technopolis group

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Study to establish a methodology to assess the societal impact of research and research-based innovation

A study commissioned by the Research Council Norway

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Table of Contents

Tables

Figures

1 Introduction

1.1 This study

This study, commissioned by Research Council Norway (RCN) to Technopolis, aims at **identifying and assessing the societal impact that research and research-based innovation activities** performed by the professional community of knowledge producers (academia, research institutes, firms and others) **has on the environment, economy, technologies, policies, culture and practice across society.** This also includes the identification of the mechanisms leading to impact. Overall, this study aimed at delivering:

- A methodological framework to identify and assess the societal impact of research relevant for solving societal challenges, focusing predominantly on research funded by the Research Council of Norway, but not exclusively so
- Identify, categorise and analyse actions, mechanisms or pathways inducing impact, for possible learning and to guide future moves to increase impact
- Provide empirical evidence of impact based on testing the suggested methodologies on at least two societal challenges
- Provide advice for a permanent system to assess the impact of RCN-funded research and research-based innovation

In fulfilling these objectives, we find that the main methodological challenges and considerations concern the setup of a framework that:

- provides suitable methods to assess impacts, but also to assess mechanisms and intermediate results, so as to allow RCN to obtain a view on the direction of travel and evolution over time
- identifies external factors (external to RCN) that may enhance or prevent the attainment of impact
- is flexible enough to accommodate shifting issues and policy priorities
- will be populated (in a pilot exercise) using a combination of data sources, including internal information held by RCN, other secondary data sources and primary data collection (when possible). Additionally, the final report will provide recommendations on methods and data collection exercises going forward, some of which could inform RCN monitoring activities

1.2 This report

This final report (D6) compiles the work conducted over the lifetime of the study and presented in six reports:

- **D1 Inception report** – This report presented some early findings emerging from the inception phase of the study that helped to inform the next stages. It provided an analysis of the RCN portfolios and its alignment with societal challenges, as well as overview of RCN's current evaluation activities, to make sure the methodologies suggested in this study added value of existing evaluation efforts.
- **D2 Short literature review** – This report provided an overview of the evolution of thinking around the measurement of impact of research and innovation activities, an overview the main approaches used to measure impact. A summary version is presented in **Section 3** of this final report.

- **D3 Conceptual report** – This report provided an impact framework that identifies three main impact dimensions (on the Economy, Society and Environment) and nine main impact pathways (all relevant to RCN's research and research-based innovation activities). It focused on *what to measure*. This is presented in **Section 2** of this final report.

  The report also outlined an overall conceptual approach that justifies our current recommendations regarding the implementation and further development of the impact framework. It provides the first guidelines on *how to measure* impact and a analytical framework, to inform the collection of empirical data. This is presented in **Section 3** and has served to inform **Section 4** of this final report (pilot exercise)
- **D4 Methodological report** – This report presented the methodological approach followed to implement two pilots to collect empirical data in the context of the study to establish a methodology to assess the societal impact of research and research-based innovation, commissioned by RCN to Technopolis. The methodology was further adjusted after completing the pilot exercises.
- **D5 Pilot exercise** – This report presented the results from the pilot exercise followed to collect empirical data in the context of the study. Both the outcomes of D4 and D5 are presented in **Section 4** of this final report.
- **Additionally, Section 5** presents recommendations and lessons learned. This includes recommendations on how to take the pilot exercises going forward, along with limitations and caveats, as well as a set of other methodologies RCN could consider applying to the analysis of the effect of its activities on societal challenges.

2 Developing a framework for RCN

2.1 Societal challenges in Norway

There is growing consensus that R&I policy has a role to play in tackling societal challenges (and that interventions should be geared towards attaining them), with the results of research going from technological progress all the way to providing evidence to tackle other social and economic policy decisions.

Norwegian R&I policy has seen a strong shift towards societal challenges since the 2009 Government White Paper on Research Policy.[1] In this, 'global challenges' were among five 'strategic priorities', and thus the 'challenge' approach became the main guiding principle, at least at the rhetorical level. At the time, observers saw this as a sign of a "growing focus on the link between societal challenges and innovation" (Cunningham and Karakasidou, 2010, p. 8), or at least a strong rhetorical shift (with limited change in 'actual policy') (Kallerud et al., 2013, p. 8) - but this situation has evolved further over recent years.

