Research Council of Finland

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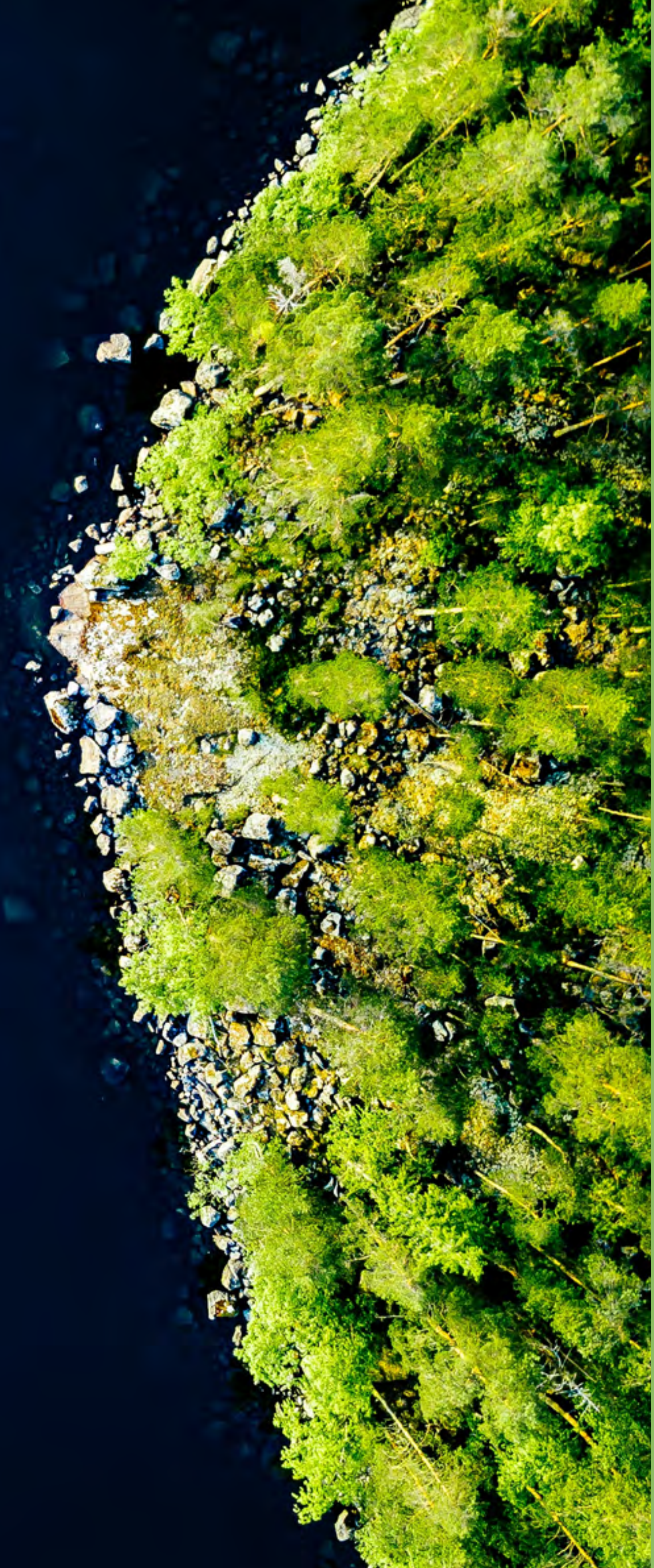

Impacts of funding from the Research Council of Finland's EU Recovery and Resilience Facility (RRF) programme on sustainable growth

Results and impacts of RRF-funded research and research infrastructure projects on the conditions for systemic change in the period 2022–2024

Erika Lilja | Jari Leppänen | Mari Leino

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completed consortium projects

EUR **29.8** million

RFF funding

~800

publications

58

degrees

This report reviews the results and impacts of EU Recovery and Resilience Facility (RRF) funding granted and managed by the Research Council of Finland in the period 2022–2024. The report covers 19 completed consortium projects intended to promote the green and digital transition, support sustainable growth and strengthen research infrastructures and competence clusters. The projects received a total of nearly EUR 30 million in RRF funding. All the projects complied with the "Do No Significant Harm" (DNSH) principle and the environmental impacts were minor or compensable.

The projects achieved their goals well and produced nearly 800 publications, 58 degrees and dozens of intellectual property rights. Among other things, the results of research projects are related to the sustainable use and recyclability of resources, climate change adaptation and environmental protection, AI-based solutions, modelling and simulation, digital twins, data integration, and support for decision-making. The research infrastructure projects improved the conditions for research, developed the openness and interoperability of research infrastructures, supported competence growth and enabled new forms of collaboration.

The projects engaged in extensive collaboration with research communities, companies, authorities and citizens in Finland and the EU. This supported the utilisation of knowledge as well as the creation and impact of new forms of collaboration. In particular, they networked with the Flagships and Centres of Excellence funded by the Research Council of Finland (RCF) and both utilised and collaborated extensively with national and European research infrastructures.

In the short term, the projects had a particular impact on enabling research, technological innovations, policy support and education. In the long term, they are expected to support climate objectives, the circular economy, the digital transition and the implementation of the European Green Deal. The projects have also created conditions for systemic change. Their impact mainly occurred through networks, co-creation and interaction rather than the direct impacts of individual projects. The projects strengthened competence clusters and created new structures for RDI cooperation.

As a whole, the RRF funding granted by the Research Council of Finland has already succeeded in strengthening the impact of research and innovation activities in Finland.

The projects have built permanent structures, a competence base and solutions that have the potential to change the operating models and structures of society. The projects will continue to actively promote the green and digital transition through new research and development projects, cooperation networks and competence development.

Based on the results of the report, recommendations can also be made for strengthening interaction and co-creation between research and society, supporting long-term RDI cooperation and development of competence clusters, making wider use of research infrastructures in different sectors, planning, monitoring and evaluating impact, and promoting the dissemination of research results and evidence-based solutions through regulation and policy measures.

1. Introduction

This report reviews the results and impacts of EU Recovery and Resilience Facility (RRF) funding granted and managed by the Research Council of Finland in 2022–2024. The objective of the report is to describe how RRF funding has promoted the green and digital transition and supported sustainable growth by means of research, research infrastructures and competence clusters, as well as strengthening competence.

The material in the report consists of information reported by consortium projects that received RRF funding in the RRF report, impact stories, self-assessments regarding implementation of the DNSH principle and survey data collected from the principal investigators of the consortia. The material covers a total of 15 research consortia on key areas of the green and digital transition that include 50 subprojects and four national research infrastructure consortia consisting of 22 subprojects.

The report examines the activities, results and impacts of the projects from several perspectives. It focuses on research collaboration, mobility, project outputs, results and impacts, stakeholder collaboration, strengthening competence clusters and competence, as well as the promotion of sustainable growth and the green and digital transition. The report also evaluates the impact mechanisms and anticipated long-term effects of projects based on self-evaluations and impact stories. DNSH self-assessments are used to examine how projects have taken environmental objectives into account in their activities.

The report serves as part of the RRF programme evaluation, and it provides a knowledge base for examining the impact of research at the programme level and supports understanding of how research and development activities can promote the sustainable renewal of society in a multi-crisis era. The results of the report will be combined with the results of a stakeholder survey being implemented in autumn 2025 and the corresponding information collected in spring 2026 from projects ending in 2025.

Evaluating the impact of research is an important but rarely simple task. Impact often occurs in the long term and the mechanism by which it comes about is not straightforward. Demonstrating impacts is a challenging process, as it can be difficult or impossible to determine which research and measure caused a specific change[1]. Despite this, the monitoring and assessment of impact is essential – especially in our current multi-crisis era. There is good reason to stop and ask if our activities support the achievement of the objectives set or whether we could still learn new things and do something in a better or different way.

A traditional linear model in which the research result progresses via the transfer of information to implementation and then generates impacts does not usually correspond to reality. Many innovation researchers have criticised this model for its simplification and unrealistic expectations. On the other hand, a non-linear model emphasises interaction, feedback loops and learning between different actors. Information is linked to individuals and organisational practices as competence, and impact is often created through tacit knowledge, everyday activities, user experiences and collective learning. Interaction is seen as enabling the transfer of knowledge, technology and expertise and being a key impact mechanism.[2]

A systemic approach to impact assessment emphasises examination at the level of larger entities. Rather than focusing on individual projects, this involves assessing the capacity of the entity to produce systemic change and create the conditions needed to ensure, for example, sustainable growth and well-being in the future. This approach recognises that change means, for example, a simultaneous change in operating models, structures and these interactions, and that impact is often created through networks, interaction and co-creation – not through the direct impact of the activities and results of individual projects.

Although this report highlights individual projects as examples, the objective was to focus on the combined effects of projects, creation and strengthening of networks and competence clusters, and development of the conditions for RDI activities. The approach makes it possible to assess the impact of RRF funding from the perspective of systemic change.

[1] See, for example, Tutkimuksen yhteiskunnallisen vaikuttavuuden arvioinnin haasteet | Vastuullinen tiede (The challenges of assessing the societal impact of research | Vastuullinen tiede)
[2] https://akavaworks.fi/wp-content/uploads/sites/2/2021/06/Perustutkimus-tieteen-ja-innovaatioiden-perustana-Artikkeli-8_2021.pdf

Responsible evaluation requires an understanding of what was stated above as well as the involvement of the evaluation targets and stakeholders in the evaluation.[3] In fact, evaluation is most beneficial when it has been performed correctly and is transparent and instructive. The principles of responsible evaluation have also been followed in this report by submitting a draft report to the leaders of the consortium projects and leaders of the subprojects for commenting in June 2025, prior to its publication.

The review conducted in this report is built on monitoring the progress and achievement of the objectives set in the Sustainable Growth Programme for Finland and in the RCF's calls for applications for EU Recovery and Resilience Facility funding. It combines the principles of formative and summative evaluation. Formative evaluation focuses on observations made during implementation of the RRF programme with the objective of supporting the development and steering of activities. Both completed research projects on key areas and national research infrastructure projects will continue to actively promote sustainable growth and the green and digital transitions after the RRF funding period.

Summative evaluation, on the other hand, aims to provide an overall picture of the extent to which the objectives set in the national Recovery and Resilience Plan (RRP) and the Sustainable Growth Programme have been achieved and the type of impacts the RRF programme has had. It also serves as an important tool for making results and impacts visible, communicating and planning the development of activities. However, the actual summative evaluation can only be carried out in spring 2026 after all the projects have ended. Even at that time, evaluation will still be premature with regard to assessing longer-term impacts.

The report has been compiled by officials from the Research Council of Finland's RRF team. Senior Science Advisor Erika Lilja was responsible for the entity, collection and review of the information in the report. Coordinator Jari Leppänen (especially Sections 4 and 6) and Science Advisor Mari Leino (especially Section 3) also contributed to the analyses and writing.

The structure of the report is as follows. Section 2 describes the structure of the EU Recovery and Resilience Facility and the national RRP plan as well as the Research Council of Finland's role in implementation and allocation of funding. Section 3 examines the project partners, mobility, publications, qualifications and intellectual property rights. Section 4 is based on the responses to the self-evaluation survey provided by the projects and reviews the achievement of project objectives, stakeholder collaboration, strengthening of competence and short-term societal impacts. Section 5 deals with actions to enhance impact taken by the projects, impact mechanisms and the anticipated effects on the green and digital transition, and EU-level impacts. Section 6 examines the environmental impacts of the projects and their implementation in relation to the DNSH principle. Section 7 summarises key observations on the results, effects and impact of projects from the perspective of promoting systemic change. The report concludes with Section 8, which presents the conclusions and recommendations for different actors. Each section ends with a summary of the main results of that section.

The objective was to focus on the combined effects of projects, creation and strengthening of networks and competence clusters, and development of the conditions for RDI activities. Evaluation is most beneficial when it has been performed correctly and is transparent and instructive.

One aim of the report was to highlight concrete examples of projects, and it contains many example boxes.

A sensible and critical approach to the information in the report is recommended. It is mainly based on the reporting information produced by the projects, self-evaluations and impact stories. The information represents the perspective of the projects well, but the results of the report may have a positive bias. The review will be supplemented with information and views collected from stakeholders in autumn 2025.

[3] 21655-scope-guide-v10.pdf

2. Funding from the Research Council of Finland's EU Recovery and Resilience Facility

This section examines the EU Recovery and Resilience Facility (RRF) and Finland's Recovery and Resilience Plan (RRP) as well as its implementation at the Research Council of Finland.

Funding allocated to Finland through the EU Recovery and Resilience Facility has enabled significant investments in research, competence and infrastructures. Projects funded through the Research Council of Finland (RCF) support the green and digital transition and strengthen the interaction between research and business.

In 2021, RCF granted a total of approximately EUR 29.8 million in RRF funding in two different funding calls. EUR 8.3 million was allocated to eight research infrastructure projects (44 subprojects) and EUR 21.5 million to 17 research projects on key areas (57 subprojects). The majority of the projects were completed by the end of 2024.

The report deals with projects completed in 2023 and 2024 that started on 1 January 2022. The review covers 19 consortium projects in which all the subprojects have ended.

The section is divided into two parts. Section 2.1 presents the role of the RRF instrument and the national RRP plan as well as the Research Council of Finland's role in implementing the plan. Section 2.2 examines the allocation of RRF funding granted by the Research Council of Finland to different action packages and projects.

EUR **29.8** million

RFF funding

EUR **8.3** million

Research infrastructure projects
44 subprojects

EUR **21,5** million

Reasearch projects on key areas
57 subprojects

2.1 EU Recovery and Resilience Facility and implementation of the National Recovery and Resilience Plan at the RCF

The NextGenerationEU recovery instrument boosts the recovery of people, the economy and society from the Covid-19 crisis. The instrument includes EUR 724 billion in funding for member states. The recovery instrument is divided into seven parts, the largest of which is the Recovery and Resilience Facility (RRF). It includes EUR 672.5 billion in funding for member states.[4]

RRF is a temporary financial instrument that entered into force in February 2021 and is used by the EU Commission to collect funds from capital markets for use by the member states. The funding can be used for investments and reforms implemented from February 2020 until the end of 2026. The objective of the RRF instrument is to support member states in their post-pandemic recovery and strengthen their resilience and capacity for the green and digital transitions. The national plans have to allocate at least 37% of their budget to the green transition and 20% to the digital transition.[5]

The RRF funding received by the member states is based on national recovery and resilience plans (RRPs). The EU Council approved Finland's Recovery and Resilience Plan in autumn 2021. The plan has since been updated to reflect the changed circumstances and priorities.

Finland's plan includes concrete reforms and investments aimed at improving energy efficiency, promoting the use of renewable energy and supporting competence development. The plan is part of the broader Sustainable Growth Programme for Finland, the goal of which is ecologically, socially and economically sustainable growth. The programme also supports the implementation of the REPowerEU plan, which aims to reduce dependence on fossil fuels and accelerate the transition to clean energy.

The Research Council of Finland is responsible for the implementation of the national RRP plan for research and research infrastructures. RCF's measures fall under Pillar 3 "Raising the employment rate and skill levels

[4] https://commission.europa.eu/business-economy-euro/economic-recovery/recovery-and-resilience-facility_fi
[5] https://energy.ec.europa.eu/topics/funding-and-financing/recovery-and-resilience-facility-clean-energy_en

to accelerate sustainable growth". The target of the pillar is to strengthen the competence base, support research and development activities, and enhance the impact of higher education and research.[6]

RCF will implement the following action packages in the RRP plan as part of the entity in the administrative branch of the Ministry of Education and Culture:

- P3C3I2 RDI funding package supporting the green transition – Accelerating key industries and boosting expertise
- P3C3I5 Promoting innovation and research infrastructures – Local research infrastructures
- P3C3I6 Promoting innovation and research infrastructures – National research infrastructures

The measures funded through the RCF focus especially on developing research infrastructures, promoting the green and digital transition through multidisciplinary research projects, strengthening the impact of research and competence clusters, and supporting international collaboration.

RCF has granted funding to research infrastructures of national importance that support the green and digital transitions. These include infrastructures related to data management, climate change research and health technology.

RCF has also funded multidisciplinary research projects on key areas of the green and digital transition that combine competence in areas such as climate research, energy technology, artificial intelligence and social sciences. The aim of the projects is to produce solutions for the dual digital and green transition of society.

One of the focuses when selecting projects involved assessing how they promote the green transition and digitalisation, the quality and impact of RDI activities and the related strengthening of competence.

RCF works closely with other authorities responsible for implementing the RRP plan and with Business Finland, which is responsible for supporting business and innovation activities in the Sustainable Growth Programme for Finland.

2.2 Allocation of RRF funding granted by the Research Council of Finland and projects included in the review

RCF has allocated funding totalling approximately EUR 90 million to research projects and research infrastructure projects on key areas of the green and digital transition that support ecologically sustainable growth, climate targets and the development of digital solutions. Under RCF authorisation, decisions were made concerning EUR 45 million in 2021 and a total of EUR 45 million in 2022 and 2023.

The 56 consortium projects that were funded have formed a programme cluster. The goal of the RRF programme is to strengthen the interaction between research and business and promote the use of research results in society. The evaluation of the projects selected for the RRF programme has emphasised cooperation between research organisations and the strengthening of competence clusters in order to make research results more readily available in society and business, and the funding promotes networking and transfer of expertise between RDI actors.

RRF projects must comply with the "Do No Significant Harm" principle. Compliance with the principle has been verified using DNSH assessments. The objective of the assessment is to ensure that projects do not cause significant harm to the environment and that they comply with EU and national legislation requirements. The DNSH assessment is described in more detail in Section 6.

The report reviews the activities, results and impacts of consortium projects that ended in 2023 and 2024. A total of EUR 29,777,896 in

RCF has allocated funding totalling approximately EUR 90 million to projects that support ecologically sustainable growth, climate targets and the development of digital solutions.

[6] Sustainable Growth Programme for Finland. Recovery and Resilience Plan

RRF funding was granted to the sites of research for projects in the 2021 call for key areas in the green and digital transition[7] and the 2021 FIRI call[8] for national research infrastructures. Figure 1 presents the distribution of RRF funding granted by the Research Council of Finland by programme and Figure 2 the distribution of granted funding by region.

Funding was granted to eight research infrastructure projects consisting of 44 subprojects. Thirty-two of the subprojects were completed by the end of 2024, and 12 will be completed at the end of 2025. RRF funding was granted to 17 research projects on key areas, which included 57 subprojects. Fifty-four of the subprojects were completed by the end of 2024 and three will be completed at the end of 2025.

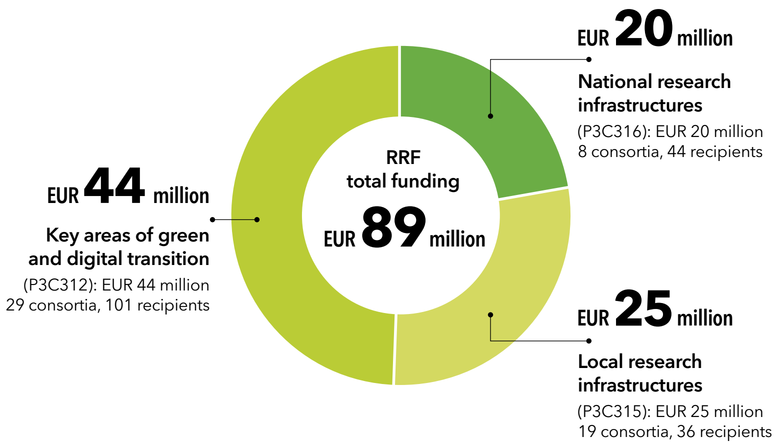

Figure 1. Distribution of RRF funding granted by the RCF by programme.

As the projects report at the consortium level, the report only covers the four research infrastructure projects presented in Table 1 and the 15 research projects on key areas presented in Table 2 for which all subprojects have already ended. This report utilises the abbreviations for consortium projects that are presented in the table.

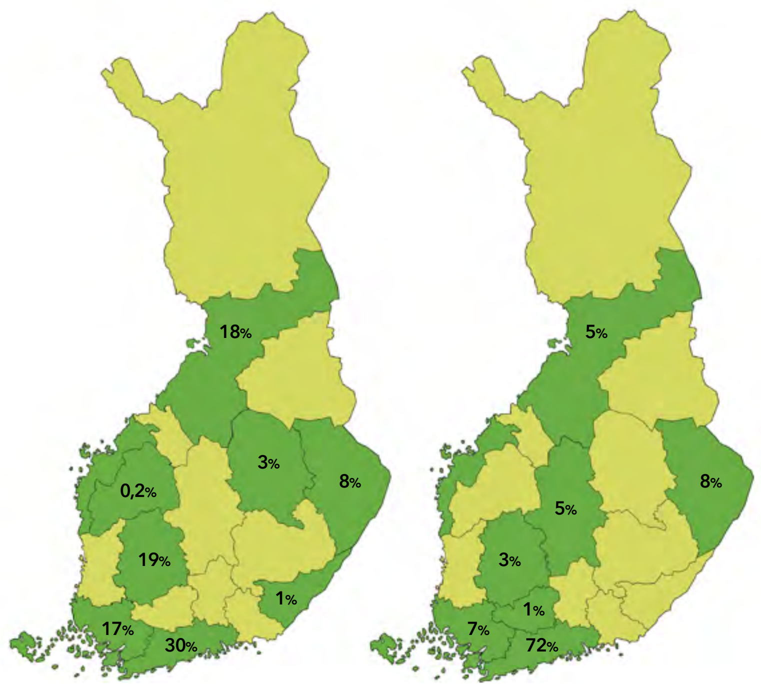

Figure 2. Distribution of funding granted by the RCF for local research infrastructure projects (left) and research projects on key areas (right) by region.

[7] Application notice: Special funding for research on key areas of green and digital transition – Research Council of Finland
[8] Application notice: FIRI2021 call – Research infrastructures on 2021–2024 roadmap and Finland's international RI memberships – Research Council of Finland

The Research Council of Finland's RRF projects bring together more than 80 research fields relevant to the green and digital transitions. The research fields reported in the applications received for research projects on key areas included in the review are presented in Figure 3 as a word cloud.

Appendix 1 lists all the subprojects of the consortia included in the review, the amount of RRF funding granted to them, the principal investigators and the implementing organisations by decision number, and Appendix 2 lists the distribution of RRF funding granted in 2021 by organisation. The allocation of realised RRF funding to different expense categories for the projects included in the review is presented in Appendix 3.

The total number of person-months was 2,295 in research projects on key areas and 597 in research infrastructure projects. The largest investments were related to doctoral students and postdoctoral researchers. Appendix 4 presents the person-months reported by the projects.

Figure 3. A word cloud that includes the research fields reported in the applications from research projects on key areas. (In Finnish).

Table 1. Research infrastructure projects covered by the review.

Name of the consortium project/research infrastructure	Project duration	RRF funding granted EUR
FIN-CLARIAH – Developing a Common RI for CLARIAH Finland (**FIN-CLARIAH**)	1.1.2022 – 31.12.2023	3 229,153
Finnish Marine Research Infrastructure (**FINMARI**)	1.1.2022 – 30.6.2024	1 665,213
Hydrological Research Infrastructure Platform (**HYDRO-RI-Platform**)	1.1.2022 – 31.12.2024	2 270,654
EuroHPC/PRACE Finland virtual research infrastructure (RI)	1.1.2022 – 31.12.2023	1 097,125
Total funding granted		**EUR 8 262,145**

Table 2. The review covers research projects on key areas.

Name of the consortium project	Project duration	RRF funding granted EUR
Aalto ENG/SCI **(AES)**	1.1.2022 – 31.12.2024	887,692
Artificial intelligence, spatial statistics and Earth observation for digital twinning of forest diversity **(ARTISDIG)**	1.1.2022 – 31.12.2024	1,557,613
Beyond carbon-neutral drone aerial deliveries with autonomous micro-airports in sustainable metropolitan areas **(AeroPolis)**	1.1.2022 – 31.12.2024	1,898,449
Capturing structural and functional diversity of trees and tree communities for supporting sustainable use of forests **(@Diversity4Forests)**	1.1.2022 – 31.12.2024	904,728
Enzyme-mediated attachment and detachment of multifunctional and biobased coating aided by digital material design **(ENZYFUNC)**	1.1.2022 – 31.12.2024	1,356,766
Evaluating integrated spatially explicit carbon-neutrality for boreal landscapes and regions **(C-NEUT)**	1.1.2022 – 31.12.2024	1,897,050
Foundations and digital infrastructure for green offshore energy production close to Finnish coasts **(GEOMEASURE)**	1.1.2022 – 31.12.2024	917,813
Green and digital transition in river basin management **(Green-Digi-Basin)**	1.1.2022 – 31.12.2024	1,875,877
Managing Forests for Climate Change Mitigation **(ForClimate)**	1.1.2022 – 31.12.2024	1,899,022
Materials Development for Flow Batteries with Help of Explainable AI **(FlowXAI)**	1.1.2022 – 31.12.2024	1,132,557
Microscopy and machine learning in molecular characterization of lignocellulosic materials **(MIMIC)**	1.1.2022 – 31.12.2024	1,352,985
Modelling engine to design, assess environmental impacts, and operate wind farms for ice-covered waters **(WindySea)**	1.1.2022 – 31.12.2024	1,367,802
UH-Aalto Sustainable Autonomous AI in Fight Against Climate Change **(UHASSA)**	1.1.2022 – 31.12.2024	1,753,931
Unmanned aerial systems based solutions for real-time management of wildfires **(FireMan)**	1.1.2022 – 31.12.2024	1,855,676
Urban environment and climate change in the arctic **(ADAPTINFA)**	1.1.2022 – 31.12.2024	857,790
Total funding granted		**EUR 21,515,751**

3. Activities, results and outputs reported by the projects

This section reviews the reporting data from research projects on key areas and national research infrastructure projects that were collected using the Research Council of Finland's online services reporting form after the projects were completed. The sub-sections examine the project partners and mobility, as well as project outputs and results. The section concludes with a summary of the activities, results and outputs reported by the projects.

3.1 Description of the information

The review carried out in this section is based on the information reported by the projects in the RRF report after the completion of the projects. The information was collected through the RCF's online services reporting form. The form consists of open-ended text fields and selection questions. The reporting information covers information reported to RCF by 15 research projects in the key areas of the green and digital transition and four national research infrastructure projects.

Projects that ended by 31 December 2024 have, as a rule, submitted a RRF report by 31 March 2025. Reports on research infrastructure projects that ended on 31 December 2023 were submitted by 31 March 2024.

3.2 Project partners and mobility

3.2.1 Project partners

This section deals with research collaboration. Stakeholder and RDI collaboration with other parties is examined on the basis of the survey information in sections 4.3 and 4.4.

The projects report on research partners that typically also conduct research related to the actual topic. However, these partners do not receive funding from the reported RCF project. The projects select the partner type on the reporting form, and they can specify the nature of the collaboration in an open-ended response. The projects have reported a total of 216 research partners, 85 of which are Finnish and 131 international.

Figure 4 presents all of the research partners in the 18 consortium projects, as reported by the projects, some of which were existing partners, while others were new. One of the projects did not report any partners. Most of the project partners were from an international research organisation or university, or from another Finnish research organisation. New partners often came from outside Finland, especially research organisations or universities.

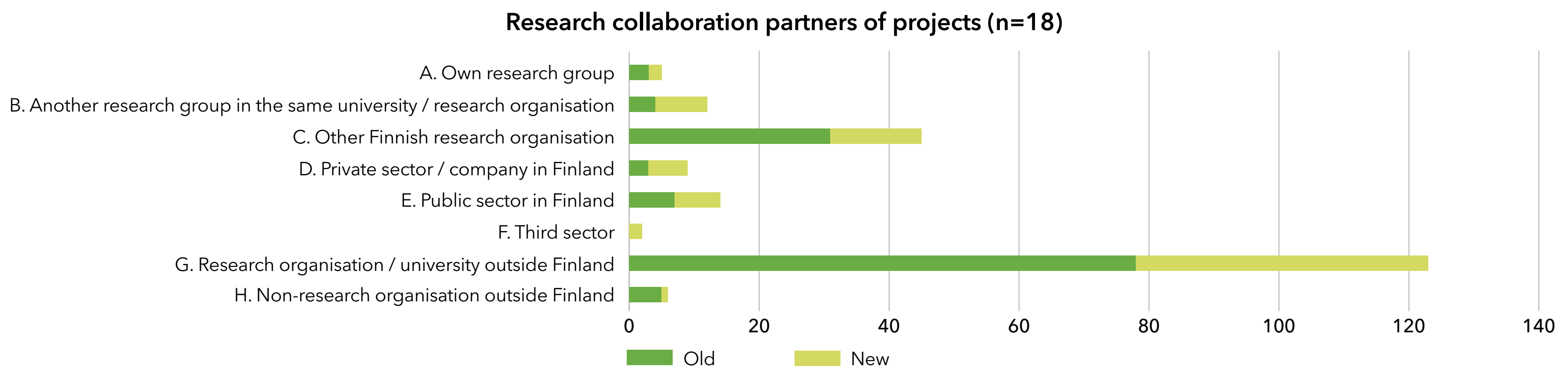

Figure 4. The number of research collaboration partners as reported by projects.

Figure 5 presents the research partners of national research infrastructure projects. Three projects reported a total of 85 research partners that were mostly international research organisations, other research groups in the same research organisation, or other Finnish research organisations. Most of the new partners came from other research groups in the same research organisation or from international research organisations and universities.

The partners of research projects on key areas of the green and digital transition are presented in Figure 6. The projects reported a total of 131 research partners. These partners were mainly research organisations outside Finland and other Finnish research organisations. The largest number of new partners came from international research organisations and universities.

