

Regarding the countable outcomes in terms of awarded degrees, number and type of publications, acquired follow-up funds, developed products, start-ups etc., one can state that the programme performed very well overall, also in comparison with national averages. The individual projects show different patterns here. These may have been due to differences in research foci and aims and are more than natural for such different projects. However, the question of an appropriate balance of the different outputs remains. Here, the SRC may discuss setting specific targets, whether these should be pursued or whether individual projects should be allowed to set these by themselves in a context appropriate way.

Finally, especially for programs running that long, it is recommendable to ask consortia to plan for "black swans", i.e., to require them to do a more comprehensive risk assessment.

3.2 Creating concrete steps towards tackling problems and needs in Finnish society

Reach and commitment of societal stakeholders

The reach of societal stakeholders by the programme covered all fields of society: political decision makers, researchers, ministries, businesses, and the civil society, when relevant for the project targets. As there was a large scientific distance between the projects, the relevant stakeholders varied between the projects and there seemed not be overlapping reach between them.

- CloseLoop focused on the circular economy of high-added-value materials and its main stakeholders included industrial partners, municipal decisionmakers, ministries, and non-governmental organisations (NGOs).
- EL-TRAN focused on a resource-efficient and climate neutral electricity system and its main stakeholders included energy sector companies, energy authorities, ministries and think tanks.
- FORBIO focused on a sustainable, climate-neutral and resource-efficient forest-based bioeconomy and its main stakeholders included forest industry companies, forest organizations, ministries, and Finnish and international universities.
- ScenoProt focused on novel protein sources for food security and the climate and its main stakeholders included ministries and food sector companies.
- SmartSea focused on the sustainable development and use of marine resources and its main stakeholders included ministries, Metsähallitus, municipalities, regional authorities, representatives from various industry sectors, and NGOs.

However, in the survey for stakeholders of the SRC programmes the response rate among the PIHI stakeholders was low, only 13 %, and there were only 6 respondents (Appendix 14). It is difficult to draw final conclusions from one survey, but based on this, the stakeholders may not have been very committed to the programme work. Of course, there can be other reasons for the low response rate, like a late (i.e., after project completion) or unsuccessful communication of the survey.

Plans for societal interaction and outreach

The societal impact of the PIHI programme was realized mainly in the form of projects' own publications, events, and meetings with societal stakeholders. Societal interaction and outreach were organized in a clear and adequate way in the individual projects. However, considering the need for systemic change, it would have been beneficial if there had been a plan for societal interaction and outreach also on the programme level. This would have required more coordination and building of bridges between different research topics from the beginning of the programme to maximise the synergies and to create joint messages for interaction and outreach, when relevant. A joint plan for societal interaction could have made it possible to have even more societal impact.

Resources for managing societal interaction and for stakeholders to take up and utilize the results

The resources of individual research projects for managing societal interaction seemed to be sufficient as there was a large number of stakeholders and stakeholder events in each research project. If there had been lack of resources for societal interaction, the research projects could have prioritized the collaboration to the most relevant stakeholders.

On the other hand, it is difficult to assess the resources for stakeholders to take up and utilize the results. Many different research teams in addition to SRC projects approach the same stakeholders with their research proposals and results. However,

the status and the mandate of the SRC research programme most probably gave certain credibility to the PIHI research teams and helped to reach the relevant change-makers in the society. It is also important to note that societal interaction does not necessarily need significant financial resources. Sometimes the most influential way for interaction, especially among decision makers, can be meetings with selected, hand-picked stakeholders who in their capacity can have a broad impact on policies.

As the nature and targets of the individual research projects were diverse, there naturally was some diversity in the amount of resources used for societal interaction. Some research projects were more technology development oriented (CloseLoop), while some focused more strongly on societal change (ScenoProt), and therefore investments in societal interaction understandably varied.

One proposal for improvement of societal interaction is to consider having more close collaboration between the research projects in order to support a holistic transition towards a carbon neutral resource scarce society. This kind of collaboration and a joint, holistic, programme-level target for systemic change could have enabled maximal synergies and use of resources within the programme regarding societal interactions. Resources for joint impact work of the projects could have been achieved by focusing the work of the projects on the basis of impact, eliminating less impactful activities. The other possibility to find sufficient resources for joint impact work is to reallocate resources within the programme to encourage more collaboration between the projects.

However, some joint events between the SRC programmes were organized. Joint events served the purpose of shedding light on issues relevant to the development of society in a more versatile manner than the results of an individual project would have been sufficient for. This made it possible to integrate the research topics to effect broader societal change. For example, the PIHI programme had a close working relationship with the SRC programme “Disruptive Technologies and Changing Institutions (TECH)”, especially with the SET project (Smart Energy Transition – Realizing its Potential for Sustainable Growth for Finland’s Second Century) and the BCDC Energy project (Cloud Computing as an Enabler of Large-Scale Variable Distributed Energy Solutions) which were close in content to PIHI.

Timely involvement of knowledge users and responsiveness to their needs

The PIHI programme has been very timely to provide research-based knowledge for the transition towards a carbon-neutral and resource-scarce society. The European Union as well as Finland have put solving ecological sustainability related issues and the opportunities they bring to the very core of the competitiveness strategy. There has been huge need for science-based knowledge as well as both technological and societal solutions to reach this target. It is obvious that the PIHI programme has provided important knowledge and tools to support the transition towards circular economy, sustainable diet, sustainable use of marine resources, and a carbon neutral energy system. Today, in Finnish society as well as globally, there is a widening recognition of the importance of these matters, and the PIHI programme has played an early role in increasing this knowledge and know-how.

One example of the success is the programme's contribution in a timely manner to several governmental strategies, proposals, and programmes. According to the programme director, the impacts of the projects' results and their proposals for measures can be clearly seen in the government programmes of Prime Ministers Antti Rinne and Sanna Marin. This impact would probably not have been achieved without the investments of the programme and the projects in policy briefs and other public outputs alongside scientific articles.

Research on the interests and conflicts of interest of different stakeholders as well as collaboration between the public, private and the third sector within the programme were beneficial in supporting systemic change, as the transition requires contribution from all sectors of the society. For example, the SmartSea project investigated how the needs of different interest groups can be taken into account and coordinated in the Gulf of Bothnia. In the region, there are several different interests: leisure activities, tourism, offshore wind power and fish farming, and all this must be carried out in a sustainable way, taking the planet's carrying capacity into account. The other example is the EL-TRAN project, which studied the role of consumers alongside energy industries and policy makers. The energy transition has normally been considered to be driven by policies and energy companies, and in 2016, research on the role of consumers was a novel and welcome approach. The programme did not provide concrete means for solving the conflicts of interest, but even raising this societally important topic on the research agenda is very welcome. This critical issue is not yet sufficiently discussed in society.

One shortcoming in the programme was that more attention should have been paid to biodiversity loss, even if the focus was on how to achieve carbon neutrality and accelerate the circular economy transition. Biodiversity loss is one of the drivers of climate change and vice versa. While the public debate on the interlinkages between climate change and biodiversity loss has become louder only during the past couple of years, the scientific community has understood this phenomenon for a long time. SmartSea was the only project that had biodiversity loss at the very core of its research agenda. Considering this, the programme could have given more consideration to biodiversity, for example, by including a question such as "how to take biodiversity loss and its solutions into account when mitigating climate change" in the programme's agenda.

Active and constructive participation by knowledge users

The knowledge users involved in the programme's work included wide representation from the public sector (the state, regions, European Commission, the Baltic Marine Environment Protection Commission HELCOM, etc.), private sector (businesses) and citizens. The knowledge users were actively involved in the implementation of the projects and/or took part in events, dialogues, and seminars. Depending on the topic and the target, some events were tailored to certain knowledge users and had a very clear focus, e.g., food seminars, while some events had a broader scope and audience. CloseLoop, for example, organised or contributed to stakeholder events reaching more than 700 participants – many of these being key stakeholders in relevant industries. The three concurrent SRC programmes (PIHI, EQUA, TECH) also

organised joint events and discussions for knowledge users and took part in the hearings of the Finnish Parliamentary Committee for the Future together. This tells that the programme succeeded in fostering active and constructive participation by knowledge users.

This is supported by feedback from the stakeholders who agreed that as a result of the programme, the interaction between researchers and stakeholders will continue (average score was 4,3 on a likert scale 1–5), that the interaction took into account the interests of different parties (4,2), that the interaction was overall successful (4,2) and that the interaction reached a wide range of target groups (4,0). The stakeholders also appreciated that the interaction was relevant, fair and easy to participate in (4,0). (Appendix 14.)

Public engagement

The engagement of the public in the work of the research projects varied between the projects depending on the scope and targets of the projects. A broader public engagement was carried out in those projects where it brought clear added value. For example, the target of the ScenoProt was to provide research results, knowledge, and know-how to accelerate the transition towards more sustainable food systems, and public engagement was used as a tool to drive the change. The project was designed to include broad public engagement, and the results were widely publicized in media, public events, and other presentations, reaching an estimated number of more than 30 000 people.

Another example is SmartSea, where the target was to design a blue-growth road map for the Gulf of Bothnia and to study how to coordinate the different interests of stakeholders including municipalities, citizens and businesses. Since this topic affects the everyday life of many people, raising their awareness supported the achievement of the project's goals. The project's public appearances have directly reached an audience of nearly 10 000 people. On the other hand, EL-TRAN, CloseLoop, and FORBIO focused on more specific areas: energy transition, circular economy of high-added-value materials, and sustainable forestry, and in their case, broad public engagement would probably not have brought so much added value. However, also EL-TRAN, CloseLoop and FORBIO clearly contributed to public debate in their specific areas.

Useful results and outputs, and their use in concrete solutions

Useful results and outputs of the PIHI programme included new science-based information for societal transition and new tools, which are needed in the systemic societal change, such as road maps (EL-TRAN, SmartSea) and life cycle assessment tools (CloseLoop). Some research results have already been taken into account in legislation, government guidelines, national strategies and programmes, and international initiatives and programmes. The programme also explored the role of citizens in societal transition and made efforts to bring about attitude changes.

The programme has contributed to the public debate in Finland, regarding, among other things, new products for sustainable diet, circular economy transition, and the

transformation of the electricity system. Businesses benefited from market research on certain new products, as the research provided outlook for businesses to determine the commercial potential of those products.

The wind power map developed in SmartSea attracted great interest among wind power developers, and the SmartSea Zonation map was used as reference material for the location guidance of aquaculture.

The high number of publications and organised events (see earlier sections) is very good. From a practical point of view, discussion about targets in this field can consider questions between the quantity versus quality of the publications, and between a focus on scientific debate and on societal impact. A high number of publications was not an explicit goal of the programme. Sometimes a smaller number of publications in very high-quality scientific journals, and more focus on actual societal change, can be more effective for systemic change than preparing a large number of events and writing a large number of publications – all of which require a significant amount of resources.

Changes in policies, practices, behaviours and attitudes

The influence of the PIHI programme on national legislation, policies, strategies, other initiatives, and changes in attitudes is obvious. The public discussion on the transition towards a carbon neutral resource scarce society has intensified during the past years, and there is a widening recognition of the importance of the subject. It is difficult to single out the concrete contribution of one research programme or individual research projects. However, the PIHI programme has clearly had an impact on accelerating the change, understanding the drivers of the change, increasing the know-how of practitioners, and changing practices, together with other research projects.

The findings of the projects have, through dialogue and engagement with key decision makers such as civil servants in the ministries and the members of the parliament, entered into emerging policies and national strategies. For example, EL-TRAN's research results have contributed to the National Energy Strategies.

The research results and their dissemination, and especially the engagement of relevant stakeholders and the public, have changed the attitude and increased the know-how among key actors, which is a prerequisite for systemic change. The programme (especially the EL-TRAN and ScenoProt projects) also identified the barriers to change and the potential for change in attitudes, habits, and expectations, and also explored the potential of active consumers to drive the changes needed in the transition.

According to the ScenoProt project, intervention research can influence the attitudes and behaviour of subjects and bring about lasting changes. The project has indeed played a role in the overall shift in attitudes to plant-based food and to a deeper understanding of the importance of food and consumption choices in addressing environmental challenges. The programme's results also show that citizens, in general, are willing to participate in Finland's energy transition but at the same time need support and steering to participate.

Conclusions

The SRC programmes, including the PIHI programme, and their research projects have contributed to the acceleration of system societal change towards a sustainable well-being society. The focus of the PIHI programme in this context was on the transition towards a carbon neutral and resource scarce society. At the same time, many other studies and research projects have contributed to the same target in Finland, and it is difficult to single out the role of an individual research programme.

However, it is obvious that the PIHI programme has significantly affected the readiness of Finnish society to accelerate the transition by engaging relevant stakeholders and by bringing science-based knowledge and know-how about the challenges, opportunities, and solutions, as well as the tools – both technological and societal – needed in the transition. The programme's impact and societal stakeholders' commitment on longer-term systemic change can be analysed only later, but the research projects did their best in the capacity of a six-year programme.

The engagement of the public was done in a meaningful way and the resources used and processes varied between the projects depending on the scope and targets. A broader public engagement was carried out in those projects where it brought clear added value. One proposal for further improvement of societal interaction is to consider having more close collaboration between the research projects within the programme in order to support the holistic transition towards a carbon neutral resource and scarce society.

One important observation was that the programme organized hundreds of different events and produced over 700 publications during the programme period. A proposal for the SRC is to consider if a recommendation for a smaller number of more impactful events and publications in higher quality scientific journals would be beneficial in the future to maximize the effective use of resources.

3.3 Strengthening research and stakeholder communities

The PIHI programme, which aimed to address a range of sustainability-related problems in Finnish society, had collaboration between researchers and societal stakeholders as its distinguishing feature. Since sustainability challenges are complex and persistent, it is essential to evaluate also the impact the programme had on strengthening research and stakeholder communities involved in the projects and the programme, both during and beyond the programme's life span, in order to prepare for ongoing and future challenges.

Involvement of a variety of actors

The PIHI programme has strengthened relevant research and stakeholder communities through its collaborative and participatory approach. The programme and its projects have brought together a range of stakeholders, including researchers, policymakers, businesses, regional authorities and municipalities, and civil society organisations and NGOs, to work together to identify and address the complex sustainability challenges facing Finnish society. Some of the projects worked with an idea of

ecosystems of actors, while others had a value chain oriented engagement of actors. For example, using a multidisciplinary approach, FORBIO devised and studied circular value chains for forest biomass. This collaborative approach has led to the development of innovative solutions, products and services, research methods and implementation processes, and dissemination and communication channels. It has helped build more robust and resilient stakeholder communities, better equipped to handle sustainability challenges after finalising the programme.

Importantly, in some cases, the explicit focus on collaborative approach unveiled deep-rooted conflicts between the perceptions of different stakeholders about the nature of the challenges and how they can be addressed. Vested interests and sunk-in costs, but also fear of change and lack of knowledge of specific steps required for change, have been identified as underlying reasons for conflicts. Reconciling these conflicts requires time and continuous dialogue. Therefore, the subsequent research programmes and changes in institutions that followed the PIHI programme are critical for providing a platform for such a dialogue.

Already at the proposal stage, researchers of transdisciplinary projects involving many stakeholders should be asked for a risk management plan, where ideas for addressing foreseen conflicts between stakeholders are elaborated on. To help manage these conflicting interests, social scientists and policy researchers could be employed to lead activities that would be beneficial for enhancing societal impact.

Resources for training and organisational learning

Many projects allocated resources for training and organisational learning. At the same time, activities with stakeholders, such as workshops and meetings, highlighted the importance of competence building and (vocational) education and training regarding, e.g., circular economy issues. Organisational learning among, e.g., ministries and regional authorities is critical for building capacity to address multiple and complex sustainability challenges. Allocating resources for training business actors and industry representatives, in turn, is critical for triggering innovation and identifying pathways to more sustainable products and services. It was suggested in one of the impact stories that there is a need for an organisation that could enhance cooperation on circular economy issues between different sectors and regions and coordinate teaching and training projects related to circular economy. The latter suggestion is relevant for other areas, too, such as a resource-efficient and climate-neutral electricity system, forest-based bioeconomy, future protein production, or protection of nature underwater.

In some projects, a teaching programme for university students or school children was developed to create societal impact and build capacity to address sustainability challenges in the long run. These are investments in long-term capacity building and scaling up projects' results and knowledge. There are also examples of PIHI projects developing educational engagements for stakeholders. For example, ScenoProt organised seminars and field events on protein crop production for primary producers and small entrepreneurs.

Promotion of responsible research

The issue of fair transition and responsible research was not on the agenda of research funding agencies in 2015. Still, the PIHI projects could extract relevant findings and were able, e.g., to submit suggestions and recommendations to the Finnish Committee on Resilience. Researchers from the ScenoProt project developed recommendations for older people's nutrition and conducted consultations with the Finnish National Nutrition Councils about them. The lesson from this is that projects need a certain degree of flexibility in their budgets to use on such issues when needed.

Setting up practices and tools for co-production, mutual learning, and capacity building

The broad range of actors engaged in the PIHI programme often had a more active role in the projects than the traditional role of recipients of produced knowledge – they engaged in the co-production of knowledge. Accordingly, the projects developed and employed tools and practices for enabling and supporting co-production, mutual learning and capacity building. These correspond well to the planned activities and outputs outlined in the projects' proposals.

Direct interactions – interactions on a personal level between researchers from different disciplines and between researchers and stakeholders – were encouraged in the projects, and forums for such interactions were created in the form of workshops, interviews, Q-method tests and similar. For example, in CloseLoop, regional workshops led to creating a joint forum (Satakunta/Pori) and forming a regional roadmap for a circular economy (South Karelia/Lappeenranta). The EL-TRAN project developed a roadmap for Finland's transition to a more resource-efficient and climate-neutral electricity system. It contains a set of recommendations divided into themes relevant to the target groups. The SmartSea project developed a roadmap for blue growth in the Gulf of Bothnia. These tools will help rewire Finnish society into a climate-neutral and resource-efficient economy long after the project and the programme are finalised.

All the projects developed websites and communicated about the project and its results in social media by writing press releases and blogs and using other ways of content production. To reach out to different stakeholders, the SmartSea produced information boxes with projections of how the conditions in the Gulf of Bothnia will develop over the next 50 years and how the changes will affect the region's maritime resources and the profitability of Finnish businesses.