In fact, the Long-Term Plan for higher education and research (2015-2024) assigns a prominent place to societal challenges as one of the three overarching priorities (listed below). In particular, it emphasises the need to diversify and increase the absorptive capacity of industry, and to prepare for the transition to a low-emission society.

- enhancing competitiveness and innovation capacity
- tackling major societal challenges
- developing academic and research communities of outstanding quality.

These three overarching priorities have remained largely unchanged in the revised plan (2019-2028), with increased emphasis on societal challenges.

This is also reflected in changes to RCN's strategic objectives, with the 2020-2024 Strategy placing more emphasis (compared with the 2015-2019 Strategy) on objectives and challenges that go beyond specific thematic areas (see Table 1). The strategic areas listed in this new strategy go beyond national social and economic needs to include "cohesion and globalization" and the need to support robust and inclusive societies (nationally and internationally) as part of its key areas of focus.

As part of this change in strategic focus, RCN is currently in a transition from a 'thematic and programme-based' structure and way of thinking, to a portfolio-based approach that focuses on broad challenges. This reflects an ambition to move away from a structure that could lead to silos (e.g. programmes focused on a particular discipline area or sector) to one where investments and activities are geared towards addressing challenges (e.g. the transition to a low-emission society) from multiple perspectives, disciplines and types of research.

Furthermore, each of the 15 portfolios have recently finalised their portfolio-based strategies and plans, with each trying to make the connection between the portfolio and the societal challenges it addresses (making a connection with RCN's overall strategy). This is further discussed and presented below.

[1] St.meld. nr. 30 (2008–2009): Klima for forskining, 2009, Kunnskapsdepartementet.

Table 1 Evolution in RCN strategic objectives

2015-2019 Strategy	2020-2024 Strategy
One of six objectives to 'Enhance Research for Sustainable Solutions in Society and the Business Sector'. The specific areas included: • Nature, Climate and the Environment • Natural Resources • Health, Care and Welfare • Education and Learning • Culture and Globalisation • Governance and Distribution	The main goals are sustainable development, boundary-breaking research and innovation, and renewal in trade and industry and the public sector. Strategic areas include: • Oceans: Clean and rich seas and competitive ocean industries • Green shift: Rapid transition to a green society and the development of a competitive green trade and industry • Technology and digitalization: Sustainable digital transformation and technological development of society • Health and welfare: Innovative healthcare and good adaptation of the welfare state to demographic changes • Cohesion and globalization: Robust and inclusive societies

Source: RCN's strategies (extracts from)

The portfolio plans are, however, less explicit about the challenges and focus more on ambitions and strategic direction. There are some aspects that are addressed, such as the need to diversify the economy and move away from a dependency on oil and gas, which is a common thread across the 'Oceans, 'Green shift' and 'Technology and digitalization' strategic areas. However, the connection with other specific societal challenges is less clear.

Other authoritative sources of information shed more light on those specific challenges, albeit with a narrower focus on economic challenges in comparison with the more systemic view supported by RCN. The OECD, for instance, identifies five key challenges with respect to Norway's ability to sustain its high living standards in the future (OECD, 2019)[2]:

- **Macroeconomic stability and managing property-market risks** – The report identifies that external demand risks (mostly related to oil prices) remain elevated, while output-growth prospects have diminished. There are also vulnerabilities stemming from property markets, despite some correction in the housing market, with household debt increasing faster than disposable income.
- **Fair access to resource wealth across generations, and value for money in public spending** – Slower expected growth in the wealth fund implies a substantial narrowing of fiscal space for the foreseeable future, calling for the need to increase the 'return' or benefits derived from a given level of public spending.
- **Diversification to non-oil activities, seizing opportunities from globalisation and digitalization** – Norway is generally well placed to harness the next generation of digital technology, while the rapid growth in research and development activity suggest stronger engagement at the frontiers of technology and know-how. However, the report states that policy improvements are still needed to further strengthen business productivity (including paring back the extensive support for the agricultural sector) as low productivity growth remains a concern for future living standards.
- **Raising employment levels and skills** – Labour-force participation has been declining and Norway is no longer among the top-ranking countries. Sick leave absence is high and