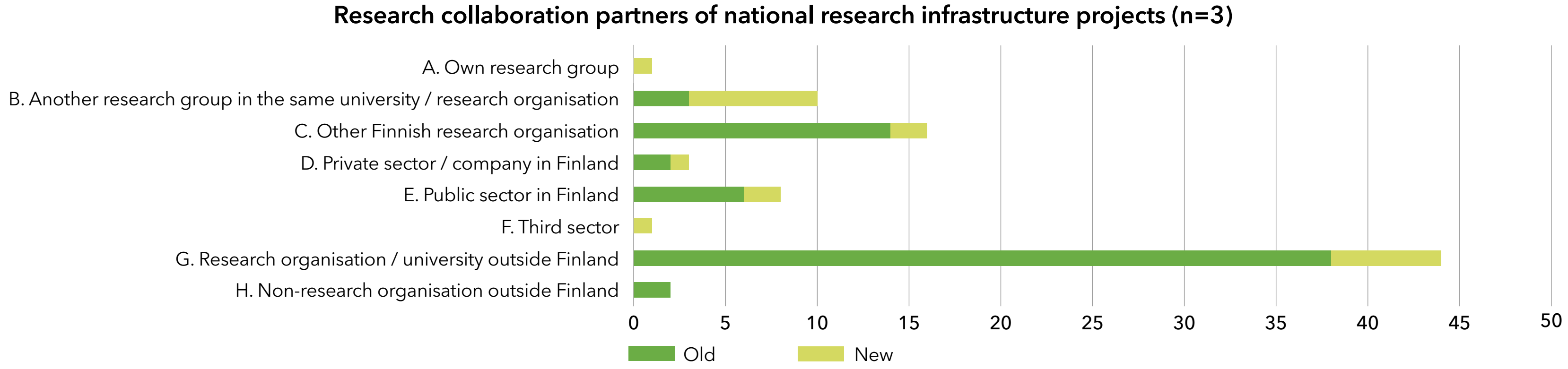

Figure 5. The number of research collaboration partners of national research infrastructure projects as reported by projects.

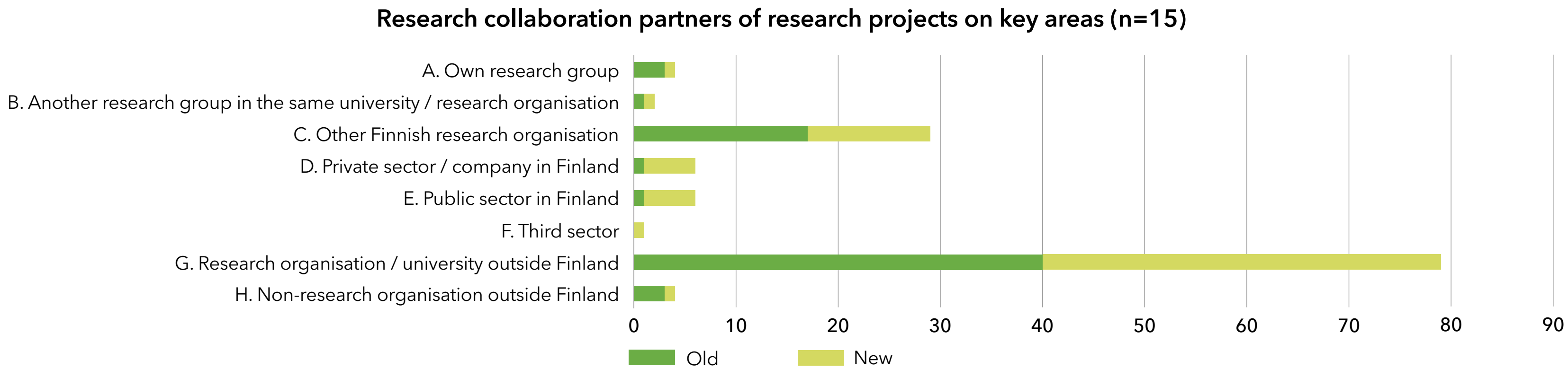

Figure 6. The number of research collaboration partners of research projects on key areas of the green and digital transition as reported by projects.

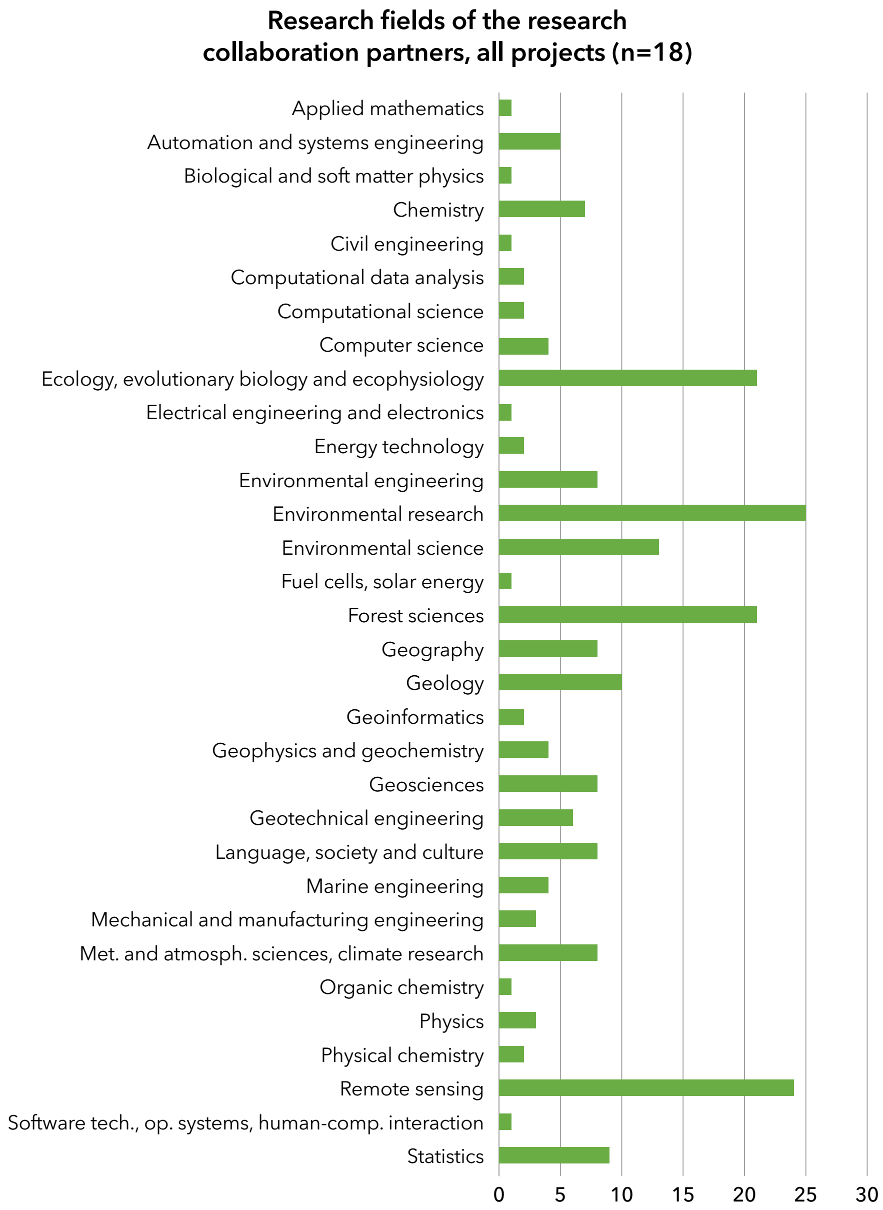

Figure 7. Research fields of the projects' research collaboration partners.

Figure 7 presents the research fields of the 216 research partners in all projects. The projects collaborated extensively in different research fields. In particular, these fields included ecology, evolutionary biology and ecophysiology, remote sensing, forest sciences and environmental research. In the report, one field of research was selected for each partner, even if the collaboration was multidisciplinary.

Figure 8 presents the research collaboration of the projects with partners from EU and non-EU countries. The projects reported a total of 131 international partners. Of these, 65% are from EU countries and 35% from non-EU countries.

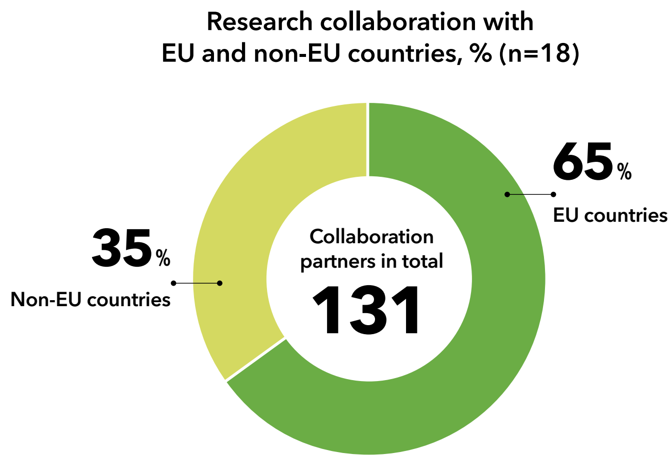

Figure 8. Research collaboration with EU and non-EU countries.

Figure 9 presents the international collaboration with different countries. The most common partner countries are Germany, Sweden, the United Kingdom, the Netherlands and the United States.

International research collaboration with different countries (n=18)

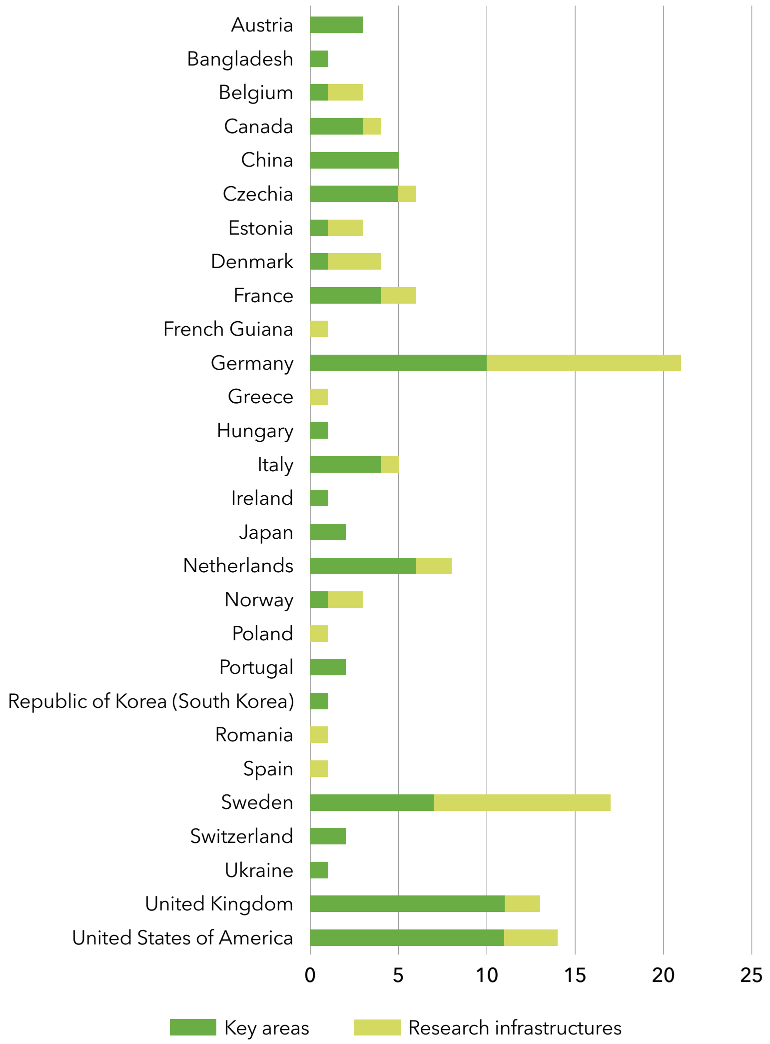

Figure 9. International research collaboration with partners working in different countries.

3.2.2 Mobility in the projects

The projects use the reporting form to provide information on the realised research visits. Short and long research visits are reported separately. The continuous duration of a short-term visit is at least five working days and less than one month. The continuous duration of a long-term visit is at least one month.

Figure 10 presents the short research visits made in the projects. A total of 122 short and 25 long research visits were made. The destination for short-term research visits was mainly outside Finland. The number of research visits to Finland was considerably lower. Both short and longer research visits took place in Finland. A total of five long research visits were made to Finland. One of these was considerably longer than the others (30 months).

Short research visits, number (n=14)

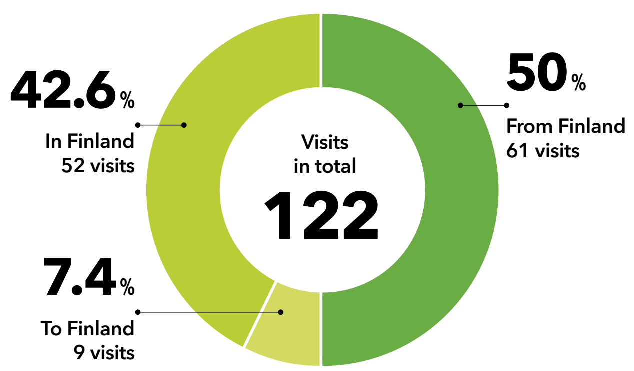

Figure 10. Short research visits reported by the projects.

3.3 Project outputs and results

3.3.1 Publications produced by the projects

The completed research and research infrastructure projects have reported a total of 784 publications. The majority of the publications are peer-reviewed scientific publications. The projects have also published theses and publications targeting professional audiences. Table 3 presents the publications reported by the projects by publication type, and Table 4 by publication type and year.

Tables 3 and 4 present the number of publications reported by the projects. In addition to attribute challenges, the accuracy and comprehensiveness of publication information is affected by factors that include discipline-specific styles of defining authorship, the emphasis on scientific publications in evaluations of research and researchers, the databases and information systems used in the university funding model, other performance indicators and publication information collection, and – especially for non-scientific publications – the researchers' own reporting activity.

Table 3.
Publications reported by the projects by publication type.

A1 Journal article – refereed	475
A2 Review article in a scientific journal	16
A3 Part of a book or another research book	76
A4 Article in a conference publication	159
B1 Article in a scientific magazine	1
B3 Non-refereed article in conference proceedings	5
C1 Separate scientific books	2
C2 Edited books	15
D1 Article in a trade journal	16
D2 Article in professional manuals or guides or professional information systems or text book material	1
D3 Professional conference proceedings	2
D4 Published development or research report or study	5
D5 Textbook, professional manual or guide or a dictionary	2
E1 Popularised article, newspaper article	3
F2 Public partial realisation of a work of art	2
G1 Polytechnic thesis, Bachelor's thesis	5
G2 Master's thesis, polytechnic Master's thesis	7
G5 Doctoral dissertation, article	2
I2 ICT software	1

Table 4.
Number of publications reported by project, by publication type and year.

	2022	**2023**	**2024**	**2025**	**Total**
A Peer-reviewed scientific articles	222	264	191	49	**726**
B Non-refereed scientific articles	1	3	2	0	**6**
C Scientific books (monographs)	9	7	1	0	**17**
D Publications intended for professional communities	16	4	6	0	**26**
E Publications intended for the general public	2	0	1	0	**3**
F Public artistic and design activities	0	2	0	0	**2**
G Theses	1	7	6	0	**14**
H Patents and innovation announcements	0	0	0	0	**0**
I Audiovisual material, ICT software	0	1	0	0	**1**
Total	**251**	**285**	**203**	**45**	**784**

3.3.2 Degrees completed in the projects

Degrees were also completed in research projects on key areas of the green and digital transition. Information about completed degrees is not collected from research infrastructure projects. Fourteen research projects on key areas reported completed degrees.

Figure 11 presents the doctoral and master's degrees completed in research projects on key areas. The projects reported a total of 58 completed degrees, 17 of which are doctoral degrees and 41 master's degrees. In total, 64% of the qualifications were completed by men and 36% by women.

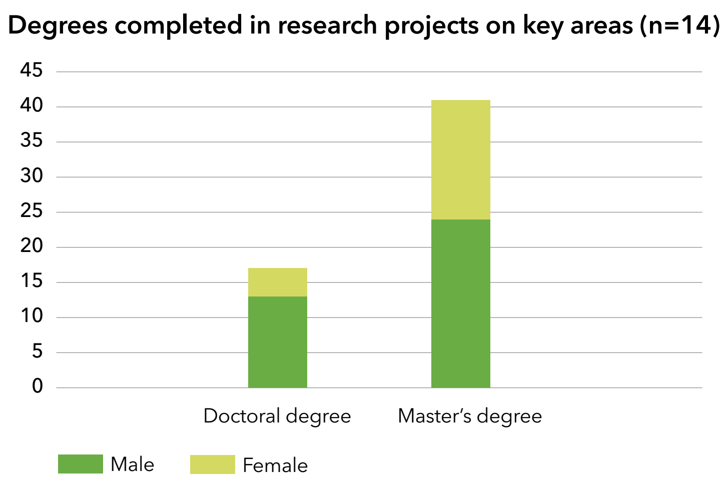

Figure 11. The number of completed degrees as reported by research projects on key areas.

3.3.3 Intellectual property rights resulting from the projects

Both research projects on key areas and research infrastructure projects reported intellectual property rights that were created in the projects. A total of six projects reported intellectual property rights.

Table 5 presents the innovation announcements, design protections and corresponding registrable intellectual property rights resulting from the projects. The projects also resulted in five innovation announcements and one written output. In addition, one research infrastructure project reported 46 intellectual property rights related to the data.

Table 5. Intellectual property rights arising from the projects.

Intellectual property right	Number	Projects
Patent	0	
Patent application	0	
Patent announcement	0	
Innovation announcement	5	MIMIC (2), FlowXAI (2), @Diversity4Forests (1)
Written or artistic output	1	C-NEUT (a case example based on project results for an energy engineering textbook)
Other, for example,	46	FIN-CLARIAH (data)

3.4 Summary

The projects reported a total of 216 research partners, the majority of which were international. New partners came primarily from international research organisations. Extensive cooperation took place in different fields of science, and international collaboration focused on EU countries such as Germany, Sweden and the Netherlands.

In terms of mobility, the projects carried out both short and long research visits, mainly from Finland to other countries. Only a few long visits were made to Finland.

With regard to outputs, the projects reported a total of 784 publications through online services, most of which were peer-reviewed scientific articles. The projects also produced theses, professional publications and digital applications and a total of 53 intellectual property rights. Six projects also resulted in new intellectual property rights, such as innovation announcements and written outputs as well as intellectual property rights related to the data.

4. Achievement of project objectives and impacts

Section 4 deals with the self-evaluation of RRF-funded research and research infrastructure projects and its results from different perspectives. Sub-Section 4.2 examines the activities, results and achievement of project objectives, especially from the perspective of the green and digital transitions. Sub-Section 4.3 analyses the stakeholder collaboration conducted in the projects, both in Finland and in the EU area. Sub-Section 4.4 focuses on RDI collaboration, strengthening of competence clusters and the use of research infrastructures. Sub-Section 4.5 examines the short-term societal impacts of projects. Sub-Section 4.6 describes how the project activities will continue after the end of the RRF funding period. The last part of the section deals with the monitoring and evaluation of project impacts and opportunities for development.

Each sub-section ends with a summary of the key observations in that section.

A sensible and critical approach to the information in the section is recommended. The survey information represents the perspective of the projects well, but the results of the report may have a positive bias. The review will be supplemented with information and views collected from stakeholders in autumn 2025.

4.1 Description of the information

The self-evaluation of the activities, results and impacts of the projects was carried out using a survey for the principal investigators of the consortia. A separate Webropol survey form was prepared for each RRF funding measure (P3C3I2, P3C3I5 and P3C3I6). The survey was a compulsory part of the final reporting in RRF funding projects.

The survey for principal investigators in the consortia involving national research infrastructure projects included 26 questions, and the survey for principal investigators of research projects on key areas of the green and digital transition included 22 questions. The surveys included questions on the following themes: background information, project implementation and the achievement of objectives, stakeholders, strengthening of competence clusters and RDI collaboration as well as societal impact: the green and digital transition and sustainable growth.

The principal investigator was responsible for answering the questions in the form and had to personally respond to the questions assessing the quality of activities on a scale or by selecting one of the options provided. Incomplete forms were returned for completion.

All principal investigators (PIs) of research projects on key areas of the green and digital transition responded to the survey on action package P3C3I2 concerning key areas. Three of the four consortium PIs of national research infrastructure projects responded to the survey on action package P3C3I6 concerning national research infrastructures.

The survey was implemented and filled out in English. The responses from the consortium PIs of research projects on key areas are presented as figures. Since the number of responses for national research infrastructure projects was small (3), the responses have been presented in figures when appropriate.

In addition to the survey material, the information reported by the projects using the Academy's online services reporting form was also utilised in sections 4.4.2 and 4.6.2.

4.1.1 Background information collected in the survey

Consortium PIs of research projects on key areas and national research infrastructure projects were asked whether they already knew the other members of the consortium. Figure 12 describes the level of familiarity with other consortium members prior to the project. Most of the consortium PIs already knew all or most of the consortium members. Four consortium PIs knew one or a few members of the consortium.

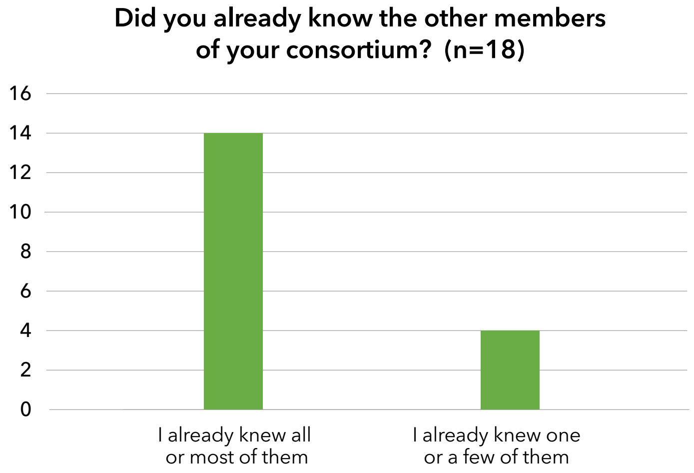

Figure 12. Familiarity with consortium members prior to the project.

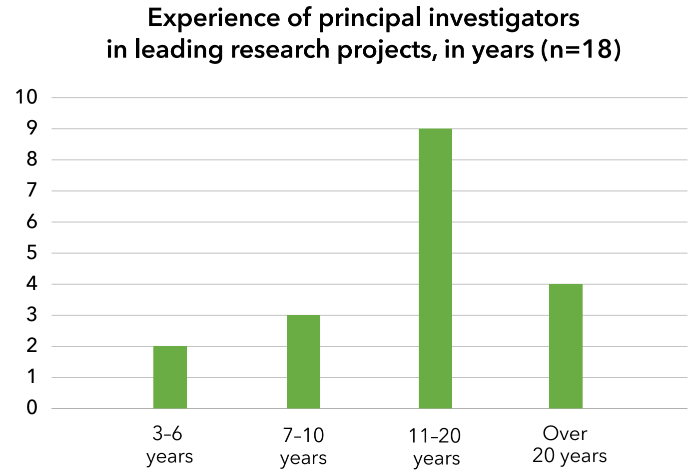

Figure 13. Experience of consortium PIs in leading research projects expressed in years.

Consortium PIs were also asked to report their years of experience in leading research projects. Figure 13 presents the experience of consortium PIs in leading research projects expressed in years. The PIs of consortium projects can be considered highly experienced. Nine had 11–20 years of experience leading a research project, and four had more than 20 years of experience.

Consortium PIs were also asked to report how many of the research projects they led had a target of societal impact. The average score for the responses was 11.2 projects (standard deviation 13.5 and median 7.5). The number of projects ranged from one to 50. Although most of the respondents had led several similar research projects, 25% had significantly less experience of similar projects (3 research projects) and 25% had more experience (over 14 research projects). These numbers do not take into account the leadership of the RRF project examined in the report.

The consortium PIs who responded to the survey also briefly described their background, most significant achievements and experience of leading research projects and coordinating different research entities and centres.

Many of the consortium PIs have several years of experience in research projects funded by different research funders, which have often been multidisciplinary and aimed at achieving societal impact. The principal investigators of the consortia also have experience of leading EU-funded projects, serving as a consortium coordinator and engaging in international collaboration. The respondents also include consortium PIs who have only recently started to accumulate experience of leading research projects.

Some work as specialists in different expert groups and research organisations. Consortium PIs also have experience of legislative work and providing support for decision-making. At least one PI also has experience of company management tasks.

4.2 Project activities, results and achievement of objectives

This section examines the results and the achievement of objectives in research and research infrastructure projects, especially from the perspective of the green and digital transitions. The section analyses how research projects on key areas have promoted sustainable growth, adaptation to climate change, resource efficiency and the strengthening of competence in different sectors. It also describes the measures taken to develop the openness and interoperability of research infrastructures and promote the achievement of the objectives of the Strategy for National Research Infrastructures.

4.2.1 Objectives and results of research projects on key areas

The research projects on key areas described the project objectives and outputs in their survey responses. The project objectives focused particularly on low-carbon solutions for sustainable growth, utilisation of artificial intelligence and AI-based innovations, development of business and industry and knowledge-based decision-making, energy solutions and energy efficiency, autonomous transport, scientific cooperation and method development, societal interaction and impact, and boosting competence. Through these objectives, the projects worked to promote the green and digital transitions, climate change adaptation and carbon neutrality, reduce environmental impacts and support sustainable growth and infrastructure in different sectors.

According to the consortium PIs, the research projects promoted the green and digital transitions and adaptation to climate change by developing and utilising new technologies, such as artificial intelligence, digital twins, unmanned aircraft (drones) and advanced measurement techniques. The projects addressed different sustainable growth challenges and also sought solutions for building a more sustainable future.

The results of the projects are linked to the sustainable use and recyclability of resources, climate change adaptation and environmental protection solutions, development of environmental monitoring and analysis solutions, development and application of computational and digital approaches and methods, development of AI-based solutions, development of modelling and simulation, development of databases and integration of data sources, and strengthening of collaboration and competence.

Appendix 6 presents the objectives of the research projects on key areas in relation to the reported results. The reported results promote the objectives of the green and digital transitions in many ways. Promotion of the green and digital transitions often happens in synergy, as digital solutions can support the objectives of the green transition and vice versa.

4.2.2 Promoting the green and digital transition in research projects on key areas

Research projects on key areas were asked to assess the success of the consortium project in promoting the green and digital transition during the RRF funding period. The survey presented six statements on achieving the key objectives of RRF funding, which were assessed on a scale from 1 to 5 (1 = totally ineffective, 5 = very effective, NS = not suitable, IDK = I don't know).

The projects promoted solutions related to the green and digital transitions and climate change mitigation in different sectors. The responses provided by the projects were mostly similar and there were no significant deviations in the responses. Figure 14 presents the average score for the responses to each statement.

The projects assessed that they had been very successful in producing new scientific knowledge to promote the green and digital transition. The average scores for responses to these statements were 4.60 and 4.67. In terms of promoting the green transition, nine of the projects estimated that the project was very successful in the objective and six estimated that they were reasonably successful in the objective. In terms of promoting the digital transition, 10 projects estimated that they were very successful and five projects estimated that they were reasonably successful in producing new information.

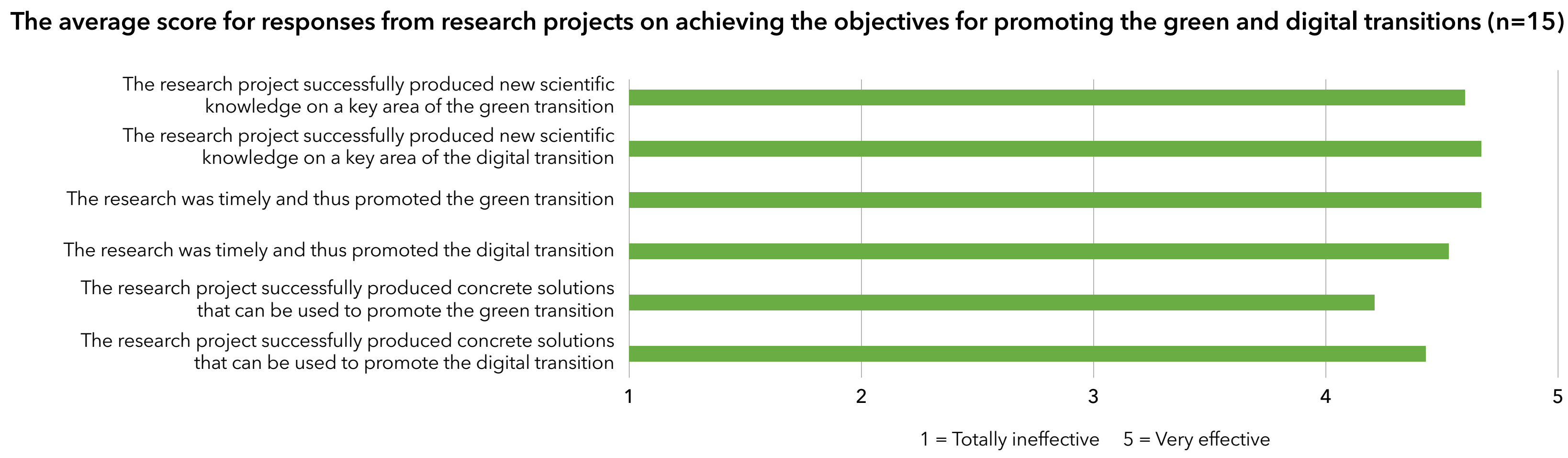

Figure 14. The average score for responses from research projects on achieving the objectives for promoting the green and digital transitions.

The projects estimated that the research was timely and thus contributed to promoting the green and/or digital transition, mainly in a very successful manner. The average scores of self-evaluations for these objectives were 4.67 and 4.53. In terms of promoting the green transition, 10 projects estimated that they were very successful in the timing of research and promoting the green transition. Five of the projects estimated that they were reasonably successful in achieving this goal. With regard to promoting the digital transition, eight projects estimated that they were very successful, and seven projects estimated that they were reasonably successful in achieving the objective.

The projects estimated that they were successful in producing concrete solutions for promoting the green and/or digital transition. Five projects estimated that they were very successful in producing solutions that promote the green transition, seven projects estimated that they were quite successful and two projects reported their success as neither good nor poor. Seven projects estimated that they were very successful and six projects reasonably successful in promoting concrete solutions for the digital transition. One of the projects estimated that the project was neither successful nor unsuccessful. One estimated that producing concrete solutions for the green and digital transitions was not part of the project's objectives. This answer was not included when calculating the average score for responses. The average score for responses was 4.21 for promoting the green transition and 4.43 for promoting the digital transition.

4.2.3 Activities of research infrastructure projects

According to the principal investigators of the consortia, the research infrastructure projects that responded to the survey also successfully promoted the development of research infrastructures during the RRF funding period. The projects focused on the digital circular economy, zero-emission energy solutions and resource efficiency, improving environmental and water security, advanced measurement and modelling technologies, and strengthening competence and collaboration. Open access to infrastructures, remote collaboration and educational opportunities increase the impact potential of research infrastructures.