The conducted and defended Master's and PhD theses in the frame of the programme can also be seen as capacity building relevant to Finnish society and its sustainability areas.

Knowledge acquired in the PIHI-funded projects has been used by different societal actors, ranging from businesses to academia, the public sector, and the general public. Especially the public sector has benefited from the programme. Specifically, the projects supported decision-making, developing policy recommendations, national strategies, sector-specific guidelines, etc., which has been critical for national and business competitiveness.

However, projects could have been more explicit and reflexive regarding the role and description of various types of collaboration within the project, in addition to excellent accounts of stakeholder activities. For example, information about collaborations in publishing, e.g., scientific and general-purpose publications and policy recommendations, would have been beneficial in assessing the programme. Also, an account of how many experts have received training and different kinds of capacity building as part of the PIHI programme would be an essential indicator of the programme's co-production capacity and mutual learning.

Results and outputs made and kept available for use by multiple beneficiaries

As indicated earlier, the projects in the PIHI programme demonstrate excellent publication records with different balances of peer-reviewed and non-peer-reviewed publications, Open Access and other publications, academic publications and those targeted to practitioners or the general public. Also from the perspective of keeping results and output available, it might be beneficial for the funder to indicate expectations regarding the scientific excellence of academic publications versus dissemination channels and types of other deliverables and results for societal impact.

In addition to producing society-relevant results, more attention should be paid to speeding up the utilisation of results. For example, in the ScenoProt project, much understanding of different alternative protein sources has been created. Still, more must be done to bring down vested interests and established power structures, as some actors (e.g., trade unions) still promote fossil fuels despite the general support for climate actions.

Ownership and licensing of intellectual property

Some projects led not only to scientific results but also to industry-relevant applications that have been patented (Appendix 10, Table 15). For example, in CloseLoop, the electrolyte used in the battery has been granted a patent, and a domestic and international patent application was submitted for the structure of the battery. Licensing of intellectual property becomes critical, especially in solution-oriented research. It defines how others can use the findings and scientific results and prevents the results from being used in unintended ways. With the growing demand for research to share not only final results but also supplementary material, it will become more critical to clearly define the ownership of scientific data, methods and outcomes in the future.

Scalability and applicability of solutions

Many projects produced policy recommendations and discussed potential new legislation with, e.g., the Ministry of Economic Affairs and Employment and the Ministry of the Environment. For example, members of EL-TRAN participated in 30 different committees and expert working groups preparing legislation or standards. Researchers of ScenoProt were also active in EU level preparation of policy measures targeting the food system's diversity, while SmartSea's wind energy map was used as a background material for the Maritime Spatial Plan for Finland. New legislation can be one of the most long-term and effective means for research to lead to societal

changes. Such developments need to be encouraged and followed up potentially at the programme level.

The scalability and applicability of solutions developed in projects can also be affected by the so-called “black swans” – unforeseen dramatic events, such as pandemics and wars – that may interfere in project implementation and totally change the realities and trends of society. Risk management plans required by the funder might help prepare researchers for such eventualities.

Enhanced capacity of stakeholders to absorb and utilize research-based knowledge

All projects led to the enhanced capacity of many stakeholders to absorb research results, knowledge, and recommendations due to their direct and indirect engagement in the research process. As noted in previous sections, this engagement included co-production of knowledge and communication and dissemination of results in different venues and channels, such as workshops, cafés and case studies, platforms and online tools, creation and collection of data, and development of open data.

Some projects developed platforms where the target audience was practitioners. For example, the Modelling Factory platform developed in the CloseLoop project helps to increase the competence of product designers in different planning steps. This tool helps practitioners in companies to utilise research-based knowledge and simulate product designs in combination with life cycle assessment data. To assist with the utilisation of the tool and enhance the cooperation of research and stakeholder networks, the researchers suggested that “a reliable and sufficiently neutral actor must be found to produce network-level results” (a comment in the self-evaluation questionnaire). One of the crucial tasks of such an independent organisation would be data quality assurance and a guarantee that data analyses meet international quality standards. This would improve the acceptability of cooperation methods and open up new opportunities for scaling up using applications and tools.

Some of the projects developed material for education in universities and material for engaging in the training and education of stakeholders in the area. This has helped to build the capacity of stakeholders to address the core issues and has facilitated the sharing of knowledge and best practices along value chains and across different sectors and organisations. In many projects, researchers heavily promoted their work and results. For example, the researchers of EL-TRAN delivered 138 media and 117 other types of presentations to stakeholders (in addition to the project's events) to promote impact and communicate results. ScenoProt was explicitly designed to engage different stakeholders from the food system. The researchers organised events such as “Food for Media” and “Food for Business”, during which sustainable products were demonstrated. The SmartSea researchers sought to communicate with a wide set of stakeholders and reported communicating with almost 10 000 people.

Some of the projects were followed up by activities at the ministerial level. For example, the Ministry of Economic Affairs and Employment launched a two-year

programme to promote the battery industry “Akkuja Suomesta” (English translation: Batteries from Finland) with Business Finland, following recommendations from the CloseLoop project. Also, Finland was invited to coordinate the battery recycling research of the European Strategic Energy Technology Plan (SET Plan). Another strategic undertaking from the programme was the presentations for the Parliamentary Committee for the Future. The PIHI programme also carried over into other SRC activities, such as the joint contribution to welfare reform in Finland.

Acquisition of new resources for continuing the work

All projects acquired significant subsequent funding from the Academy of Finland, Nordic funders, ministries, and the EU (Appendix 11).

Researchers from the CloseLoop project were granted funding, e.g., to develop the battery material ecosystem and battery manufacturing technology after the project's finalisation. This demonstrates that the PIHI programme was forward-looking and created permanent research communities to bring the programme results forward.

FORBIO, for example, managed to acquire large-scale follow-up funding of 12 M€, including the Academy of Finland Flagship of Science “Forest-Human-Machine Interplay (UNITE)”. In total, follow-up funding a 4:1 ratio in comparison to the initial project funding was achieved, which is excellent.

Some projects reported building new consortia with the same partners to acquire external funding for future projects. This demonstrates that consortia in the PIHI programme have built internal capacity and found a common language and ways of working in multi- and transdisciplinary teams, which is commendable.

At the same time, there is room for improvement by extending these research consortia with researchers from social sciences. Several PIHI projects focused on natural or engineering science, with social sciences being a minor add-on part with low resources and hard-to-achieve results. At the same time, manuals, recommendations and knowledge from the projects are being co-produced, available and disseminated; yet, societal change is still not at the desired pace. Social sciences can contribute to filling this knowledge-action gap by offering insights into changing the behaviour of stakeholders and the public, policymakers and businesses, thereby improving the implementation of research results and increasing societal impact.

Promotion of new and versatile career paths

Another way in which the PIHI programme has strengthened relevant research and stakeholder communities is through its focus on knowledge sharing and capacity building. The programme has supported the development of new research and knowledge on various sustainability-relevant topics. One of the tools extensively used in the programme was the research visits, with a total number of visits amounting to about 5 000 days. This includes both researchers in the programme visiting a broad range of universities and research institutes in different European countries, China, Japan, Cuba and the USA, and vice versa, researchers from European countries visiting the Finnish researchers. (Appendix 10, Table 14.)

The PIHI programme has also contributed to developing new networks and partnerships that are likely to continue beyond the programme's lifespan. These partnerships will provide a strong foundation for ongoing research, advocacy, and action on these issues in Finnish society. Multiple activities for engaging with policymakers have impacted the policy formation processes. However, information on whether collaboration with policymakers has led to novel career paths is missing.

Conclusion

The conclusion is that the PIHI programme:

- provided versatile opportunities for conducting research aimed at solving grand societal challenges in collaboration with stakeholders;
- produced new and, in many cases, cutting-edge society-relevant knowledge; and
- engaged different stakeholders in implementing the research findings and solutions developed for societal benefit.

Overall, the PIHI programme seems to have significantly strengthened relevant research and stakeholder communities in dealing with sustainability challenges in Finnish society, judged by the diversity and the number of ways of engaging with stakeholders in different projects. Through its collaborative and participatory approach, its focus on knowledge sharing and capacity building, and its development of new networks and partnerships, the programme has helped build more robust and resilient stakeholder communities, better equipped to address these challenges during and beyond the programme's life span.

However, judging by the answers of stakeholders who were asked to provide feedback about the PIHI programme, some areas for improvement remain. First, the limited number of survey responses (13%) and very few elaborations or explanations included in the answers show, perhaps unsurprisingly, low interest and/or lack of time among stakeholders to contribute to the evaluation and potential improvement of the programme (Appendix 14). Perhaps soliciting feedback at the end of the programme, instead of after its conclusion, would yield a better response rate.

Second, the most appreciated channels for collaboration with stakeholders were stakeholder events, policy advocacy and international collaboration. Research and communication-related activities, such as participation in research experiments and social media, were less valued. Thus, projects and programmes could allocate more and better-targeted resources in the future.

There is a clear need to demonstrate and communicate to stakeholders the relevance and usefulness of participating in research activities. Already in proposals, researchers could be asked to specify in what form and through what channels the results of different research activities can be communicated to stakeholders. When it comes to participation in social media, perhaps stakeholders themselves should assume a more active role in disseminating results or information about their participation in the programme on issues important to them.

4 Conclusions, lessons and recommendations

4.1 Key findings on the programme's performance

The strategic research programme on a theme “A climate-neutral and resource-scarce society” was adopted by the SRC in 2015. The research under the theme was planned to focus on improving resource efficiency and on circular economy involving efficient recycling of renewable and non-renewable natural resources, making full use of material and energy flows, and moving towards a climate-neutral and resource-scarce society as a result of changes in consumption, lifestyles and human activity. The theme also included seeking solutions with which to address identifiable obstacles to exports and competence-based growth. The focus areas were transition and risk management, resilience and sustainable growth.

Overall, the evaluation panel came to a positive evaluation of the funding programme. The question and target setting of the programme was carefully done and sought to find answers to essential questions and challenges related to the systemic transition towards a carbon neutral resource scarce society. All projects addressed relevant and timely questions in the programme's focus area. They developed new knowledge, both in terms of scientific innovation and in terms of adding insights to critical societal debates and solving challenges. While the participating projects differed with respect to their emphasis on academic inputs versus civic and stakeholder engagement, all contributed essential knowledge and relevant tools for the transition to a more sustainable society. Given the fundamental challenges inherent in this transition, the programme also proved very timely with its start in 2015. At that time, the climate strategy for Finland was still unclear. From that point of view, the chosen research areas were well selected and provided significant contributions in their own fields to systemic change.

However, to reach the ambitious goals, more co-operation and coordination between the funded projects as a part of comprehensive well-orchestrated change would have been desirable. Considering the target setting of the programme, the research consortia would also have benefitted from having more competencies related to social sciences, primarily to the political and economic perspectives. Most of the research projects were driven by and strongly focused on natural sciences and technology development and insufficiently considered political obstacles or barriers to market entry. These are undoubtedly challenging research areas due to their interaction (e.g., obstacles to the market entry of new solutions often depend on political choices). To find answers to these challenges, some market analyses for new products and policy analyses on stakeholder perspectives were carried out under the programme. Similarly, obstacles to the adoption of new solutions in the markets as well as hindrances for systemic transition were touched on. However, deeper and further analysis and a real crossing of disciplinary borders was not possible given the time and resources awarded to it within the programme’s and projects' domains. Including the perspectives and insights of social sciences could help address divergent stakeholder perspectives and interests, improve the acceptance of proposed

measures among policy-makers and the public, and facilitate the successful implementation of results, thereby speeding up the sustainability transition.

Key findings on criterion 1

Overall, the programme and the projects successfully reached most of the programme's aims. The multi- and interdisciplinary set-up of the projects contributed to this. At the same time, more synergies, cross-pollination and learning between and across the projects in the programme would have been beneficial. Considering the broad sustainability focus of the programme, it was difficult to create synergies among the projects in the PIHI programme. Therefore, continuing project themes in subsequent programmes proved beneficial for leveraging synergies with other Finnish and international projects and funding schemes. Still, more synergies could have been created and made use of even within the PIHI programme.

Even in the case of projects with rather diverse substantive foci, cross-pollination of ideas and learnings is possible on matters of project management, such as conflict resolution among stakeholders or communication of projects' results to different audiences, in particular to stakeholders with an overarching interest and to the general public. An important element of the programme director's role should be to identify such opportunities for cross-pollination among projects. Appropriate resources should be allocated to ensure that they fulfill this task.

The programme produced an impressive number of publications, awarded degrees, developed products, and start-ups. At the same time, the individual projects demonstrated diverse results, with some of them producing more high-quality publications. In contrast, others had more impressive results in terms of practice-oriented outcomes and events. Providing more explicit guidance to projects about the expected or desirable balance between different outputs could perhaps ensure more uniform results, if this is intended. This is, however, a point the SRC could discuss. Leaving this point open, especially for such a broad program, may also yield a better appropriateness of the outcomes depending on the topic and discipline.

Finally, all project teams managed to secure substantial follow-up funds, which indicates that the PIHI programme performed well overall. The programme built the foundation for a number of further relevant research themes, such as the security and resilience of the electricity system, biodiversity as one objective of forest management, and the diversity of food system and political and societal support of its transformation.

Key findings on criterion 2

With regard to the creation of concrete steps towards tackling the problems and needs of Finnish society, the evaluation panel noticed that the programme covered stakeholders from all sectors of society, with some overlap among the project-specific stakeholder groups. Here, mapping stakeholders involved at the start of such a programme may prove beneficial in the future. Not only, but also due to stakeholder engagement (which however varied among the projects), all projects funded under the PIHI programme were clearly able to create important knowledge and innovative

insights for Finnish society and the problems it is facing. They added to larger societal debates, policy deliberations and strategy development, as well as business and civil society based tools and practices, supporting especially efforts aimed at the required sustainability transformation. In this context, the high number of public events and related communication activities is noteworthy.

Key findings on criterion 3

With respect to the strengthening of research and stakeholder communities in the programme's domain, the PIHI programme provided versatile opportunities for a broad range of forms of dissemination and engagement aimed at solving grand societal challenges. These spanned from unidirectional information provision (e.g., media contributions) to efforts to co-create and co-produce knowledge with stakeholders. Again, the projects funded under the programme differed in their foci, but overall, the number of activities and events is very impressive. They helped the progamme to contribute to the production of new and, in many cases, cutting-edge societally relevant knowledge, including publicly accessible data. Acknowledging that evaluating the uptake and impact of research findings is extremely difficult, the evaluation panel still noticed differences in the impacts the projects were able to make. In this context, the question of how to obtain stakeholder commitment is crucial.

The PIHI programme thus offered opportunities for long-term engagement both for researchers and stakeholders. This increases the possibility of unforeseen events interfering with or interrupting planned activities. To help avoid disruptions from unforeseen events, such as the COVID-19 pandemic, it might be beneficial to put more focus on risk assessment. Especially for programmes running that long, it is recommendable to ask consortia to plan for "black swans", i.e., to require them to do a more comprehensive risk assessment.

In addition to that, it would be desirable to see more reflexive accounts about various types of collaborations within the projects. Stakeholder engagement can range from being informed to being involved in the co-production of knowledge. Thus, consortia should be asked to reflect on who they involve, how, and why. In this context, information about collaborations in publishing and an account of how many experts have received what kind of training would also be desirable.

4.2 Lessons learned and recommendations

While the overall evaluation of the programme by the panel is positive, there are several areas where the panel noticed possibilities for improvement in the design of future programmes or, at least, where some questions remained.

First, the evaluation panel would recommend even more focus on interdisciplinarity, both in terms of the mix of disciplines and the balance between them. While all projects funded under the PIHI programme were interdisciplinary in some way, several could have benefitted from a (larger) involvement of social sciences, including the political and economic perspectives. A number of the projects noticed political barriers to the uptake of relevant insights that resulted from stakeholder opposition, for

instance, but were unable to address these further due to limited resources, both in terms of finances and time. This underlines that more focus on relevant questions and dynamics from the outset of the projects and the corresponding treatment of social science perspectives as an integral part of the analysis would be necessary. The SRC should strive for programmes emphasising a good balance between natural and social science/humanities elements and avoid using small fig leaves (in either direction) that characterised earlier foci on interdisciplinarity, not just in Finnish project funding. Here, not the funding amounts are crucial but especially the roles, i.e., the eye-to-eye level of the different project partners needs to be ensured.

Furthermore, the transdisciplinary ambitions and design of programmes also deserve attention. Transdisciplinarity (like interdisciplinarity) should not be an add-on to projects but an integral part of the design of the individual projects and the coordination between them. Given the ecological and societal challenges Finnish and global society face, transdisciplinarity is a condition for success in transformative research. Engagement takes time and requires various sets of skills and appropriate methodological designs. This implies that research proposals seeking to engage with stakeholders need to allocate appropriate resources to these tasks and ensure that relevant skills and capacities are developed during projects. In this context, stakeholder engagement skills are also important elements of training and career development for early career researchers. The SRC should therefore address, provide, and require relevant information and resources at the programme and project level, taking into account that successful transfer also requires a certain amount of flexibility in resource investments.

The evaluation panel acknowledges, however, that real and successful transdisciplinarity also depends on the commitment of stakeholders. Such commitment can be enhanced by certain methods, such as their integration into research from the start of the project preparation to ensure the research's relevance for stakeholders. At the same time, stakeholders, just like researchers, tend to suffer from time scarcity, and in the case of civil society organisations (CSOs), often from limited financial resources. For CSOs/NGOs, the availability of funding within the projects may be very beneficial for project outcomes and the uptake of results among broader audiences and the general public. For business representatives, securing funding from the project is more problematic. Indeed, it should be avoided in cases where research outcomes have direct implications and benefits for business interests, for instance, in the context of product innovation. It may be considered for small and medium-sized enterprises when a project's focus is beyond their immediate business interests.