[2] OECD (2019): Norway Economic Survey. December 2019. https://www.oecd.org/economy/surveys/Norway-2019-OECD-Economic%20Survey_Overview.pdf

numbers on disability benefits remain elevated. Moreover, early retirement remains common. Improving education and training is part of the solution to the productivity-growth slowdown and weakening labour-force participation, and some challenges remain in this area. PISA test results are only around the OECD average, many vocational upper-secondary students fail to complete courses, apprenticeship places are in short supply and students taking degree-level courses graduate comparatively late. Additionally, the report states that labour-market integration of low-skilled immigrants requires further attention. Migrants with low education and skills are now more numerous, partly due to an increased share of refugees. This has deepened the challenges for labour-market integration policy, especially as demand for low-skill workers is limited in Norway.

- **Moving towards green growth** – Thanks to extensive hydropower, Norway has comparatively low baseline emissions, but substantial emission reduction is needed to hit targets. More specifically, Norway will need to substantially reduce transport-related greenhouse-gas emissions to achieve targets. Around half of emissions are outside the European Trading Scheme and a large share of these relate to transport. Under current policies, programmed measures for reducing domestic non-ETS emissions will need to be combined with non-ETS reductions purchased from EU-countries for goals to be met.

The understanding of RCN strategy and portfolio objectives and alignment, as well as acknowledgement of the challenges described above have informed the impact framework described below.

2.2 An impact framework

The aim of this study is to arrive to a methodology (or, more precisely, a methodological toolbox) to assess the societal impact of research and research-based innovation supported by RCN. The societal impact is to be interpreted with a wide focus to cover impact on the economy, society and environment, understanding that these are highly interconnected.

Figure 1 provides a framework to identify key impact pathways across multiple societal challenges. It helped to inform the methodology implemented at the pilot stage, and it establishes *what to measure* in terms of impact. The framework identifies **three main impact dimensions (on the Economy, Society and Environment) and nine main impact pathways (all relevant to RCN's research and research-based innovation activities)**. Figure 1 also highlights the fact that the impact dimensions are highly interconnected, with benefits from one area feeding into other aspects (e.g. better policies to improve productivity or to improve protection on natural ecosystems), and any set boundaries are -in practice- a device to provide focus (and guide practical decisions) when measuring or communicating impact.

This framework has been developed in an iterative way, by establishing an initial set of impacts, reviewing the aims and objectives of each of the main RCN portfolios (as set out in their current strategy plans), and subsequently updating the framework to make sure it captures the range of objectives covered in those portfolios.