The FIN-CLARIAH project focused on the green transition and digital circular economy. The research infrastructure enables the reuse of digital data in research, which reduces the need for physical materials and promotes resource efficiency. The Language Bank of Finland and the LUMI supercomputer maintained by CSC – IT Center for Science enable the efficient processing of large amounts of data. LUMI's carbon footprint is negative, and its waste heat provides 20% of the district heating in Kajaani. The services of the FIN-CLARIAH research infrastructure support skill development and multi-location studies. The utilisation of large SSH datasets supports AI-based decision-making to develop better services.

The FINMARI project focused on the green transition and the blue economy. The project laboratories support zero-emission energy systems and climate and environmental solutions. During the funding period, algae biomass cultivation platforms were updated to meet the needs of industrial collaboration, and the project developed state-of-the-art equipment such as a photobioreactor, LED lighting updates and fluorometer devices that support blue growth capacity and open access to the infrastructure. Autonomous measurement instruments improve the number, quality and cost-effectiveness of observations, thus providing support for decision-making and protection measures.

The HYDRO-RI-Platform project focused on water security and environmental monitoring. The project developed autonomous measurement methods, video technologies and optical sensors to monitor the status of water systems and carried out extensive bathymetric surveys using autonomous vessels and LiDAR technology. During the funding period, the project also developed a better carbon model for lakes based on data from the TIETO I research vessel. The research infrastructure enables real-time monitoring of ice conditions and improves water security and navigation. New and updated models improve the anticipation of and ability to respond to water system-related events.

4.2.4 Advancing the openness and interoperability of research infrastructures

All three research infrastructure projects advanced the openness and interoperability of research infrastructures in different ways. The FIN-CLARIAH project emphasised ethical access to data and international interoperability, and the FINMARI project focused on the accessibility of infrastructure and openness of data, especially in marine environment research. The HYDRO-RI-Platform project, on the other hand, combined technical development and collaboration between organisations, which supports the interoperability of both infrastructures and data.

The FIN-CLARIAH project developed an agreement framework that enables access to language materials (text, speech, video) with personal and copyright restrictions for research use. The research infrastructure provides training to advance the processing of open science and ethical research data, which supports the national core curriculum. In addition, FIN-CLARIAH developed the Language Bank Rights (LBR) system, which enables the use of data with restricted access for research purposes. FIN-CLARIAH also participates in the European Open Science Cloud (EOSC) collaboration, which strengthens interoperability internationally.

The FINMARI project applies an "open bench" policy at field stations. This means that the infrastructure can be openly reserved by researchers. The project has developed a service catalogue and a device gallery that makes the infrastructure easier to find and access, also internationally. Transnational access programmes implemented through EU research infrastructure projects have improved accessibility protocols, and the FINMARI Data Working Group has promoted the collection of metadata and the openness of data flows – especially with regard to autonomous measurement instruments and experimental data.

The HYDRO-RI-Platform operates according to the principles of open access and accessibility and open infrastructure, and the project has developed a national hydrological database that combines data from several organisations. The HYDRO-RI-Platform serves as a platform for infrastructure sharing and collaboration between organisations, and the Uomari project is an example of research in which several research institutes and companies test new technologies together.

4.2.5 Supporting the objectives set for research infrastructure projects and the objectives of the Strategy for National Research Infrastructures

The survey for national research infrastructure projects included six different statements related to the key objectives of RRF funding for research infrastructures, assessed on a scale from 1 to 5 (1 = totally ineffective, 5 = very effective, NS = not suitable, IDK = I don't know). Figure 15 presents the average scores for responses to each statement.

The research infrastructure projects that responded to the survey estimated that they had been successful in achieving the objectives set for them. All principal investigators of the consortia fully agreed with the statement that the research infrastructure project improved the conditions for research and innovation that promote the green transition. All of the respondents also fully agreed with the statement that the research infrastructure project contributed to the renewal and development of nationally important infrastructures. The principal investigators agreed to at least some extent with the other statements concerning the achievement of the objectives.

The principal investigators of the consortia were also asked to assess how the research infrastructure project had implemented the objectives of the Strategy for National Research Infrastructures in Finland 2020–2030[9]. The objectives being measured were:

- Promoting the quality, renewal and competitiveness of research
- Strengthening the broad-based impact of research environments
- Increasing the international attraction of the Finnish research, education and innovation system
- Increasing national and international collaboration
- Supporting research-related capabilities and competence upskilling

Success in achieving the objectives set for national research infrastructures (n=3)

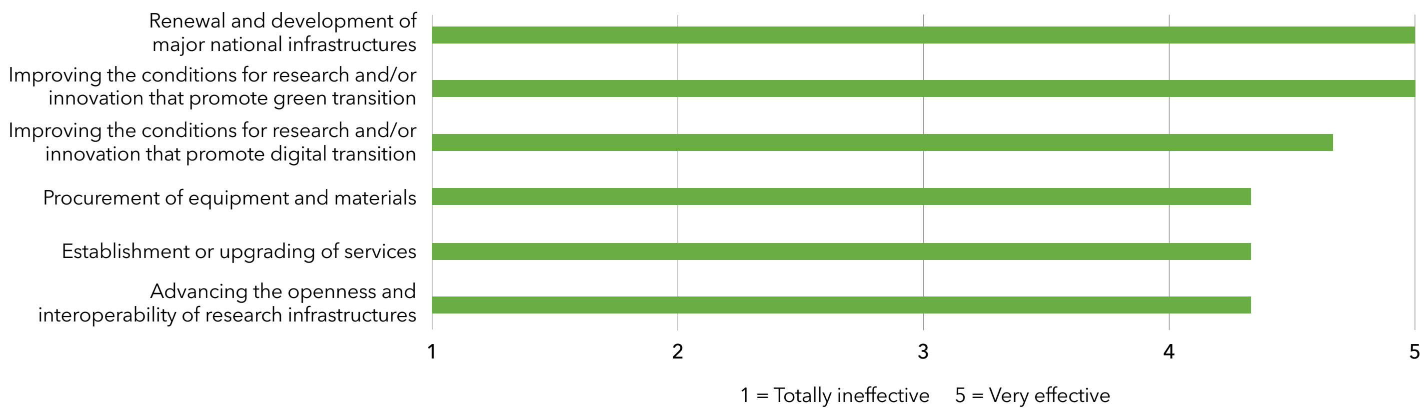

Figure 15. Success in achieving the objectives set for national research infrastructures.

[9] Strategy for National Research Infrastructures in Finland. Research Council of Finland: www.aka.fi/globalassets/2-suomen-akatemian-toiminta/4-julkaisut/julkaisut/kansallisten-tutkimusinfrastruktuurien-strategia-2020-2030.pdf

All the principal investigators of the consortia were in complete agreement (average score 5) concerning the achievement of these objectives, with the exception of the statement on supporting research-related capabilities and competence upskilling. The average score for responses to this statement was 4.66.

The survey also asked the projects to describe the concrete ways in which they promoted achievement of the objectives of the Strategy for National Research Infrastructures during the RRF funding period.

In line with the objectives of the national strategy, the FIN-CLARIAH project promoted the digital transition, strengthening of competence, international collaboration and sustainable development through several concrete measures. The project implemented an extensive Donate Speech campaign and launched the LAREINA project, which is developing a speech interface for large language models (LLMs) in cooperation with industry and the public sector. As a result of LAREINA, Finland joined the Alliance for Language Technologies (ALT-EDIC) in 2024. The project also utilised Open Language Bank resources and used text data to develop Finnish-language LLMs.

In line with the objectives of the national strategy, the FINMARI project promoted sustainable development, the quality and impact of research, and open science through several concrete measures. The project developed the marine research infrastructure by investing in measurement devices and data management, and secured ecosystem services by developing automated measurements to monitor environmental gradients and observe changes in biodiversity. The infrastructure has also been utilised in marine education at universities.

In line with the objectives of the national strategy, the HYDRO-RI-Platform project promoted adaptation to climate change, the competitiveness of research and competence upskilling through many concrete measures. The project renewed the hydrological monitoring network and developed the national network with new technologies that enable measurements that were impossible to perform previously. In addition, the project organised international workshops and promoted the use of mobile infrastructure in EU projects and open access to data and the infrastructure. The HYDRO-RI-Platform also provided support for developing the competence of doctoral candidates and utilising data in studies.

4.2.6 Summary

Both research projects and research infrastructure projects were successful in promoting the key objectives of RRF funding and laying the foundation for a long-term green and digital transition in Finland.

Research projects on key areas produced significant results to promote the green and digital transition by utilising new technologies, such as artificial intelligence, digital twins and advanced measurement methods. The projects were particularly successful in producing new scientific knowledge and timely research and, among other things, developed concrete solutions for sustainable resource use, climate solutions and digital innovations.

Research infrastructure projects, on the other hand, have strengthened research environments and enabled new forms of collaboration and competence upskilling. The projects focused on areas that include the digital circular economy, zero-emission energy solutions, water security and language technologies. They advanced the openness and interoperability of infrastructures and supported the objectives of the Strategy for National Research Infrastructures in Finland 2020–2030 with concrete measures, such as the introduction of new technologies, education and international collaboration.

4.3 Stakeholder collaboration in the projects

This section examines the stakeholder collaboration in research projects on key areas and research infrastructure projects in Finland and the European Union. The aim is to describe the type of stakeholders reached by the projects, the type of collaboration carried out with different sectors and how the projects assessed the impact and added value of their cooperation.

4.3.1 Stakeholders, collaboration and interaction in Finland

The projects answered two questions about their stakeholders in Finland. The projects were first asked to select the Finnish stakeholder groups that they reached from a list of options. The projects were then asked to describe the stakeholders reached.

Research projects on key areas and national research infrastructure projects engaged in wide-ranging and multi-level stakeholder collaboration in Finland, and they reached many companies, authorities, research institutes, organisations, media and citizens. The main stakeholders of the projects in Finland were the research community, companies and industry. Other important stakeholders in Finland were authorities and public administration.

Figure 16 presents the responses of the research projects on key areas for each stakeholder. All of the projects estimated that they had reached Finnish stakeholders. Fourteen projects estimated that they had reached an external research community, 12 projects estimated that they had reached companies and 11 projects estimated that they had reached industry representatives. Ten of the projects reported that they reached authorities, other public administration and media. The stakeholder groups reached by the smallest number of projects were assessed as being other economic actors (6 projects), political decision-makers (5 projects) and individual people or groups (3 projects). One project reported that it had reached stakeholders who were not listed in the responses.

All of the national research infrastructure projects estimated that they had reached research communities, authorities, political decision-makers,

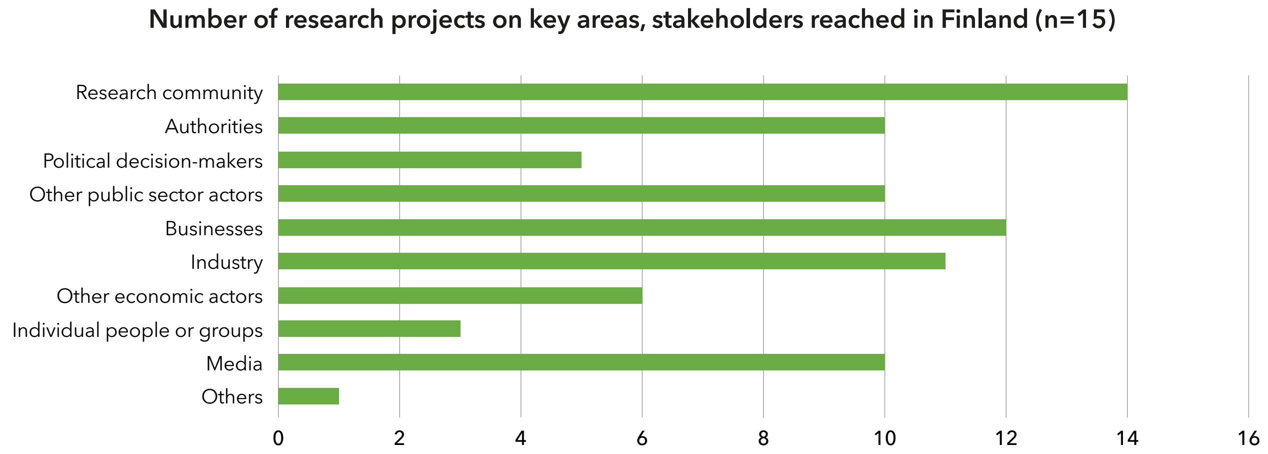

Figure 16. Number of research projects on key areas that reached stakeholders in Finland.

other public administration, companies, industry representatives, individual people and groups, and the media. Two projects estimated that they had also reached other economic actors.

In the open-ended responses, the research projects on key areas and research infrastructure projects reported that they had reached a diverse group of stakeholders in Finland and that they engaged in extensive stakeholder collaboration with different sectors. Research and education collaboration was carried out with different universities and state research institutes. The research collaboration was multidisciplinary and international, and it covered many different fields of research.

Stakeholder collaboration was carried out with industry and companies in particular, and the projects attempted to build collaboration with commercial actors. In many projects, companies participated in technology development, testing or follow-up projects. The companies that were reached included Orion, Huld, Telia, Savox, Viima Aerospace Technologies, ALD Trade, Kelluu, NSION, Arbonaut, Roadscanners Ltd., Suomen Hyötytuuli Oy, Ramboll Finland, WSP, Field, Aari Metsä and Cence Analytics.

Research projects on key areas collaborated with public sector authorities and other public sector actors. These included several ministries (such as the Ministry of Agriculture and Forestry, Ministry of the Interior, Ministry of Defence, Ministry of Transport and Communications), the Emergency Services Academy Finland, Metsähallitus, Finnish Transport Infrastructure Agency, Finnish Transport and Communications Agency (Traficom), ELY Centres, the cities of Helsinki and Vantaa, HSL, Helsinki Region Environmental Services Authority HSY, Finnish Air Rescue Association, Finnish Forest Centre. The collaboration took place in areas that included climate objectives, forest carbon sinks, water resource management and infrastructure security. Some of the projects also reached political decision-makers and participated in the preparation of strategic research programmes (e.g. Water4All SRIA).

The projects also reached various organisations and associations, such as Forestry Management Associations, Central Union of Agricultural Producers and Forest Owners, Emergency Services Academy of Finland, Finnish Association of Fire Officers, and Finnish Geotechnical Society.

Some of the projects also reported that they reached stakeholders through networks, such as the Hinku network, which brings together municipalities, companies, citizens and experts to create and implement solutions to reduce greenhouse gas emissions.

Some of the projects reported that they reached the media. Media participation was extensive, and the projects mentioned the following as examples: MTV, Yle, Tekniikan Maailma magazine, Turun Sanomat and Helsingin Sanomat newspapers. Citizens and non-governmental organisations were reached through online courses, seminars and public events.

In the same manner as research projects on key areas, the research infrastructure projects engaged in stakeholder collaboration with different public sector authorities. Participants in the projects included Metsähallitus, Finnish Border Guard, Finnish Transport and Communications Agency, Finnish Navy, Finnish Heritage Agency, Finnish Food Authority, and Radiation and Nuclear Safety Authority STUK. Regional-level authorities, such as ELY Centres and the regional government, were also involved. One of the projects reported that it engaged in stakeholder collaboration with five ministries, five funding bodies, 10 cities, seven ELY Centres and more than 100 companies in the water sector. Collaboration was also carried out with the private sector and organisations. The following actors participated in and were reached by the projects: Voimalohi, Raisioagro, Keep the Archipelago Tidy ry, Demos and CEMIS Oulu.

The FIN-CLARIAH research infrastructure project made language technology and corpus data part of teaching in schools and universities, and made it easier for citizens to access historical newspapers and for Sámi communities to access their own research data. The project also engaged in business collaboration and supported the introduction of language technology in companies, such as Lingsoft, Kielikone and Script, and served as a mentor and advisor for approximately 50 companies with an interest in language technology.

4.3.2 Stakeholders, collaboration and interaction in the EU area

The projects answered two questions about their stakeholders in the European Union. One of these questions asked the projects to describe the stakeholders reached in the EU. The primary target of stakeholder collaboration in the EU area was the research community, and this was followed by companies and industry.

Figure 17 presents the stakeholders reached in the EU area by research projects on key areas. All of the research projects on key areas estimated that they reached a research community outside their own research project in the EU. The projects reached a smaller number of other stakeholders in the EU than in Finland. Eight projects estimated that they reached industry representatives. Six projects estimated that they reached companies. Five projects estimated that they reached political decision-makers and business actors. Four projects estimated that they reached authorities and media. Two projects estimated that they reached other public administration, and one project estimated that it reached individual people or groups in the EU.

All of the research infrastructure projects reached research communities and authorities. Two of the projects also reached political decision-makers, other public administration representatives, as well as companies and media. One project reached industry, other business actors and individual people and groups.

In the open-ended responses, research projects on key areas reported collaboration with many universities, which also involved researcher mobility, in which researchers visited several different countries. The results of the projects were extensively presented at international conferences, and also published in scientific journals and online publications. International media, such as ChemistryViews and ATL.nu, also interviewed the researchers and highlighted the results of the projects. The results were presented to citizens and non-governmental organisations at events and through open online courses. Efforts were made to promote EU-level impact by participating in Horizon Europe funding calls and, for example, the Water4All partnership network. The projects also interacted with decision-makers at the EU level and visited, for example, the European Parliament.

The FIN-CLARIAH research infrastructure project reported that it participated in European language technology projects, such as the European

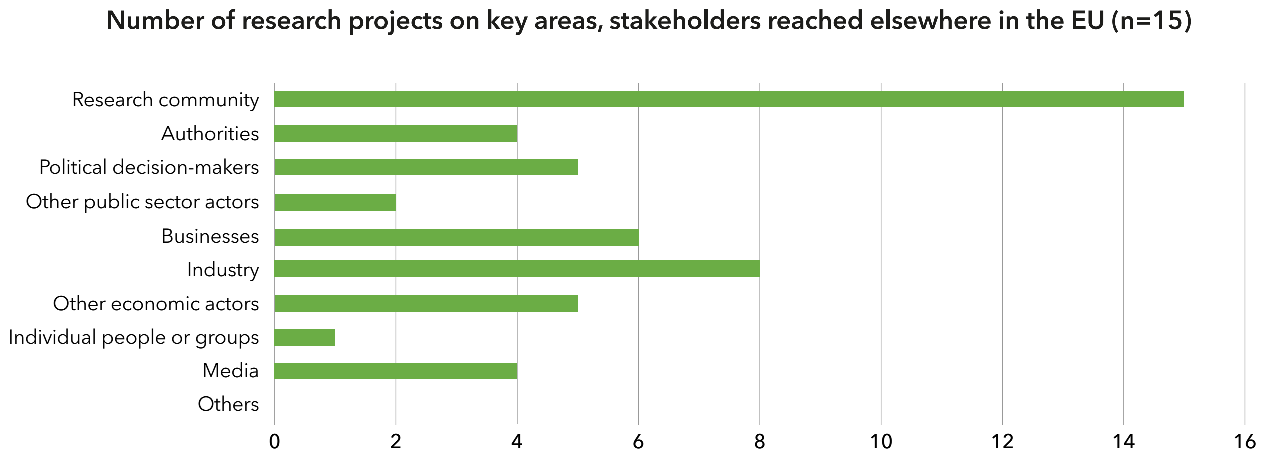

Figure 17. Number of research projects on key areas that reached stakeholders in the EU.

Language Equality project and the ALT-EDIC initiative, which involved collaboration with, among others, the French Ministry of Culture and the European Commission. Close cooperation with CLARIN ERIC and DARIAH ERIC supports research infrastructures in linguistic and humanities research.

Similarly, the FINMARI project served as a national hub for international marine research networks, such as GOOS, EOOS and EuroGOOS, and participated in international projects that include IODP and ECORD, as well as in EU H2020 projects (e.g. JERICO, AQUACOSM, EUROFLEETS+). The project also played an active role in the SUBMARINER network, which promotes the sustainable use of marine resources. The aim of EU-level stakeholder collaboration was to support policy preparation and expert work at the EU level. For example, the FINMARI project participated in EU, ICES and HELCOM expert groups that support, among others, the implementation of the EU Marine Strategy Framework Directive and the Habitats Directive.

Strategic impact and regional collaboration were emphasised in the development of the water sector and in HYDRO-RI-Platform project activities. Through the Water4All partnership, the project mapped more than 150 EU water-related research infrastructures, participated in the EU's Water Oriented Living Lab Atlas 2024 publication and strategy work, and supported the establishment of the MEP Water Group in the EU. The Water4All partnership supports the mapping of water-related research infrastructures in the EU, the sharing of information and the preparation of the EU's Strategic Research and Innovation Agenda (SRIA) for the water sector.

Both research projects on key areas and research infrastructure projects also reported stakeholder collaboration with companies. Research projects on key areas reported collaboration with, for example, Stora Enso, UPM Kymmene, SCA, Ponsse Oyj, John Deere and KPMG. Research infrastructure projects reported partnerships with international companies, such as SILO AI, Tietoevry and Submarine Store.

4.3.3 Success of stakeholder collaboration

The survey also examined the success of stakeholder collaboration in projects. Both research projects on key areas and national research infrastructure projects found that stakeholder collaboration was clearly successful and felt that it provided added value.

The success of stakeholder collaboration on key areas was examined with five statements, which the projects assessed on a scale from 1 to 5 (1 = strongly disagree, 5 = strongly agree, NS = not suitable, IDK = I don't know). The response options also included "not suitable" and "I don't know". These response options were not taken into account when calculating average scores for responses to the questions.

Figure 18 presents the average scores for responses to the statements that were provided by research projects on key areas. Most of the projects estimated that stakeholder collaboration was successful from the perspective of producing new knowledge (average 4.14). Five of the projects strongly agreed with the statement and six agreed somewhat. Three of the projects did not agree or disagree with the statement. One project reported that producing new knowledge was not applicable to stakeholder collaboration in the project.

Nine of the projects felt that they consolidated and simplified the research results to some extent in order to promote utilisation among stakeholders (average 3.92). Six projects somewhat agreed and three projects strongly agreed with the statement. Four of the projects did not agree or disagree with the statement. One project reported that the statement was not applicable to stakeholder collaboration in the project. One project selected the "I don't know" option for the statement.

On average, the projects estimated that they identified the relevant information needs of stakeholders to a certain extent (average 3.92). Four of the projects strongly agreed and five somewhat agreed with the statement. One of the projects disagreed somewhat with the statement. Three of the projects did not agree or disagree with the statement. One project reported that identifying the needs of stakeholders was not applicable to the project activities, and one project was unable to assess this statement.

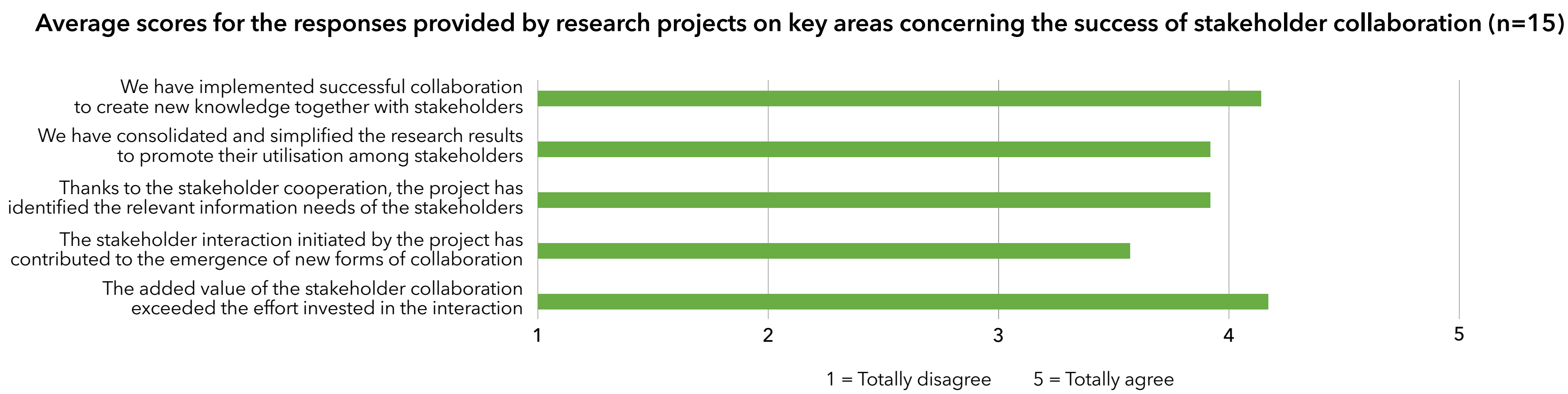

Figure 18. Average scores for the responses provided by research projects on key areas concerning the success of stakeholder collaboration.

On average, the projects estimated that stakeholder interaction contributed to the emergence of new forms of collaboration to some extent (average 3.57). Seven of the projects somewhat agreed with the statement. One project strongly agreed with it. Five projects did not agree or disagree with the statement, while one project could not assess the realisation of the statement. One project estimated that the objective in question did not apply to stakeholder collaboration in the project.

Most of the projects estimated that stakeholder collaboration had produced added value (average 4.17). Four projects completely agreed, six somewhat agreed and two neither agreed nor disagreed with the statement. One project reported that this statement did not apply to the project. Two of the projects were unable to assess whether the added value of stakeholder collaboration exceeded the effort invested in the interaction.

Research infrastructure projects were also asked about the success of stakeholder collaboration. The three infrastructures that responded mostly agreed about the success of stakeholder work. The average scores for responses were as follows:

- We have implemented successful collaboration to create new knowledge together with stakeholders (4.33)
- We have consolidated and simplified the study and/or its results to promote its utilisation among stakeholders (4.00)
- Thanks to the stakeholder collaboration, the project has successfully identified the relevant information needs of the stakeholders (4.67)
- The stakeholder interaction initiated by the project contributed to the emergence of new forms of collaboration (4.00)
- The added value of the stakeholder collaboration has exceeded the effort we invested in the interaction (4.00)

4.3.4 Summary

The projects engaged in extensive and multi-level collaboration in Finland, especially with research communities, companies and industry. Other important stakeholders included authorities, public administration, media and citizens. The collaboration was multidisciplinary and international, and it extended to areas such as technology development, climate objectives and infrastructure security.

Stakeholder collaboration in the EU area emphasised research communities, but also reached companies, industry and authorities. The projects participated in international networks and funding programmes and reached EU-level decision-makers.

The success of stakeholder collaboration was mainly assessed very positively. The projects feel that the collaboration produced new knowledge, supported the utilisation of research results and identified the information needs of stakeholders. The interaction also contributed to the emergence of new forms of collaboration and brought added value to the projects.

4.4 Strengthening of RDI collaboration, competence clusters and competence

This section examines the collaboration projects carried out with different competence clusters, research infrastructures and other RRF-funded projects. It also assesses the impact of the projects on strengthening competence clusters and competence.

4.4.1 Collaboration with competence clusters

The survey used a multiple-choice question to assess the collaboration that research projects on key areas and national research infrastructures carried out with competence clusters. The open-ended responses to the options provided an opportunity to specify the competence cluster with which the project collaborated. The majority of the projects collaborated with flagships and Centres of Excellence (CoE) funded by the Research Council of Finland.

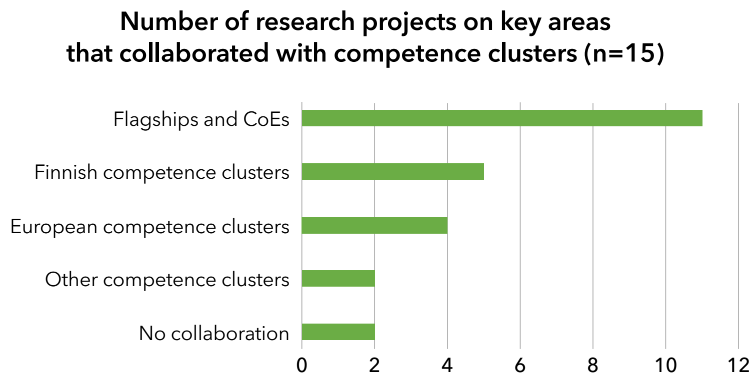

Figure 19. Number of research projects on key areas that collaborated with competence clusters.

Figure 19 presents the collaboration between research projects on key areas and different centres of excellence. Many of the projects collaborated with Finnish flagships or CoEs. Five of the projects also reported collaboration with other Finnish competence clusters. Four projects reported collaboration with European competence clusters. Two projects collaborated with other competence clusters, and two projects did not collaborate with any competence clusters.

Several projects collaborated with the same competence cluster. The following flagships and centres of excellence were mentioned more than once:

- Finnish Center for Artificial Intelligence FCAI (5 projects)
- UNITE (5 projects)
- Atmosphere and Climate Competence Center ACCC (3 projects)
- FinnCERES (2 projects)
- Digital Waters DIWA (2 projects)

All of the research infrastructure projects collaborated with flagships or CoEs. Two of the projects also collaborated with Finnish competence clusters, one with European competence clusters and one with other competence clusters.

4.4.2 Use of research infrastructures in the projects

The survey examined the use of research infrastructures and collaboration with them in research projects on key areas and in research infrastructure projects. The open-ended responses to the options provided the opportunity to specify the research infrastructure in question.

Figure 20 presents the use of research infrastructures and collaboration for research projects on key areas. All of the projects used some of the research infrastructures listed in the question.

All of the projects that responded (n=15) reported using Finnish research infrastructures or their international memberships. Eight of the projects reported using European research infrastructures and three reported using other research infrastructures.

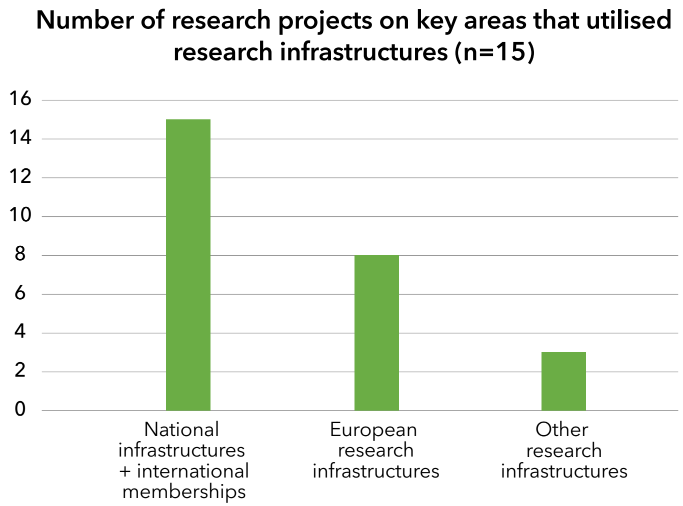

Figure 20. Number of research projects on key areas that utilised research infrastructures.