The commitment of policy makers is probably the most difficult. Indeed, the time and resource scarcity on the regulatory side tend to create a substantial barrier to the uptake of relevant research insights into policy making. Such uptake is further hindered by power relations in the political (and economic) realm, which researchers need to recognise and be able to analyse and navigate, if not transform. For this reason, the integration of political stakeholders and attention by the general public at the programme level is highly recommendable. This can take the form of joint deliberative formats, if not co-creation workshops for transfer strategies, or jointly designed policy briefs and recommendations. Activities and involvement beyond

individual projects are likely to be able to generate more attention and commitment from political (and other) stakeholders. To facilitate programme level coordination and activities, a more narrow substantive clustering of projects than was the case in the PIHI programme would be helpful.

Research funders can play an essential role in strengthening research and stakeholder communities during the programme period and ensuring that the new networks and constellations continue after the projects' finalisation. By facilitating collaborative and participatory research, supporting knowledge sharing and capacity building, providing funding for follow-up activities, encouraging dissemination and outreach, and encouraging sustainability planning, research funders can help to build stronger and more resilient research and stakeholder communities that are better equipped to address social and environmental challenges.

At the most fundamental level, therefore, the review panel recognises the need for the SRC to make certain strategic decisions. For example, the desired balance between scientific excellence, reflected in scientific publications, and communication and engagement activities directed at the general public, relevant stakeholders, and professional communities needs to be pondered. Even within each of these two areas, priorities might need to be set. Is the vast number of scientific publications typically resulting from programs such as PIHI really needed, or could a smaller number of high-quality and open-access publications be preferable? What is a reasonable expectation from an ethical and sustainability point of view, especially considering the problems associated with the overheated publication industry? And how do you set the targets appropriately for different topics and disciplines?

In summary, the PIHI programme had a lot of good characteristics and impressive results. Future funding strategies, however, may want to strive for real inter- and transdisciplinarity. To that end, decisions regarding requirements for programme design, proposals, and resource allocation will have to be taken. These decisions will also have to consider questions of a conducively narrower substantive focus and scientific and societal emphasis setting, as well as the sustainability of science as such. In view of the evaluation panel, setting specific goals for the programmes and projects in these areas will be extremely helpful for Finland in its aim to be a lighthouse for sustainability research.

Appendix 1: Bios of the panel members

Magnus Fröhling holds the Professorship of Circular Economy at the Technical University of Munich (TUM). He works on quantitative approaches for the analysis, assessment and planning of circular economy and bioeconomy systems for a more sustainable resource use. This covers technologies for recycling and biomass conversion as well as biorefineries, local, and regional production and recycling networks and global material cycles. He is chair of the scientific commission Sustainability Management of the German Association of Business Research Professors (VHB), Founding Board Member of the Sustainable Circular Economy Section of the International Society for Industrial Ecology (ISIE) and Co-speaker of the TUM Mission Network Circular Economy (CirculaTUM). He served, e.g., in the German Federal Governmental working group elaborating the German Biorefineries Roadmap, the Stakeholder Platform Resource Efficiency of the Federal State of Baden-Württemberg and several VDI guideline commissions. He studied industrial engineering and management at Karlsruhe University and holds a PhD and a habilitation in Business Research from Karlsruhe Institute of Technology (KIT).

Doris Fuchs is Professor of International Relations and Sustainable Development as well as Speaker of the Center for Interdisciplinary Sustainability Research at the University of Münster. She works on sustainability governance and transformation, with a particular focus on aspects of power and participation, as well as the political economy of consumption. She is a member of the governing board of the Sustainable Consumption Research and Action Initiative Europe (SCORAI EU), the evaluation committee of the German Environmental Foundation (DBU), and the expert group on the world economy and social ethics of the German Conference of Bishops. She has led and participated in numerous international and interdisciplinary research consortia, including EU1.5°Lifestyles and INCITE-DEM. After studies in German and English language and literature, she died her PhD in Politics & Economics at the Claremont Graduate University and completed a habilitation in Political Science at the University of Munich.

Oksana Mont is Professor in Sustainable consumption governance. She conducts trans-disciplinary and international research on sustainable business models, sustainable consumption and lifestyles and sustainable consumption policy. She has over 20 years of project leadership. She is involved in high-level consultancy for international and national public and private organisations. In 2022, she was a member of an expert group in the Swedish Environmental Objectives Committee that discussed the Swedish environmental goals for 2045. She is an editor of the book “Research Agenda for Sustainable consumption governance” (2019, Edward Elgar), and co-editor of the book with Max Koch “Sustainability and the Political Economy of Welfare (2016, Routledge). She is the author of more than 200 academic publications and official reports on various aspects of sustainability. She has a PhD in Technology from Lund university (2004), MSc in Environmental Management and Policy from Lund (1996), and MSc in Biology and Chemistry from Ukraine (1987).

Mari Pantsar is Adjunct Professor in Environmental chemistry at the University of Helsinki and Cleantech Chemistry at the Technical University of Lappeenranta and

Lahti, Finland. She has been working in field of Cleantech business development for over 20 years in both the public and private sectors. After working for forestry giant UPM in environmental affairs, she led, among other things, the Finnish Cleantech Cluster (2007–2011) and the Finnish government's cleantech strategy programme (2012–2013). She worked as a Director of Sustainability solutions at the Finnish Innovation Fund Sitra in 2014–2022. She has served on the boards of several cleantech companies and Finnish Universities. In 2019, she wrote an awarded book "Crossroads – Leadership in the age of climate change" together with Dr. Jouni Keronen. She has a PhD in Analytical Chemistry from the University of Helsinki (1997).

Appendix 2: Evaluation framework

Table 4. Performance of the SRC programme: key criteria

	1. Promoting high-quality, multidisciplinary research on the problems and needs in the programme's domain	2. Creating concrete steps towards tackling those problems and needs in the Finnish society (and even beyond)	3. Strengthening research & stakeholder communities in the programme's domain (even beyond the programme life span)
Input	• multidisciplinary competence of research teams • relevance and synergy of research plans • resources for managing multidisciplinary collaboration	• reach and commitment of societal stakeholders • appropriate plans for societal interaction and outreach • resources for managing societal interaction and for stakeholders to take up and utilize the results	• involvement of a broad variety of actors in programme activities • resources for training and organizational learning
Activities	• appropriate methods and practices for multi- and transdisciplinary research and collaboration, and for researchers' capacity building • national and international networking, keep up with the state of the art • training and supervision	• timely involvement of knowledge users; responsiveness to their needs • active and constructive participation by knowledge users • public engagement	• promotion of responsible research: equality and nondiscrimination, research ethics, open knowledge and innovation • setting up practices and tools for co-production, mutual learning, and capacity building
Output	• productivity • significance, novelty, and innovation of results beyond single disciplines • dissemination, visibility and accessibility of publications and other outputs	• useful results and outputs • effective, timely, and easy-to-understand communication of results to stakeholders and relevant publics	• useful results and outputs made and kept available for use by multiple beneficiaries • clear ownership and licensing of intellectual property • scalability and applicability of solutions
Outcomes	• enhanced knowledge of the state of the art and best practices • integration or transformation of existing disciplinary knowledge, methods, and practices • advancement of multidisciplinary research careers	• new knowledge used in concrete solutions, such as models, practices, guidelines, technologies, etc. • changes in practices, policies, behaviours, attitudes, etc., influenced by the research • specific expectations of the programme	• enhanced capacity of stakeholders to absorb and utilize research-based knowledge • acquiring new resources for continuing the work • promotion of new and versatile career paths, including mobility across organisations and sectors

Appendix 3: List of evaluation materials

Background information of the SRC funding scheme and the specific programme

- Strategic research brochure (updated in 2023)
- 2015 calls by the SRC (original calls for funding for this programme)
- 2017 call for a second funding period
- SRC funding principles 2022
- Kivistö et al. 2022: Evaluation of SRC funding instrument (machine translation) + original evaluation report in Finnish

Information from the projects' funding applications etc.

- Original funding applications of the five projects (2015)
- Publicly available "situational picture reports" written by the projects at the start of the programme in 2015 (machine translation) + original situational picture reports in Finnish
- Composition of the programme: involved organizations, involved key research fields, amounts of funding awarded
- List of the projects' collaborators

Information from the projects' research reports

- Research implementation and results (text, ~30 pages altogether)
- Important new research funding (list)
- Research visits from Finland to abroad and vice versa (list)
- Degrees completed within the projects (list)
- Produced data sets (list)
- Immaterial rights (list)
- Personnel key figures (number of staff, career stages, gender)

Publications

- 10 most important publications of each project (as a list and full text pdf-documents)
- List of all publications produced under the programme
- Publication analyses (overall statistics of all publications produced under the programme, and more detailed statistics of verified peer-reviewed scientific publications)

Survey results

- Results of a self-evaluation questionnaire for consortium members (12 respondents from the PIHI programme, 75 respondents in total)
- Results of a survey for stakeholders of SRC programmes (6 respondents from the PIHI programme, 33 respondents in total)

Impact stories etc.

- All impact stories by the projects (altogether 16 stories) at the end of the programme (machine translation) + original impact stories in Finnish
- Summaries of the impact stories, written by Academy staff
- Impact story by the programme director at the end of the programme (machine translation) + original impact story in Finnish
- Annual reports from the programme director: 2019, 2020, 2021 (machine translation)
- Programme directors' view of the developments in the programme's domain, early 2022 (machine translation) + original narrative in Finnish
- One-page syntheses of the impacts of each project, written by the programme director together with the projects in early 2023

Interview material

- Video recording of the interviews on 1 March
- Notes / transcription of the interviews on 1 March
- Powerpoint (+ video) presentations of the interviewees
- List of 10 key stakeholders of each project and the programme director, and emailed responses from selected stakeholders to the panel's questions

Appendix 4: List of interviewees

Consortium leaders

- Pami Aalto, EL-TRAN
- Jari Haapala, SmartSea
- Maarit Karppinen, CloseLoop
- Heli Peltola, FORBIO
- Anne Pihlanto, ScenoProt

Programme director

- Mikael Hildén

Stakeholder representatives who responded via email

- Mikko Peltonen, Ministry of Agriculture and Forestry (MMM)
- Sixten Sunabacka, Tornator Oyj
- Heikki Pajuoja, Metsäteho
- Tuomas van der Meer, Outotec Oyj
- Esa Lindell, Nornickel

Appendix 5: Personnel key figures

The figures below show simple statistics of the academic and other staff who worked in the projects under the PIHI programme during the years 2015–2021. The figures are based on salary payment data and refer to the number of persons (headcount) instead of full-time equivalent person years. The total number of staff in Figure 1 is different from the total number in Figures 2–3, because several persons among the academic staff had worked at different career stages during the funding period.

Figure 1. Number of staff by career stage and gender in PIHI programme.

The academic staff have been divided into four categories according to a model of four-stage research career path which is used at Finnish universities. The stages of the research career path are as follows:

Stage I: Doctoral student, early-career researcher, etc.
Stage II: Postdoctoral researcher, etc.
Stage III: University lecturer, Academy Research Fellow etc.
Stage IV: Professor, Academy Professor, research professor, research director, etc.
Other: Support and management staff, who did not act as researchers in a project; for example, research assistants, interaction coordinators, "technical" PIs

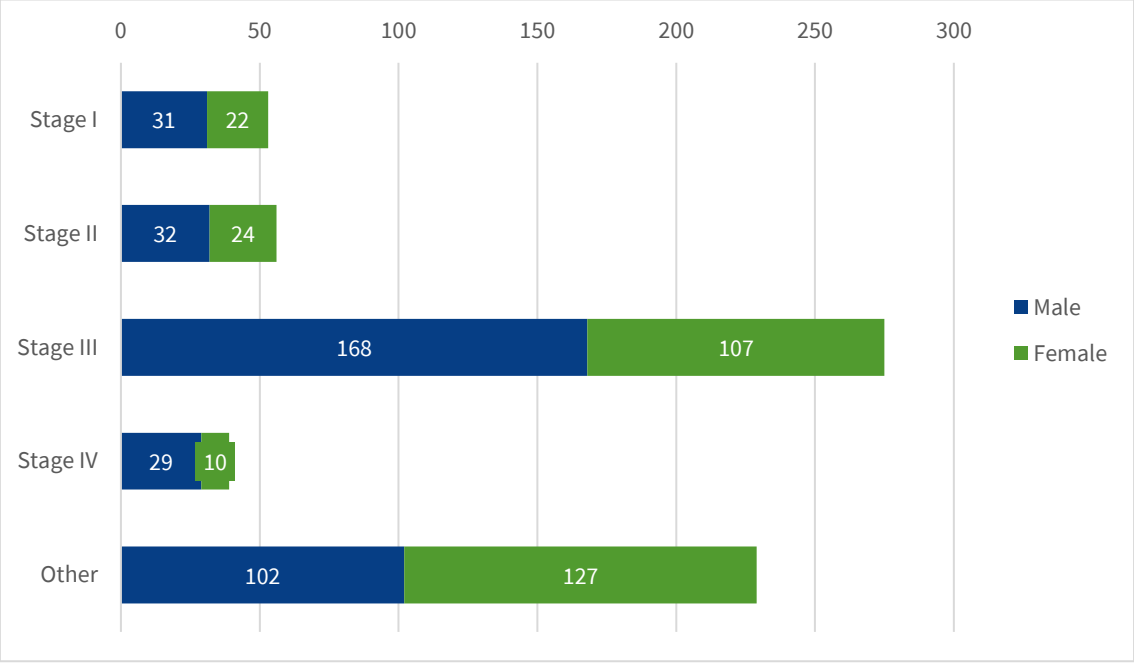


Figure 2. Number of staff by nationality in PIHI programme.

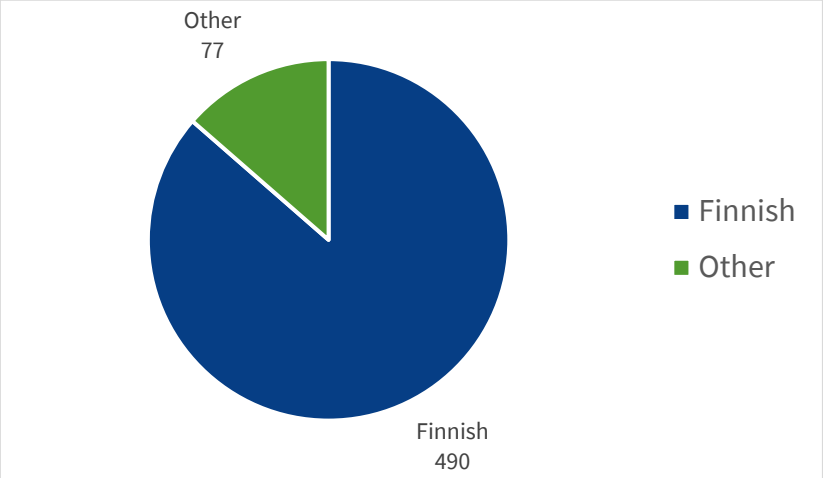
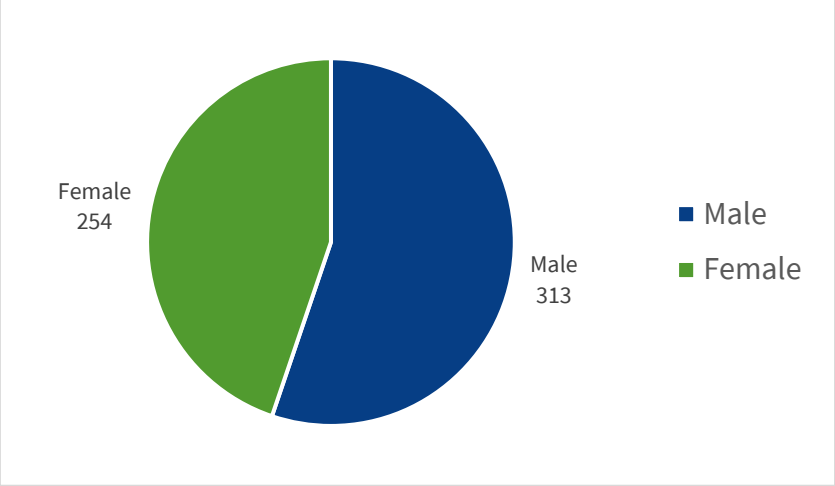


Figure 3. Number of staff by gender in PIHI programme.



Appendix 6: List of projects' collaborators

List of projects' collaborators (organisations) mentioned in the funding applications.