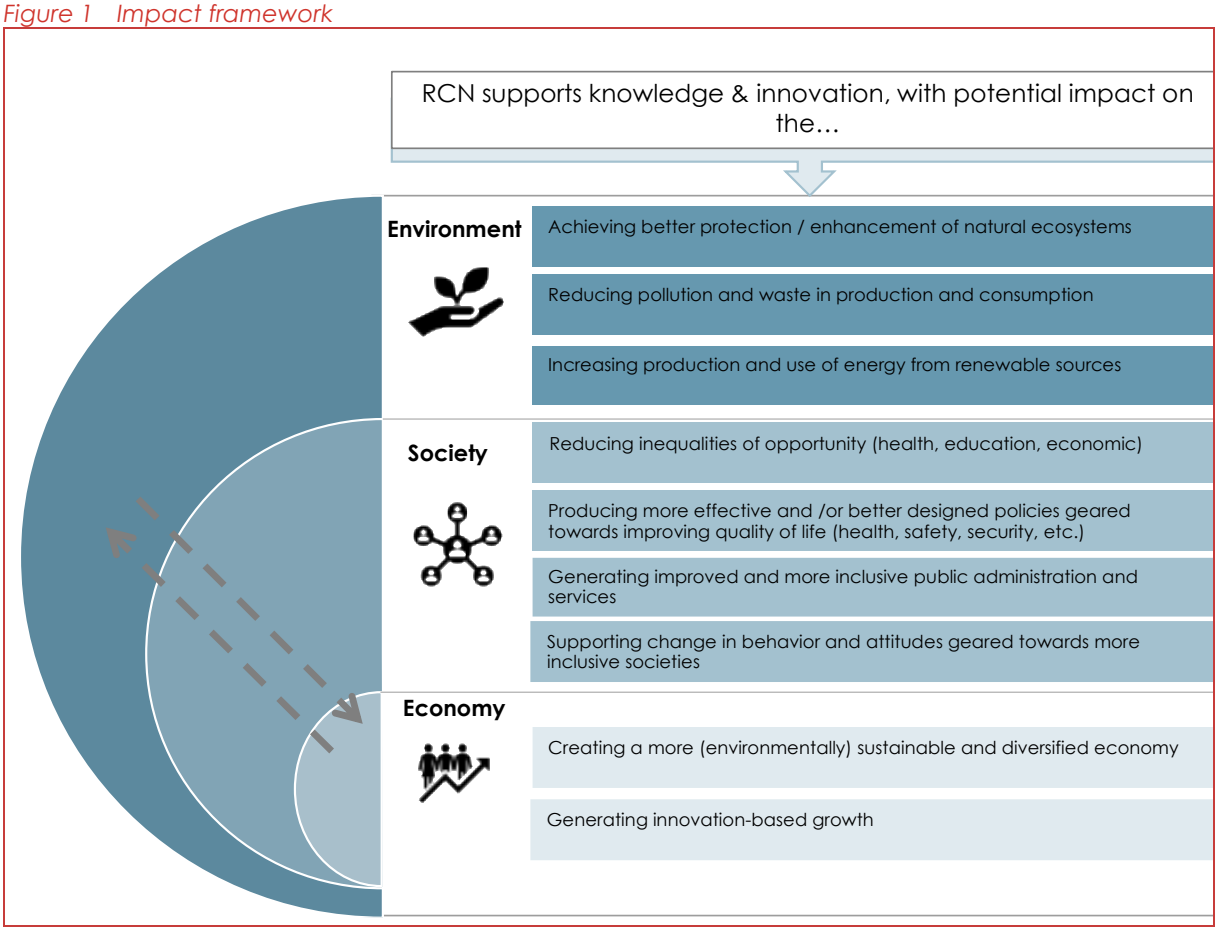
The framework does not include 'public policy or services' as an individual category as this is taken as an intermediate mechanism to attain impact on the society (e.g. producing more effective and/or better designed policies geared towards improving quality of life).

The framework is intended to be flexible and modular, with the nine key impact pathways being relevant to one or multiple societal challenges and portfolios, as well as able to capture the end-goals/objectives across all different interventions.

Finally, the framework presented below does not capture intermediate outcomes since those are expected to be multi-faceted and activity specific, and this is a level of granularity that

needs to be tackled separately. This is further captured in the methodology applied to the pilot exercise, following a logic model approach.

Figure 1 Impact framework



2.3 RCN portfolio and societal challenges

As part of the process of developing the framework above, we have linked the different portfolios to high-level objectives and relevant societal challenges/objectives to inform the impact categories selected. This exercise is shown in Appendix A[3]. For completeness, we have also mapped the portfolios based on their own stated links with the RCN strategy's strategic areas and objectives (as presented in their portfolio plans), as also shown in Appendix A.