In the open-ended responses provided by research projects on key areas, the following national and European research infrastructures were mentioned more than once:

- CSC IT Center for Science (9 projects)
- INAR RI (4 projects)
- ScanForest (2 projects)
- FINMARI Finnish Marine Research Infrastructure (2 projects)
- Integrated Carbon Observation System ICOS (3 projects)
- European Long-Term Ecosystem Research eLTER (2 projects)

All of the research infrastructure projects that responded also collaborated with the following infrastructures:

- National infrastructures + international memberships: 3 projects
- European research infrastructures: 3 projects
- Other research infrastructures: 3 projects

Research projects on key areas of the green and digital transition also used the RCF online services reporting form to specify the research infrastructures they used that are included in the Roadmap for Finnish Research Infrastructures and the European Strategy Forum on Research Infrastructures (ESFRI). The projects could also report other research infrastructures that they utilised. Figure 21 presents the national roadmap and ESFRI research infrastructures utilised by the projects.

Seven projects also reported that they utilised other research infrastructures. These are listed in Table 6. They are typically research infrastructures and data from the sites of research.

National roadmap research infrastructures and ESFRI roadmap research infrastructures utilised by the projects (n=15)

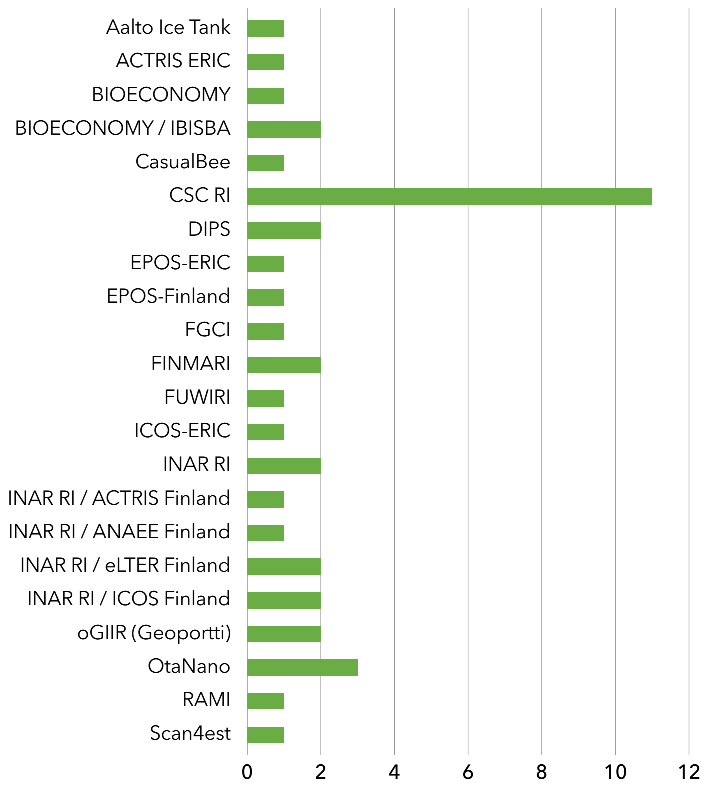

Figure 21. Number of national roadmap and ESFRI research infrastructures utilised by the projects.

Table 6.
Other research infrastructures and data utilised by the projects.

Research infrastructures	■ Hydrological Research Infrastructure Platform ■ Cryosphere Research Infrastructure, CRYO-RI ■ VTT's Mobility and Transport Technology Platform infrastructure ■ Special Equipment Register for Drones ■ HAKKU Service of the Geological Survey of Finland: digital data, reports, maps ■ FMI measurement station network (stations not in ICOS) ■ University of Helsinki tree ecophysiology and aerosol laboratories ■ EuroHPC JU – LUMI supercomputer ■ Aalto Scientific Computing ■ Aalto Materials Digitalization Platform AMAD ■ Aalto University laboratory facilities, including geotechnical laboratory
Data	■ Finnish Environmental Institute hydrological monitoring ■ Finnish Meteorological Institute: Yearly statistics ■ Finnish Meteorological Institute open data, meteorological data ■ Finnish Meteorological Institute hydrological monitoring snow statistics ■ Era5-land hourly data from 1950 to present. Copernicus Climate Change Service (C3S) Climate Data Store (CDS). ■ Soilgrids 2.0 ■ Topographic vector database 1:100k. National Land Survey of Finland. ■ National Forest Inventory data by Luke ■ Data from Long-term experiments in Luke's research forests

4.4.3 Collaboration with other projects funded by the RRF

The survey also examined the collaboration of research projects on key areas and research infrastructure projects with other RRF-funded projects. The projects were asked about collaboration with other RRF projects funded by the Research Council of Finland and with other RRF projects funded by authorities in Finland and Europe.

Figure 22 presents the collaboration between research projects on key areas and other RRF-funded projects. Most of the projects did not collaborate with RRF projects or were not aware that the collaborating project had received RRF funding. The majority of projects that collaborated with RRF projects worked with other RRF projects funded by the Research Council of Finland. One of the projects reported collaboration with an RRF project funded by Business Finland and one with an RRF project funded by other authorities. No project reported collaboration with a project funded in another EU member state.

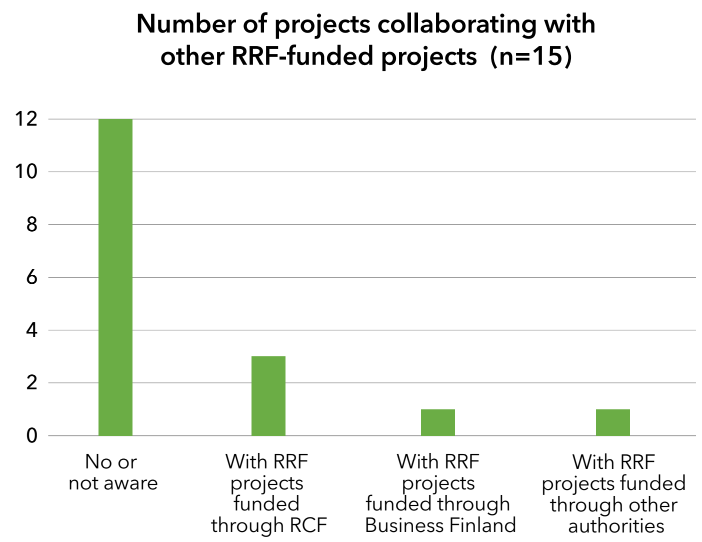

Figure 22. Number of projects collaborating with other RRF-funded projects.

Two research infrastructure projects reported collaboration with an RRF project funded by the Research Council of Finland and one with an RRF project funded by other authorities. One of the projects reported that it had no such collaboration or was not aware that the collaborating project had received RRF funding.

4.4.4 Strengthening of RDI collaboration, competence clusters and competence in research projects on key areas

The survey examined the impacts that research projects on key areas had on RDI collaboration and the strengthening of competence clusters and competence.

Figure 23 presents the average scores for responses provided by research projects on key areas to statements concerning the results and impacts of the projects, which the projects assessed on a scale from 1 to 5 (1 = strongly disagree, 5 = strongly agree, NS = does not apply to the project, IDK = I don't know). The projects estimated that they were most successful in generating new research knowledge and enhancing expertise relevant to strategically important industries in Finland (average 4.60). Ten of the projects strongly agreed and four somewhat agreed with the statement. One of the projects did not agree or disagree with the statement.

The projects estimated that they were also successful in complementing existing European research cooperation initiatives (average 4.62). Eight of the projects strongly agreed and five somewhat agreed with the statement. One of the projects was unable to assess the achievement of this objective, and one project reported that this objective did not apply to the project. The projects estimated that they were successful in promoting established and emerging cross-border European collaborations (average 4.29). Seven of the projects strongly agreed and four somewhat agreed with the statement. Three of the projects did not agree or disagree with the statement. One of the projects reported that the objective did not apply to the project.

The projects estimated that they enhanced the resilience of companies in strategically important industries in Finland (average 3.75). Three of the projects strongly agreed and three somewhat agreed with the statement. Six of the projects did not agree or disagree with the statement. One of the projects was unable to assess the achievement of this objective, and two projects reported that this objective did not apply to the project.

The project assessments of improving the competitiveness of enterprises in the EU show slightly more variation, and three projects were unable to assess the achievement of the objective. The average score for the responses provided by the projects was 3.70. One of the projects strongly agreed and six somewhat agreed with the statement. Two projects did not agree or disagree and one project disagreed somewhat. Two of the projects estimated that this objective was not suitable for the project's activities.

Similar variations can be observed concerning how the projects assessed strengthening of the EU's strategic independence in its relevant industry sectors (average 3.45). Seven of the projects agreed with the statement to some extent. Two of the projects did not agree or disagree and one project disagreed somewhat. Two of the projects were unable to assess the achievement of this objective, and two projects reported that this objective did not apply to the project.

Approximately half of the projects (eight projects) did not agree or disagree with the statement on improving the recovery of society, industry and companies, and one of the projects disagreed somewhat. Two of the projects strongly agreed and three somewhat agreed with the statement. The average score for the responses was 3.38. One project was unable to assess the achievement of this objective, and one project reported that this objective did not apply to the project.

The responses of projects to the statement on fostering new business operations showed the greatest variation (average 2.90). Two of the projects reported that they strongly disagreed with the statement and six projects did not agree or disagree. One project strongly agreed and one

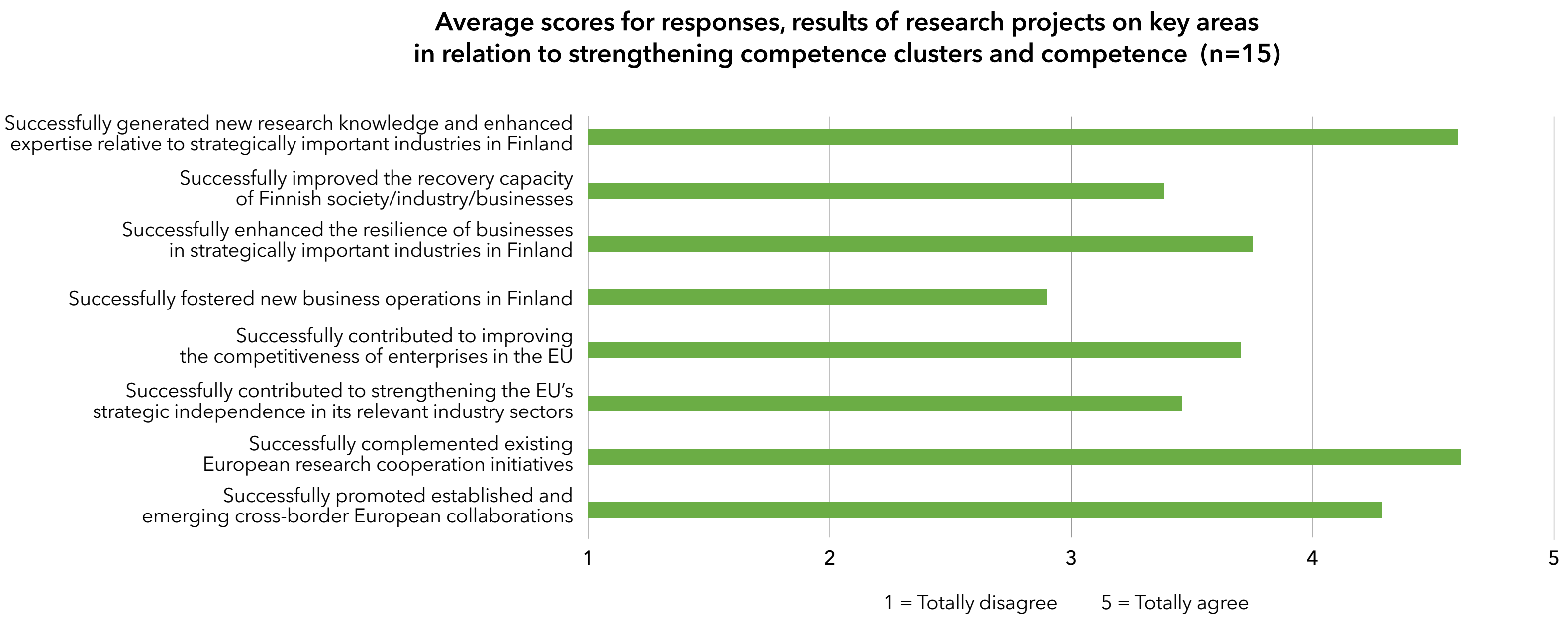

Figure 23. Average scores for responses, results of research projects on key areas in relation to strengthening competence clusters and competences.

somewhat agreed with the statement. Four projects were unable to assess the achievement of the objective. One of the projects estimated that the objective did not apply to the project in question.

Research projects on key areas were also asked to describe the concrete ways in which they strengthened competence clusters and promoted RDI collaboration. The key ways were

- the creation and expansion of new competence clusters,
- use of flagships and national infrastructures,
- multidisciplinary collaboration and combining competence,
- international collaboration and networking,
- industrial collaboration and commercialisation, and
- education and development of competence.

For example, the FlowXAI project formed a new competence cluster around flow battery technology, which was not part of previously identified competence clusters. The development has led to a Centre of Excellence application and new EU projects. The MIMIC project, on the other hand, created a new kind of multidisciplinary competence cluster by combining molecular-level imaging, machine learning and quantum simulation.

FireMan is a good example of a project that integrated with several flagships (UNITE, 6G, FCAI, FAME, DIWA). This enabled the dissemination of research results and the development of new forms of collaboration. The C-NEUT project used data from the INAR RI infrastructure and developed modelling frameworks in the ACCC flagship collaboration. The Diversity4Forests and Green-Digi-Basin projects operated in the UNITE and DIWA flagships and strengthened their competence clusters. The Green-Digi-Basin project was involved in establishing a national water cluster network and the Freshwater Competence Centre (FWCC) competence cluster, which provided the foundation for the DIWA flagship project.

Several projects reported that they brought together experts from different disciplines, which increased the projects' ability and readiness to solve complex problems and create new collaboration networks. Projects like Green-Digi-Basin and WindySea also expanded their collaboration to international networks (e.g. RESIST, Water4All, DestinE). This strengthened the international dimension of competence clusters.

Several projects reported that they promoted technology transfer and commercialisation. For example, the FireMan project described how it engaged in active collaboration with industry via two projects funded by Business Finland. The supports the transfer of competence into practice.

Students and early-career researchers actively participated in the activities of several projects. This is considered to strengthen future competence clusters. The projects also invested in doctoral education and postdoc recruitments. According to the projects, this has expanded the expert base and ensured the continuity of competence.

Example box 1 highlights three projects and describes how they strengthened competence clusters and RDI collaboration.

Example Box 1. Strengthening of competence clusters and RDI collaboration in three projects.

The role of the FireMan project in strengthening competence clusters and RDI collaboration during the RRF funding period

During the RRF funding period, the FireMan project played a key role in strengthening competence clusters and promoting RDI collaboration. This involved active participation in leading research flagships, innovation networks and industry stakeholders.

Within the framework of the UNITE flagship, FireMan's research results were presented at internal and stakeholder events, which contributed to the cross-disciplinary exchange of information. Interaction activities successfully integrated FireMan's development work related to autonomous wildfire management and autonomous technologies into discussions on digital forestry and environmental monitoring. A concrete result of the collaboration was the DRONE4TREE Proof of Concept project funded by the Research Council of Finland, which further strengthens the cooperation between FireMan and UNITE.

FireMan worked with the 6G flagship to promote research on non-terrestrial networks (NTNs), with a particular focus on UAV applications. The project furthered understanding of UAV communication requirements and identified the most promising technologies for seamless connectivity in emergency situations. FireMan also actively participated in the activities of the FCAI flagship, disseminating key information on AI-based drone autonomy by means of presentations and blog posts. Collaboration with the FAME flagship led to a doctoral dissertation project related to the flagship in its doctoral education pilot. This will contribute to ensuring the continuity of competence and strengthening research collaboration in the field of autonomous systems.

FireMan also participated in the Digital Waters (DIWA) flagship, which was launched in 2024. The principal investigator of FireMan serves as the leader of the work package in DIWA, and the autonomous real-time drone technologies it developed are utilised in DIWA's digital twin systems. FireMan's contribution will continue through two ongoing doctoral dissertations in the DIWA doctoral education pilot.

FireMan also collaborated with several of the Research Council of Finland's RRF-funded projects, such as Aeropolis, MULTIRISK, RoboMesh and MRAT-SafeDrone (CWC).

The FUAVE network has played a key role in disseminating FireMan's research results to the general public, and it contributes to ensuring that the project results reach key stakeholders in terms of UAV research, policy and applications.

In addition to academic research collaboration, FireMan was actively involved in two Business Finland projects related to RRF. The Drolo 2 project is coordinated by VTT and focuses on the development of autonomous drone logistics. The 6G-SatMTC project is also coordinated by VTT in cooperation with CWC. The project studies satellite-based 6G communications solutions.

Through these initiatives, FireMan has strengthened Finland's RDI ecosystem, promoted autonomous drone technologies and established long-term partnerships that support continuous innovation in AI, connectivity and crisis management.

The MIMIC project strengthened competence clusters and research collaboration in a multidisciplinary manner

The MIMIC project strengthened competence clusters and promoted research collaboration in several concrete ways. MIMIC promoted multidisciplinary collaboration, increased research capacity and supported strategic priorities, thus strengthening both competence clusters and the global research field.

The project combined molecular scanning probe microscopy (SPM), machine learning (ML) and quantum simulations and created a multidisciplinary framework to address complex challenges. The approach strengthened collaboration between experts in nanotechnology, computational chemistry and artificial intelligence, and contributed to building a common knowledge base.

The development of a new workflow that combines ML energy sampling, ML potentials and quantum simulations required close collaboration between computational researchers and experimental researchers. This synergy created a collaborative competence cluster where methods were developed, tested and refined interactively.

The project also promoted the technological competence of research institute partners by introducing state-of-the-art SPM technologies and ML analytics. University researchers, on the other

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hand, gained access to practical applications and received feedback to develop their methods.

The young researchers, postdoctoral researchers and post-graduate students involved in the project received multidisciplinary training. This increased the number of experts in molecular imaging, machine learning and sustainable materials science. Workshops and seminars organised by the project disseminated knowledge among the participating organisations and strengthened competence clusters.

The project results were shared through co-publications, conferences and collaborative research. The dissemination of the results has strengthened international research networks in the fields of sustainable materials, nanotechnology and artificial intelligence.

The project supports the promotion of the green and digital transitions and is in line with global priorities, such as sustainable development and digital innovation. The project strengthened its position in competence clusters, such as the FinnCERES flagship. MIMIC has positioned itself as a key project in these networks by solving challenges related to materials characterisation at the molecular level.

The Green-Digi-Basin project promotes water research competence clusters and international RDI collaboration

The Green-Digi-Basin project strengthened competence clusters and RDI activities in several ways.

The project used multidisciplinary approaches by combining novel technologies and smart solutions to solve water resource management challenges. By creating digital twins for river basins, the project furthered next-generation modelling research in flowing water environments.

The project collaborated with a large group of stakeholders, which made it possible to share resources and competence with different sectors. Cooperation with international researchers, such as the RESIST and Water4All projects, has expanded the impact of Finnish water research and promoted the adoption of best practices on a global scale.

The project team will also continue its work in the DIWA flagship and DIWA doctoral education pilot, both of which recently received funding to train new-generation water researchers. The team will also continue to develop the digital tools launched in the project. The DIWA flagship recently hired approximately 60 new doctoral candidates, 20 new postdoctoral researchers and several experienced researchers. The team has expanded to three universities and three research institutes that collaborate in DIWA. This will make it possible to utilise the extensive international network that these organisations and approximately 150 researchers bring with them, and also enable collaboration with the business sector and organisations like the Finnish Water Forum.

4.4.5 Strengthening RDI collaboration, competence clusters and competence in research infrastructure projects

The survey also examined the impacts of research infrastructure projects on RDI collaboration and the strengthening of competence clusters and competence.

The impact of national research infrastructure projects was examined by means of eight statements assessed on a scale from 1 to 5 (1 = strongly disagree, 5 = strongly agree). According to their assessment, all of the projects developed the conditions for research and enhanced expertise relevant to strategically important industries in Finland (average 5.00) and complemented existing European research cooperation initiatives (average 5.00). The projects also promoted established and emerging forms of European cross-border collaborations (average 4.66) and contributed to fostering new business operations in Finland (average 4.00).

On average, the project responses for the other statements were neutral. The averages for the statements were as follows:

- Improved the recovery capacity of the Finnish society/industry/companies affected by economic challenges: 3.66
- Enhanced the resilience of companies in strategically important industries in Finland: 3.33

- Contributed to improving the competitiveness of enterprises in the EU: 3.33
- Contributed to strengthening the EU's strategic independence in its relevant industry sectors: 3.00

The research infrastructure projects were also asked to describe concrete ways in which they strengthened competence clusters and promoted RDI collaboration. The FIN-CLARIAH, FINMARI and HYDRO-RI-Platform projects all described different concrete methods.

The FIN-CLARIAH project focused on developing language technology and language research infrastructure in five modules. RDI collaboration played a key role in this process, especially in terms of developing research methods and technologies. The modules support different areas of language technology and data science, which strengthens competence in these fields. Metadata harmonisation and open data services promote interoperability, accessibility and open sharing of information and data between different actors.

The FINMARI project developed and provided other actors with access to research infrastructure (e.g. vessels, field stations, laboratories) and services (e.g. data services, expert services, calibration services) for a wide range of users (including researchers, authorities, companies, citizens). The infrastructure was used for joint research, harmonisation of methods and teaching, while the experimental biotechnology facilities in the project supported the circular economy and green energy. The versatility of services and the wide range of users strengthened the marine research competence cluster. The project also participated in EU research projects that involved 160 partners and led to the creation of an extensive European collaboration network.

The HYDRO-RI-Platform project tested new water research sensors and produced new data aimed at understanding the impacts of climate change and hydrology while also strengthening environmental competence related to boreal and sub-Arctic bodies of water. The project collaborated with the CRYO-RI (RRF), Green-Digi-Basin (RRF) and VISIO projects. The research infrastructure joined the EU's Water-Oriented Living Lab network and was selected for the EU's WOLLs Atlas. The project also established a national water cluster network and the Freshwater Competence Centre (FWCC) competence cluster. FWCC served as the foundation for the DIWA flagship project and has organised regular seminars with different stakeholders.

4.4.6 Summary

Both research projects on key areas and research infrastructure projects estimated that they strengthened RDI collaboration and competence clusters in a versatile manner. The majority of the projects collaborated with flagships and Centres of Excellence (CoE) funded by the Research Council of Finland. The collaboration focused on the FCAI and UNITE competence clusters, which were mentioned in the responses from five projects. ACCC, FinnCERES and DIWA were also mentioned in several responses. All of the research infrastructure projects collaborated with flagships or centres of excellence.

The use of research infrastructures was extensive, and all research projects on key areas utilised Finnish research infrastructures or their international memberships. Research projects on key areas mentioned that they had made the most use of the following infrastructures: CSC, INAR RI, ICOS and eLTER. Research infrastructure projects also made versatile use of infrastructures and participated in European networks.

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Collaboration with other RRF-funded projects was limited. Most of the projects did not collaborate with RRF-funded projects or did not know the source of funding in the collaborating project. The largest amount of collaboration was with other RRF projects funded by the Research Council of Finland.

Research projects on key areas felt that they were particularly successful in generating new research knowledge and enhancing expertise relevant to strategically important industries in Finland, as well as complementing European research collaborations. By contrast, the impacts on fostering new business and on the recovery capacity of society were assessed as being smaller.

The projects described concrete ways of strengthening competence clusters, such as forming new clusters and strengthening existing ones, utilising flagships and infrastructures, multidisciplinary collaboration, international networking, industrial collaboration and education.

The research infrastructure projects estimated that they particularly contributed to improving the conditions for research and enhancing expertise in Finland, as well as complementing European cooperation initiatives.

4.5 Short-term societal impacts

This section deals with the short-term societal impacts of research projects on key areas and national research infrastructure projects, which were examined by means of a survey.

4.5.1 Short-term societal impacts of research projects on key areas

The survey examined the short-term impacts that research projects on key areas had on research and society. The principal investigators for research projects on key areas were asked to assess the short-term societal impacts of the project in different areas. For each area, the projects assessed whether the project had a major or minor impact. If the project assessed the impact as major, it was asked to provide concrete examples of the impacts. All projects responded to the question (n=15). As it was possible for the project to respond that the impact was both minor and major in each area, the number of responses varies for each area.

Figure 24 presents the assessments of the research projects on key areas concerning their short-term impacts in different areas. The projects estimated that they had the greatest short-term impact on enabling research and producing technological innovations. All of the projects estimated that the project had an impact on these areas. With regard to enabling research, 14 projects estimated that the impact was major, and only one project estimated that the impact was minor. In terms of producing technological innovations, 12 projects estimated that the impact was major and three projects estimated that the impact was minor.

The next highest impact of the projects was on policy support, raising public awareness, education and skill development. In terms of policy support, nine projects estimated the impact to be major and five estimated it as minor. One of the projects estimated that it had no impact on policy support. Seven projects estimated that the impact on raising public awareness was major and eight estimated that the impact was minor. Nine projects estimated that the impact on education and skill development was major, and five projects estimated that the impact was minor. One of the projects estimated that it had no impact on education and skill development.

Twelve projects estimated that the project had some impact on both community engagement and the transformation of industries. Five of these projects estimated that the impact on community engagement was major and seven projects estimated that the impact was minor. Seven projects estimated that the impact on raising the transformation of industries was major and five estimated that the impact was minor. Three projects estimated that the project had no short-term impact on community engagement and the transformation of industries.

Nine projects estimated that the project had a major impact on building resilience and adaptation, while four projects estimated that the impact was minor. Two projects estimated that the project had no impact on that area. Four projects estimated that the project had a major impact on economic development and market shifts, while nine projects estimated that the impact was minor. Two projects estimated that the project had no impact on economic development and market shifts.

Two projects estimated that the impact of the project on equity and inclusion was major, and 11 projects estimated that the impact was minor. Two projects estimated that the project had no impact on that area. Five projects estimated that the project had other societal impacts. Four of those projects estimated the impact was minor and one estimated that the impact was major.

4.5.2 Short-term societal impacts of research infrastructure projects

The survey examined the short-term impacts that national research infrastructure projects had on research and different areas of society. Figure 25 presents the short-term impacts of the projects. For each area, the projects assessed whether the project had a major or minor impact. If the project assessed the impact as major, it was asked to provide concrete examples of the impacts.

The activities of the projects had an impact on all the areas in question in the short term. All the projects estimated that their activities had at

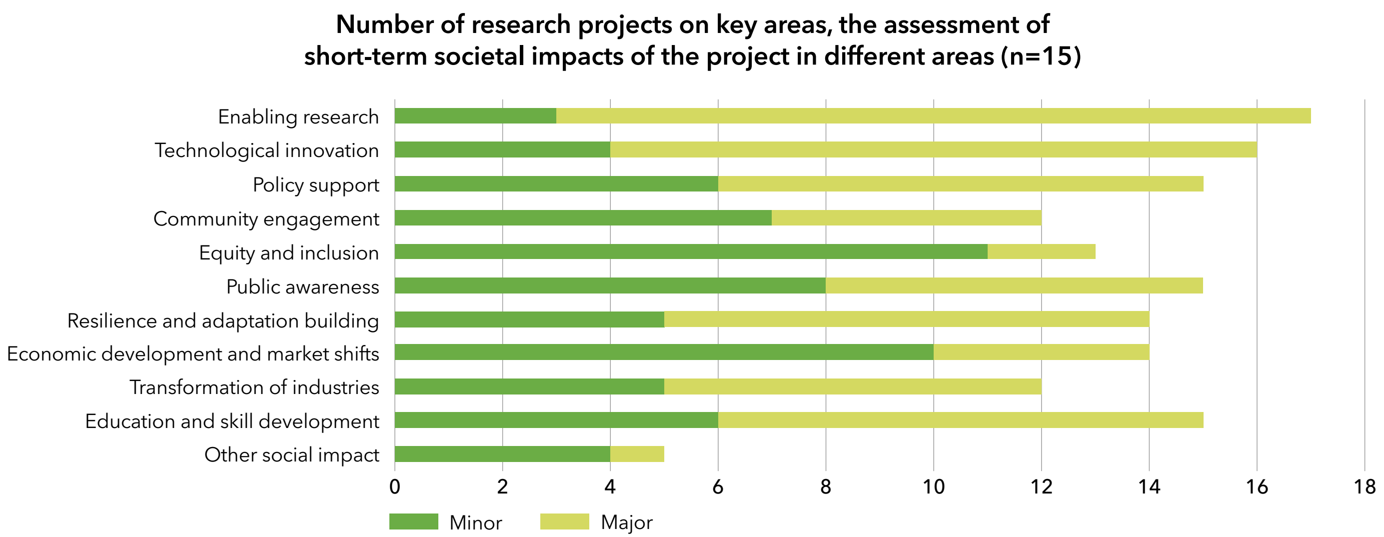

Figure 24. Number of research projects on key areas, the assessment of short-term societal impacts of the project in different areas.

least some impact on enabling research, community engagement, equity and inclusion, economic development and market shifts, as well as on education and skill development.

At least one of the three projects estimated that their activities had a major impact on enabling research, technological innovations, policy support, community engagement, equity and inclusion, increasing public awareness, economic development and market shifts, as well as education and skill development.

Two of the projects also estimated that the project's activities had a minor impact on building resilience and adaptation, and the transformation of industries. In addition, two of the projects estimated that the project activities had other societal impacts.

The research infrastructure projects were also asked to describe concrete ways in which the project contributed to achieving the objectives of the National Recovery and Resilience Plan and the Sustainable Growth Programme for Finland. All of the research infrastructure projects reported that the experiences gained and the new and strengthened partnerships lay the foundation for new green and digital transition projects and other cooperation initiatives. This simultaneously strengthens the long-term impact of the national RRF plan and the Sustainable Growth Programme.