In Finland

- Caruna Ltd
- CLEEN Oy (Cluster for Energy and Environment)
- CLIC Innovation Ltd
- Climate Leadership Council
- Electrical Contractors' Association of Finland (STUL)
- Elenia Oyj
- Empower Oyj
- European Forest Institute
- Fingrid Oyj
- Finnish Energy Industries (ET)
- Finnish Forest Association
- Finnish Forest Centre (Metsäkeskus)
- Fortum Oyj
- Fortum Power and Heat Oy
- Helen Ltd
- Huoltovarmuuskeskus
- Metsä Group
- Metsähallitus
- Ministry for Foreign Affairs (UM)
- Ministry of Agriculture and Forestry (MMM)
- Ministry of Agriculture and Forestry (MMM)
- Ministry of Economic Affairs and Employment (TEM)
- Ministry of Economic Affairs and Employment (TEM)
- Ministry of Environment (YM)
- Ministry of Social Affairs and Health (STM)
- Ministy of Environment (YM)
- Motiva Oyj

- National Emergency Supply Agency (Huoltovarmuuskeskus)
- Omakotiliitto ry.
- Stora Enso Wood Supply Finland
- Tampereen sähkölaitos
- The Central Union of Agricultural Producers and Forest Owners (MTK)
- The Consumers' Union of Finland
- The Energy Authority
- Tornator Oyj
- University of Helsinki
- UPM-Kymmene Ltd
- Valmet Oyj

Beyond Finland

- BOKU (University of Natural Resources and Life Sciences), Austria
- Joint Research Center, European Commission, Forest Resources and Climate Unit
- INRA Centre de Bordeaux Aquitaine, France
- National Research Institute of Science and Technology for Environment and Agriculture (IRSTEA), France
- LCA and Ecodesign Laboratory, Italy
- Wageningen University, the Netherlands
- Norwegian University of Life Sciences, Norway
- Linnaeus University, Sweden
- Skogforsk, Sweden
- Swedish University of Agricultural Sciences (SLU), Sweden
- ABB Oy
- University of Sussex, Science Policy Research Unit & Sussex Energy Group, United Kingdom
- Florida State University, United States

Appendix 7: Top10 outputs from each project

Table 5. CloseLoop

Year	Authors	Title	Journal or Publisher
2017	Tavakkoli, M., Nosek, M., Sainio, J., Davodi, F., Kallio, T., Joensuu, P.M., Laasonen, K.	Functionalized Carbon Nanotubes with Ni(II) Bipyridine Complexes as Efficient Catalysts for the Alkaline Oxygen Evolution Reaction	ACS Catalysis
2017	Karppinen, M., Karttunen, A. J.	Atomic Layer Deposition of Thermoelectric Materials	Chapter 9 in J. Bachmann: Atomic layer deposition in energy conversion applications; Wiley
2018	Pajarre, R., Koukkari, P.	CALPHAD aqueous solution model based on the BET approach: General theory	Calphad
2018	Nisula, M., Karppinen, M.	In-situ lithiated quinone cathode for ALD/MLD-fabricated high-power thin-film battery	Journal of Materials Chemistry A
2018	Linnera, J., Karttunen, A.J.	Ab initio study on lattice thermal conductivity of Cu2O using the generalized gradient approximation and hybrid density functional methods	Physical Review B
2018	Antikainen, M., Uusitalo, T., Kivikytö-Reponen, P.	Digitalisation as an Enabler of Circular Economy	Procedia CIRP
2018	Repo, P., Anttonen, M., Mykkänen, J., Lammi, M.	Lack of congruence between European citizen perspectives and policies on circular economy	European Journal of Sustainable Development
2019	Porvali, A., Aaltonen, M., Ojanen, S., Velazquez-Martinez, O., Eronen, E., Liu, F., Wilson, B.P., Serna-Guerrero, R., Lundström, M.	Mechanical and hydrometallurgical processes in HCl media for the recycling of valuable metals from Li-ion battery waste	Resources, Conservation & Recycling
2019	Velázquez Martínez, P., Van Den Boogaart, K.G., Lundström, M., Santasalo-Aarnio, A., Reuter, M., Serna-Guerrero, R.	Statistical Entropy Analysis as Tool for Circular Economy: Proof of Concept by Optimizing a Lithium-Ion Battery Waste Sieving System	Journal of Cleaner Production
2019	Karhu, M., Lagerbom, J., Solismaa, S., Honkanen, M., Ismailov, A., Räisänen, M-L., Huttunen-Saarivirta, E., Levänen, E., Kivikytö-Reponen, P.	Mining tailings as raw materials for reaction-sintered aluminosilicate ceramics: Effect of mineralogical composition on microstructure and properties	Ceramics International

Table 6. EL-TRAN

Year	Authors	Title	Journal or Publisher
2017	Ruostetsaari, I.	Stealth democracy, elitism, and citizenship in Finnish energy policy	Energy Research & Social Science
2017	Rönkkö, T. et al.	Traffic is a major source of atmospheric nanocluster aerosol	Proceedings of the National Academy of Sciences
2018	Panula-Ontto, J., J. Luukkanen, J. Kaivo-oja, T. O'Mahony, J. Vehmas, S. Valkealahti, T. Björkqvist, T. Korpela, P. Järventausta, Y. Majanne, M. Kojo, P. Aalto, P. Harsia, K. Kallioharju, H. Holttinen, S. Repo	Cross-impact analysis of Finnish electricity system with increased renewables: Long-run energy policy challenges in balancing supply and consumption	Energy Policy
2018	Rinne, E., Holttinen, H., Kiviluoma, J., Rissanen, S.	Effects of Turbine Technology and Land Use on Wind Power Resource Potential	Nature Energy
2019	Kotilainen, K., Aalto, P., Valta, J., Rautiainen, A., Kojo, M., Sovacool, B.K.	From path dependence to policy mixes for Nordic electric mobility: Lessons for accelerating future transport transitions	Policy Sciences
2019	Pääkkönen, A., Aro, K., Aalto, P., Konttinen, J., Kojo, M.	The potential of biomethane in replacing fossil fuels in heavy transport – A case study on Finland	Sustainability
2019	Kilpeläinen, S., Aalto, P., Toivanen, P., Lehtonen, P., Holttinen, H.	How to Achieve a More Resource-Efficient and Climate-Neutral Energy System by 2030? Views of Nordic Stakeholders	Review of Policy Research
2019	Penttinen, S-L., Reins, L.	System boundaries of nearly zero-energy buildings in the European Union: rethinking the legal framework for active consumer participation	Journal of Energy & Natural Resources Law
2020	Järventausta, P., Peltonen, L., Uski, S., Valta, J., Aalto, P.	Microgrids: Impact on Development of Sustainable Electric Energy Systems	in W. Leal Filho, A. Azul, L. Brandli, P. Özuyar, T. Wall (eds): Affordable and Clean Energy. Encyclopedia of the UN Sustainable Development Goals; Springer, Cham
2021	Aalto, P. (ed.)	Electrification: Accelerating the energy transition	Elsevier/Academic Press

Table 7. FORBIO

Year	Authors	Title	Journal or Publisher
2017	Heinonen, T., Pukkala, T., Mehtätalo, L., Asikainen, A., Kangas J., Peltola, H.	Scenario analyses for the effects of harvesting intensity on development of forest resources, timber supply, carbon balance and biodiversity of Finnish forestry	Forest Policy and Economics
2017	Karvonen, J., Halder, P., Kangas, J., Leskinen, P.	Indicators and tools for assessing sustainability impacts of the forest bioeconomy	Forest Ecosystems
2017	Nabuurs, G.-J., Delacote, P., Ellison, D., Hanewinkel, M., Hetemäki, L., Lindner, M.	By 2050 the Mitigation Effects of EU Forests Could Nearly Double through Climate Smart Forestry	Forests
2018	Anttila, P., Nivala, V., Salminen, O., Hurskainen, M., Kärki, J., Lindroos, T.J., Asikainen, A.	Regional balance of forest chip supply and demand in Finland in 2030	Silva Fennica
2018	Hurmekoski, E., Jonsson, R., Korhonen, J., Jänis, J., Mäkinen, M., Leskinen, P., Hetemäki, L.	Diversification of the forest industries: Role of new wood-based products	Canadian Journal of Forest Research
2019	Hassan, M.K., Villa, A., Kuittinen, S. Jänis, J., Pappinen, A.	An assessment of side-stream generation from Finnish forest industry	Journal of Material Cycles and Waste Management
2019	Seppälä, J., Heinonen, T., Pukkala, T., Kilpeläinen, A., Mattila, T., Myllyviita, T., Asikainen, A., Peltola, H.	Effect of increased wood harvesting and utilization on required greenhouse gas displacement factors of wood-based products and fuels	Journal of Environmental Management
2020	Hurmekoski, E., Myllyviita, T., Seppälä, J., Heinonen, T., Kilpeläinen, A., Pukkala, T., Mattila, T., Hetemäki, L., Asikainen, A., Peltola, H.	Impact of structural changes in wood-using industries on net carbon emissions in Finland	Journal of Industrial Ecology
2020	Venäläinen, A., Lehtonen, I., Laapas, M., Ruosteenoja, K., Tikkanen, O-P.,Viiri, H., Ikonen, V-P., Peltola, H.	Climate change induces multiple risks to boreal forests and forestry in Finland: A literature review	Global Change Biology
2022	Hetemäki, L., Kangas, J., Peltola, H. (Eds.)	Forest Bioeconomy and Climate Change	Managing Forest Ecosystems – book series. Open access Springer book.

Table 8. ScenoProt

Year	Authors	Title	Journal or Publisher
2017	Pihlanto, A., Mattila P., Mäkinen S., Pajari A-M.	Bioactivities in alternative protein sources and their potential health benefits	Food & Function
2017	Kuhmonen, et al.	Suomen proteiinijärjestelmän vaihtoehtoiset tulevaisuudet	Tutu-julkaisuja (University of Turku)
2021	Pellinen, T., Päivärinta, E., Isotalo, J., Lehtovirta, M., Itkonen, S.T., Korkalo, L., Erkkola, M., Pajari, A.M.	Replacing dietary animal-source proteins with plant-source proteins changes dietary intake and status of vitamins and minerals in healthy adults: a 12-week randomised controlled trial	European Journal of Nutrition
2018	Pihlanto, Kurppa, Keskitalo, Rokka, Tapiola	Policy brief: Monipuolisuus lautasella on monipuolisuutta pellolla	(Natural Resources Institute Finland)
2019	Sorjonen JM, Valtonen A, Hirvisalo E, Karhapää M, Lehtovaara VJ, Lindgren J, Marnila P, Mooney P, Mäki M, Siljander-Rasi H, Tapio M, Tuiskula-Haavisto M, Roininen H.	The plant-based by-product diets for the mass-rearing of Acheta domesticus and Gryllus bimaculatus	PLoS One
2020	Rinne, M., Leppä, M.M., Kuoppala, K., Koivunen, E., Kahala, M., Jalava, T., Salminen, J.-P., Manni, K.	Fermentation quality of ensiled crimped faba beans using different additives with special attention to changes in bioactive compounds	Animal Feed Science and Technology
2020	Päivärinta et al.	Replacing Animal-Based Proteins with Plant-Based Proteins Changes the Composition of a Whole Nordic Diet—A Randomised Clinical Trial in Healthy Finnish Adults	Nutrients
2021	Paloviita A.	Developing a matrix framework for protein transition towards more sustainable diets	British Food Journal
2020	Pap, N., Hamberg, L., Pihlava, J. M., Hellström, J., Mattila, P., Eurola, M., & Pihlanto, A.	Impact of enzymatic hydrolysis on the nutrients, phytochemicals and sensory properties of oil hemp seed cake (Cannabis sativa L. FINOLA variety)	Food chemistry
2021	Koskela, J., Leskinen, H., Mattila, P., Airaksinen, S., Rinne, M., Pihlava, J-M., Pihlanto, A.	The effect of gradual addition of camelina seeds in the diet of rainbow trout (Oncorhynchus mykiss) on growth, feed efficiency and meat quality	Aquaculture Research

Table 9. SmartSea

Year	Authors	Title	Journal or Publisher
2018	Virtanen, E.A., Viitasalo, M., Lappalainen, J., Moilanen, A.	Evaluation, gap analysis, and potential expansion of the Finnish Marine Protected Area network	Frontiers in Marine Science
2022	Virtanen, E., Lappalainen, J., Nurmi, M., Viitasalo, M., Tikanmäki, M., Heinonen, J., Atlaskin, E., Kallasvuo, M., Tikkanen, H., Moilanen, A.	Balancing profitability of energy production, societal impacts and biodiversity in offshore wind farm design	Renewable and Sustainable Energy Reviews
2019	Hordoir, R., Axell, L., Höglund, A., Dieterich, C., Fransner, F., Gröger, M., Liu, Y., Pemberton, P., Schimanke, S., Andersson, H., Ljungemyr, P., Nygren, P., Falahat, S., Nord, A., Jönsson, A., Lake, I., Döös, K., Hieronymus, M., Dietze, H., Löptien, U., Kuznetsov, I., Westerlund, A., Tuomi, L., Haapala, J.	Nemo-Nordic 1.0: a NEMO-based ocean model for the Baltic and North seas – research and operational applications	Geoscientific Model Development
2019	Kaikkonen, L., Virtanen, E. A., Kostamo, K., Lappalainen, J., & Kotilainen, A. T.	Extensive coverage of marine mineral concretions revealed in shallow shelf sea areas	Frontiers in Marine Science
2020	Kaikkonen, L., Parviainen, T., Rahikainen, M., Uusitalo, L., & Lehikoinen, A.	Bayesian Networks in Environmental Risk Assessment: A review	Integrated Environmental Assessment and Management
2020	Kallio-Nyberg, I., Saloniemi, I., Koljonen, M.-L.	Increasing temperature associated with increasing grilse proportion and smaller grilse size of Atlantic salmon	Journal of Applied Ichthyology
2020	Virtasalo, J.J., Österholm, P., Kotilainen, A.T., Åström, M.E.	Enrichment of trace metals from acid sulphate soils in sediments of the Kvarken Archipelago, eastern Gulf of Bothnia, Baltic Sea	Biogeosciences
2021	Tikanmäki, M., Jaakko Heinonen, J.	Estimating extreme level ice and ridge thickness for offshore wind turbine design: Case study Kriegers Flak	Wind Energy
		Climate model results on the changing state of the Gulf of Bothnia (Data available from the Finnish Meteorological Institute on request)	(Finnish Meteorological Institute)
		SmartSea information boxes	https://smartsea.fmi.fi/tulevaisuuden-pohjanlahti/

Appendix 8: Publication profile

All publications

The projects under the PIHI programme reported several types of publications in their final reports according to the national publication type classification[5]

A. Peer-reviewed scientific articles

B. Non-refereed scientific articles

C. Scientific books (monographs)

D. Publications intended for professional communities

E. Publications intended for the general public

F. Public artistic and design activities

G. Theses

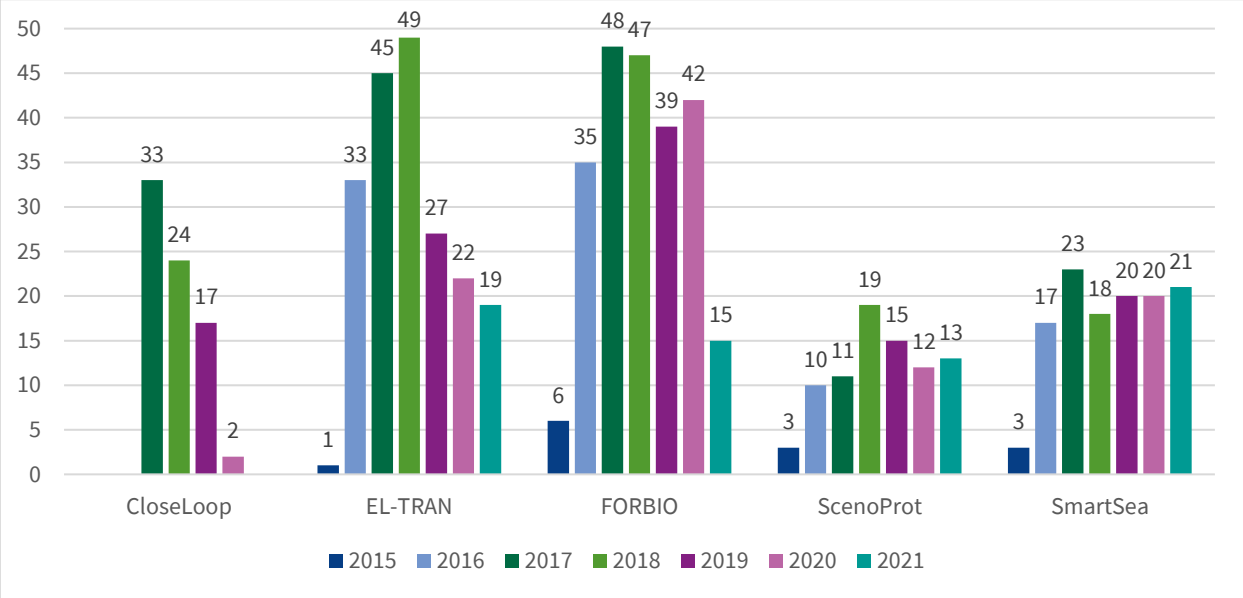
H. Audiovisual publications and ICT applications

Table 10. Number of publications reported by the PIHI projects and the programme as a whole in 2015–2021.

Project	All publications	Scientific publications (A, B, C)
CloseLoop	76	76
EL-TRAN	196	158
FORBIO	232	134
ScenoProt	83	32
SmartSea	122	78
PIHI programme	**709**	**478**

[5] More information about the publication type classification: https://wiki.eduuni.fi/display/cscsuorat/Julkaisutiedon-keruun+tutkijaohjeistukset?preview=/39984924/256871940/2021_Publication%20data%20collection%20instructions%20for%20researchers.pdf, pages 7–11. [referred to 12 May 2023]

Figure 4. Number of publications by year reported by the PIHI projects and the programme as a whole.