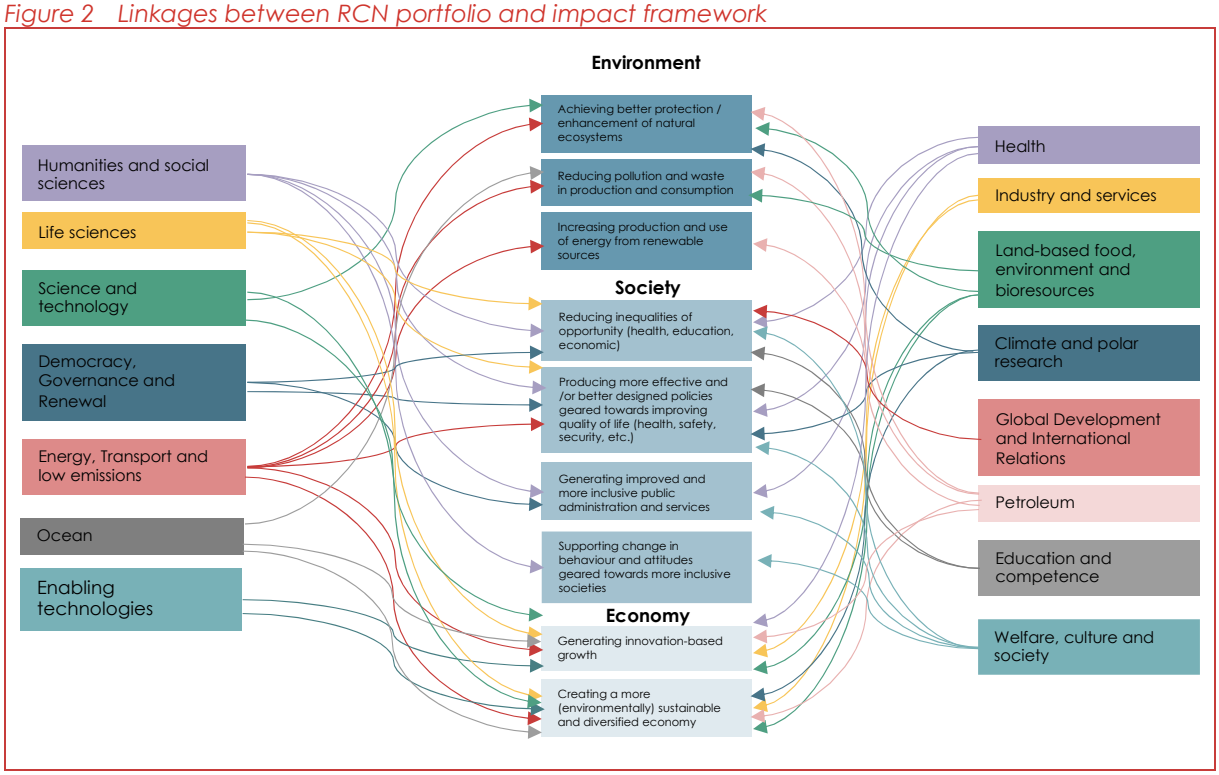
In their strategic plans, all portfolios explain their link to the government's Long-term plan for Research and Higher Education (with three overarching goals) and the strategic areas of the 2020-2024 RCN Strategy (listed above, in Table 1). As such, all have indicated some link to societal challenges - although this link is more explicit for some than others. Additionally, in most cases we have been able to identify portfolio aims that can be linked to societal objectives, rather than challenges. This means that a degree of interpretation and adjustment have had to be implemented to arrive to a final mapping of portfolios against the impact framework.

[3] Our understanding of those links have been informed by (i) interviews with portfolio directors/managers and (ii) a review of the strategic plans.

Figure 2 presents the results from this analysis and shows the extent to which one should expect a specific portfolio to contribute to one or more of the nine impact pathways listed in the framework. To aid the visualisation of connections between the portfolios and impact pathways we also present figures for each of the three impact dimensions separately (in Figure 3 - Figure 5).

Table 2, in Appendix A, then presents a similar analysis, but with more detail. It includes the specific programmes[4] that sit within each portfolio, the overall aims of the portfolio that are linked to societal challenges / objectives, and our assessment of their alignment with impact dimensions and impact pathways identified in our framework. This analysis have been validated by RCN.

Figure 2 Linkages between RCN portfolio and impact framework



[4] We are aware that RCN is moving away from programmes as the operating unit. Still, we find it useful to link programmes and societal challenges as at the time of analysis the programme plans were the most specific documents describing the aims of RCN investments. Later reference will have to be towards portfolio and investment plans.