The FIN-CLARIAH project particularly supports the objectives of the digital transition and increasing the level of competence. It provides large language datasets for developing artificial intelligence and machine learning innovations, which improves the international competitiveness of Finnish research groups and the software sector. Collaboration with Technology Industries of Finland and FCAI brought the research close to industry and commercial application. The project reported that it developed language resources to support commercial AI research, collaborated

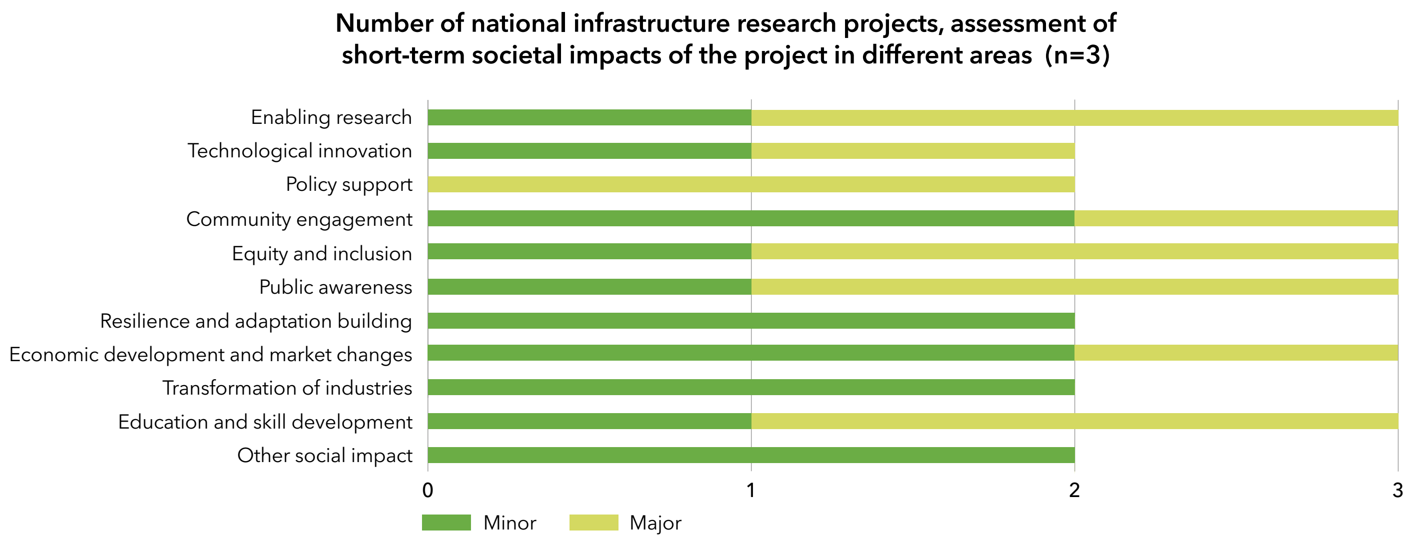

Figure 25. Number of national infrastructure research projects, assessment of short-term societal impacts of the project in different areas.

with companies to develop new language technology applications, promoted the use of an open term tank (e.g. HTB) in commercial learning environments and translation services, and used resources to implement the Accessibility Directive (e.g. automatic speech and video commenting). The project also promoted the strengthening of competence by training new experts in language technology and data analytics, who are particularly needed to meet automation needs in industry.

The FINMARI project particularly supported the objectives of developing the green transition, the circular economy and environmentally friendly technology and strengthening the related RDI activities. The project developed methods for using wastewaters from fish farming to cultivate microalgae. Microalgae are used to produce fish feed. This supports nutrient recycling and reduces environmental loading. The project also developed a cost-effective fungal-based treatment solution that converts wastewater from the food industry into biomass. This removes nutrients from the wastewater, simultaneously reducing environmental impacts. The project activities involved the use of collaboration networks (e.g. the EU SAFE project). This contributed to strengthening international and national research collaboration in the green transition area. The solutions developed by the project are directly applicable to industry, which supports the creation of sustainable business.

The HYDRO-RI-Platform project supports the objectives of the green transition and climate resilience. It enabled large-scale and mobile monitoring of water quality, which supports the assessment of environmental status and modelling the impacts of climate change. The project developed mobile and fixed measurement systems (e.g. drones, underwater devices, cameras), collaborated with companies and universities in solutions related to nutrient recycling and wastewater treatment, and enabled real-time hydrological monitoring and modelling. The collaboration between research institutes and companies resulted in high-quality publications and the co-creation of technology. The project supported the commercialisation of research-based environmental solutions and enabled more detailed scenarios of climate change impacts, especially in northern regions.

4.5.3 Summary

The projects on key areas reported significant impacts, especially related to enabling research and producing technological innovations. Policy support, raising public awareness, education and skill development were also highlighted as key areas of impact. The projects also estimated that they had impacts on community engagement, transformation of industries, building resilience and adaptation, and economic development. The impacts on equity and inclusion were smaller.

The research infrastructure projects estimated that their activities had an impact on all the areas in question. The impacts on enabling research, technological innovations, policy support, community engagement, equity and inclusion, as well as education were particularly emphasised. The projects also described a number of concrete ways in which they supported the objectives of the National Recovery and Resilience Plan and Sustainable Growth Programme for Finland, such as the digital and green transition, strengthening competence and commercialising research-based solutions.

4.6 Future efforts to advance activities and research related to sustainable growth and the green and digital transition

This section examines the continuation of research projects and research infrastructure projects after the end of the RRF funding period.

4.6.1 Continuation of research in research projects on key areas

Research projects on key areas of the green and digital transition used an e-services reporting form to describe the continuation of research after the end of the project. All research projects on key areas reported that the research in these projects will continue. In most cases, the research will continue in the same research group.

The survey also examined in more detail the continuation of activities to promote the green and digital transitions in research projects on key areas and research infrastructure projects.

Figure 26 presents the continuation of activities to advance the green and digital transitions in research projects on key areas. All research projects on key areas (n=15) responded that their activities to promote sustainable growth, the green transition and the digital transition would continue in at least some way.

With the exception of one project, all the projects reported that they had applied for new funding and that they had started or planned to start new research collaborations. Thirteen projects reported that they would continue the research collaboration initiated in the RRF project and 13 reported that they had started or planned to start a new European collaboration. Twelve of the projects reported that they had already received new funding to continue their activities, and 12 projects indicated that they had started or planned to start new business collaborations. Eleven projects reported that they would continue the business collaboration initiated in the project, and 10 projects indicated that they would continue the European collaboration initiated in the project.

The survey also requested a more detailed description of how the activities would continue. All the projects on key areas described their future plans.

Promoting sustainable growth and the green and digital transition will continue and expand in multidisciplinary national and EU projects, and

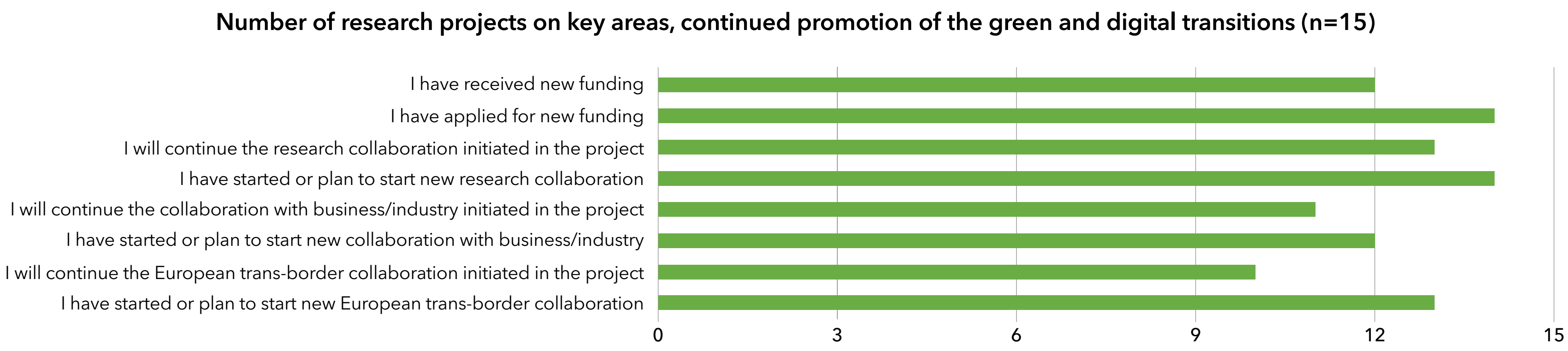

Figure 26. Number of research projects on key areas, continued promotion of the green and digital transitions.

many projects plan to continue supporting green technology development and climate change mitigation objectives in the future. For example, several research groups will continue their work in EU projects (e.g. Horizon Europe, EDF, RRF) and are planning new research projects. One focus for further projects is the interaction between wind power and ice conditions in the Baltic Sea. The impact that forests and the atmosphere have on each other will also be studied using new cost-effective methods, and the development of hybrid solar fuel cells will continue. Funding applications related to AI and drone technology are pending.

Several projects will also continue to utilise digital twins to model the environment and support decision-making. AI will also be widely applied, for example, to promote green technology, forecast the catalytic properties of materials and develop SPM guidance in cooperation with instrument manufacturers.

The descriptions also emphasise close collaboration with industry and international research organisations and networks. In the future, collaboration will be conducted at least with research organisations in Sweden, the Netherlands and Italy.

4.6.2 Continuation of activities in research infrastructure projects

Based on the survey responses submitted by national research infrastructure projects, all these projects will continue to promote sustainable growth and the green and digital transition in the future.

The FIN-CLARIAH project will continue in at least two new projects. The LAREINA project is currently in progress, and a new Business Finland leading company project is being planned. The aim of the OpenEuroLLM project, on the other hand, is to develop large language models for official EU languages and key partners. The objective is to create reusable models for industrial use.

Activities in the FINMARI project will continue, and the research infrastructure will keep promoting networking with the private sector in order to accelerate technological innovations and strengthen Finland's competitiveness. One example of this is the international SUBMARINER network, which aims to develop the sustainable use of marine resources in the Baltic Sea. Another example provided by the project involves collaboration with companies working with the Natural Resources Institute Finland in research related to marine recirculation aquaculture and sea basin aquaculture. Microalgae biotechnology research includes contract research projects with industry that will continue in the future.

FINMARI will also continue to collaborate with JERICO-RI's international ICOS partners to support the development of sensors for monitoring marine biodiversity and carbon dioxide systems. The aim is to also promote the utilisation of competence related to sustainable marine research, development and innovation activities among FINMARI partners.

The future actions of the HYDRO-RI-Platform project to promote sustainable growth and the green and digital transition are particularly linked to utilising the infrastructure developed in the project. The aim is to create digital twins of river systems in catchment areas extending from Southern Finland to Northern Finland. Digitalisation and automated data processing will be further developed through the Freshwater Competence Centre and DIWA flagship project. The continuous updating of sensor systems and the development of data transfer and analytics taking place in this process will enable the digital and green transition to progress at the national level in different catchment areas.

The Freshwater Competence Centre has already launched a wide range of new research and development tasks. The new catchment area and river data produced by the centre will be utilised in several research and development models, research initiatives and existing operative catchment area modelling systems. These aim to improve existing hydrological services and create new ones with stakeholders. In the future, the main objective of the project is to gain roadmap status for the infrastructure and become part of or a partner in European freshwater and coastal infrastructures. HYDRO-RI will also continue to map societal needs and engage in dialogue with stakeholders in order to target the benefits obtained from digital twins and infrastructures to local and national actors in the optimal way.

4.6.3 Summary

Both research projects on key areas and national research infrastructure projects will continue to actively promote sustainable growth and the green and digital transition after the RRF funding period.

All research projects on key areas reported that they will continue the research, often in the same research groups. The majority of the projects have applied for new funding and have either started or plan to start new research, business and European collaboration. Collaboration with industry and international research organisations will continue to play a key role in the future.

All of the research infrastructure projects will also continue their activities. The infrastructures are being utilised in, for example, the development of language models, the sustainable use of marine resources and when building digital twins for river systems. The projects support the continuity, networking and societal impact of research at the national and European level.

4.6 Monitoring and evaluation of projects

The survey asked for a description of possible indicators or frameworks that could be used to evaluate the impacts of projects on RDI ecosystems, employment and business development.

This section starts with a description of the responses provided by the research infrastructure projects and continues with the responses from research projects on key areas. The last subsection focuses on discussing opportunities for developing monitoring and evaluation.

4.7.1 Monitoring and evaluation of projects

Two of the national research infrastructure projects responded to the question. Both described monitoring indicators that are already in use.

One of the research infrastructures highlighted indicators related to the status of the environment and ecosystem as key indicators. They are used to monitor how ecosystems function, identify important impacts caused by human activities, and to steer the development of activities between different sectors.

The other research infrastructure focused on user statistics, networks, social media followers, the number of new projects started on the basis of the research infrastructure and collaboration as concrete indicators. These projects and collaboration highlight the role of the research infrastructure in developing innovation, research capacity and business, especially with regard to technologies, and they can be used to demonstrate the input achieved by the infrastructure with regard to the green and digital transition and sustainable growth.

Fourteen of the research projects on key areas responded to the question. One of the projects described the comprehensive Key Performance Indicator (KPI) that is already in use. This categorises different indicators for data production, technology transfer, workforce development and economic impacts, and presents the measurement method for each indicator.

Other indicators mentioned by the projects included the following, which are related to generating scientific information and evaluating processes and quality of data production:

- generation of scientific knowledge: number of peer-reviewed publications, citations and conference presentations
- collaboration and networks: number of multidisciplinary and international research partnerships, number of different stakeholder events, number of participants in those events, and feedback
- technology development: number of patents, open data and software tools
- development of research infrastructure: number of new test platforms, measurement methods and databases
- number of new research projects and their national/international dimension and success

With regard to indicators related to employment and competence, the projects highlighted the following areas for quantitative monitoring:

- jobs created: jobs created directly or indirectly in relation to RDI activities
- impacts on education: number of master's and doctoral degrees completed, number of courses and workshops organised, number of participants and feedback
- mobility between different sectors: researcher transfer to companies and industry, traineeships and competence exchange programmes

In terms of business development, the responses emphasised the following indicators to describe new business initiatives and the use of solutions and competence produced in the projects:

- start-ups and spin-offs: number of new companies generated from the research
- industrial and business collaboration: new collaboration projects and licensing agreements
- funding and investments: amount of attracted capital investment, research funding and private investments, willingness of companies to fund further research
- technology transfer: number of Finnish and EU companies using the project results/solutions/competence, number of RDI projects using the project results/solutions/competence

With regard to policy impacts, the projects highlighted the following areas that could be monitored:

- policy changes based on the research results
- policy changes that support development in line with the project objectives
- policy changes related to regulation that enable the utilisation of a method/solution that was studied or developed in the projects in RDI activities
- utilisation of researcher competence in societal decision-making, such as participation in expert panels and discussions related to societal decision-making
- technology transfer to societal decision-making processes

The frameworks mentioned in the project responses may provide good starting points for systematic evaluation (see Example box 2).

Example box 2. Frameworks for monitoring and evaluating impacts.

1. OECD innovation indicators

The indicators developed by the OECD provide an internationally comparable method of evaluating the performance of research and development activities, innovation activities and the dissemination of technology. They cover, for example, R&D expenditure, human resources, patents and collaboration networks.

2. Triple Helix model

The model examines interactions between universities, industry and the public sector as a driver of innovation activities. This helps to evaluate how well different actors collaborate and how this collaboration supports the creation of new knowledge and solutions.

3. Technology Readiness Levels (TRL)

The TRL scale describes the development stage of a technology from idea to commercial application. It is particularly useful when assessing readiness to move into practice and the market. The scale ranges from level 1 (basic research) to level 9 (proven and ready for commercial deployment).

4. HEInnovate framework

A self-assessment tool for higher education institutions developed by the European Commission and OECD. It supports the development and assessment of entrepreneurship and innovation capability through different dimensions, such as leadership, organisational capacity, teaching and learning, digital transformation, and external networks and impact areas.

5. KPI (Key Performance Indicators)

KPIs are key performance indicators used to monitor the progress of an organisation or project in relation to the objectives set for it. They can be quantitative (e.g. publications, new jobs) or qualitative (e.g. stakeholder feedback, policy impacts).

4.7.2 Opportunities for developing monitoring and evaluation

According to the projects, a diverse pool of indicators could be formed for monitoring their impacts. This pool could include different quantitative and qualitative indicators covering areas from research and education to societal decision-making and the development of competence, industry and business. Only one of the responding projects monitors its activities according to a comprehensive monitoring and evaluation plan.

The challenges of monitoring effects and impact are already well recognised in general, and they are also visible in the responses to the self-evaluation survey. The responses provided by the projects mention challenges that include delays in impact, problems related to verification, the availability of data, the difficulty of measuring qualitative impacts (e.g. the generation of tacit information or policy impacts is difficult to measure without a separate follow-up study) and the lack of uniform practices (e.g. the use of indicators frameworks varies by project, which makes comparisons and forming an overall picture difficult).

When monitoring longer-term effects and impact, it is important to examine impact as a whole: rather than assessing projects as individual and separate units, they should be seen as part of a broader goal-oriented system and entity in which the projects and the inter-sectoral collaboration taking place within them complement and strengthen each other.

Longer-term monitoring also requires continuous data collection, for which methods such as annual surveys, automated data analytics and stakeholder feedback can be utilised. However, collaboration between actors is a key factor in terms of successful data collection. Research, industry and companies also need to work together when monitoring and developing joint activities. In other words, stakeholder collaboration is also needed when assessing effects and impact.

Evaluations require information on changes in the activities of stakeholders. At best, this would mean involving actors from different sectors in the assessment process already at the planning stage. Long-term collaboration networks can provide excellent opportunities for joint longitudinal monitoring and assessment, and thus make it possible to further develop collaboration.

Cooperation in long-term monitoring and evaluation can be used to verify concrete and inspiring case examples that can be updated during the life cycle of ongoing projects and also during the life cycle of projects generated from earlier ones.

This allows the creation of impact profiles for long-term collaboration and networks that describe the impacts achieved through cooperation. Impact profiles would be particularly useful when applying for international funding, reporting to funders and stakeholders, planning strategic activities and allocating resources, attracting new partners, demonstrating impact and in communications.

4.7.3 Summary

Both research projects on key areas and research infrastructure projects described the possible indicators and frameworks in a versatile manner. Three of the responding projects described monitoring indicators that are already in use.

The indicators mentioned by the projects focus on quantitative monitoring and evaluation targeting the generation of scientific knowledge and collaboration. Potential indicators and frameworks were also proposed for monitoring business and policy impacts. In general, monitoring and evaluation of these areas is still developing as part of research evaluation.

The views expressed by the projects show that a diverse pool of indicators could be developed for monitoring impacts, covering the areas of research, education, decision-making, and competence and business development. The challenges associated with monitoring impacts include delays in impact, difficulty in measurement, availability of data and a lack of uniform practices.

The need to examine projects as part of a broader whole and to utilise continuous data collection is emphasised in long-term monitoring. The requirements for successful monitoring include close cooperation between different actors and ensuring that stakeholders are already involved in evaluation during the planning stage.

Long-term networks make it possible to monitor joint impact and highlight concrete examples. This means that impact profiles can be built to support strategic planning, resource allocation and communications to, for example, funders and international partners.

5. Actions to enhance impact taken by projects, impact mechanisms and the anticipated longer-term effects

This section examines the actions to enhance impact taken by research projects on key areas and research infrastructure projects, impact mechanisms and the anticipated long-term effects. The impact stories written by the projects were utilised as data.

This begins with a presentation of the concrete measures implemented by projects aimed at promoting sustainable growth, especially from the perspectives of technology, digitalisation, climate change mitigation and adaptation, the circular economy and biodiversity. The measures include utilising artificial intelligence and machine learning, developing infrastructure, building digital twins and modelling environments, stakeholder collaboration and knowledge transfer.

The second part of the section focuses on impact mechanisms, i.e. the processes through which research outputs – such as methods, technologies and competence – lead to concrete societal, environmental and economic impacts. Examples illustrate how the research results are deployed and how they affect areas like decision-making, business and the daily lives of citizens.

The third part of the section looks at the anticipated long-term impacts. These include supporting the green and digital transition, promoting climate objectives and the circular economy, strengthening competence and infrastructure, and developing new innovations and markets. Several projects also support the EU Green Deal and the UN Sustainable Development Goals. The section highlights how research can generate systemic changes in society and lay the foundation for wide-ranging and long-term impact.

5.1 Description of the data

As part of the RRF reporting, all consortium projects (n=19) submitted at least one impact story. Projects were asked to address the advancement of sustainable growth in their impact story, and it had to be related to at least one of the following three dimensions of sustainable growth:

1. Sustainability of public finances
2. Sustainable society
3. Sustainable well-being

Only a few of the impact stories clearly stated the dimension of sustainable growth to which they related. However, all the stories could be linked to at least one dimension of sustainable growth.

The majority of the impact stories addressed the advancement of sustainable growth from the sustainable society perspective. This included impact stories dealing with environmental sustainability. Three projects focused on the sustainability of public finances and two projects on sustainable well-being in their impact stories.

The impact story also had to assess the achievement of the project's impact objectives, identify impact mechanisms and forecast impact in the future on the basis of research.

Projects that ended in 2023 received separate guidelines for the impact story in autumn 2023. The guidelines were updated in autumn 2024 for projects that ended in 2024. The guidelines state that the structure of the impact story is flexible, but the following issues should be addressed in its content: 1) impact objectives, 2) actions, 3) successes and challenges, 4) impact mechanisms, 5) medium- and long-term impact and systemic effects, 6) EU-level impact, and 7) monitoring and evaluation. As the structure of the impact stories was flexible, there are differences in the way they were written. The stories also vary in terms of their content.

All 19 consortium projects submitted at least one impact story. Two projects submitted more than one story. All 23 of impact stories are included in this report. Six of these were submitted by national research infrastructure projects and 17 by research projects on key areas of the green and digital transition.

Some of the researchers have more experience in writing impact stories gained in previous projects. Training was provided to support the preparation of stories: two training sessions on writing impact stories were organised in autumn 2024. The first part of the training focused on communicating about impact in the story, and about 60 participants attended the training session. The second part involved producing draft impact stories, and approximately 30 participants attended this session. The trainers were external researchers and experts from Tampere University.

There are differences in the way the projects perceive and describe impact in their stories. Some stories focused on describing the research conducted in the project and its impact by reflecting on who could utilise the results and how, but did not present the actions taken by the project to promote that utilisation. Other stories described the project's stakeholder networks in detail and outlined how the research data was communicated to different stakeholders. The diverse quality of the data has an effect on the review. For this reason, the review primarily focused on using examples to describe the areas that were examined.

5.2. Actions taken to enhance impact

The impact methods can be examined by means of researcher or project selections and the actions that were implemented. The actions are concrete measures aimed at achieving the desired impact. The guidelines requested that the impact stories include the actions taken in the project to advance the selected dimension of sustainable growth.

The impact stories submitted by most of the projects described actions related to technological and digital development. The target of the actions was to support research, decision-making, environmental management and societal services through technology and digitalisation, and they focused on developing technology, digital solutions and modelling environments. The development work aims to promote research, automation and knowledge-based decision-making as well as to develop infrastructure. Actions related to technological and digital development can be classified, for example, in the following manner:

- Utilisation of artificial intelligence and machine learning. The aims include promoting smart systems, analysing data and supporting decision-making.
- Infrastructure development. The aims include promoting the building and improvement of physical and digital research environments.
- Digital twins and modelling environments. The aims include promoting virtual simulations and environments that mimic reality.
- Development of models and simulations. The aims include promoting mathematical and computational models, scenarios and forecasts.
- Autonomous systems and drones. The aims include promoting and utilising robotics, automation and systems that operate independently.

Eight projects described actions related to climate change mitigation and adaptation. Four projects described actions related to materials research and the circular economy, and five projects described actions related to biodiversity and ecosystem protection. One of the projects also described actions related to language technology and cultural heritage. Visualisation, user interfaces and accessibility were also highlighted in the actions taken by two research infrastructure projects.

The projects successfully identified the stakeholders who can benefit from the results and outputs of the project. The impact stories described the actual actions related to disseminating knowledge and outputs and transferring technology in a varying manner. Scientific publication and open data sharing have traditionally been key ways of promoting the scientific impact of research. The projects also engaged in extensive stakeholder collaboration and were successful in ensuring commitment on the part of knowledge users. Many projects engaged in business-related collaboration with industry and enterprises, which are often described as knowledge users.

Actions related to stakeholder collaboration included the development of training and learning materials, networking, event organisation and communications, as well as collaboration with companies and public administration authorities. Some of the projects were primarily aimed at achieving scientific impacts through research collaboration. Some participated in a development project (e.g. a citizen science development project). Some projects also use key figures to monitor the impacts of their actions.

Example box 3 describes the project outputs that can be utilised in different sectors of society.

Example box 3. Outputs that can be utilised in different sectors of society described by the projects in their impact stories.

Methods and tools

- A wildfire management and response support system (FireMan)
- A method for assessing carbon dioxide emissions from traffic (AIforLessAuto)
- A simulator that can forecast the impacts of forest management and climate change (not openly available yet). (ForClimate)
- A method for observing and predicting northern conditions and the condition of roads that can be used to facilitate road maintenance and produce savings. (ADAPTINFA)
- Seabed research work and methodological development that enables better design of structures in the seabed (e.g. offshore wind power and cables) (GEOMEASURE)

Research data

- An online course on forests and climate change that is open to everyone (ForClimate)
- Better knowledge of ice conditions and conditions in the northern Baltic Sea that, for example, provides benefits for planning and building offshore wind power (WindySea)
- New understanding of utilising the birch bark produced as forest industry waste as coatings in textile and packaging materials (ENZYFUNC)

Research infrastructures

- Equipment and laboratories that make it possible to observe marine phenomena. Shared use opportunities for researchers and companies (FINMARI)
- Measurement devices, data and digital twins that can be used to observe waters and catchments in Finland (Green-Digi-Basin and HYDRO-RI-Platform)
- Supercomputer and high-performance computing services for researchers (PRACE/EuroHPC)
- A language research infrastructure to which recognition of everyday Finnish speech has been added, opportunities for processing unstructured text and opportunities for supporting metadata-based research (FIN-CLARIAH)

5.3 Impact mechanisms

An impact mechanism refers to a process through which research and its results bring about changes in, for example, society, the environment or the economy. Impact mechanisms can be used to describe how research outputs (such as new knowledge, a developed method, technology, tool or other solution and competence) result in concrete impacts. Impact mechanisms express what happens or should happen in order to achieve the desired effect.

The actions described in the impact stories that were examined above are conscious choices made by researchers and projects. Impact mechanisms also represent the choices made and actions taken by others. Impact mechanisms are described in several stages, and they can be categorised in different ways.

The impact stories typically described impact mechanisms related to the utilisation of research- and evidence-based methods and data. Utilisation of research outputs was described as typically occurring in societal decision-making and, in terms of business, in industry and enterprises. The mechanisms related to competence development that were mentioned included nurturing a new generation of researchers and education that is open to everyone, as well as collaboration and technology transfer with research users and partners in different sectors. The competence of the latter increases when they collaborate with research projects and when methods and tools developed in research are implemented in stakeholder activities.

The following uses examples to describe impact mechanisms in the projects. All of the examples are simplified and do not provide an accurate

picture of the interactivity and non-linear nature of the impacts. The examples are being used to illustrate how research outputs generate changes and affect society, the environment, the economy or other sectors.

Large-scale deployment and long-term effects and impact often require measures related to deployment and also regulation after completion of the project. In other words, this requires action on the part of legislators, public administration and business actors – not only the research community.

The underlying operating principle for impacts in all the examples is research evidence produced in the project. Research evidence is based on measurements, modelling, experiments, pilots and demonstrations performed in the projects, also in practical conditions.

Example box 4. Progression of impacts generated from research results and solutions in the FireMan project.

Research in the FireMan project led to concrete impacts via different stages. Large-scale deployment and long-term effects and impact require measures related to deployment and regulation after completion of the project.

1. Research activities and objectives

The objective of the project was to develop autonomous drone systems for wildfire management. The project studied AI-based environmental modelling and developed AI-controlled unmanned aerial systems (UAS) that enable the creation of a scalable and cost-effective situational picture of the environment in real time.

2. Research results and new solutions

The AI-based UAS system developed as a result of the study provides continuous monitoring in a crisis area, which improves situational awareness during rescue operations. Real-time data enables rapid detection of wildfires and early intervention, which may prevent fires from spreading over large areas.

3. Knowledge transfer and technology testing in practice

The research results were published, presented to the authorities, and the technology was tested with rescue departments.

4. Tested and observed impact

An improved situational picture and faster response to wildfires. AI models and autonomous systems enable optimal resource use and planning of fire-fighting operations, which reduces costs and improves efficiency.

5. Impact potential related to deployment

The solution that was developed enables knowledge-based decision-making by combining a real-time aerial photograph with spatial datasets and forecast models. This supports more accurate and effective decision-making.

6. Realisation of the impact potential requires action from decision-makers and industry partners

Large-scale deployment of the technology requires regulatory coordination and industrial partnerships that support scalability and long-term impact.

7. Effects and longer-term impact

In the long term, the technologies that were developed can change the way crisis management operates by enabling a scalable, AI-based and proactive response to natural disasters.

5.4 Impact of projects on the green and digital transition

The impact stories submitted by the projects described how they advanced sustainable growth in the short and long term by producing new research knowledge, methods, tools and data and how these were actively communicated to and deployed to different actors. The impact stories of the projects typically described scientific and environmental impacts in accordance with their dimension of sustainable growth. The stories submitted by some projects also describe economic impacts and those related to well-being.

Projects that focused on AI and digitalisation have increased research efficiency and the accessibility of information and developed solutions that support preparedness, monitoring and knowledge-based decision-making in public administration and business. The outputs of the projects support the green and digital transition as well as forecasting and the resilience of society in different sectors – from water management to forestry, from material development to transport and disaster management. The impacts of the projects primarily focus on the following areas:

- AI and digitalisation
- Water and adaptation to climate change
- Forestry and biodiversity
- Materials and the circular economy
- Energy and storage
- Transport and emission reductions
- Disaster management and security
- Arctic conditions

Example box 5 describes the impacts of various projects in these different areas.

Example box 5. Project impacts in different areas.

AI and digitalisation

Several projects developed solutions based on AI and digitalisation. For example, the AIcon project developed AI-controlled catalysts for utilising carbon dioxide in methanol production. The aim is to promote the green transition and circular economy.

The EuroHPC/PRACE Finland project expanded the use and accessibility of supercomputing by developing user-friendly interfaces and AI infrastructure. Improving the accessibility of AI and supercomputing can increase deployment and lower the threshold for utilising supercomputing in different fields of science. This supports the introduction of new research methods and enables extensive data analysis in areas such as medicine, climate research and materials research.