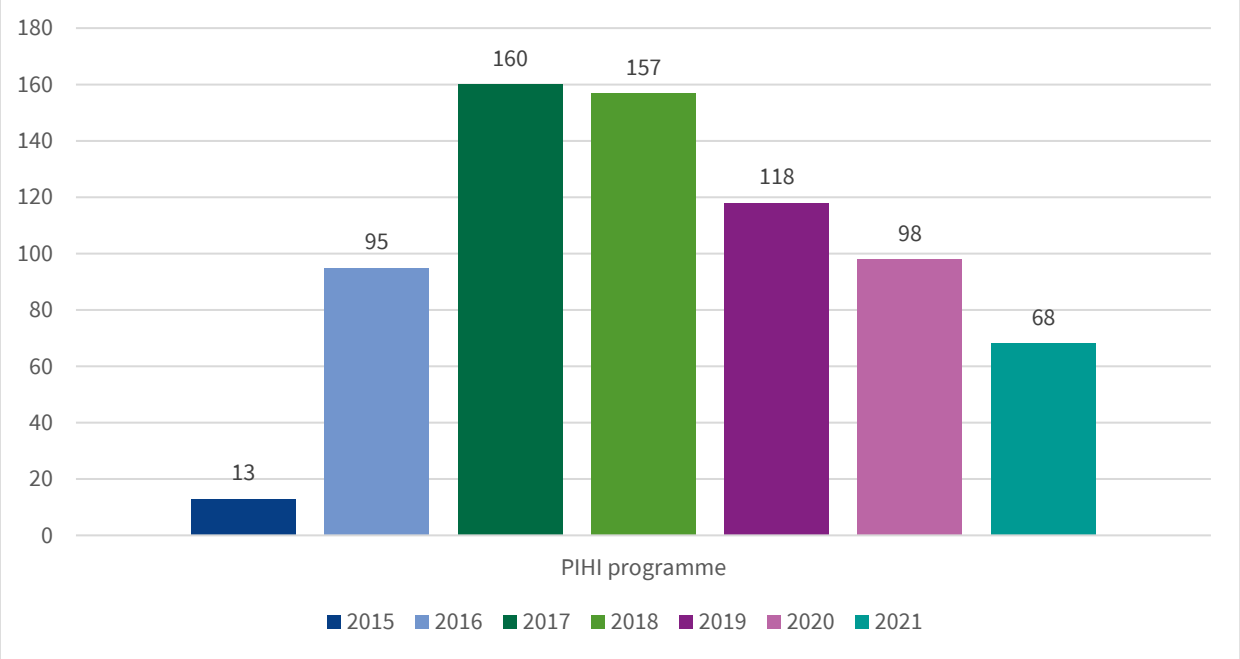
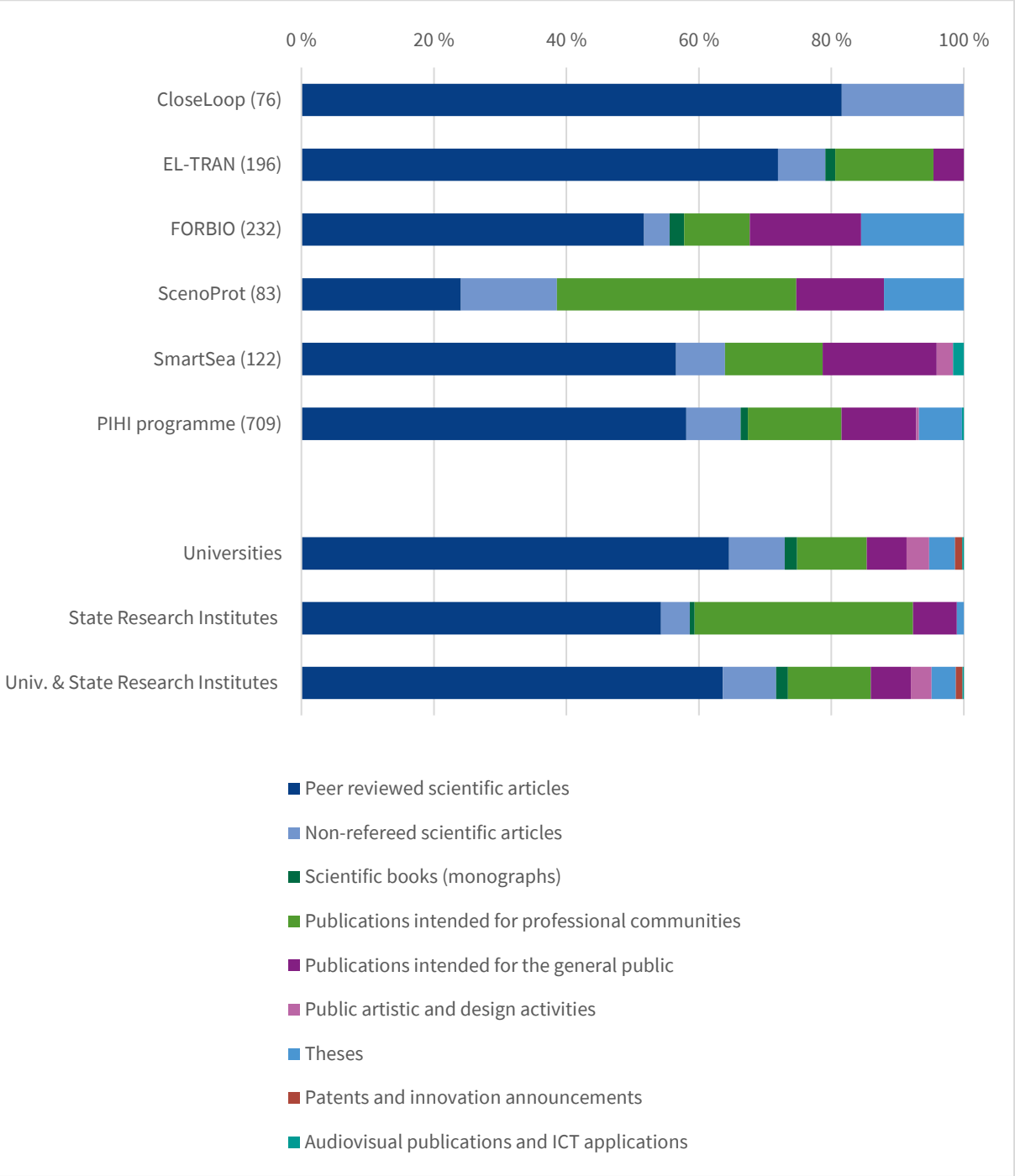


Figure 5. Share (%) of different publication types reported by the PIHI projects and the programme as a whole, as well as in Finnish universities and state research institutes (as separate categories and together).



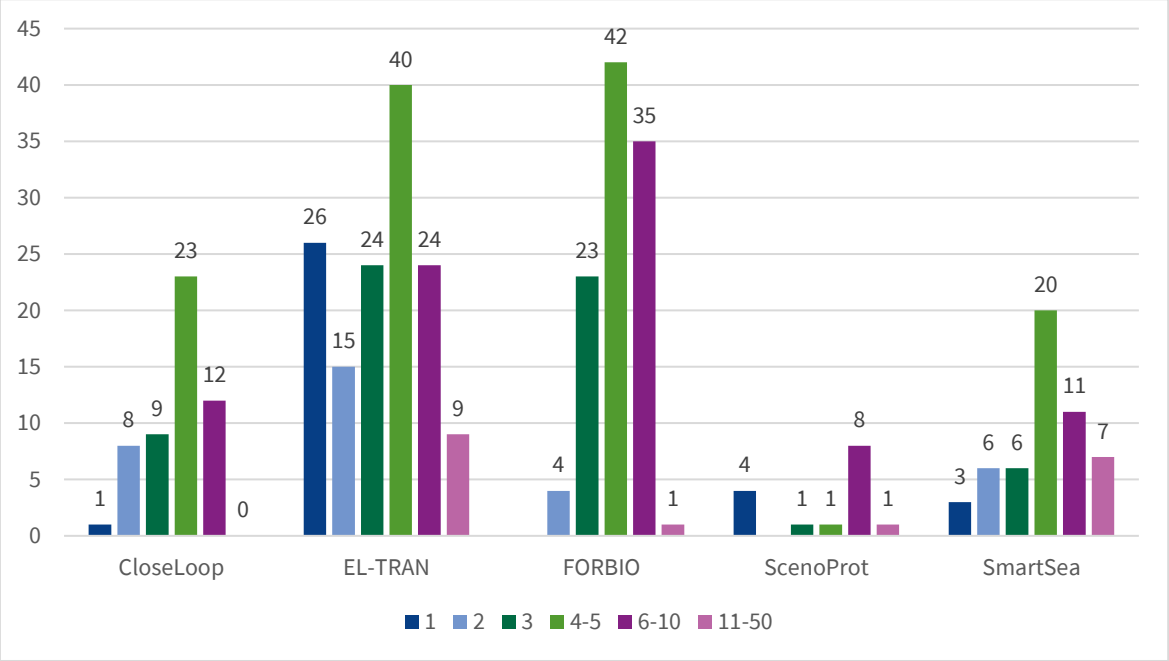
Appendix 9: Analysis of peer-reviewed publications

For a more detailed analysis of peer-reviewed scientific publications of the PIHI programme, publication data reported by the projects was supplemented with metadata from the national publication data collection VIRTA. VIRTA covers most publications from Finnish universities, universities of applied sciences, university hospitals and most state research institutes. The coverage of VIRTA data in terms of the publications reported by the PIHI projects is presented in Table 11. The analyses presented in this appendix include only those PIHI programme publications that were found in VIRTA.

Table 11. Number of peer-reviewed PIHI publications in VIRTA data and their share of the peer-reviewed publications reported by the projects in 2015–2021.

Project	Number of peer-reviewed publications in VIRTA	Share in reported publications
CloseLoop	53	85 %
EL-TRAN	138	96 %
FORBIO	105	84 %
ScenoProt	15	75 %
SmartSea	53	77 %
PIHI programme	**364**	**87 %**

Figure 6. Number of authors per publication in the PIHI projects and the programme as a whole.



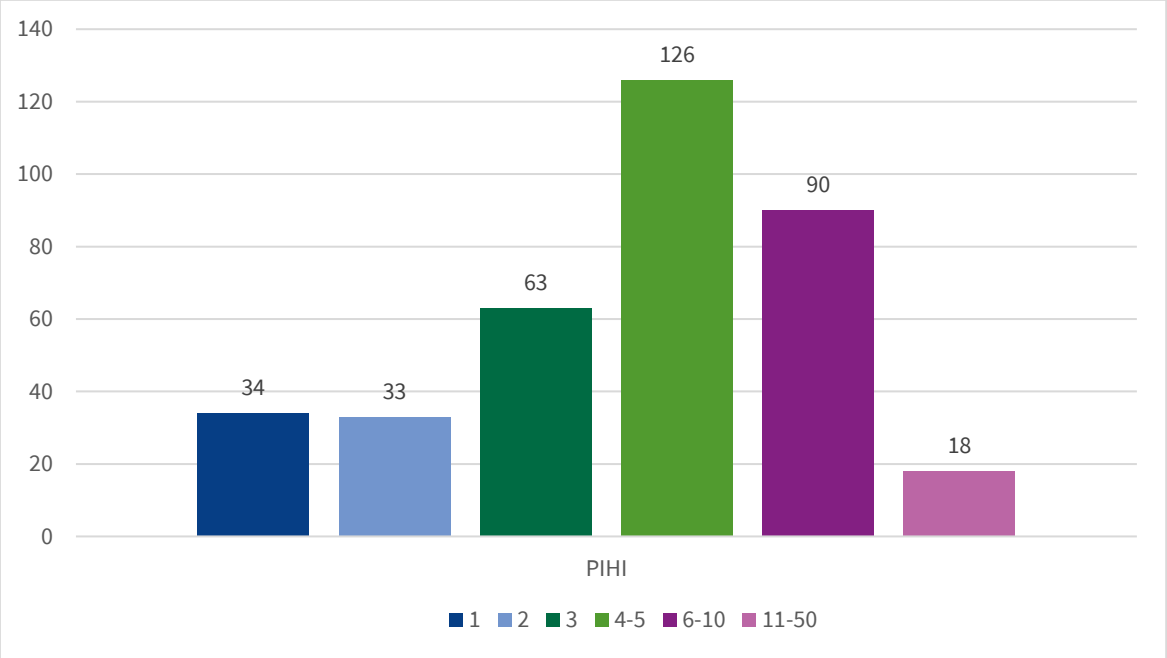


Figure 7. Language of publications in the PIHI projects and the programme as a whole.

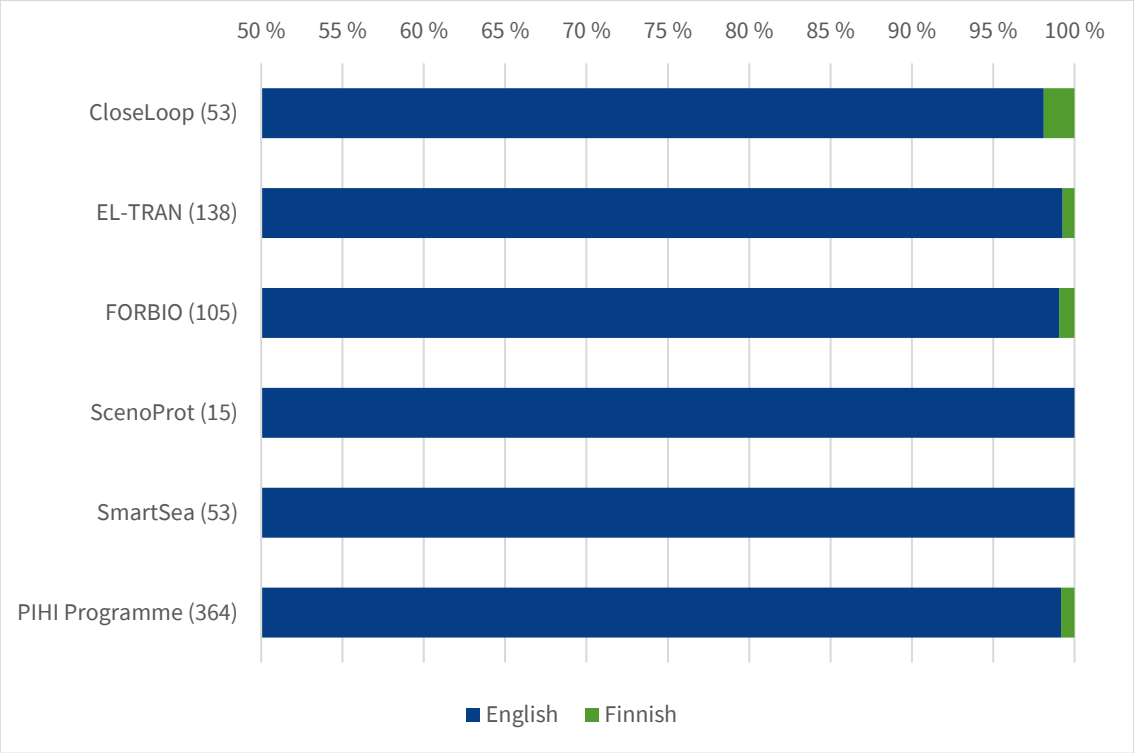


Figure 8. Share of national and international publications (%) in the PIHI projects and the programme as a whole, as well as in Finnish universities and state research institutes (as separate categories and together)

A national publication means a publication that is published by a Finnish publisher or is primarily published in Finland. An international publication means a publication that is not published by a Finnish publisher or is primarily published elsewhere than in Finland. For conference publications, publisher means the publisher of the conference publication.

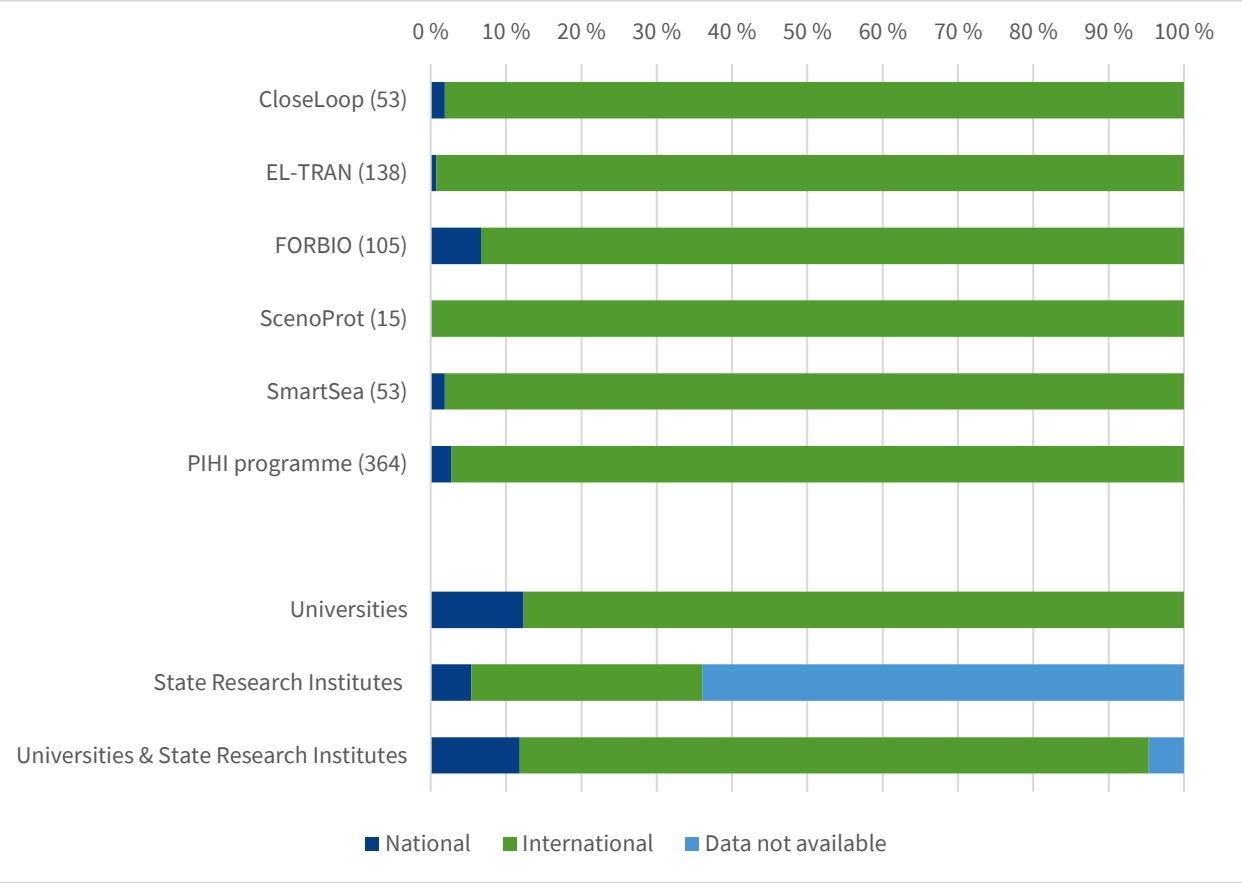


Figure 9. Share of international co-authoring (%) in the PIHI projects and the programme as a whole, as well as in Finnish universities and state research institutes (as separate categories and together)

At least one author of an internationally co-authored publication is affiliated to a non-Finnish organisation (the author may also be affiliated to both a Finnish and a foreign organisation). The foreign editor of the publication channel does not yet meet the criteria for international co-publication.