The FIN-CLARIAH project, on the other hand, enabled the use of language technology and large datasets in social sciences and humanities research. The use of language technology and large datasets in research supports the digitalisation of social sciences and humanities and opens up new opportunities, for example, related to developing language models, cultural heritage research and evaluating policy measures.

Water and adaptation to climate change

Several projects developed digital twins, mobile laboratories and AI-based forecast models that support, for example, the monitoring of the status of water systems, flood risk management and infrastructure resilience. These solutions can be used to produce scenarios to support decision-making, improve preparedness for extreme phenomena and advance the green transition.

The HYDRO-RI Platform project built a national water research infrastructure that enables better monitoring of water quality and supports marine analytics and the modelling of scenarios to support

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decision-making. The Green Digi Basin project developed digital twins of northern catchment areas and tools for assessing the ice cover on rivers and producing scenarios to forecast the impacts of climate change. The digital twins developed by HYDRO-RI Platform and Green-Digi-Basin and continuous monitoring of water quality allow the generation of more accurate and up-to-date scenarios concerning the status of water systems and the impacts of climate risks. This supports knowledge-based decision-making in areas such as flood risk management and water resource use.

The Soil Scout collaboration in the Green-Digi-Basin project developed new wireless sensors that can be used to monitor soil moisture, temperature and movement in when managing river bank erosion. The wireless sensors developed by Soil Scout particularly support risk management in cold conditions and enable real-time monitoring of soil changes, which improves the ability to respond to erosion and other environmental risks, especially in cold and remote conditions.

The ADAPTINFA project studied frost quakes and developed an AI-based forecast model that combines weather and soil data to support proactive maintenance. The aim is to improve the durability of infrastructure and reduce repair costs in the Arctic areas. The AI-based forecast model developed in the ADAPTINFA project makes it possible to forecast frost quakes and frost damage, which supports proactive maintenance and reduces infrastructure repair costs.

Forestry and biodiversity

Several projects developed tools for assessing forest carbon sinks, monitoring biodiversity and modelling the climate impacts of forest management. The solutions can be used to promote knowledge-based management, knowledge-based societal decision-making at the national and regional levels, and to assess the effectiveness of policy measures, such as balancing forest use and protection, and reconciling climate and biodiversity objectives.

The ForClimate project developed a new forest growth simulation tool called Motti C+, which combines traditional growth modelling (Motti) with a process-based climate model (PREBAS). This makes it possible to assess the combined effects of climate change and forest management on the basis of scenarios. The tool is compatible with national forest inventories and supports climate-wise forest management planning, decision-making by forest owners and the achievement of national climate targets.

The C-NEUT project produced detailed spatial data-based estimates of greenhouse gas emissions and sinks in different regions. It developed methods to assess the impacts of forests and other forms of land use on carbon neutrality targets. The results support regional climate policy and forest management planning and provide tools for assessing the combined effects of biodiversity and carbon sinks.

The ARTISDIG project developed methods for identifying the structural diversity of forests and individual trees using hyperspectral imaging and machine learning. The results support the development of digital twins of forests and enable more accurate monitoring of biodiversity and the utilisation of individual tree information in forest management and wood tracking.

The Diversity4Forests project developed methods based on laser scanning for identifying individual trees and measuring tree-specific attributes. For example, identification based on tree branches makes it possible to track a tree from forest to factory. The project also developed methods for assessing the structural diversity of forests, which supports sustainable forest management and the protection of biodiversity.

Materials and the circular economy

Several projects promoted the development of biodegradable materials by combining machine learning, enzyme technology and utilisation of side streams. The results of these projects support the circular economy, reduce dependence on fossil raw materials and provide safe alternatives to PFAS compounds. At the same time, they open up new business opportunities for the forest and chemical industries and strengthen Finland's position as a pioneer in biotechnology and material technology.

The MIMIC project developed a method that combines atomic microscopy and machine learning for detailed characterisation of the structure of lignocellulosic materials. This makes it possible to design biodegradable materials at the molecular level and promotes the replacement of fossil-based materials with renewable alternatives.

The ENZYFUNC project developed enzyme-based coatings that utilise, for example, lignin and birch bark side streams. This resulted in breathable and

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recyclable coatings for textiles and fibre-based packaging that are both water and dirt-repellent. Digital modelling tools were also developed to forecast the properties of coatings and accelerate material design.

Energy and storage

The FlowXAI project developed AI-based methods to screen and synthesise materials in flow batteries. The project combined quantum chemical computing, machine learning and automated synthesis, which enabled pre-screening of thousands of molecules prior to laboratory testing. The project also developed a new high-performance AZON material family, which meets the performance requirements of flow batteries and which was subject to an innovation announcement. Other achievements in FlowXAI included the construction of a synthesis platform and the development of methods for assessing the electrochemical performance of materials.

The project outputs will accelerate the development of new energy storage solutions and support the large-scale deployment of renewable energy, especially for balancing the electricity network.

Transport and emission reductions

The AIforLessAuto project (UHASSA consortium) developed AI-based optimisation models that support the reduction of urban traffic emissions. The project created multi-level modelling methods to estimate CO_2 emissions in different traffic scenarios and combines optimisation of individual vehicles, urban traffic arrangements and electric vehicle charging infrastructure. The methods that were developed enable, for example, a 3% reduction in emissions during peak hours at a 100% autonomous vehicle utilisation rate without separate traffic optimisation.

The project also produced an easy-to-use table for evaluating traffic emissions in different cities using the Local Climate Zone framework. AI models support the development of smart transport and can, in the long term, contribute to the EU's climate targets, such as a 55% reduction in emissions by 2030.

Disaster management and security

The FireMan project developed autonomous drone systems and AI models for managing wildfires. The project created a digital twin of wildfire situations by combining real-time drone observation data, spatial datasets and forecast models, which enables faster and more accurate decision-making in fire extinguishing situations.

The UAS (Unmanned Aerial Systems) that were developed are capable of operating in GNSS-free environments and autonomous coordination, which improves operational efficiency and security, especially in hard-to-reach areas. In the long term, these technologies can change the way disaster management operates by enabling a scalable, AI-based and proactive response to natural disasters.

Arctic conditions

Several projects developed solutions that support sustainable development and resilience in Arctic and northern regions. The projects demonstrate how research and technology can collaborate to address the specific challenges of Arctic regions and support the green transition and climate change adaptation.

The WindySea project developed modelling methods and scale model tests to assess the impacts of ice on offshore wind farms. The results support the development of design standards and the implementation of an offshore wind strategy, especially in the Baltic Sea region. The Green-Digi-Basin and HYDRO-RI-Platform projects collected data on northern mire areas, and Green-Digi-Basin also developed a tool for assessing the ice cover of rivers. The ARTISDIG project created a digital twin of northern forests, which makes it possible to model climate impacts and biodiversity in Arctic ecosystems. The ADAPTINFA project studied the effects of frost quakes on roads and developed new tools for road maintenance in northern regions, thus improving the sustainability of infrastructure in extreme conditions.

5.5 Impacts on collaboration, competence clusters and competence

EU Resilience and Recovery Facility funding was allocated to research that promotes solutions to enhance carbon neutrality and climate change adaptation and the related digital technologies. The objective was to strengthen existing competence clusters (such as research flagships) and to increase competence outside them. A competence cluster combines strong research expertise with the impact produced through research and collaboration with the users of research results and other actors (see Figure 27).

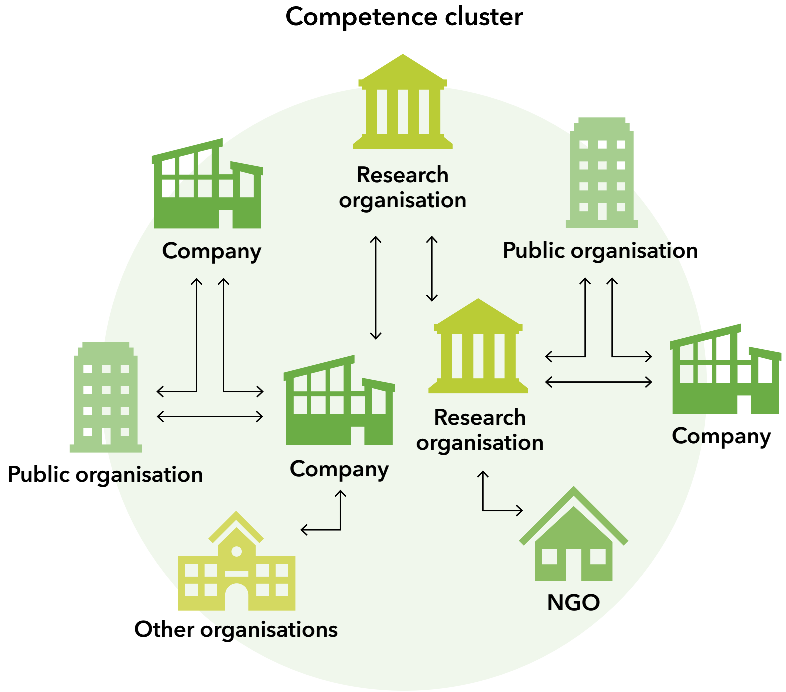


Figure 27. Competence cluster[10].

[10] Competence clusters – Research Council of Finland

The projects already strengthened collaboration between different RDI actors while they were in progress. They were built in multidisciplinary and multi-actor consortia where the participants included universities, research institutes, companies and authorities in particular. Co-creation was also carried out in some projects. Collaboration strengthens the competence base and transfer of competence and supports the creation of innovations that further the green and digital transition and promote sustainable growth.

In particular, the projects involved business and industrial collaboration, which promotes the transfer of competence into practice. For example, the ENZYFUNC project developed enzyme-based coatings and assessed their safety and functionality. The results support the development of new bio-based materials and offer competence that can be utilised, for example, in the textile and packaging industry. The Soil Scout collaboration in the Green-Digi-Basin project developed new wireless sensors that were tested in research use and provided the company with valuable feedback on the development of its products. Example box 6 describes this collaboration, which laid the foundation for new commercial applications and competence transfer from research to business.

The activities of the projects also deepened and expanded permanent networks and structures that will strengthen cooperation in the long term after the projects have ended. For example, the HYDRO-RI Platform and Green-Digi-Basin projects led to the establishment of the Freshwater Competence Centre (FWCC). This cluster brings together researchers, authorities and companies and provides training and research infrastructure to support water research and management. The Digital Waters flagship launched via FWCC includes 60 new doctoral candidates and several new postdoctoral researchers, and it will strengthen competence in the long term.

The projects developed new technologies, methods and digital solutions as well as data services in a wide-ranging manner. These can be considered to strengthen competence clusters and research and innovation ecosystems in Finland and more broadly in Europe. For example, the FINMARI project developed the marine research infrastructure, while EuroHPC/PRACE Finland expanded the use of the LUMI high-performance computing environment and developed user interfaces that lower the threshold for utilising computing power in different fields of science.

The projects also strengthened international networking and competence export to international research projects. For example, the results of the C-NEUT project were presented at international conferences and in the EU's eLTER RI network. The methods and materials data by the project are being used in several international research projects, such as FESTiVAL and BioClima. The FIN-CLARIAH project strengthened language technology competence in Finland and exported it to international networks, such as CLARIN and DARIAH. The results of the project are also utilised in companies and teaching.

The projects significantly promoted competence development at different levels, from individual researchers and students to national competence clusters and international networks. The impacts of competence development are also visible in the education of new researchers and supporting career paths. For example, the ADAPTINFA project, which developed AI-based tools for maintaining the Arctic infrastructure, offered research positions and educational opportunities for early-career researchers in cooperation with schools such as Duke University. The FlowXAI project developed AI-based methods for screening materials, and the competence created in the project led to a new doctoral dissertation that combines robotics and physical organic chemistry. This was implemented in collaboration with Orion.

The projects also produced new educational materials and open learning environments. For example, the ForClimate project implemented the online "Forests and Climate Change" course, which is open to all interested parties. This supports the wide dissemination of competence related to the climate impacts of forests. The results of the C-NEUT project, on the other hand, have been utilised in an environmental technology textbook and teaching, and they are also being used for climate and energy transition planning in the national REPower-CEST project.

Example Box 6. Business collaboration in the Green-Digi-Basin project.

Promotion of the digital and green transition: From golf courses and fields to river banks – business collaboration led to innovation

In the Green-Digi-Basin project, Aalto University and Soil Scout started a collaboration in which wireless soil sensors originally developed for golf courses and agriculture were tested and applied to monitoring river bank erosion. The new sensor versions measured soil moisture, temperature, salinity and movement simultaneously for the first time.

The sensors were installed in three different areas: the Vantaanjoki, Oulankajoki and Pulmakijoki rivers, and their operation was evaluated in different climate and terrain conditions. The results were compared to, e.g., UAV imaging, time-lapse images and geophone measurements.

This collaboration promoted the digitalisation of erosion monitoring and the green transition. The sensors send data to the cloud service every 20 minutes for up to 10 years without physical service visits. This reduces monitoring costs and environmental impacts. The temporal accuracy of the sensors (0.0004% of the period checked) is many times better than that of traditional methods.

The new measurement method enables a more detailed understanding of erosion processes, especially in cold climates. The sensors reveal the impacts of seasons and climate change on riverbank dynamics. The results support risk management in communities and the protection of water ecosystems.

The aim is to have similar systems widely deployed in the boreal zone by 2030. This can support the adaptation of critical infrastructure and natural environments to erosion risks

5.6 Anticipated long-term effects

The projects were also asked to include a description of anticipated long-term effects and how those effects can promote sustainable growth in their impact stories. The long-term impact of the projects is built on key mechanisms for research and research infrastructures. The focus is on scientifically validated digital tools and modelling solutions, the development of new technologies and materials to support the green and digital transition, the national and international strengthening of expertise and infrastructure, and extensive collaboration between companies, industry, authorities and research institutes.

As several projects laid the foundation for new innovations and commercial applications, strengthened support for policy and promoted education and competence transfer, the projects can be expected to also have longer-term effects. The reports estimated that large-scale utilisation of project results and the solutions and methods developed in them can achieve not only environmental and climate benefits but also economic and scientific benefits in the long term. Example box 7 describes the projected long-term impact of the MIMIC project on all these areas.

The large-scale deployment of project outputs may also have combined effects and strengthen the conditions for systemic change, which will be reflected in, for example, the widespread introduction of new operating models, changes in legislation or policy, renewal of skills and education, and the creation of new markets. Rather than being the result of an individual programme or project impact, systemic change represents a broader change in operating methods, structures and thinking based on combined effects that often extend to several sectors and change the interaction between them.

For example, several projects such as ForClimate, C-NEUT, ARTISDIG, FlowXAI and ENZYFUNC have developed technologies and methods to support climate neutrality objectives and the sustainable use of natural resources. The outputs of these projects can be used to extensively change practices in forest management, land use and energy storage, as well as waste stream utilisation, to support the EU Green Deal, the LULUCF Regulation and the national Climate Act, and to enable knowledge-based decision-making and regional climate work. Systemic impact is created when research data and modelling tools (e.g. Motti C+, PREBAS, JSBACH) are implemented in policy preparation, forest owner decision-making and regional planning.

On the other hand, the HYDRO-RI Platform, Green-Digi-Basin and the Digital Waters (DIWA) flagship created on the basis of them have built a national and international research infrastructure that enables real-time monitoring of water quality, digital twins for water systems, scenario tools to support decision-making and strengthen education and competence (e.g. 60 new doctoral candidates). In the longer term, the impact of the research infrastructure activities may be visible as part of a broader change in water management in which the combined impacts of several actors and sectors cause a shift from reactive management to proactive, data-driven and cross-sectoral decision-making.

The projects also developed AI-based solutions for infrastructure and environmental management, such as wildfire management (FireMan), energy storage (FlowXAI), traffic optimisation (AIforLessAuto, UHASSA consortium) and road maintenance (ADAPTINFA). Integrating artificial intelligence and digital solutions into critical infrastructure management in Finland makes it possible to simultaneously change the operating models in these different areas, which saves money and improves the functional capacity of Finnish society.

In the long term, many of the projects also support the achievement of the following UN Sustainable Development Goals:

- SDG 6 Clean water and sanitation. The aim is to ensure the availability and sustainable management of water and sanitation for all.
- SDG 11 Sustainable cities and communities. The aim is to make cities and human settlements inclusive, safe, resilient and sustainable.
- SDG 13 Climate action. The aim is to take urgent action to combat climate change and its impacts.
- SDG 14 Life below water. The aim is to conserve and sustainably use the oceans, seas and marine resources for sustainable development.
- SDG 15 Life on land. The aim is to protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, halt and reverse land degradation, and halt biodiversity loss.
- SDG 17 Partnerships for the goals. The aim is to strengthen the means of implementation and revitalise the Global Partnership for Sustainable Development.

Table 7 presents examples of justification for the anticipated effects.

Example Box 7. Anticipated longer-term effects of the MIMIC project.

Research in the MIMIC project led to a technology breakthrough via different phases. Large-scale deployment and long-term effects and impact require measures related to deployment and regulation after the completion of the project.

The MIMIC project engaged in cross-disciplinary collaboration and combined competence in the fields of physics, chemistry, biotechnology and computational sciences. The collaboration between several sectors accelerated innovation.

The project combined atomic force microscopy (AFM) and machine learning (ML), which made it possible to examine the structure of biomaterials at the molecular level. The breakthrough made it possible to perform analyses that were previously considered impossible.

The project produced detailed information on the molecular structures and organisation of lignocellulosic materials. The data produced helps to develop the structure of bio-based materials and new applications, such as biohydrogels and coatings.

The project activities make it possible to accelerate the development of biodegradable materials, reduce dependence on fossil raw materials and improve biomass fractionation processes, which will improve efficiency in production and reduce waste.

The results of the project are likely to affect development in which molecular characterisation becomes an established part of biomaterial research. This will promote the design of sustainable materials and related technological and commercial innovation. This will simultaneously strengthen the EU's position as a pioneer in bioeconomy and circular economy research.

In the long term, the project activities are likely to contribute to the achievement of the global sustainable development goals, especially in terms of the circular economy and climate change mitigation.

Table 7. Examples of anticipated long-term effects and the justification for them.

Project name	Anticipated long-term effect	Justification for the anticipated effect
FireMan	The deployment of UAS technology in crisis management will change operating methods and improve prediction	Real-time situational awareness and AI models improve decision-making and resource allocation
ForClimate	Better management of forest climate impacts will change operating methods and interaction between actors	The Motti C+ model combines forest growth and climate models and enables scenario-based planning
Green-Digi-Basin	Use of digital twins in water management will change operating methods and interaction between actors	Real-time monitoring and modelling support decision-making and citizens' participation
ADAPTINFA	Proactive maintenance will save up to 60% in maintenance costs	Modelling and AI-based forecasting are based on measurement data and physical models
ARTISDIG	Modelling the structure and diversity of forests will support climate policy	Hyperspectral imaging and machine learning enable detailed monitoring

5.7 EU-level impacts

The projects estimate that their results and outputs are mostly applicable internationally and in other EU countries. This section uses examples to present the key EU-level impacts. These impacts of the example projects are related to the following EU-level areas:

- EU climate targets and Green Deal
- Strengthening EU research infrastructures and competence
- EU digital transition and AI strategy
- Renewing the EU's internal market and industry
- EU security and crisis resilience

Several projects, such as ForClimate, C-NEUT, ARTISDIG, FlowXAI and FireMan, directly support the EU's climate policy and Green Deal. The ForClimate project's Motti C+ model can increase Finland's carbon sink by up to 48 Mt CO_2 per year by 2050, which supports the EU's LULUCF regulation and climate neutrality objectives. The C-NEUT project produced regional carbon neutrality scenarios that can be utilised in the EU's regional climate policy and implementation of the Nature Restoration Law.

ARTISDIG and FlowXAI developed AI-based solutions for forest and energy management that support the EU's digital transition and sustainable growth. These projects provide scalable solutions that can be used in EU member states to achieve common climate and biodiversity objectives.

Projects such as the HYDRO-RI Platform and Green-Digi-Basin developed research infrastructures that have already been linked to EU-level initiatives. The HYDRO-RI Platform has received Water4All Partnership status and Water-Oriented Living Lab (WOLL) status, which are Horizon Europe partnerships. The Digital Waters flagship created on the basis of the projects is educating 60 new doctoral candidates and operates as part of the EU's research infrastructure ecosystem.

The results of the C-NEUT project will be used in the eLTER RI network, which is an EU ecosystem research infrastructure. The infrastructure enables research collaboration between EU countries, competence transfer and the development of common data standards.

FIN-CLARIAH, FlowXAI and AIforLessAuto (UHASSA consortium) support the EU's digital transition and AI strategy. FIN-CLARIAH is developing a language technology infrastructure that supports the development of large language models and the accessibility of language data in EU languages. FlowXAI is developing AI-based methods to find new energy materials, supporting the EU's energy transition and AI strategy. By developing low-emission autonomous traffic, AIforLessAuto (UHASSA consortium) supports the EU's transport strategy and its mission for 100 climate-neutral cities. These projects strengthen the EU's digital sovereignty and support the responsible deployment of AI across different sectors.

The ENZYFUNC project developed enzyme-based coatings that can replace PFAS compounds in textiles and packaging. This supports the EU's chemicals strategy and the Circular Economy Action Plan. The project utilises side streams from the forest industry, which supports the EU's bioeconomy and forestry strategies. The results can lead to new EU-level standards and regulations that will steer the introduction of PFAS-free materials.

The FireMan project developed autonomous drone swarms and digital twins for wildfire management. This supports the EU's Union Civil Protection Mechanism (UCPM) and climate risk management. Technologies can be scaled across the EU, especially in areas sensitive to wildfires in southern Europe. The project can have an impact on the EU's common rescue and crisis management practices and the standardisation of technological solutions.

Example box 8 presents the impact pathways through which five projects achieved EU-level impacts.

Example box 8. A simplified and linearly presented impact pathway by which five projects achieved EU-level impacts.

How will the project actions lead to impacts at the EU level or between EU countries?

ForClimate – climate-smart forest management

Multidisciplinary research project and stakeholder interaction

- Development of the Motti C+ model, which combines forest growth models and climate scenarios.
- The model makes it possible to assess the climate impacts of forest management in different scenarios.
- The model is compatible with national forest inventory data. Its deployment will lead to better management of forest climate impacts.
- EU impact: The model supports the implementation of the EU's LULUCF Regulation and can be scaled to other boreal forests in the EU.

HYDRO-RI Platform – Water research infrastructure and EU partnerships

Multidisciplinary research infrastructure project and stakeholder interaction

- Development of the HYDRO-RI-Platform research infrastructure and a mobile measurement laboratory (TIETO I).
- Networking resulting in the achievement of Water4All Partnership status and Water-Oriented Living Lab (WOLL) status.
- Participation in Horizon Europe partnerships and the DIWA flagship.
- EU impact: The HYDRO-RI-Platform makes it possible to monitor the status of water ecosystems and produce commensurable data through long-term structures created to support the EU's water policy.

FireMan – AI-controlled drones for wildfire management

Multidisciplinary research project and stakeholder interaction

- Technology development: Development of autonomous drone swarms and a digital twin for wildfires.
- The tool that was produced enables real-time situational awareness and models to forecast the spread of fire.
- Demonstrations and cooperation with the rescue authorities were carried out during the testing phase.
- The deployment of UAS technology in crisis management improves decision-making and resource allocation. In the long term, the technologies that were developed can change the way crisis management operates by enabling a scalable, AI-based and proactive response to natural disasters.
- EU impact: The technology is scalable at the EU level, which supports the EU's Green Deal, Union Civilian Protection Mechanism and technology leadership in crisis management.

C-NEUT – Regional carbon neutrality and situational awareness

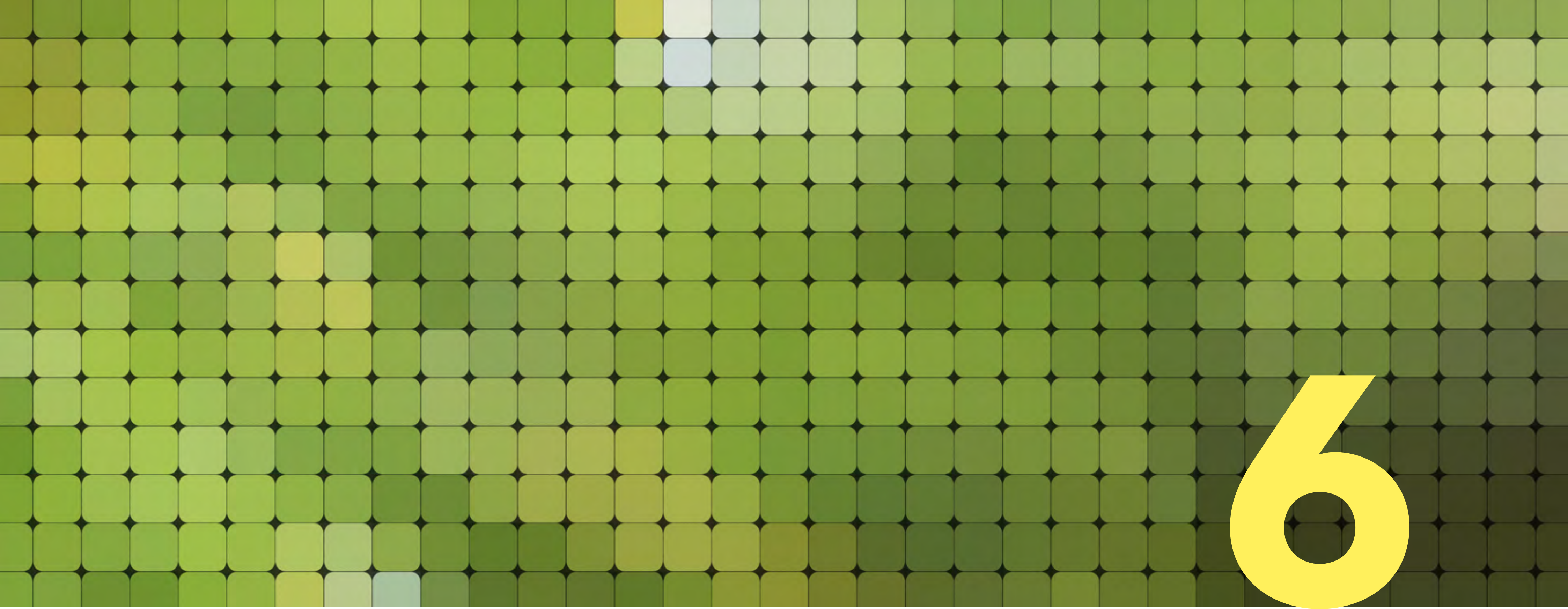
Multidisciplinary research infrastructure project and stakeholder interaction

- Production of high-resolution emission and sink maps for all ELY regions in Finland.
- The scenarios were used to model the impacts of forest management and climate policy on the carbon balance.
- Biodiversity and climate impacts were combined in the same assessment framework.
- Deployment of the new method makes it possible to assess the effects of forests and other forms of land use on carbon neutrality objectives, supports regional climate policy and forest management planning, and provides tools for assessing the combined effects of biodiversity and carbon sinks.
- EU impact: The method is scalable at the EU level, which supports the EU's LULUCF legislation and implementation of the Nature Restoration Law.

ENZYFUNC – PFAS-free coatings from forest industry side streams

Multidisciplinary research infrastructure project and stakeholder interaction

- Utilisation of new raw materials, lignin and birch outer bark as nanoparticles.
- Hydrophobic and antibacterial coatings were developed for textiles and packaging.
- The toxicity and ecotoxicity of nanoparticles were assessed in accordance with the EU's REACH Regulation.
- Biodegradable textiles and packaging can be utilised extensively in the textile and packaging industry, and the results and competence also support the development of new bio-based materials.
- EU impact: Supports the EU chemicals strategy and PFAS bans by providing a biodegradable alternative across the EU.



6. Implementation of the DNSH principle in projects

This section examines the implementation of the Do No Significant Harm (DNSH) principle in RRF projects. The objective of the DNSH assessment is to ensure that projects do not cause significant harm to the environment and that they comply with the requirements of EU and national legislation.

The review utilises the self-evaluation material submitted by the projects at the beginning and at the end of the project. The self-evaluation required the project to assess its activities in relation to six environmental objectives.

6.1 Description of the data and DNSH assessment

In connection with the RRF reporting, the projects submitted a Do No Significant Harm (DNSH) self-assessment, in which the project assessed compliance with the principle after completion of the project. The self-assessments ensure that the project was implemented in accordance with the technical guidelines on the 'Do No Significant Harm' principle (2021/C58/01)[11] and that the funding provided by the Research Council of Finland supported projects that are fully compliant with Article 5, paragraph 2[12] of Regulation (EU) 2021/241 of the European Parliament and of the Council establishing the Recovery and Resilience Facility. At the same time, it ensures that project implementation complied with European and national environmental legislation.

The purpose of the DNSH self-assessment is to ensure that the project did not include the following activities (so-called exclusion list): (i) activities related to fossil fuels, including downstream use; (ii) actions under the EU ETS to achieve projected greenhouse gas emissions that do not fall below the relevant benchmarks; (iii) activities relating to landfills, incineration plants and mechanical biological treatment plants; and (iv) activities where long-term waste disposal can cause environmental damage.

In the self-assessment, the project must describe the implementation in relation to the following RDI actions: (i) RDI actions leading to a technology-neutral outcome at the level of their application; (ii) RDI actions supporting options with low environmental impact; or (iii) RDI actions focusing primarily on developing options with minimal environmental impact in the sector in question, where there is no technically and economically viable low impact option.

In the self-assessment, the project must also examine its activities and procurements during the project implementations concerning six environmental objectives: (1) mitigation of climate change, (2) adaptation to climate change, (3) sustainable use and protection of water and marine resources, (4) transition to a circular economy, including prevention and recycling of waste, (5) prevention and control of environmental pollution, and (6) protection and restoration of biodiversity and ecosystems.

The final DNSH self-assessment after completion of the projects was implemented with a separate structured form. The projects used the form to assess whether the project caused significant adverse impacts related to the six environmental objectives ("yes"/"no") and provided justifications for their response.

This corresponds to general assessment in the DNSH procedure[13]. In the case of incomplete responses, the principal investigators of the consortia were asked to supplement the assessment as a whole or its individual justifications.

6.2 DNSH self-assessments submitted by the projects

Not a single project assessed that the project activities caused significant harm in terms of the environmental objectives. Even if a project's activities had caused significant harm that was not included in the above-mentioned "exclusion list", the project could still be compliant with the DNSH principle. In this case, a more detailed assessment to evaluate the significance, duration and extent of the identified adverse effect and the possibility of mitigating the adverse effect to render it insignificant should be performed as a follow-up to the general assessment.