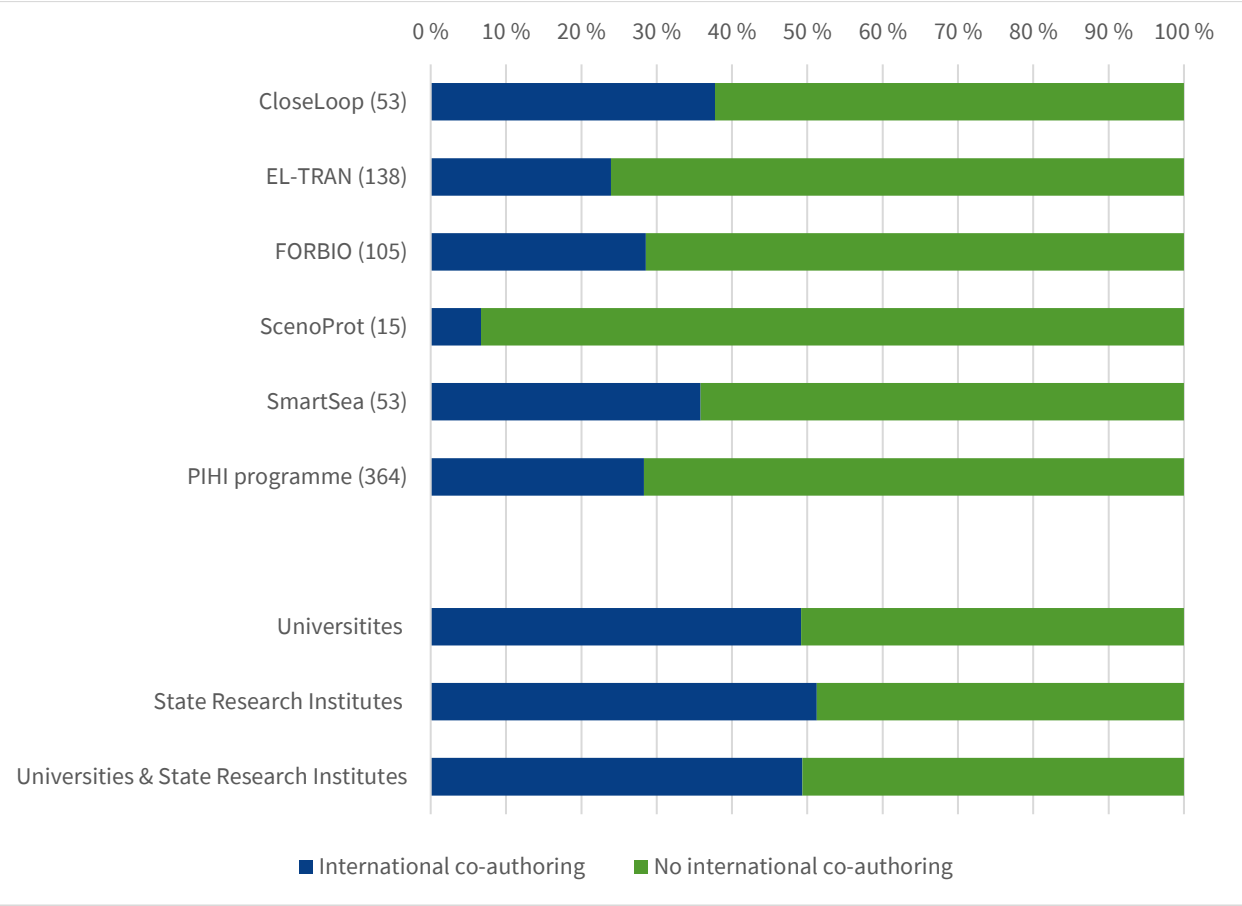
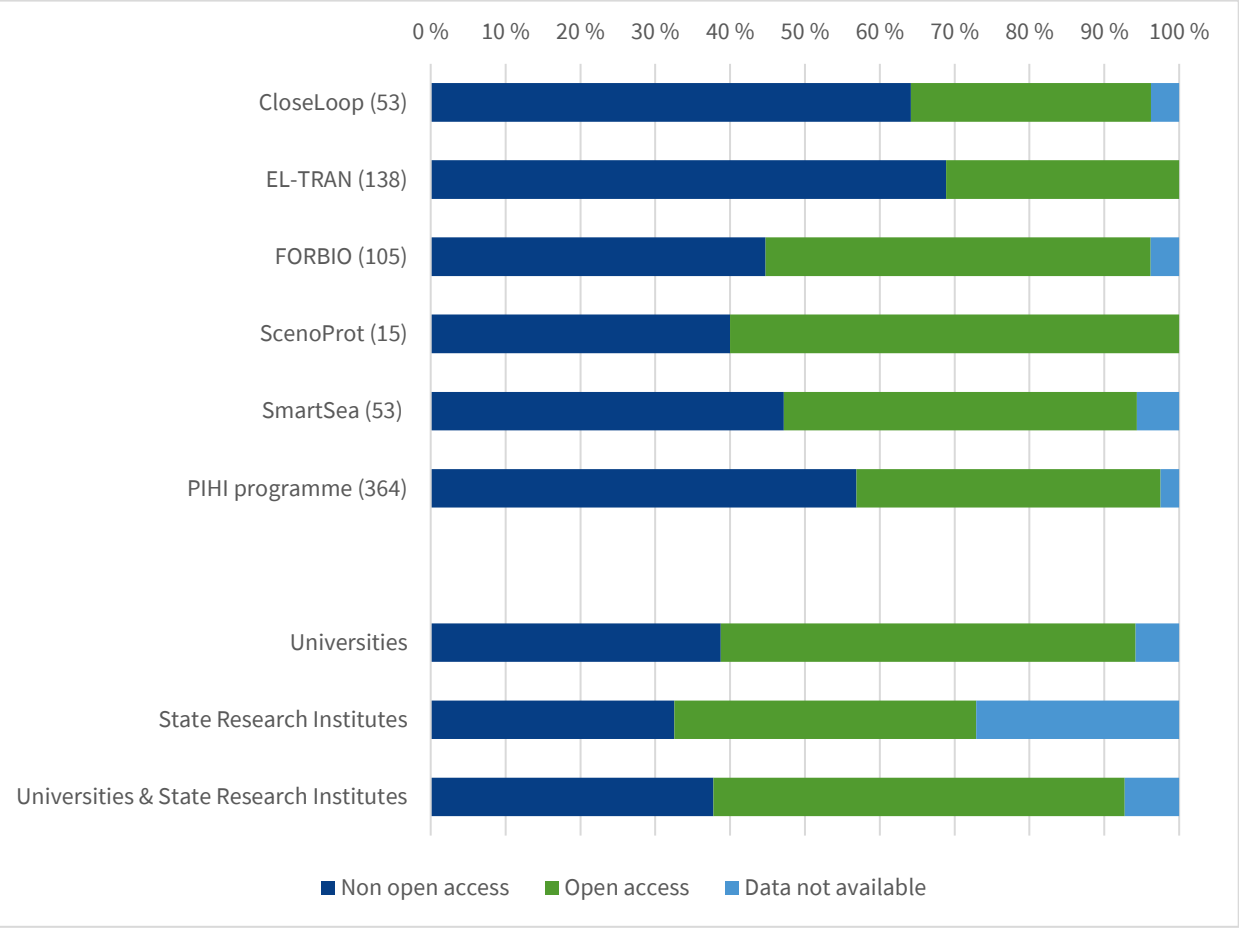


Figure 10. Share of open access publications (%) in the PIHI projects and the programme as a whole, as well as in Finnish universities and state research institutes (as separate categories and together).

Open access refers here to all modes of open access publishing defined in the national publication data collection. [6]

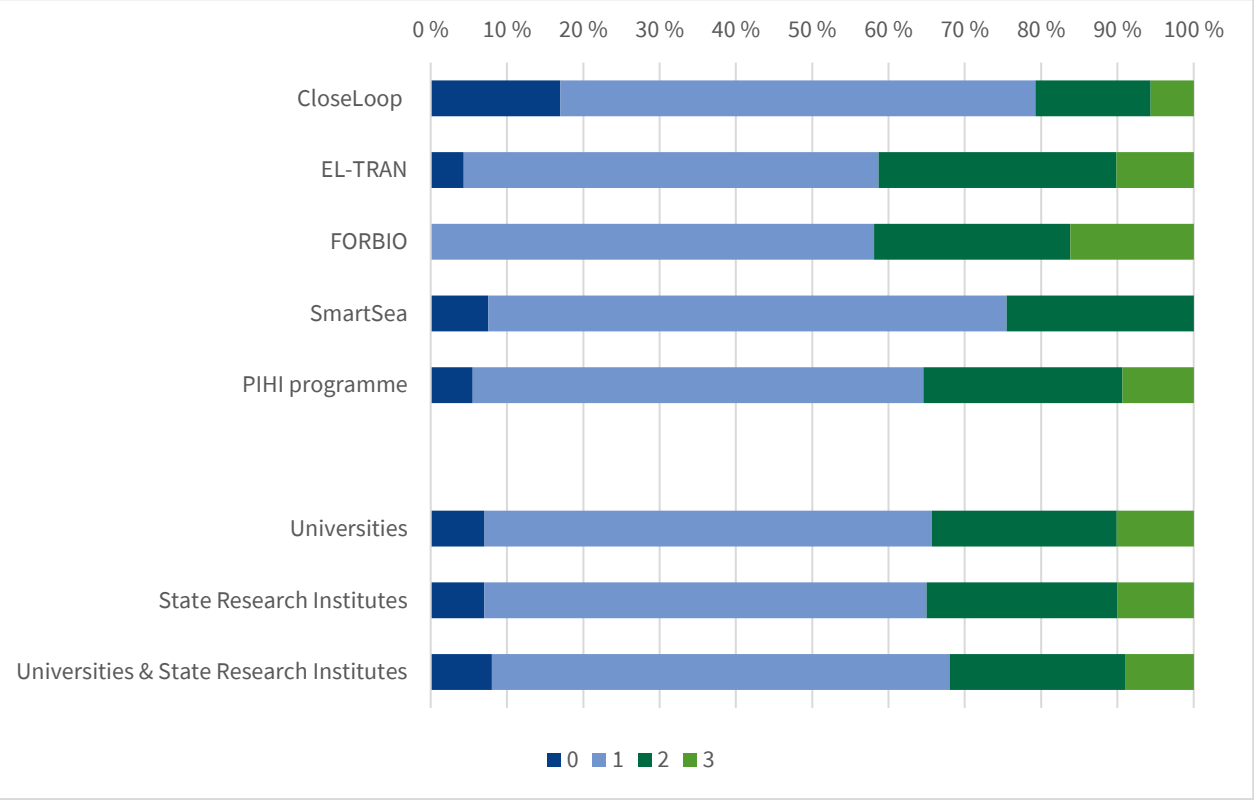


[6] More information about open access publishing: https://wiki.eduuni.fi/display/cscsuorat/Julkaisutiedon-keruun+tutkijaohjeistukset?preview=/39984924/256871940/2021_Publication%20data%20collection%20instructions%20for%20researchers.pdf, pages 12–13. [referred to 12 May 2023]

Figure 11. Share of publications at different Publication Forum (JUFO) levels (%) in the PIHI projects and the programme as a whole, as well as in Finnish universities and state research institutes (as separate categories and together).

Information on ScenoProt publications is excluded because the number of publications is less than 50).

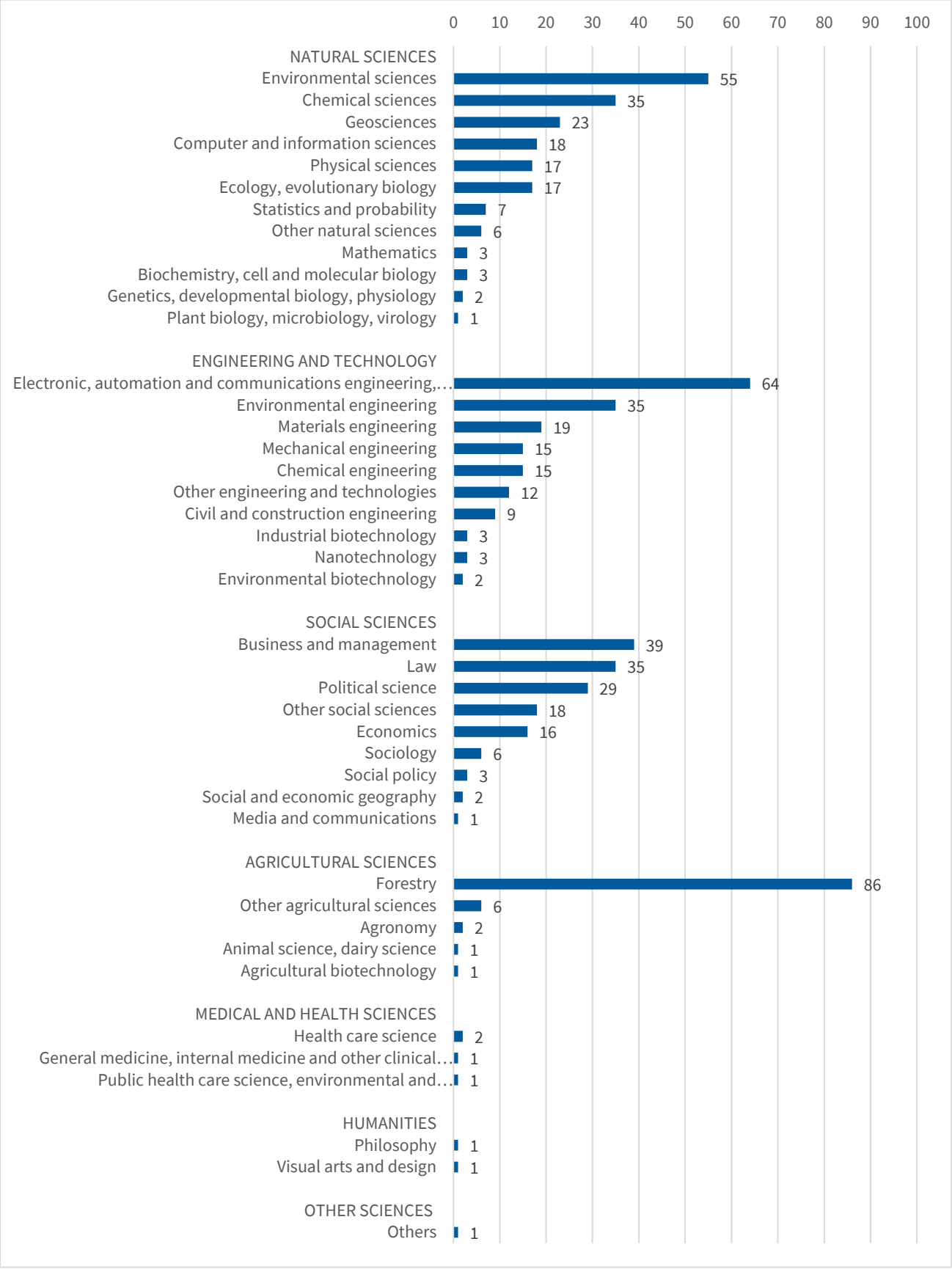
JUFO is a rating and classification system to support the quality assessment of research output. The four-level classification rates the major foreign and domestic publication channels of all disciplines as follows: 1 = basic level; 2 = leading level; 3 = highest level; 0 = publication channels that don't (yet) meet the criteria for level 1. To account for the different publication cultures characteristic of various disciplines, the classification includes academic journals, book series, conferences as well as book publishers.[7]



[7] Publication Forum 2022: https://julkaisufoorumi.fi/en/publication-forum [referred to 12 May 2023]

Figure 12. Fields of science assigned to publications in the PIHI programme.

In the national VIRTA publication data collection, one or more fields of science[8] is assigned to a publication. The number of publications is 364, and the number of field assignments is 616.



[8] Fields of science are derived from Statistics Finland field of science classification: https://www.stat.fi/en/luokitukset/tieteenala/. [referred to 12 May 2023]

Appendix 10: Other research output

Table 12. Research data reported by the PIHI projects.

The SRC requires that the projects take charge of the responsible management and opening of research data. The degrees of data openness may justifiably vary, ranging from fully open to strictly confidential. If the research data cannot be made openly available, the metadata must be stored in a Finnish or international data finder.

Project	Research data	Openness	Location
CloseLoop	Consumer survey on the circular economy	Ongoing	
CloseLoop	Lithium Aryloxide Thin Films with Guest-Induced Structural Transformation by ALD/MLD	Yes	https://doi.org/10.17172/NOMAD/2018.10.12-2
CloseLoop	Calculations of lattice thermal conductivity of Cu2O using the generalized gradient approximation and hybrid density functional methods	Yes	https://doi.org/10.17172/NOMAD/2018.10.12-1
EL-TRAN	Citizens' survey data 2016	Ongoing	
EL-TRAN	Q-methodological interview data 2016 Bioenergy interviews 2016–17	No	
EL-TRAN	Bioenergy interviews 2016–17	No	
EL-TRAN	IRENA Flextool Finnish energy system modelling material 2030/2050, 2020–21	No	
EL-TRAN	Cross-impact analysis of the energy system	No	
FORBIO	Frequency levels of strong winds	Yes	https://www.csc.fi/paituli
FORBIO	Snow load on tree branches	Yes	https://www.csc.fi/paituli
FORBIO	Conditions for harvesting trees	Yes	https://www.csc.fi/paituli
FORBIO	Number of days of high forest fire risk	Yes	https://www.csc.fi/paituli
ScenoProt	Contributions to National Food Composition Database in Finland (FINELI)	Yes	https://fineli.fi/fineli/en/index?
ScenoProt	Focus group transcripts	No	
ScenoProt	Inteview transcripts	No	
ScenoProt	Crop data for protein crops	Research ongoing	
SmartSea	Nemo-Nordic and Nemo-GoB are available to the SmartSea Project under the terms of the CeCiLL licence.	Ongoing	http://www.cecill.info/licences/Licence_CeCILL_V2.1-en.html
SmartSea	Important commercial fishing areas along the coast: traps and nets	Yes	https://opendata.luke.fi/dataset/pyydyspaikat-rysapisteet-ja-verkkoalueet
SmartSea	Multielement data of sediment samples from the Kvarken Archipelago, eastern Gulf	Yes	https://doi.org/10.1594/PANGAEA.920857

Project	Research data	Open-ness	Location
	of Bothnia, impacted by metal loading from acid sulphate soils		
SmartSea	Grain size data of sediment samples from the Kvarken Archipelago, eastern Gulf of Bothnia, impacted by metal loading from acid sulphate soils	Yes	https://doi.org/10.1594/PANGAEA.920850
SmartSea	Seabed substrate data from the Gulf of Bothnia at the scales of 1:100 000, 1:250 000, and 1:1 000 000	Yes	https://www.emodnet-geology.eu/data-products/
SmartSea	Sedimentation rate data from the Gulf of Bothnia, available online.	Yes	https://www.emodnet-geology.eu/data-products/
SmartSea	Full model scenario dataset; as of writing available at request, will be published online once technical solution to share over 40 TB is available	Ongoing	

Table 13. Number of higher education degrees reported by the PIHI projects and the programme as a whole.