[11] Official Journal of the European Union: https://eur-lex.europa.eu/legal-content/FI/TXT/?uri=oj:JOC_2021_058_R_0001
[12] Official Journal of the European Union: https://eur-lex.europa.eu/eli/reg/2021/241
[13] Do no significant harm (DNSH) principle in Finnish Recovery and Resilience Plan projects. Website of Finland's environmental administration: www.ymparisto.fi/fi/osallistu-ja-vaikuta/ei-merkittavaa-haittaa-periaate (in Finnish)

A general assessment was sufficient for all projects on key areas and national research infrastructures covered by this report. The projects either had no impact on the listed environmental objectives, the impact was insignificant, or the project significantly enhanced a listed environmental objective.

As the aim of the projects was to promote the green and digital transition, many projects had a positive impact on the environmental objectives examined in the DNSH assessment. For example, the aim of the FINMARI research infrastructure was to increase the understanding of the ecosystem impacts that climate change has on the Baltic Sea and thus promote climate change mitigation and adaptation. The Diversity4Forests project developed remote sensing methods to map and monitor forest biodiversity, and the main target of the ENZYFUNC project was to develop sustainable textile coatings and promote their recyclability.

The self-assessments completed by the projects focused on identifying the potential environmental impacts of activities during the project. The impacts during the projects were related to the energy use required by research equipment and computational applications. These impacts were identified as the type that could be minimised, for example, by recycling equipment, reducing procurement and prioritising computing power.

The potential risks identified for indirect impacts and the application of results were related to energy and resource consumption, an increase in waste, and biodiversity impacts. These identified environmental impacts were either slight or could be compensated for by the overall impact of the project, considering that the project promoted the environmental objective in question.

For example, the ENZYFUNC project recognised that high concentrations of the nanoparticles used in the coating developed in the project can cause algae growth in water systems, but these particles can also replace compounds that are even more harmful to water systems. This means that the overall impact of the project is positive and its activities do not cause significant harm in relation to the environmental objectives. Another example is the method for seabed modelling developed by the GEOMEASURE project, which can be applied when building offshore wind power. The project's self-assessment reported that increasing offshore wind power may have impacts on marine ecosystems, which means that comprehensive environmental impact assessments must be carried out in construction projects.

6.3 The funding authority's view on the DNSH assessments

The justifications presented by the projects in their self-assessments were mainly considered credible. All of the projects had a link to advancing the green transition, and activities that were not compliant with the 'Do No Significant Harm' principle had already been excluded by the DNSH assessment carried out by the funding authority at the time funding was granted. The fact that this is a self-assessment means that verification of the impacts remains weak. This can be considered a general challenge for DNSH assessment rather than a specific feature of DNSH self-assessments for the RRF projects covered by this report.

As a whole, it can be stated that no significant adverse environmental impact was identified for any of the six environmental objectives in the activities to promote the green and digital transition and sustainable growth that were funded in the RRF programme. DNSH self-assessment at the beginning and end of the project can be seen as a cost-effective way of excluding activities that are harmful to the environment and ensuring that environmental objectives are taken into account in publicly funded activities.

The challenges of the procedure are associated with verifying the assessments, the know-how required to perform the assessments, a lack of clear indicators, and monitoring of the impacts identified in the assessment. The method is relatively new, and only limited guidance and know-how are available, which also presents a challenge. This is reflected, among other things, in the fact that the assessments submitted by the projects had to be supplemented in order to meet the formal requirements set for them. The clarity of the DNSH assessment procedure can be increased and its administrative burden reduced by developing competence and guidelines and harmonising the assessment process.

The use of external competence and an external evaluator may be justified if the DNSH assessment must be performed in detail and in a verifiable manner. A general self-assessment at the beginning and end of a project is a cost-effective method of excluding environmentally harmful activities in projects. A more detailed assessment requires experience in the expert assessment of each environmental impact. The projects or the experts and evaluation panels that assess he project funding applications may not necessarily possess this type of competence.

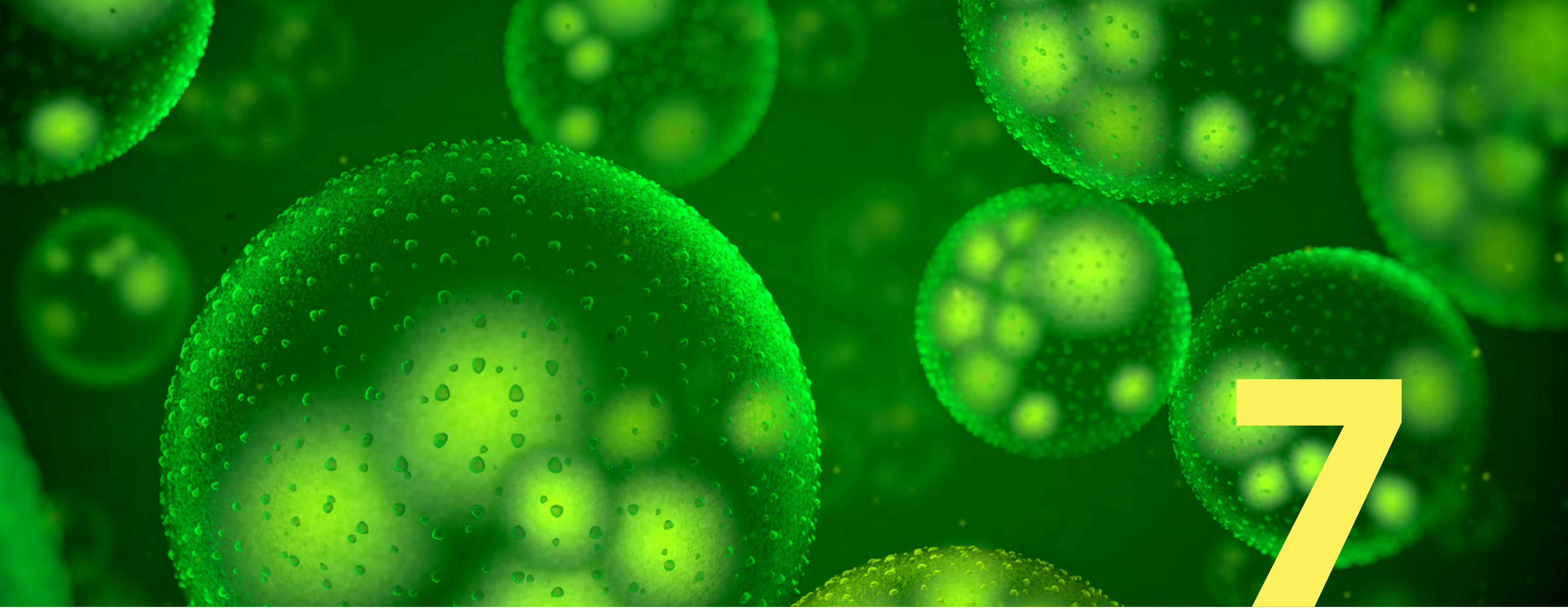
Models for an external assessment procedure could be found, for example, in environmental and ecosystem accounting practices[14] or by including Life Cycle Assessment (LCA) performed for products, services and larger systems in the DNSH assessment[15]. Practices related to DNSH assessment are expected to develop as more experience and competence are accumulated for both project implementers and funders.

6.4 Summary

All projects complied with the DNSH principle. Several projects actively promoted the environmental objectives, and no project reported significant harmful impacts on the environmental objectives. The assessments identified some indirect environmental impacts during the project, such as energy consumption and waste generation, but these were assessed as being slight or compensable.

The funding authority mainly considers the justification presented by the projects in their DNHS self-assessments to be credible, but it recognises the limitations of the self-assessments regarding verification and practical assessment. However, the DNSH assessment procedure is a cost-effective way of excluding harmful activities if the assessment is carried out in more detail and verified. External expertise and life cycle assessments could be utilised in its development. The development of assessment experience and competence will improve DNSH assessment practices in the future.

[14] Towards a sustainable society with ecosystem accounting. Finnish Environment Institute: www.syke.fi/en/services/modeling/ecosystem-accounting
[15] Life cycle assessment supports sustainability transformation. Finnish Environment Institute: www.syke.fi/en/services/modeling/life-cycle-assessment



7. Summary: Conditions for systemic change

This report examines the results and impacts of EU Recovery and Resilience Facility funding granted by the Research Council of Finland for research and research infrastructure projects that ended in 2023–2024.

The review covered the activities, results and impacts of 19 completed consortium projects. The aim of the projects was to promote the green and digital transition, support sustainable growth and strengthen research infrastructures and competence clusters. A total of approximately EUR 30 million in RRF funding was granted to the projects in 2021. The funding targeted research projects on key areas of the green and digital transition as well as national research infrastructure projects, which were selected on the basis of high scientific standard, impact, competence and collaboration.

The projects reported a total of 784 publications, 58 degrees and 53 intellectual property rights. Collaboration involved 216 research partners, 60% of which were international. Mobility was active, especially from Finland to other countries. A large number of outputs have been reported, but their qualitative impact was not fully described in the report. A citation analysis can be implemented for the publications in spring 2026.

The projects estimate that they succeeded well in their objectives. Projects on key areas promoted the green and digital transition by means of AI, energy solutions and climate change research. The research infrastructure projects developed the conditions for research prerequisites and competence, and also successfully promoted the openness and interoperability of research infrastructure.

According to their assessment, the projects were particularly successful in producing new scientific knowledge to support the green and digital transition. Many concrete solutions, such as AI solutions, digital twins and modelling environments, were also developed, but there is less evidence of their utilisation in practice.

The projects were built in multidisciplinary and multi-actor consortia that included universities, research institutes, companies and authorities. The projects collaborated extensively with stakeholders in Finland and the EU. The collaboration involved research communities and companies in particular. Stakeholder interaction was perceived as providing added value and supporting the emergence of new forms of collaboration.

The projects strengthened existing competence clusters and also created some new clusters. The use of research infrastructures was extensive and networking was active. Collaboration with other RRF projects was slight.

All the projects will continue their activities, often through new funding and collaboration networks. Continuity is particularly visible in the strengthening of competence clusters, competence development and utilisation of infrastructures.

The projects described their activities and the anticipated impacts well in impact stories, but with varying degrees of accuracy. However, some of the project impact stories submitted illustrated the impact chains well (e.g. FireMan, MIMIC, Green-Digi-Basin, HYDRO-RI-Platform). The impact mechanisms of the projects were related to the utilisation of research data in decision-making, business and education. However, the description of impact mechanisms and impact pathways remained general in many cases.

Short-term impacts were observed especially in the areas of promoting research, technological innovations and support for decision-making. Equity and inclusion were mentioned less often. The projects developed solutions that support, for example, climate objectives, the circular economy and resource efficiency. Long-term impacts support the EU Green Deal, climate objectives and many of the UN Sustainable Development Goals.

However, the anticipated long-term impact of the projects emphasises a long-term change in the area of sustainable growth and the green transition. Promoting the digital transition and technological transformation are particularly highlighted in the results, solutions and impacts of projects focused on AI and digitalisation. These projects also increased research efficiency and the accessibility of information.

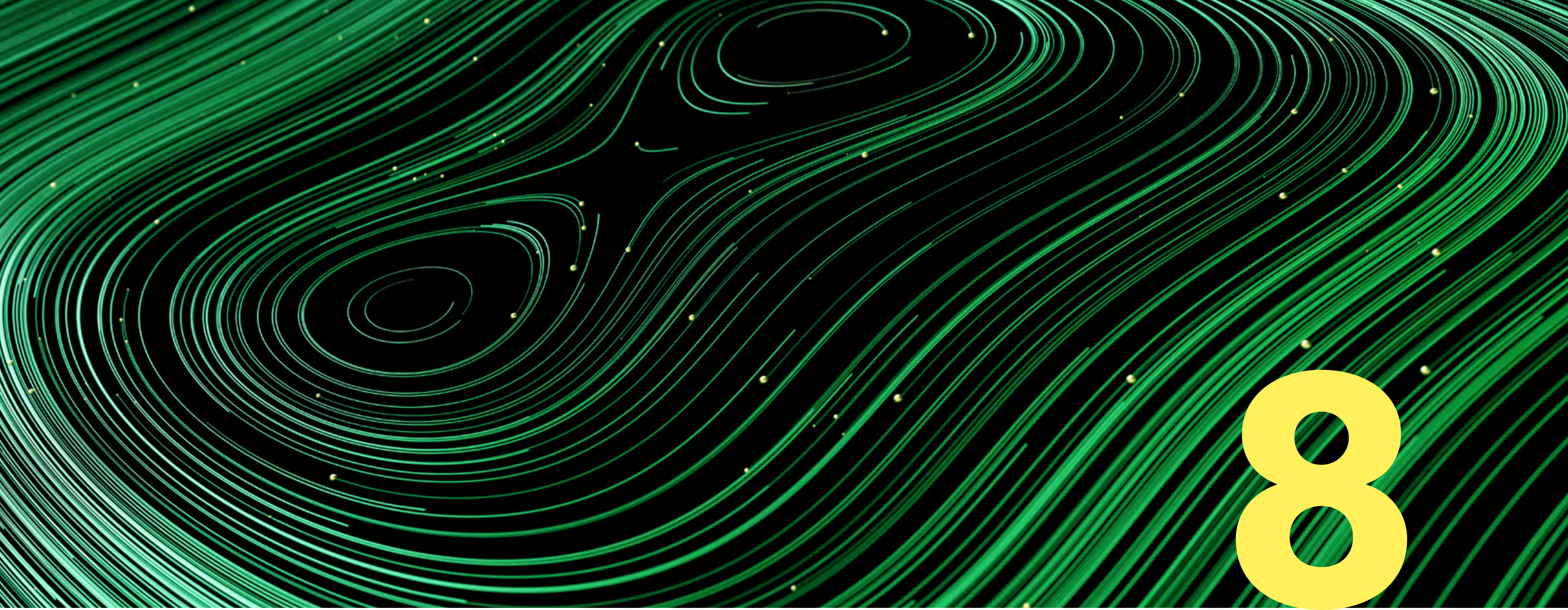
All the projects complied with the DNSH principle in their activities. The observed environmental impacts were minor or compensable. However, the assessment was based on a self-assessment. External validation could increase the reliability of the DNSH assessment procedure. However, the self-assessments indicated that the projects were in line with EU and national environmental objectives.

Based on the review carried out in the report, it can be concluded that the completed RRF projects strengthened the conditions for systemic change, especially by means of the competence base, competence clusters, infrastructures and permanent networks. The projects created and strengthened permanent RDI structures that support long-term impact in different areas of society, including science, and expanded RDI collaboration.

The strengthening of competence clusters was visible as new networks, education and the transfer of technology and competence. The projects engaged in extensive collaboration with research communities, companies, authorities and citizens in Finland and the EU. Stakeholder interaction produced new knowledge, supported the utilisation of research results and contributed to the emergence of new forms of collaboration. This supports the creation of impact and achievement of changes, as impact is not a linear transition from research to practice, but is created via interaction, learning and co-creation.

The projects have also trained new researchers and developed open learning environments. This supports the continuity of competence and enables systemic change by growing the competence base.

Although the projects have promoted co-creation between different RDI actors and interaction, which are key mechanisms for systemic change, the short time frame means that impacts on change have not yet been realised on a large scale. Promoting systemic change requires extensive deployment of results, changes in regulation and wider adoption in society. It is impossible to perform an assessment of the combined impacts at this stage. The time for assessing programme-level impact will also come later.



8. Conclusions and recommendations

In conclusion, it can be stated that the research projects and research infrastructure projects were successful in promoting the key objectives of RRF funding and laying the foundation for a long-term green and digital transition in Finland. As a whole, the completed RRF programme projects had an impact on the creation of networks and permanent structures as well as the strengthening of co-creation, interaction, competence and conditions for research. The likely long-term impacts of the projects thus support systemic change in society.

The short-term impacts of the projects do not arise from the direct impacts of individual projects, but through collaboration, networks, interaction, and collaboration and co-creation with different RDI actors. The projects have also developed permanent structures, strengthened the competence base and created solutions that have the potential to more extensively change operating models and structures in society. This is also a prerequisite for a systemic approach to impact.

Supporting and monitoring the impact of the continuum aiming to promote the green and digital transition and sustainable growth emerges as the key development objective.

Monitoring and evaluation of impacts requires a more systematic approach and strengthening of monitoring related to the deployment of concrete solutions. More evidence is needed concerning how results are transferred to practice. The examination of collaboration also remained largely quantitative in this report. A qualitative analysis of the depth and long-term nature of collaboration would be beneficial. Demonstration of the effects and impact could benefit from more concrete impact mechanisms, monitoring the deployment of the results and assessment of the combined effects. This will require the development of monitoring and evaluation in collaboration with different stakeholders.

Synergies between RRF projects also clearly remained slight at the overall RRF instrument level. More coordinated instrument-level steering could have strengthened the combined instrument and national-level impacts. This can be attributed to the rapid implementation of RRF funding, which could not be avoided at the national level.

A sensible and critical approach to the information in the report is recommended. It is mainly based on the reporting information produced by the projects, self-evaluations and impact stories. The information represents the perspective of the projects well, but the results of the report may have a positive bias. The review will be supplemented with information and views collected from stakeholders in autumn 2025. External evaluation may also provide added value, even if it is always performed within the limits of the available data. The challenges of verifying impact and attribution cannot be overcome even with external evaluation.

Despite its limitations, the report provides valuable information for funding providers and projects as well as for RDI actors. The RRF projects were successful in creating the conditions for systemic change, but any conclusions concerning impact and systemic change made on the basis of the report would be premature.

Based on the results of the report, the following recommendations can be made for research actors, funders of RDI activities and various research stakeholders in order to develop the impact and continuity of research and development activities:

Research actor

- Invest in planning and documenting impact. Impact is not created by accident, and it requires systematic actions. Research projects should identify potential impact mechanisms and stakeholders and plan how the research results will be put into practice while the project is still in its early phase.
- Develop collaboration with stakeholders. Engaging stakeholders while the research is still in the planning phase will improve the utilisation of knowledge and increase the potential for the research to have societal impact.
- Utilise research infrastructures and competence clusters. National and European research infrastructures provide a platform for collaboration, knowledge sharing and competence development. Their use should be strengthened and expanded.

RDI funders

- Encourage long-term RDI collaboration. Funding instruments should support long-term networks and collaboration structures that make it possible to create and strengthen the conditions for systemic change.
- Favour a systemic approach to strengthening and evaluating impact. Support competence related to the research impact and developing its monitoring and evaluation in cooperation with different stakeholders by creating frameworks for impact assessment that take both quantitative and qualitative impacts into account.
- Encourage RDI actors to develop collaboration regarding impact, highlight impact profiles and monitor and describe the emergence of combined impacts. Support the collection and utilisation of shared data and cooperation related to evaluation.

Industry and business representatives and authorities

- Actively participate in long-term research collaboration. Companies and authorities can already participate in research projects during the planning stage and provide insights on practical needs and applications. Try to simultaneously understand the different time spans of research, business and societal decision-making.
- Develop your organisation's competence and ability to accept new scientific knowledge, new competence and technology.
- Utilise research results and infrastructures and solutions that are based on research evidence. Research projects create methods, tools and data that can be utilised in decision-making, product development and service improvement.
- Cooperate when monitoring and evaluating impact. This makes it possible to develop RDI activities in the right direction during cooperation.

Decision-maker

- Enable the deployment of evidence-based solutions. In many cases, research results require large-scale implementation of regulatory changes or policy measures. Decision-makers and decisions play a key role in the realisation of impact.

Appendices

Appendix 1.
The projects included in the review, including information on all of the subprojects in the consortia, the amount of RRF funding granted to them, principal investigators and implementing organisations.

Research infrastructure projects

Name of the consortium project/ Research infrastructure	Decision number	Applicant organisation	Responsible person	Funding granted EUR
FIN-CLARIAH – Developing a Common RI for CLARIAH Finland **(FIN-CLARIAH)**	345610	University of Helsinki	Lindén, Krister	1,301,771
	345613	University of Helsinki	Lagus, Krista	241,755
	345614	University of Helsinki	Lilja, Johanna	130,470
	345617	CSC – IT Center for Science Ltd	Lehtovuori, Pekka	538,347
	345618	Tampere University	Kumpulainen, Sanna Wilhelmiina	180,581
	345619	University of Jyväskylä	Koskimaa, Raine	208,356
	345630	University of Turku	Laippala, Veronika	237,659
	345640	University of Eastern Finland	Laitinen, Mikko	196,983
	346323	Aalto University	Hyvönen, Eero	193,231
Finnish Marine Research Infrastructure **(FINMARI)**	345494	Finnish Environment Institute	Lehtiniemi, Maiju	574,055
	345495	University of Helsinki	Norkko, Joanna	241,462
	345496	Finnish Meteorological Institute	Tuomi, Laura	177,074
	345497	Geological Survey of Finland	Kotilainen, Aarno	271,199
	345498	University of Turku	Hänninen, Jari	136,064
	345499	Åbo Akademi University	Snickars, Martin	117,696
	345500	Natural Resources Institute Finland	Leskelä, Ari	147,663
Hydrological Research Infrastructure Platform **(HYDRO-RI-Platform)**	346161	University of Turku	Alho, Petteri	577,729
	346162	Finnish Geospatial Research Institute FGI at the National Land Survey of Finland	Kaartinen, Harri	582,296
	346163	University of Oulu	Marttila, Hannu	352,773
	346165	Finnish Environment Institute	Heiskanen, Anna-Stiina	387,621
	346167	Aalto University	Lotsari, Eliisa	370,235
EuroHPC/PRACE Finland virtual research infrastructure (RI)	345560	CSC – IT Center for Science Ltd	Ignatius, Janne	1,097,125

Research projects on key areas

Name of the consortium project	Decision number	Applicant	Organisation	Funding granted EUR
Aalto ENG/SCI **(AES)**	348179	Santasalo-Aarnio, Annukka	AALTO	482,330
	348180	Rinke, Patrick	AALTO	405,362
Artificial intelligence, spatial statistics and Earth observation for digital twinning of forest diversity **(ARTISDIG)**	348035	Mõttus, Matti	VTT LTD	569,075
	348152	Rautiainen, Miina	AALTO	180,418
	348153	Laaksonen, Jorma	AALTO	333,102
	348154	Myllymäki, Mari	LUKE	475,018
Beyond carbon-neutral drone aerial deliveries with autonomous micro-airports in sustainable metropolitan areas **(AeroPolis)**	348479	Röning, Juha	UO	506,901
	348480	Westerlund, Tomi	UT	470,350
	348481	Edelman, Harry	TU	474,706
	348754	Oksanen, Jani	AALTO	446,492
Capturing structural and functional diversity of trees and tree communities for supporting sustainable use of forests **(@Diversity4Forests)**	348643	Vastaranta, Mikko	UEF	461,324
	348644	Hyyppä, Juha	FGI	443,404
Enzyme-mediated attachment and detachment of multifunctional and biobased coating aided by digital material design **(ENZYFUNC)**	348870	Österberg, Monika	AALTO	399,954
	348872	Koivula, Anu	VTT LTD	562,430
	349052	Saranpää, Pekka	LUKE	394,382
Evaluating integrated spatially explicit carbon-neutrality for boreal landscapes and regions **(C-NEUT)**	347848	Forsius, Martin	SYKE	503,199
	347860	Aurela, Mika	FMI	464,778
	347862	Kumpula, Timo	UEF	465,472
	347863	Mäkelä, Annikki	UH	463,601
Foundations and digital infrastructure for green offshore energy production close to Finnish coasts: from marine investigations to the numerical estimation of undrained shear strength of the seabed deposit layers under cycling loading **(GEOMEASURE)**	347602	Solowski, Wojciech	AALTO	544,413
	347603	Virtasalo, Joonas	GTK	373,400
Green and digital transition in river basin management **(Green-Digi-Basin)**	347701	Alho, Petteri	UT	375,482
	347702	Kaartinen, Harri	FGI	375,193
	347703	Lotsari, Eliisa	AALTO	374,582
	347704	Marttila, Hannu	UO	375,513
	348022	Ronkanen, Anna-Kaisa	SYKE	375,107

Research projects on key areas

Name of the consortium project	Decision number	Applicant	Organisation	Funding granted EUR
Managing Forests for Climate Change Mitigation **(ForClimate)**	347780	Kulmala, Markku	UH	569,694
	347782	Lintunen, Anna	UH	474,756
	347793	Hynynen, Jari	LUKE	512,736
	347794	Lohila, Annalea	FMI	341,836
Materials Development for Flow Batteries with Help of Explainable AI **(FlowXAI)**	348326	Peljo, Pekka	UT	404,382
	348327	Laasonen, Kari	AALTO	391,535
	348328	Pihko, Petri	UJ	336,640
Microscopy and machine learning in molecular characterization of lignocellulosic materials **(MIMIC)**	347319	Foster, Adam	AALTO	383,738
	347611	Liljeroth, Peter	AALTO	406,756
	347612	Lehto, Joni	VTT LTD	562,491
Modelling engine to design, assess environmental impacts, and operate wind farms for ice-covered waters **(WindySea)**	348586	Polojärvi, Arttu	AALTO	498,093
	348587	Haapala, Jari	FMI	475,128
	348588	Heinonen, Jaakko	VTT LTD	394,581
UH-Aalto Sustainable Autonomous AI in Fight Against Climate Change **(konsortio UHASSA, projekti AIforLEssAuto)**	347197	Ruotsalainen, Laura	UH	468,963
	347198	Järvi, Leena	UH	420,352
	347199	Kyrki, Ville	AALTO	427,936
	347200	Roncoli, Claudio	AALTO	436,680
Unmanned aerial systems based solutions for real-time management of wildfires **(FireMan)**	346710	Honkavaara, Eija	FGI	457,017
	348008	Hänninen, Tuomo	UO	565,710
	348009	Pölönen, Ilkka	UJ	321,026
	348010	Saffre, Fabrice	VTT LTD	511,923
Urban environment and climate change in the arctic: data-driven intelligence approach to multihazard mitigation **(ADAPTINFA)**	348802	Kozlovskaya, Elena	UO	323,619
	348810	Okkonen, Jarkko	GTK	262,749
	348811	Suutala, Jaakko	UO	271,422

Appendix 2.
Distribution of RRF funding granted to projects by organisation.

	RRF funding granted EUR
Research infrastructure projects	
CSC – IT Center for Science Ltd	1,097,125
University of Helsinki	3,229,153
University of Turku	2,270,654
Finnish Environment Institute	1,665,213
Total	**EUR 8 262 145**
Research projects on key areas	
Aalto University	5,883,058
University of Helsinki	3,652,953
University of Eastern Finland	904,728
Finnish Geospatial Research Institute FGI at the National Land Survey of Finland	1,855,676
University of Oulu	2,756,239
Finnish Environment Institute	1,897,050
VTT Technical Research Centre of Finland Ltd	1,557,613
University of Turku	3,008,434
Total	**EUR 21 515 751**

Appendix 3.
Allocation of RRF funding to different expense categories for projects completed in 2023 and 2024.

	Allocation of funding EUR
Expense categories in research infrastructure projects	
Materials, supplies	314,466
VAT	130,777
Indirect employee costs	982,936
Equipment, etc.	2,459,728
Travel expenses	143,705
Other expenses	42,985
Salaries	2,034,626
Purchased services	198,203
Revenue from the project	415
Overhead costs	1,849 447
Total	**EUR 8,157,288**
Expense categories in key areas	
Materials, supplies	181,960
VAT	30,558
Indirect employee costs	3,595,000
Equipment, etc.	140,984
Travel expenses	512,006
Other expenses	508,245
Salaries	7,438,116
Purchased services	343,441
Overhead costs	8,598 263
Total	**EUR 21,348,574**

Appendix 4.
Person-months in the projects as reported by projects.

	Person-months
Research projects on key areas	
Assisting personnel	444.76
PhD student	832.20
Professor	73.81
Researcher	410.87
Postdoctoral researcher	533.60
Total	**2,295.23**
Research infrastructure projects	
Assisting personnel	358.66
PhD student	107.53
Professor	26.12
Researcher	43.45
Postdoctoral researcher	60.76
Total	**596.52**

Appendix 5.
Main results reported by research projects on key areas with the RRF report.

Project / consortium	Results
Green-Digi-Basin	■ Architecture of the digital twin of a river basin. ■ New soil moisture-motion-temperature-salinity sensor network has been built to Pulmanki, Oulanka and Vantaa sites for understanding the river channel evolution due to freeze-thaw cycles. ■ Novel hydrological, sediment transport, river dynamics, and water quality monitoring network for enabling present and future simulations of environmental change impacts.
C-NEUT	■ Publication of special issue (Carbon sequestration and biodiversity impacts in forested ecosystems) in the journal Ambio in 2023, documenting key project results. ■ Derivation of freely available detailed spatial datasets on greenhouse gas emissions for different landuse classes and scenarios for forest carbon fluxes and storages, for 18 admininistrative regions in Finland. ■ Arrangement of special session 'Managing for diversity: A call for a better understanding of linkages between forest structure, biodiversity and carbon cycle' at the international IBFRA conference 'Climate Resilient and Sustainable Forest Management.
MIMIC	■ Integration of Machine Learning in Material Analysis ■ Advanced Imaging Techniques ■ Isolation and fractionation of hemicelluloses and LCCs ■ Characterization of LCC fractions from biomasses ■ Hybrid hydrogels from hemicellulose and bark extracts ■ New enzymes for processing hemicellulose and LCCs
FireMan	■ Stakeholder demonstration event. The project successfully demonstrated all key development outcomes at a stakeholder event held at the Emergency Services Academy of Finland's test area in Kuopio on September 17–18, 2024. A total of 55 participants from industry, practice, and media attended the full-day event, which featured outdoor technical demonstrations, presentations, and posters. ■ A Digital Twin Concept was developed to serve as the decision support system for the wildfire management. ■ An implementation of a pre-commercial UAS Traffic Management (UTM) system, Astra UTM, as part of the FireMan project.
ADAPTINFA	■ Progress in understanding processes related to effect of unusual winter weather conditions (rapid freezing) on physical properties in the uppermost soils. We have compiled a digital model of uppermost soil conditions for Finland using HydroBlocks software, which can be used to simulate soil temperature and soil ice content (and many other variables as well) at any given time at spatial scale of 90 m. ■ Progress in developing AI and machine learning tools, models, and applications for prediction and forecasting climate change adaptation studies. ■ Experimental study of the fracturing processes in the uppermost soils and on the roads surfaces due to unusual winter weather conditions (rapid freezing).