Project	Master's degree	Doctoral degree
CloseLoop	10	4
EL-TRAN	-	11
FORBIO	25	11
ScenoProt	8	1
SmartSea	5	6
PIHI programme	**48**	**33**

Table 14. Number of research visits reported by the PIHI projects and the programme as a whole.

Long-term visits are visits with a total uninterrupted duration of at least one month. Short-term visits are visits with a total uninterrupted duration of at least five working days but less than one month.

Project	Incoming long-term visits	Incoming short-term visits	Outgoing long-term visits	Outgoing short-term visits
CloseLoop	4	4	4	10
EL-TRAN	-	-	9	8
FORBIO	1	6	3	9
ScenoProt	-	-	1	1
SmarSea	-	-	4	7
PIHI programme	**5**	**10**	**21**	**35**

Table 15. Immaterial rights reported by the PIHI projects.

Project	Type	Identifier
CloseLoop	Invention disclosures	Transparent and flexible Li-organic 3D thin-film microbattery
CloseLoop	Invention disclosures	Method and system for measuring UV intensity
CloseLoop	Invention disclosures	Method for co-depositing detonation nanodiamonds and diamond-like carbon
CloseLoop	Invention disclosures	Ultra low Pt electrocatalyst, FI20185970
CloseLoop	Patents applied for	Method for co-depositing detonation nanodiamonds and diamond-like carbon onto a substrate and composite films comprising detonation nanodiamonds and diamond-like carbon, PCT/FI2017/050350
CloseLoop	Patents applied for	Transparent and Flexible Li-Organic 3D Thin-Film Microbattery PCT/FI2018/050295
CloseLoop	Patents applied for	Ultra low Pt electrocatalyst, FI20185970
CloseLoop	Patents granted	Method for producing lithium phosphorus oxynitride layer, Pat. US2017067161 (A1)
SmartSea	Intellectual property rights	SmartSea MSP toolbox, Finnish Environment Institute (open source licence)
SmartSea	Invention disclosures	Jaakko Heinonen, VTT Technical Research Centre of Finland: Ice load mitigation concept for marine structures
SmartSea	Patents applied for	Jaakko Heinonen, VTT Technical Research Centre of Finland: Offshore system and manufacturing method, Patent application (pending)
SmartSea	Intellectual property rights	VTT Technical Research Centre of Finland: Ice load design portal (web-portal)

Appendix 11: New research funding

Table 16. New research funding reported by the PIHI projects and the programme as a whole.

The projects were asked to report important new research funding applications (including at least two members of the SRC project) that continue or advance the research carried out in the SRC programme. The table presents the total amount of reported new funding from national and international funding sources.

Project	National funding, €	International funding, €
CloseLoop	26 114 604	1 723 809
EL-TRAN	2 274 250	3 723 867
FORBIO	12 220 259	225 000
ScenoProt	2 725 249	1 711 460
SmartSea	7 038 691	28 720 952
PIHI programme	**50 823 053**	**36 105 088**

Appendix 12: Titles of impact stories

The societal impact of SRC consortia is monitored with the help of impact stories. The impact stories are reports that describe and discuss the research and interaction carried out in the project in relation to the joint impact objectives of the programme and the project's own impact targets.[9] Each consortium in the PIHI programme was expected to prepare at least three impact stories and update them during the entire period the consortium was active. Most impact stories will be accessible via the strategic research website.[10]

CloseLoop

- Lithium batteries as an example of precious metals in circular economy
- Designing a sustainable cycle
- Opportunities for regional promotion of circular economy

EL-TRAN

- As Finland's electricity system is to be made more resource efficient, how do we put flexibility solutions at the heart of this development?
- How to ensure support from the entire society for a more resource-efficient electrical energy system?
- How do we promote more resource-efficient regulation and planning in the Finnish electricity system?

FORBIO

- Better management of different risks in forest management and use
- Promoting low-carbon solutions and resource efficiency and sustainability in the forest bioeconomy
- Making better use of forest bioeconomy knowledge in decision-making in Finland and the wider European Union

ScenoProt

- A carbon-neutral and resource-efficient protein system supports climate goals
- A diversified food system is part of public health
- A self-sufficient and diverse protein system supports crisis resilience and the security of supply

[9] Strategic research, Reporting and monitoring: https://www.aka.fi/en/strategic-research/for-applicants-and-projects/for-projects/reporting-and-monitoring/ [referred to 12 May 2023]

[10] Impact in strategic research, Impact stories: https://www.aka.fi/strateginen-tutkimus/strateginen-tutkimus/strateginen-tutkimus-pahkinankuoressa/vaikuttavuus-strategisessa-tutkimuksessa/vaikuttavuuskertomukset

- Benefits of increasing the use of plant proteins

SmartSea

- Impact on the economy
- Impact on the maritime spatial planning
- Influencing climate change mitigation, adaptation and attitudes towards sustainable development

Appendix 13: The self-evaluation questionnaire

The aim of the self-evaluation questionnaire was to collect information on the success of the completed SRC programmes (EQUA, PIHI, TECH, CITIZEN) and on needs to develop SRC programme funding. The self-evaluation questionnaire was targeted at the consortium PIs and deputy PIs, work package and team leaders, and interaction coordinators, to whom we sent a personal invitation to respond.

The questionnaire was open between May 2 – May 27, 2022. The total number of recipients was 148, of whom 75 responded to the survey (response rate 51%). The number of recipients in the PIHI programme was 35, of whom 12 responded to the survey (response rate 34%).

The questionnaire data will be available at the Finnish Social Science Data Archive (FSD).

Responses:

Select the consortium you were part of. (n=12)

EL-TRAN	4
SmartSea	3
FORBIO	2
ScenoProt	2
CloseLoop	1

What was your (primary) role in the consortium? (n=12)

Consortium Principal Investigator	5
Research team leader, Work Package leader, or both	3
Interaction coordinator	3
Other	1
Consortium debuty Principal Investigator	-

In what kind of organisation did you work during the funding period? (n=12)

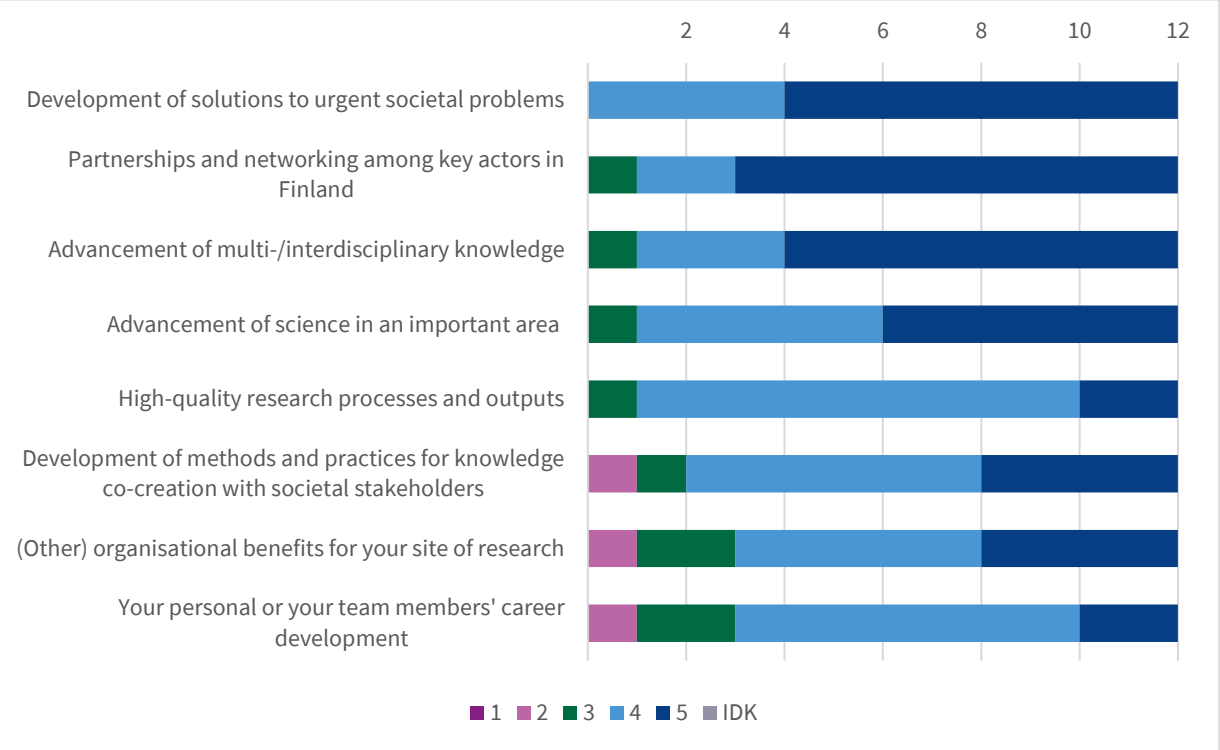
Government research institute	6
University	5
University of applied sciences	1

Did you know the other partners of your consortium before this SRC programme? (n=12)

I knew one or a few of the partners before the programme	7
I knew all or most partners before the programme	5
I did not know the partners before the programme	-

Assess the effectiveness of your consortium in advancing the following goals of SRC funding, based on your own experiences and impressions. (n=12)

(1=ineffective, 5=very effective, IDK=I don't know)

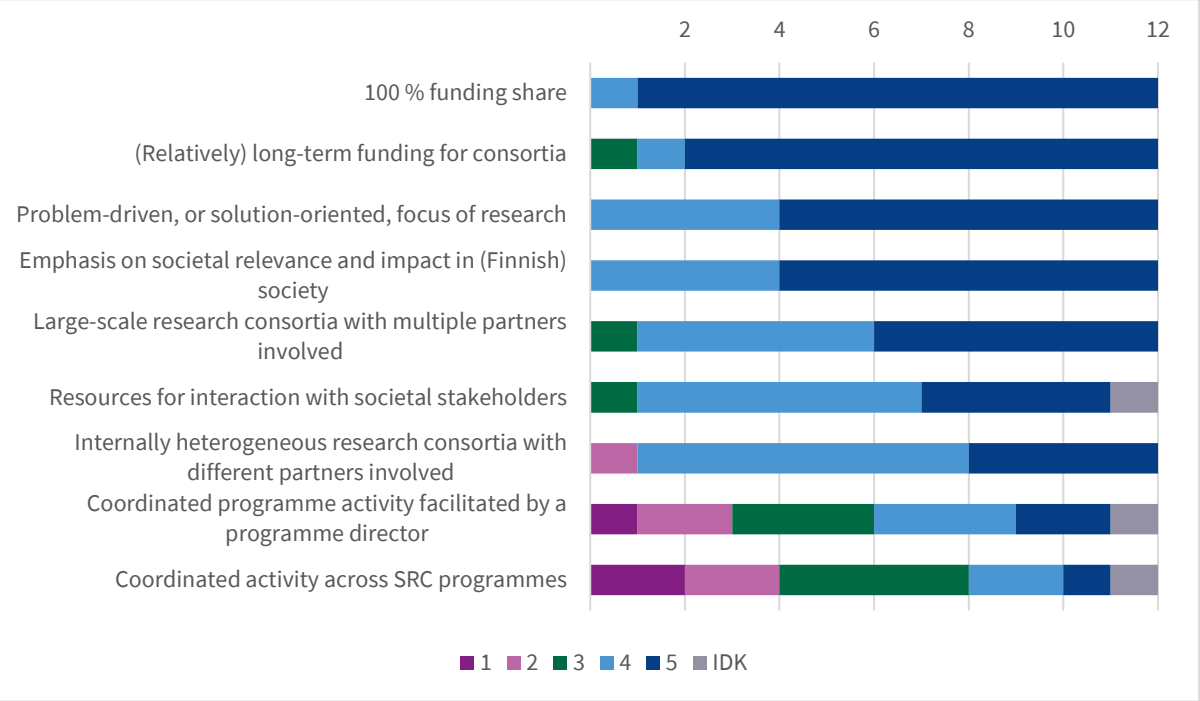


Tell us more about the effectiveness of your consortium in advancing the goals of SRC funding. (n=7)

Long-term interaction and interdisciplinary work with stakeholder inclusion were stated to be the most significant aspects in achieving high quality research and practical outcomes. Collaboration did extend outside the consortium networks and produced inputs for future research as well.

Assess the added value of the following features of SRC funding, based on your own experiences and impressions of the SRC programme you were part of. (n=12)

Please consider the added value vis-à-vis your other/regular research activities. (1=no added value, 5=high added value, IDK=I don't know)

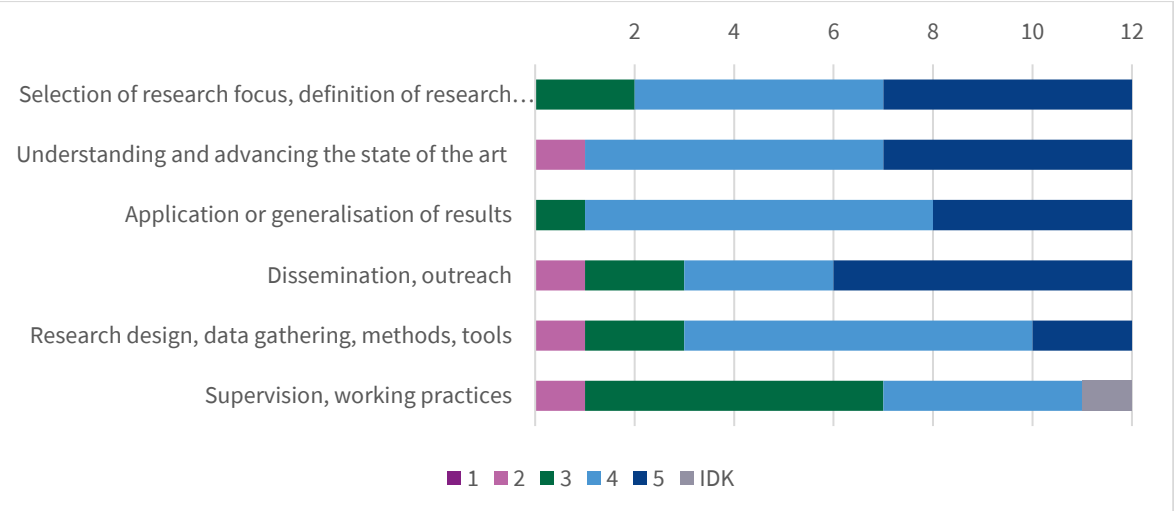


Tell us more about the most important added value of SRC funding. (n=8)

Great societal impact, emphasis on collaboration with expertise of multiple fields already in research planning were perceived as important factors of SRC funding. Also, gathering actors from all levels of society was thought to be significant for the projects.

Assess the importance of multidisciplinary collaboration within your consortium. As a consortium partner, how important was the collaboration for the following aspects of your work? (n=12)

(1=unimportant, 5=very important, IDK=I don't know)



Tell us more about the importance of multidisciplinary collaboration in your consortium. (n=5)

Diverging viewpoints were presented. Some respondents stated that the multidisciplinary approach enabled complementing methodological decisions, whereas some stated that joint approach should have been negotiated during the project. Advantage during article and book writing was mentioned emerging from multidisciplinary collaboration.

Did your consortium have research collaboration with other SRC consortia (within or beyond the SRC programme you were part of)? (n=12, number of selected answers 14)

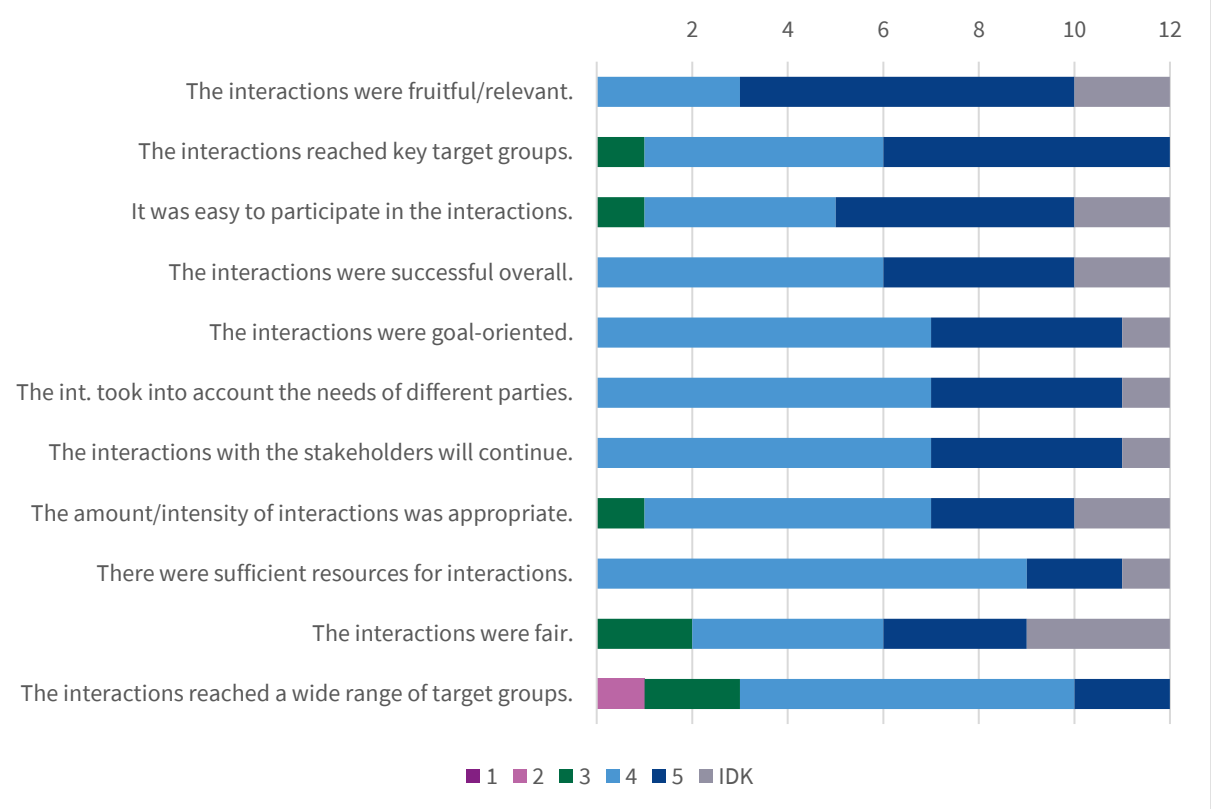
No, or I am not aware of it	5
Yes, within the SRC programme	5
Yes, across the SRC programme borders	4

Tell us more about the added value of your research collaboration with other SRC consortia. (n=4)

The respondents mentioned collaboration between consortiums and programmes leading to producing publications together, sharing the results between consortiums and EU projects, and discovering common interests.