Project / consortium	Results
ForClimate	■ New information on forest GHG dynamics and how forest management affects them. We gained new results on forests growing on mineral and organic soils. ■ Other climate impacts of boreal forests (albedo, aerosols). We have gained new scientific knowledge on the comprehensive climate impacts of forests, including the albedo and aerosol effect. ■ Development of modelling tools to tackle the forest-climate impacts under different management scenarios: modelling tool (Motti C+), in which two different models (Motti and PREBAS) are used interactively to provide best available prediction on the effects of forest management and climate change.
ARTISDIG	■ Tools to quantify forest structural diversity in a realistic and meaningful way. ■ The subtle relationship between forest structural diversity and its spectral reflectance can be used to improve the mapping of forest diversity for large-scale applications. ■ Machine learning can be used to efficiently emulate the physical forest productivity models used in Forest Digital Twin, thus making large-scale predictions on forest development more accessible to decision-makers and the general public.
WindySea	■ One key result was the development and application of advanced numerical sea ice modeling techniques aligned with the project's goals. We were able to demonstrate state-of-the-art high-resolution large-scale sea ice modeling capabilities, which set a new standard in the field. ■ A key highlight was model-scale testing of ice loading on wind turbines (Petry et al., 2025), which provided new insights into offshore turbine design for icy conditions. ■ Analysis of full-scale sea ice condition data from the Baltic Sea from the aspect of implementation of offshore wind turbines and farms.
UHASSA	■ Bochenina, K., Agriesti, S., Roncoli, C., Ruotsalainen, L. From urban data to city-scale models: A review of traffic simulation case studies // IET Intelligent Transport Systems. Accepted ■ Bochenina, K., Pyykölä, S., Al-Jaghbeer, O., Fung, P.L., Jarvi, L- Ruotsalainen, L. Deep reinforcement learning for emission reduction at scale: a case study for Helsinki city area // To be submitted to Transportation Research Part D: Transport and Environment. ■ We generated an easy-to-use lookup table for traffic related CO_2 emissions enables an efficient upscaling of traffic CO_2 emissions across European cities.
AeroPolis	■ Drones as a Service (DaaS) Digital Platform requirements specification and edge computing. ■ The most tangible highlight of the energy conversion research has been the demonstration of the hybrid solar-cell fuel-cell functionality by a semiconductor pn-diode, laying the foundation for the future research of the related chemovoltaic effect. ■ UTurku's main research results emphasise advancements in AI-based localization, mapping, and tracking technologies using multi-modal LiDAR, inertial sensors, and vision-based systems, particularly in challenging environments such as GNSS-denied areas and indoor settings.

Project / consortium	Results
AES	■ The machine-learning assisted catalyst discovery framework is under review, and was published as a pre print with the working title "Machine-learning Accelerated Descriptor Design for Catalyst Discovery: A CO_2 to Methanol Conversion Case Study". ■ The manuscript associated with the experimental dataset will be submitted to Scientific Data in 2Q2025 with the title "AI-ready experimental dataset to the thermochemical hydrogenation of CO_2 to methanol". ■ A manuscript of the experimental studies on novel catalysts developed in the project is under preparation and will be submitted in 2Q2025.
GEOMEASURE	■ Generalized Interpolation Material Point Method Replication of Fall Cone Tests ■ Generalized Interpolation Material Point Method Replication of Laboratory Scale Free Fall Cone Tests ■ How to use oedometric tests to estimate the undrained shear strength of sensitive marine clay? ■ Optimization of Berm construction to reduce Settlement of Submarine Power Cables in Soft Clay Seabeds ■ Cyclic behaviour of soft clays from Gulf of Bothnia ■ Assessment of near-surface undrained shear strength of soft seabeds with free fall cone penetrometer testing in the northern Baltic Sea ■ In situ free-fall cone penetrometer (FF-CPT) and laboratory fall cone characterisation of soft marine sediments in the Gulf of Finland, Baltic Sea ■ Replication of fall cone test in marine clay with a Generalized Interpolation Material Point Method simulation ■ Numerical Simulation of a Laboratory-Scale Free Fall Cone Penetrometer Test in Marine Clay with the Material Point Method ■ Geological, geophysical and mechanical identification of marine deposits from the Gulf of Finland ■ Combined Geophysical, Geological and Geotechnical Study of Offshore Soft Sediments at a Planned Wind farm Area ■ Numerical simulation of in-situ free fall cone penetrometer tests using the material point method ■ Impact of a spacing reduction in a fall cone test ■ Free fall cone penetrometer testing of near-surface undrained shear strength at the Tahkoluoto wind energy production site, northern Baltic Sea ■ Measurement of three-dimensional shrinkage deformations and volumes of stabilised soft clay during drying with Structure from Motion photogrammetry
@Diversity4Forests	■ Branch fingerprint of Trees (Yrttimaa et al. 2025): We have developed a unique method for tree identification. In this method, we recognize individual branch points on the stem. ■ Cimdins et al. explored the use of laser scanning technologies to assess forest structural complexity and its development over time. ■ We studied the use of high-density ALS point clouds for accurate and direct stem curve and volume measurements at the individual tree level.

Project / consortium	Results
ENZYFUNC	■ One significant outcome was the demonstration of successful enzymatic attachment of biobased, multifunctional coatings for both textiles and as barrier materials for fibre-based packaging, thus answering the main objective. ■ We demonstrated, using standard testing methods according to EU Reach and CLP regulations, that the developed nanoparticles from suberin (SNPs), softwood kraft lignin (LNPs), and tall oil fatty acid ester of softwood kraft lignin (TOFA-LNPs) were not cytotoxic, irritant, or corrosive to skin enabling their use in textile coating. ■ Digital tools were developed at VTT for predicting material properties and thus accelerate the design and development of new biobased coatings.
FlowXAI	■ Discovery of AZON3, a new family of redox flow battery negolytes. This discovery is highly relevant to the goals of the entire project as it enabled us to bring organic redox flow battery materials to a new level of volumetric efficiency while maintaining good stability. ■ The information in this research challenges the conventional understanding of borane-catalyzed carbene transfer reactions and provides valuable insights into the factors governing pathway selection and catalyst performance. The presented findings have implications for the rational design of efficient catalysts for borane-catalyzed carbene transfer reactions. ■ Method of high throughput combinatorial synthesis of metal complexes and their high throughput electrochemical characterization.

Appendix 6.
Objectives and results of research projects on key areas based on the survey responses.

Project	Objectives	Results
348870 Enzyme-mediated attachment and detachment of multifunctional and biobased coating aided by digital material design (ENZYFUNC)	■ To develop durable coating strategies, with a particular focus on coating removal and recyclability. ■ To produce advanced technology solutions, particularly by replacing harmful chemicals with bio-based, degradable and non-toxic alternatives to improve textile properties and packaging plastics. ■ To reduce climate impacts by using processes that place less burden on the environment, and to increase recycling and cascade treatment. ■ To use side streams to produce valuable materials and mitigate climate change by binding carbon to long-lasting and recyclable materials. ■ To create new business opportunities for the forest industry.	**Utilisation of bio-based side streams:** The project made use of underutilised bio-based side streams when developing hydrophobic coating materials to replace the hazardous substances that are currently used. These streams are available worldwide, which will contribute to local resource adequacy around the world. **Use of enzymes as catalysts:** The project utilised enzymes as biosynthetic and biodegradable catalysts in cross-linking and synthesis reactions, which enables milder reaction conditions and can also reduce the formation of difficult-to-treat waste. **Development of nano- and microparticles:** The project developed simple methods for producing nanoparticles and microparticles from bark extracts, which were used to produce coatings for textiles and packaging. The development work will make it possible to replace coatings that are harmful to the environment and increase the opportunities for using bio-based solutions. **Life cycle and safety assessment:** The project performed a life cycle and safety assessment, which demonstrated, which parts of the processes have to be optimised to increase sustainability and showed that nanoparticles are generally safe to use, but can be harmful to aquatic organisms. **Use and recyclability of renewable resources:** The project utilised renewable side streams as a resource and achieved good functionality with very thin coatings, which enhances material efficiency, reduces harmful chemicals and recycles materials and promotes environmentally friendly production methods. **Promotion of biodiversity:** In the longer term, the project results can promote biodiversity by reducing the use of virgin raw materials and harmful chemical load in the environment. **Development of computational approaches:** The project developed two computational approaches for virtual testing of hydrophobic coating design. These can have a significant impact on the design of future materials. **Strengthening of expertise and competence:** Research carried out in the project has increased the level of expertise in this field. A multidisciplinary project involving close cooperation with experts from different disciplines promoted the researchers' ability to communicate, collaborate and utilise the strengths of different disciplines when solving common problems. This also applies to the students who worked in the project.

Project	Objectives	Results
346710 Unmanned aerial systems based solutions for real-time management of wildfires (FireMan)	■ To promote research and innovations. To facilitate technology transfer. To promote collaboration that supports the green and digital transition. ■ To replace or supplement traditional fuel-powered aeroplanes and helicopters with electric autonomous drones, thus significantly reducing emissions caused by monitoring and response activities. ■ To improve efficiency with an optimised drone swarm and connections, enabling extensive monitoring with minimal energy consumption. ■ To support the green and digital transitions, improve climate resilience and accelerate the uptake of sustainable autonomous technologies for environmental monitoring and disaster management by developing AI-based, low-emission and data-driven solutions.	**Development of low-emission AI and drone technologies:** The technologies developed in the project improve the prevention and management of wildfires, support climate change adaptation and mitigation, enable early detection and rapid response, and prevent small fires from growing into large and high-emission fires. Autonomous drone operations and AI-driven analytics enable real-time, data-driven decision-making in wildfire prevention, improve efficiency and accuracy in emergency situations, and enable efficient data collection in dynamic wildfire situations. Advanced AI and remote sensing enable real-time detection of fires and collect critical data concerning, for example, the spread, intensity and environmental impacts of a fire. **Development of a model to predict the spread of fire:** The model developed in the project provides insights into fire-fighting strategies, helps authorities target measures in high-risk areas and optimise resource use. It also integrates GIS and environmental data, helping authorities to more effectively anticipate and mitigate the spread of fire. Drone-based situational awareness improves the decision-making of first responders by providing accurate and up-to-date data in real time. UAS traffic management (UTM) and sustainable connectivity solutions ensure seamless coordination of autonomous drones even in challenging conditions. **AI-controlled remote sensing and real-time environmental monitoring:** The solutions developed in the project support sustainable forest management, land use and precision agriculture, help to optimise forest thinning, detect drought stress and improve biomass monitoring, and healthier and more sustainable ecosystems. The solutions are also suitable for monitoring and mitigating floods, oil spills and storm damage. **Applicability of digital methods:** The digital methods developed in the project can be extended to other environmental monitoring sites, such as air quality assessment, ecosystem health monitoring and infrastructure inspection. **Strengthening of national and international collaboration:** Working with the UNITE and 6G flagships, FUAVE RDI network, international scientific community and key Finnish wildfire management stakeholders facilitates the transfer of high technology and AI to practical applications and promotes the societal and environmental impact of the project.

Project	Objectives	Results
348802 Urban environment and climate change in the arctic: data-driven intelligence approach to multihazard mitigation (ADAPTINFA)	■ To promote climate change adaptation and reduce greenhouse gas emissions into the atmosphere. ■ To develop related digital technologies that mitigate the impact of extreme and unusual weather conditions in urban and rural environments and in the related infrastructures. ■ To protect urban environments, related infrastructures and industrial facilities by reducing the risk of natural disasters due to extreme and unusual weather conditions caused by climate change in these areas. ■ To ensure sustainable road operations in Arctic and sub-Arctic (boreal) regions by preventing serious damage to pavements and roads that may cause service interruptions in urban and rural areas. ■ To promote the digital transition and AI-based solutions for climate change adaptation by sharing scientific knowledge, participating in cooperation studies with industrial partners and increasing competence related to multidisciplinary topics.	**Development of methods to simulate the impacts of climate change:** The project developed methods for understanding freezing and melting cycles and the formation of ice lenses in soil and roads. The methods can be used to simulate the effects of climate change and to identify how certain factors (parameters) affect the condition of roads and the soil in northern areas. The method can be utilised to maintain the condition of roads and adapt to changes caused by climate change. **Development of software to detect frost quakes:** The project developed software based on Python libraries to detect and locate frost quakes. **Development of a hydrological model:** The project compiled information on Finland's ground, soil and long-term meteorological data into a database for a large-scale hyper-resolution hydrological model. The results of HydroBlocks modelling can be used to calculate heat stress in Finland's soil and roads during rapid drops in air temperature and to select areas with increased risk due to cryoseismic phenomena and assess the risk they pose to infrastructures in these areas. **Solutions for integrating multiple data sources:** The project produced new solutions for integrating several data sources that are based on artificial intelligence and machine learning. The integrated data sources include on-site land surveying, weather observations and satellite remote sensing data. Integration of data sources promotes several aspects of climate adaptation and mitigation with regard to built infrastructure and the environment. **Development of long-term road quality forecasting:** The project developed solutions for forecasting road quality (a use case that provided good results) based on diverse historical International Roughness Index measurements, detailed seasonal weather data, maintenance data, soil type data and spatial properties of roads.

Project	Objectives	Results
347602 Foundations and digital infrastructure for green offshore energy production close to Finnish coasts: from marine investigations to the numerical estimation of undrained shear strength of the seabed deposit layers under cycling loading (GEOMEASURE)	■ To carry out research and develop innovations related to marine energy and cable safety that link offshore infrastructures with land. ■ To focus on the low-carbon economy, infrastructure sustainability and climate change adaptation by exploring offshore wind energy.	**Promotion of research and innovations:** The results of the research can reduce the risks and costs of future structures and linking infrastructure. The results are in line with the objectives of the National Recovery and Resilience Plan (RRP), as the project promoted research and innovations. **Support for technology transfer:** The project supported technology transfer through discussions with industry and other stakeholders and promoted cooperation between companies. **Development of digital technologies to promote the green and digital transition:** The project supported the green and digital transitions, promoted solutions for carbon neutrality and climate change adaptation and developed related digital technologies, such as numerical methods for design.
347780 Managing Forests for Climate Change Mitigation (ForClimate)	■ To promote the green transition and carbon neutrality and solutions for climate change adaptation.	**Production of new knowledge:** The project produced scientific data on the overall impacts that forests and their management have on the climate. The project produced new information on, for example, how forest management in organic and mineral soils affects the forest carbon sink. **Development of a method for measuring local aerosol production of a forest:** The project developed a new method for measuring and analysing local aerosol production in forests. The method provides a more comprehensive picture of the climate impacts of forests that consist of different tree species, grow in different soil types and are managed in different ways. **Development of modelling methods to analyse the climate impacts of forests:** The project developed the Motti C+ method, which involves using two different models (Motti and PREBAS) interactively to produce a forecast of forest management and climate change impacts. Motti C+ is a tool for performing scenario analyses and assessing the role of forests in climate change mitigation. The development of this model and the user interface currently under development as well as new instrumentation for measuring local aerosol production (Cluster Ion Counter) also promote digital technologies.

Project	Objectives	Results
347701 Green and digital transition in river basin management (Green-Digi-Basin)	■ To promote the green and digital transition and sustainable water management in Finland and the EU.	**Development of digital twins for water resources management:** The project played a key role in promoting digital twins in water resources management at the national and international levels. A roadmap was created for their deployment, and the project cooperated with experts in more than 10 countries. **Optimised solutions for protecting natural waters:** Based on hydrological modelling in the Oulanka river basin, the project developed an optimisation process to identify the most effective restoration measures to improve water protection and carbon sequestration. **Improvement of nutrient and carbon modelling in the Vantaanjoki river basin:** The project produced new spatial data on water quality and inorganic carbon measurements, an area in which very little information was previously available. This data was used to identify carbon load peaks and to simulate the impacts of land use on carbon emissions in different climate change scenarios. **The impact of climate change on winter hydrology and terrain changes in rivers:** The new measurement techniques used in the project revealed that spring floods are occurring earlier and are weaker, while the number and intensity of winter floods have increased. Over 70% of these changes have occurred in the last decade. The observations support better preparation for the impacts of climate change in water resource management. **The combination of long-term monitoring data and computational modelling:** The project studied how seasonal changes affect the loading of solids and particle phosphorus in the agricultural river basin in the Archipelago Sea catchment area. The changing winter conditions caused by climate change pose increasing challenges to water protection in Southern Finland. Real-time on-site monitoring and catchment-wide analysis are key tools in terms of mitigating these impacts. **Development of climate change adaptation and digital modelling:** The project promoted the green and digital transitions by combining long-term hydroclimate data and digital measurement techniques for river morphology to improve climate change adaptation and digital modelling. The project produced information on how climate change will shift hydroclimate systems in the boreal region from snow-dominated to rain-dominated. The findings support river restoration strategies, digital modelling, sediment flow management and infrastructure planning. The models and tools developed will be integrated into the national system for modelling catchment areas, which will improve the accuracy of water situation assessments and pollution calculations. The aim is to ensure that the solutions produced in the project have a permanent impact on national water management practices.

Project	Objectives	Results
348586 Modelling engine to design, assess environmental impacts, and operate wind farms for ice-covered waters (WindySea)	■ To promote the green and digital transition by developing offshore wind energy solutions for cold sea regions. These objectives directly support the objectives of carbon neutrality and climate change adaptation. ■ The project addressed key challenges in the deployment of offshore wind power in the Baltic Sea, especially concerning the ice conditions that increase technical and economic barriers.	**Development of a prototype for a digital twin:** The project developed a digital twin prototype for wind farm design and environmental impact assessment, and for improving cost-effectiveness by integrating state-of-the-art technology. **Development of sea ice modelling:** The project developed and promoted numerical sea ice modelling using the discrete element method and supercomputers such as LUMI. High-resolution models enable more advanced simulations of sea ice dynamics and their interaction with wind farms. Modelling can be used to better inform design. Ice load tests also revealed new turbine-ice interactions that will affect future work to ensure the safety, durability and resilience of offshore wind structures. **Strengthening of collaboration:** The project strengthened collaboration between Aalto University, VTT Technical Research Centre of Finland and the Finnish Meteorological Institute. The partnership strengthens Finland's leadership in marine technology in cold regions and ensures long-term innovation in renewable energy solutions. State-of-the-art research, technology innovation and strategic partnerships have allowed the project to boost Finland's role in the global transition towards sustainable, resilient offshore wind energy solutions, which supports the production of long-term benefits for both the environment and industry. **Clarification of industrial standards:** The project helped to specify industrial standards for offshore wind power in icy conditions, which supports both national and EU climate targets. During the RRF funding period, the project laid the foundation for future progress, and a follow-up project funded by the Finnish Transport Infrastructure Agency will examine the impacts of wind farms on sea ice conditions that are important for shipping. Continuation of the project's research highlights the systemic impact of the RRF project, as the new project combines the development of renewable energy with marine safety and environmental sustainability.
348179 Aalto ENG/ SCI Alcon (AES)	■ To accelerate the development of digital and low-carbon technologies.	**Development of computational databases and AI-based solutions:** The project developed experimental and computational databases for the hydrogenation of carbon dioxide into methanol and AI-based solutions for finding new catalyst materials. The project tested new materials and optimised operating conditions through knowledge-based experimental design. The experimental design method was applied to electrothermal energy storage systems, i.e. emerging green technologies. The project's databases, workflows and catalysts will be made available to the public at no cost. This can contribute to the discovery of low-carbon technologies and digital (AI-based) materials.

Project	Objectives	Results
348643 Capturing structural and functional diversity of trees and tree communities for supporting sustainable use of forests (@Diversity4Forests)	■ To influence state organisations and their activities (Natural Resources Institute Finland, Finnish Environment Institute and Finnish Forest Centre) and thus improve forest policy-making and forest management planning in Finland. ■ To carry out research and development work that creates new companies in Finland to provide a variety of forest assessment services for which there is likely to also be international demand.	**Development of new technologies:** The project developed new technologies, such as terrestrial laser scanning (TLS), mobile laser scanning (MLS) and drone-based measurements. The introduction of these technologies in the Finnish Forest Centre's surveying tasks improves the quality of information, which in turn improves the services provided. The technologies developed are essential for tracking the origin of wood and preventing illegal logging. The methods can also be used to improve forest cultivation and treatment by increasing our understanding of the relationships between growth conditions and the end product. The technologies that were developed have export potential. **Methodology development:** The project developed methods for measuring the individuality of trees, mapping tree mortality and assessing the structural complexity of forests. These enable better decision-making on forest management in society and companies. **Strengthening of competence:** Through methodological development, the project strengthened the competence and expertise needed in society and companies to halt biodiversity loss and increase carbon stocks.

Project	Objectives	Results
348035 Artificial intelligence, spatial statistics and Earth observation for digital twinning of forest diversity (ARTISDIG)	■ To promote the green and digital transitions by developing advanced AI-based algorithms to interpret Earth observation data.	**Development of quantification and monitoring of structural and spectral forest variation:** The project strengthened existing research collaboration networks in Finland, combining forest research with AI development. This promotes the use of advanced digital technologies to monitor and manage forest ecosystems and strengthen the project's impact on carbon neutrality and climate change adaptation. The project developed the digital twinning of forest diversity by creating tools for integrating boreal forest diversity with the Digital Twin Earth project, which is an EU flagship project being implemented in parallel projects. The ongoing integration increases understanding of the impacts that forest management policies have on the changing climate and produces high-resolution data. The project combined 3D airborne laser scanning with hyperspectral remote sensing to improve the parametrisation and validation of forest digital twins. The scalable technologies produce data on forest structure and activity, which is essential for making accurate carbon estimates. The use of digital technologies, such as AI and advanced remote sensing, strengthens forest sector competence in Finland and combines forest research with AI development and other advanced mapping methods. **Development of solutions for carbon neutrality and climate change adaptation:** The project developed methods for accurately quantifying and monitoring structural and spectral forest variation, which are needed to understand and manage carbon stocks in forests that are critical in terms of carbon sequestration and climate regulation. The project results will enable knowledge-based decision-making in conservation and management practices, and the data sets produced will be essential elements in improving forest monitoring with future hyperspectral satellites (such as Sentinel-10 CHIME, which will be launched by the European Space Agency in 2029) in order to assess the impact of different forest management strategies on carbon sequestration and to develop adaptation measures to mitigate the impacts of climate change. **Development of digital technologies for carbon neutrality and climate change adaptation:** The solutions developed in the project are all digital technologies that support carbon neutrality and climate change adaptation. Integration of advanced mapping technologies: airborne laser scanning is known for its accurate quantification of forest structure into a digital twin of forests. Spectral data provides additional information on species diversity, activity and structural variation. The high-resolution data sets produced by the project support knowledge-based decision-making in protection and management practices. The project also promoted the digital twinning of Destination Earth development by combining field measurements with advanced mapping methods. This will increase understanding of forest dynamics in a changing environment and facilitate the development of adaptation measures to mitigate the impacts of climate change.

Project	Objectives	Results
347199 UH-Aalto Sustainable Autonomous AI in Fight Against Climate Change (UHASSA)	■ To understand how autonomous electrified traffic should be organised and managed to maximise the reduction of transport-related CO_2 emissions in cities.	**Development of a reference framework for modelling tools:** The project developed a reference framework for computational modelling tools that assesses CO_2 emissions from the deployment of automated electrified vehicles in urban road environments. **Development of AI-based control and optimisation strategies:** The project developed AI-based control and optimisation strategies for traffic management from the vehicle level to the urban level, which will minimise CO_2 emissions. The study dealt with a transition phase in which the vehicle fleet simultaneously includes manually driven and autonomous vehicles, as well as internal combustion engine and electric vehicles. **Development of reinforcement learning models (machine learning models) for traffic optimisation:** The project developed new multi-target reinforcement learning models for traffic optimisation. The model is based on the scenarios that are most important in terms of emission reduction scenarios, and which were selected with project stakeholders. The scenarios dealt with the travel time and emissions of individual vehicles, the electric vehicle charging station infrastructure and last-mile traffic via carpooling. The scenarios developed methods for modelling human drivers to, for example, create strategies for reducing transport emissions by encouraging more sustainable driving behaviour in automated traffic.

Project	Objectives	Results
347848 Evaluating integrated spatially explicit carbon-neutrality for boreal landscapes and regions (C-NEUT)	■ To provide better estimates of carbon processes/stocks and net greenhouse gas emissions for different land use categories at high resolution. ■ To produce estimates of the regional potential to reduce anthropogenic greenhouse gas emissions based on the current plans in the National Climate and Energy Strategy. ■ To develop impact scenarios and descriptions in the key model processes that are used in evaluations. ■ To develop new concepts for regional extrapolation of data (empirical data, modelling, remote sensing). ■ To identify ecosystem turning points and their uncertainties. ■ To develop new approaches to high-resolution Earth Observation (EO) techniques and machine learning. ■ To produce integrated, spatially explicit carbon-neutrality scenarios on different scales (individual habitats, communities, regions, national scale) that also take into account biodiversity (BD) and sustainability aspects. ■ To identify the potential for using the developed technologies in other regions/countries through the project team's established close contacts with international networks and research infrastructures (e.g. eLTER, ICOS, ILTER).	**Production of new knowledge:** The project collected and analysed greenhouse gas flux data from ecosystems and the atmosphere. The flows were measured using the micrometeorological eddy covariance method (EC) in different ecosystems around Finland as part of international networks (e.g. ICOS, eLTER and Fluxnet). The data was used as input data for different model systems used in the project and to estimate greenhouse gas balances. Regional data sets were produced from different land use categories for end users. **Improvement of the spatial datasets used in modelling:** The project developed spatial datasets on carbon processes and biodiversity, which were utilised in modelling by means of high-resolution remote sensing (ALS, multi- and hyperspectral airborne imaging), time series analysis of historical aerial images and machine learning algorithms. **Utilisation of large-scale modelling tools:** The project utilised large-scale dynamic modelling tools to develop scenarios for carbon processes/stocks on natural lands and to analyse the results from the perspective of climate change mitigation, adaptation and biodiversity conservation. The project also developed disturbance modules to analyse forest resilience. **Production of status databases:** The project produced detailed status databases on the current net greenhouse gas emissions in different land use categories. The project results and tools are currently being used in the REPower-CEST project (Clean Energy System Transition), which is funded by the NextGenerationEU instrument.

Project	Objectives	Results
347319 Microscopy and machine learning in molecular characterization of lignocellulosic materials (MIMIC)	■ To develop and apply molecular scanning probe microscopy and machine learning analysis for the characterisation of lignocellulosic materials. ■ To understand how sustainable materials could be imaged with high-resolution scanning probe microscopy.	**Development of criteria for imaging biomolecules:** The project created criteria for the systematic comparison of experiments and simulations when imaging complex biomolecules. **Integration of machine learning with material analysis:** The project developed workflows that combine ML and SPM with molecular analysis, improve data processing and accelerate the discovery of materials. The approach automates tasks that traditionally require extensive manual effort and makes them more efficient and scalable. **Development of advanced imaging techniques:** Achieving molecular and atomic resolution for LCM bridges the gap between experimental imaging and simulation. This enables more accurate digital models of sustainable materials, which is crucial for the industry that is transitioning to data-driven design and simulation. **Development of a Molecular Discovery Pipeline:** By integrating ML energy sampling, ML potentials and quantum simulations, the project lays the foundation for high-throughput digital workflows. This innovation can be extended to other material systems, thus promoting the development of computational materials science and nanotechnology. **Focus on sustainable materials:** Characterisation of lignocellulosic materials (LCM) derived from renewable biomass supports the development of environmentally friendly alternatives to petrochemical products. By increasing understanding of their molecular structure and properties, the project accelerates the adoption of sustainable materials in industry, such as the packaging, construction and textile industries. **Efficient use of resources**: High-resolution imaging and computational approaches optimise material development processes, thus reducing the use of the experimental trial and error method and minimising the waste of valuable resources. This is in line with the principles of sustainable production. **Electrospray and biomolecule analysis:** The ability to accurately store and analyse biomolecules using electrospray techniques promotes understanding of biocompatible and biodegradable materials. These insights can help design green technologies, such as bioelectronics or environmentally friendly coatings. **Synergy between digital and green objectives:** The project demonstrates how digital innovations, such as ML-based workflows, can meet the challenges of developing sustainable materials. It creates a feedback loop where computational advances support green initiatives while insights gained from sustainable materials simultaneously take digital technologies into new areas. This synergy is essential for a future in which digital tools and green materials develop together to meet societal and environmental needs.

Project	Objectives	Results
348479 Beyond carbon-neutral drone aerial deliveries with autonomous micro airports in sustainable metropolitan areas (AeroPolis)	■ To develop a secure and transparent digital infrastructure for the use of autonomous drones in a modern urban environment. ■ To enable the extensive utilisation of drones in, for example, transport and data collection services by promoting the creation of service ecosystems and increasing the acceptability of autonomous drones in society.	**Development of the digital infrastructure concept and reference architecture:** The project developed a digital infrastructure concept and reference architecture for the operation of autonomous drones in a modern urban environment. The digital infrastructure concept describes how drones operate in regulated spaces, thus providing traceability and responsibility, which increases the overall acceptability of autonomous drones. Service-based approaches developed in the practical reference architecture can be used to promote service ecosystems and enable the use of drones in different services, such as transport and data collection. **Technology development: Technology development was divided into two main lines.** The first line focused on increasing autonomy, which enables the wider deployment of autonomous drones in different sectors. In particular, relative positioning algorithms that combine UWB, camera and LiDAR data significantly improve situational awareness, for example, during drone take-offs and landings. This advance supports the wider deployment of autonomous drones, accelerates the digitalisation of industry and improves operational efficiency. It also provides solutions for low visibility and GNSS signal interference situations and improves real-time monitoring in counter-drone systems. These technological advances will not only solve critical problems in GNSS-free environments but will also contribute to the development of cost-effective and accurate positioning methods, thus supporting sustainable growth and the resilience of society. The second line of development included extensive research on suitable semiconductor materials and technologies, manufacturing methods and electrochemical processes in the state-of-the-art Micronova cleanroom facilities. The project utilised and produced competence on multidisciplinary topics ranging from electrochemistry to process technology and applications. The project designed, manufactured and characterised hybrid devices that use both light and chemical energy sources to produce electricity, which differs from conventional fuel cells based on ion transport and separate electrodes. These actions culminated in the first demonstrations of the device capabilities, which provided promising results in converting chemical energy into electrical energy.

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