Assess the consortium's interactions with societal stakeholders (those you were involved in) using the following statements. (n=12)

(1=I disagree, 2=I disagree to some extent, 3=I neither agree nor disagree, 4=I agree to some extent, 5=I agree, 5=I agree, IDK=I don't know)



Tell us more about the consortium's interactions with societal stakeholders. (n=5)

The respondents' answers regarding interactions were very varied. Some stated that due to the COVID-19 pandemic it was not possible to conduct the interactions in a way it was planned, and they needed to be done online. Others reported that interactions were even more diverse and active than originally planned due to interest of the stakeholders and lead to for example case studies, open lecture series, contribution to stakeholder events and delivering different kinds of datasets.

In your view, what should be done to further strengthen the societal relevance and impact of strategic research programmes? (n=7)

More profound collaboration with an even broader group of stakeholders was suggested to strengthen societal relevance and impact. The events should be targeted to certain groups to avoid burdening the stakeholders too much, but also it was mentioned that it is challenging for researcher to identify the relevant stakeholders and support for this would be needed. The respondents suggested that in addition to long-term goals, the programmes should also establish short-term goals and perhaps even possess some expertise already in the application phase.

Appendix 14: The survey for stakeholders

The survey was designed to collect information on the societal interaction of the completed SRC programmes (EQUA, PIHI, TECH, CITIZEN) and the significance of the programmes' research and interaction for project partners and stakeholders. The aim was to examine the achieved and expected societal impact of the programmes. The target group of the survey were the main stakeholders and partners designated by the projects and programme directors funded in these programmes.

The survey was open between March 15 – April 22, 2022. The total number of recipients was 195, of whom 33 responded to the survey (response rate 17%). The number of recipients among the PIHI stakeholders was 45, of whom 6 responded to the survey (response rate 13%).

The survey data will be available at the Finnish Social Science Data Archive (FSD).

Responses:

Select one or more research projects (under the PIHI programme) with which you have interacted. (n=6)

EL-TRAN	2
FORBIO	2
ScenoProt	2
SmartSea	1
CloseLoop	-

To which of the following does your organisation/ stakeholder group primarily belong? (n=6)

Ministries	2
Companies	2
Research institutes	1
NGOs, other civil society actors	1
(Several other alternatives)	-

What (formal) role did you have in relation to the research programme or project? (n=6)

Stakeholder representative (without formal relationship)	4
Collaborator	2
Service provider	-
Other	-

Which of the following best describes your previous relationship with the researchers with whom you interacted within the programme or project? (n=6)

I knew the researchers from before.	4
I did not know the researchers, but my organisation has worked with them before.	1
I did not know the researchers, and my organisation has not worked with them before (or I am not aware of such collaboration).	1
Other relationship	-

What kind of cooperation or interaction has your organisation engaged in overall with researchers or research organisations before this programme? (n=6)

Occasional contacts, meetings, joint events, etc.	3
Long-term institutional collaboration	2
At least one joint project	1
None/I don't know	-

What role did you play in relation to the research carried out in the research programme or project? Please select two most suitable roles. (n=6)

End-user of research knowledge	4
Expert or information source	3
Other role	2
Supervisor, leader, or adviser	1
Knowledge broker	1
Supporter, participant, or assistant	1
Experimenter or tester	-

If necessary, tell us more about your role in the research of the programme or project. (n=1)

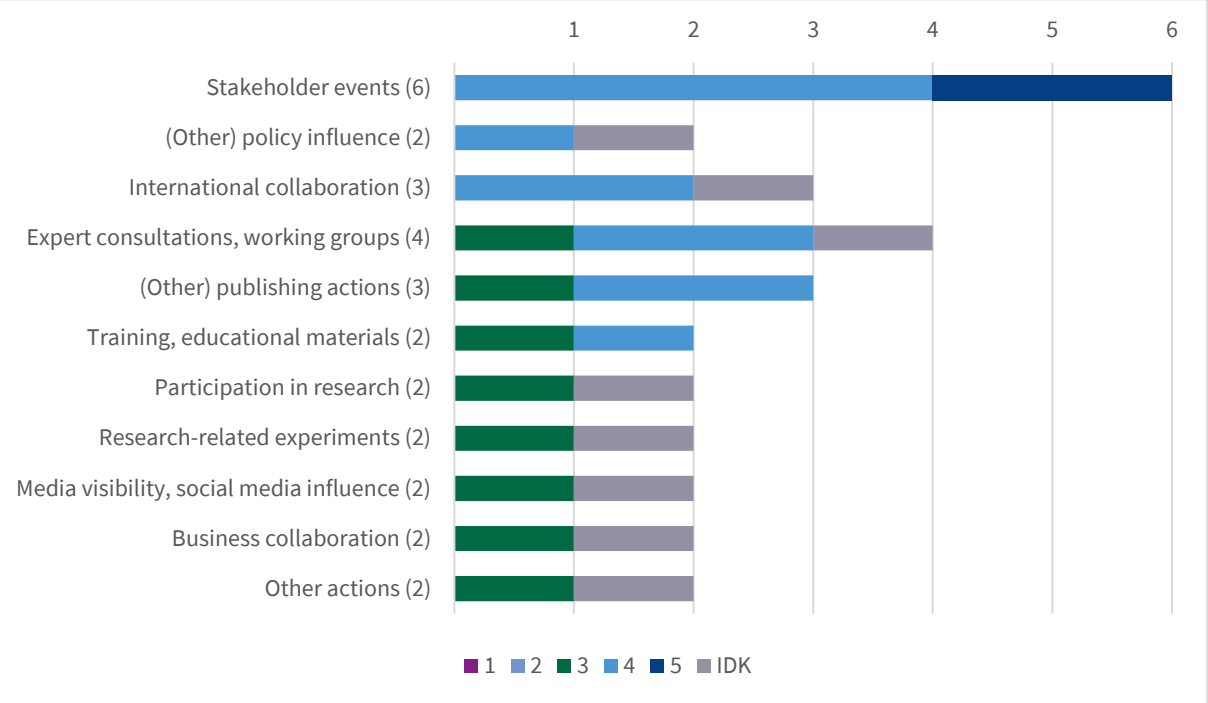
Experts from our company participated in panel/stakeholder discussions organised in connection with the programme.

How often did you interact with or work on the research programme or project? (n=6)

Several times a year	3
Once a year or less often	2
Monthly	1
Weekly	-
Once during the whole programme period	-

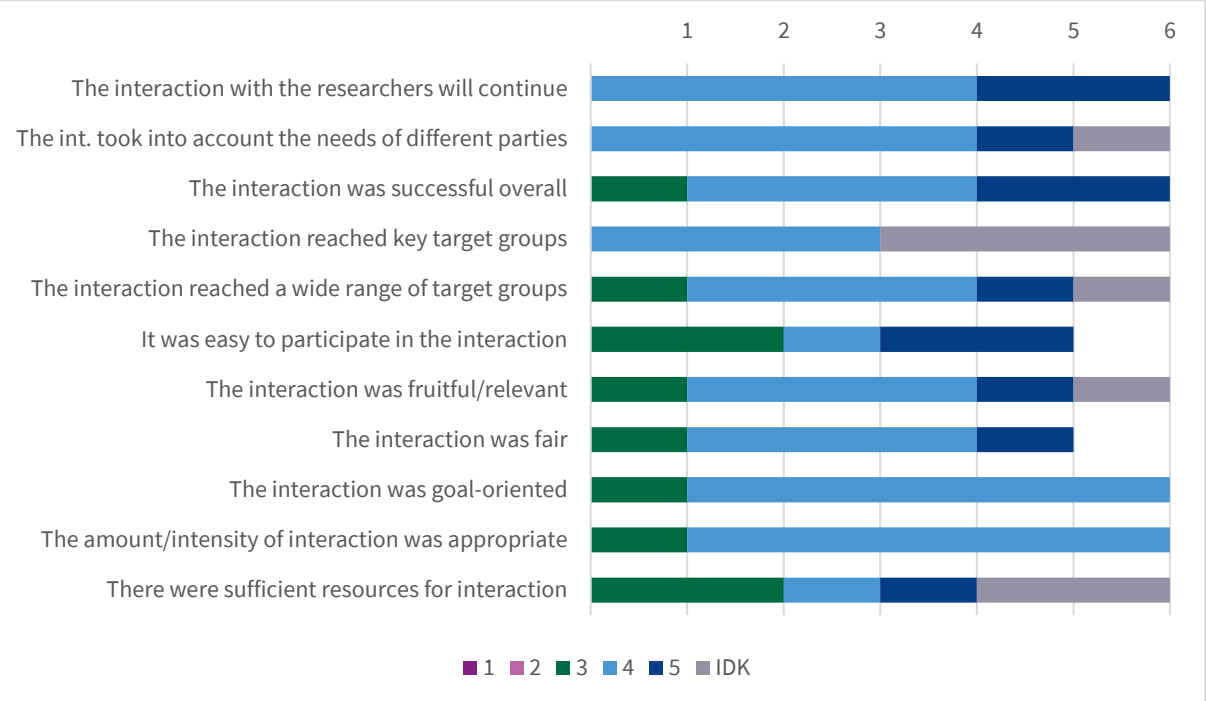
In what form were you involved in the research programme or project? Also assess the usefulness of the actions in terms of the societal impact of research. (n=6)

(1=useless, 2=quite useless, 3=neither useless nor very useful, 4=quite useful, 5=very useful, IDK=I don't know)



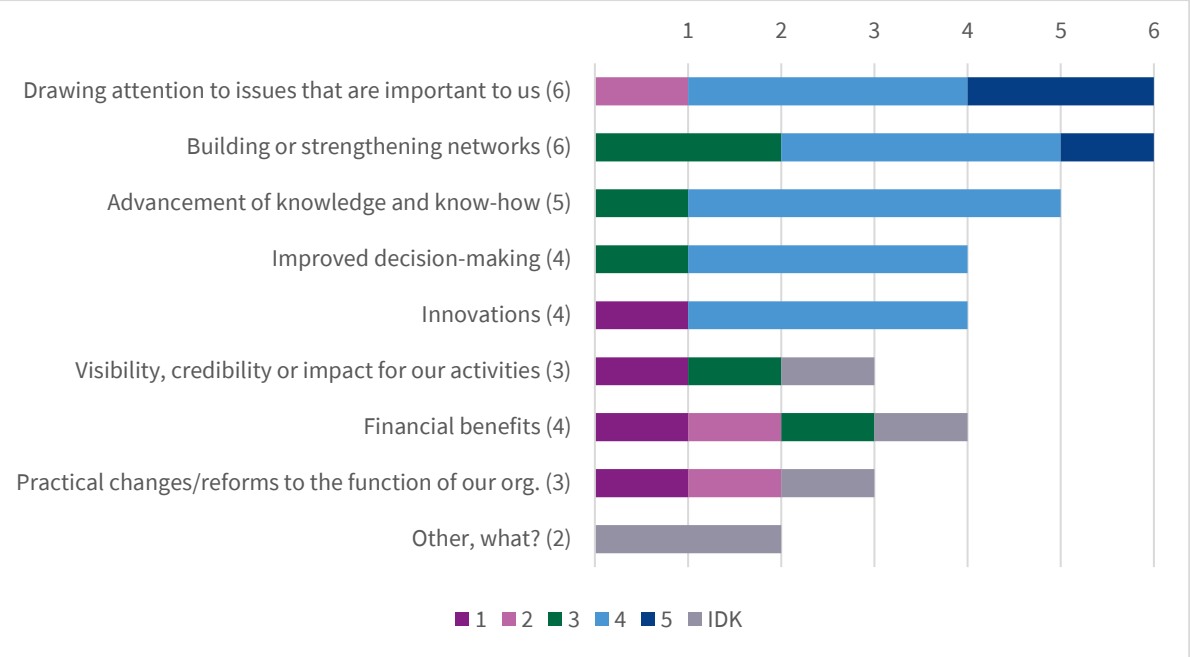
Assess the interaction with the research programme or project using the following statements. (n=6)

(1=I disagree, 2=I disagree to some extent, 3=I neither agree nor disagree, 4=I agree to some extent, 5=I agree, IDK=I don't know)



What were your aims for the interaction with the research programme or project? Please also assess how well your objectives were achieved. (n=6)

(1=not realised, 2=not realised to the expected extent, 3=realized to some extent, 4=realized fairly well, 5=fully realised, IDK=I don't know)



Please describe briefly one of the results, perspectives or solutions of the research programme or project that you consider significant. (n=2)

The final report as well as the roadmap with a successful set of recommendations were mentioned as the most significant results from the projects.

What practical significance has the work of the research programme or research project had for you? To what change has the research led or contributed? Please provide concrete examples, if you can. (n=5)

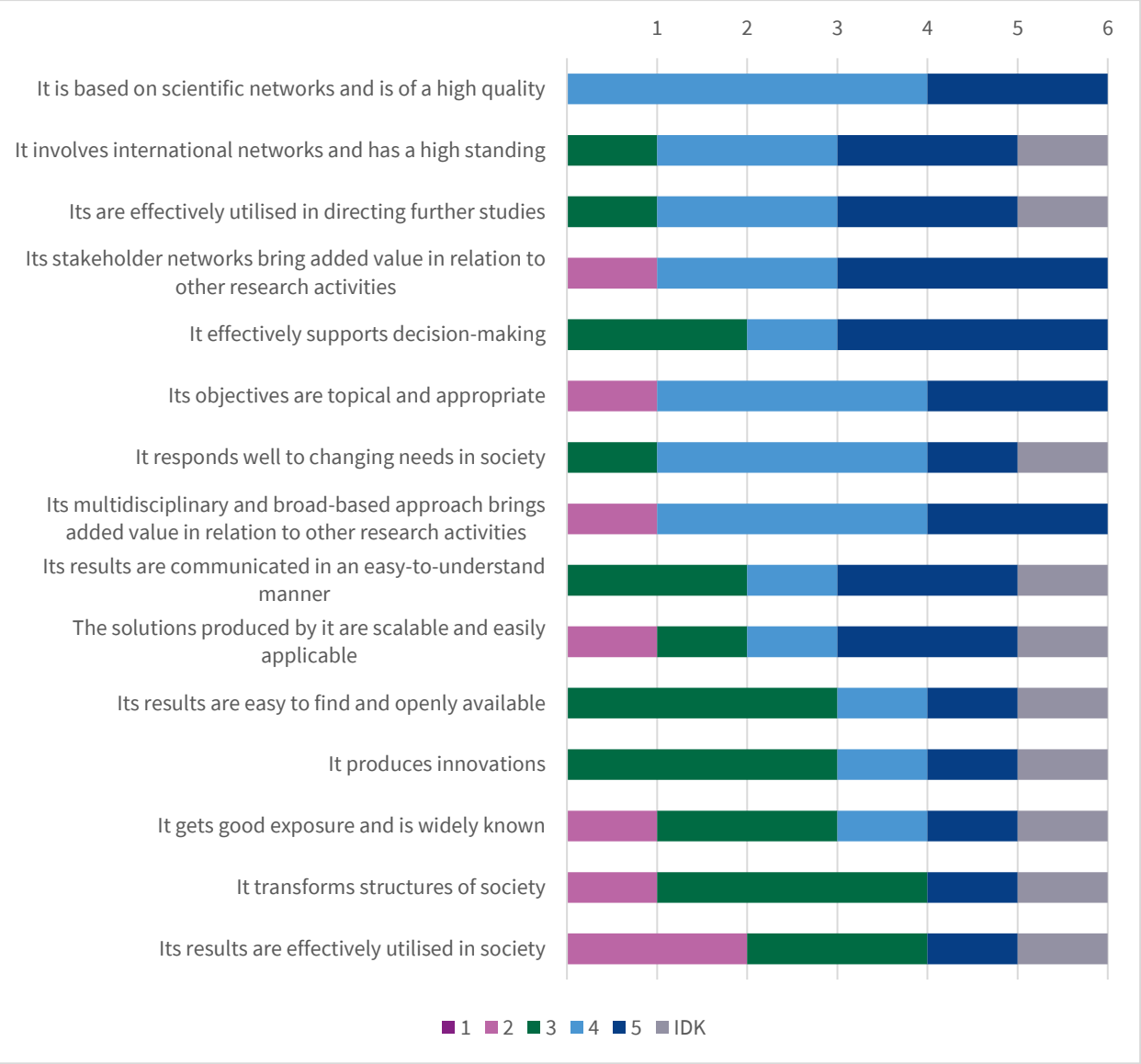
One respondent stated that the roadmap produced in the project could be used as a checklist in practice. Another one mentioned that information received from other programmes' research was helping them to reflect on their own goals. Three of the respondents could not point out any practical effects or concrete change and some even perceived the programme as being irrelevant to what they do.

How do you think the research programme or project managed to influence society more generally, in other ways than from your own perspective or from the perspective of your organisation? Tell us why you think this. (n=3)

It was mentioned that the societal impact will be realized later in the future. Currently keeping up the discussion and new research projects are examples of impacts.

Please assess the below statements on strategic research based on your own experience and views. (n=6)

(1=I disagree, 2=I disagree to some extent, 2=I neither agree nor disagree, 4=I agree to some extent, 5=I agree, IDK=I don't know)



What do you think should be done to further strengthen the social relevance and impact of strategic research? (n=2)

The respondents thought there should be more opportunities to influence the research, and a respondent also wished for more practical recommendations when communicating the results. Also following the field should be done to be able to influence the themes of strategic research. It was also mentioned that the amount of funding should not be reduced.

What could you do yourself to strengthen the social relevance and impact of strategic research? (n=3)

Using the results in steering decision-making and RDI, monitoring the research field, and actively influencing the research themes were mentioned. Also, practical

measures aligned with research recommendations could be added in the communication of the results.