Figure 3 Linkages between RCN portfolio and impact framework - Environment

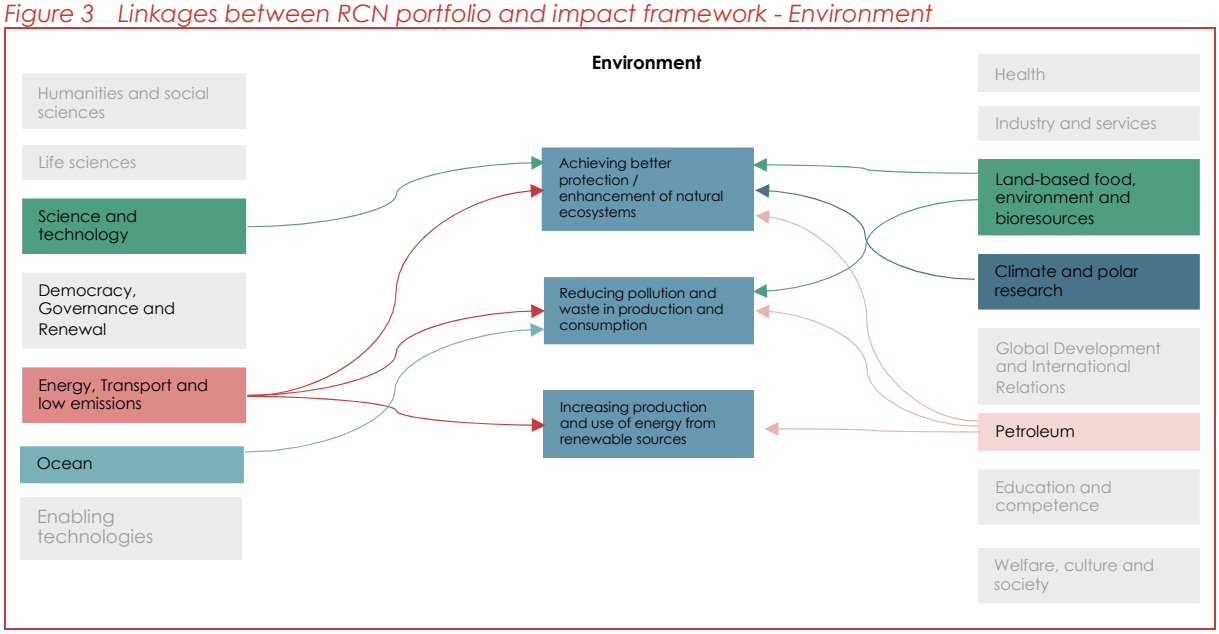


Figure 4 Linkages between RCN portfolio and impact framework - Society

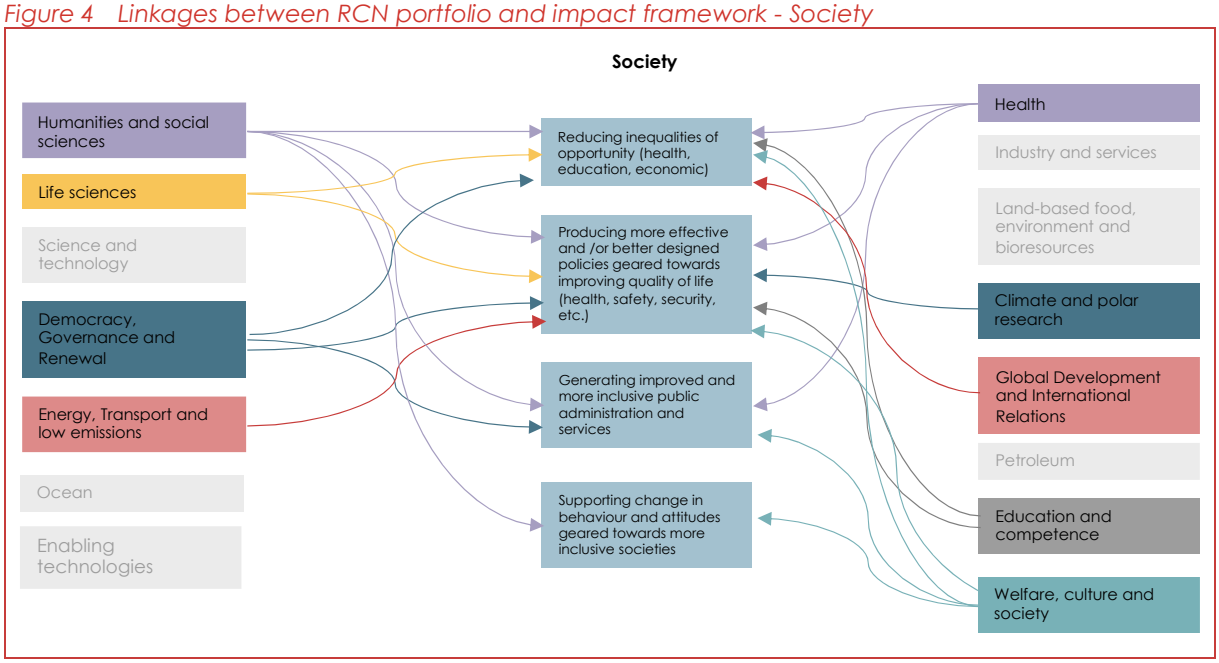
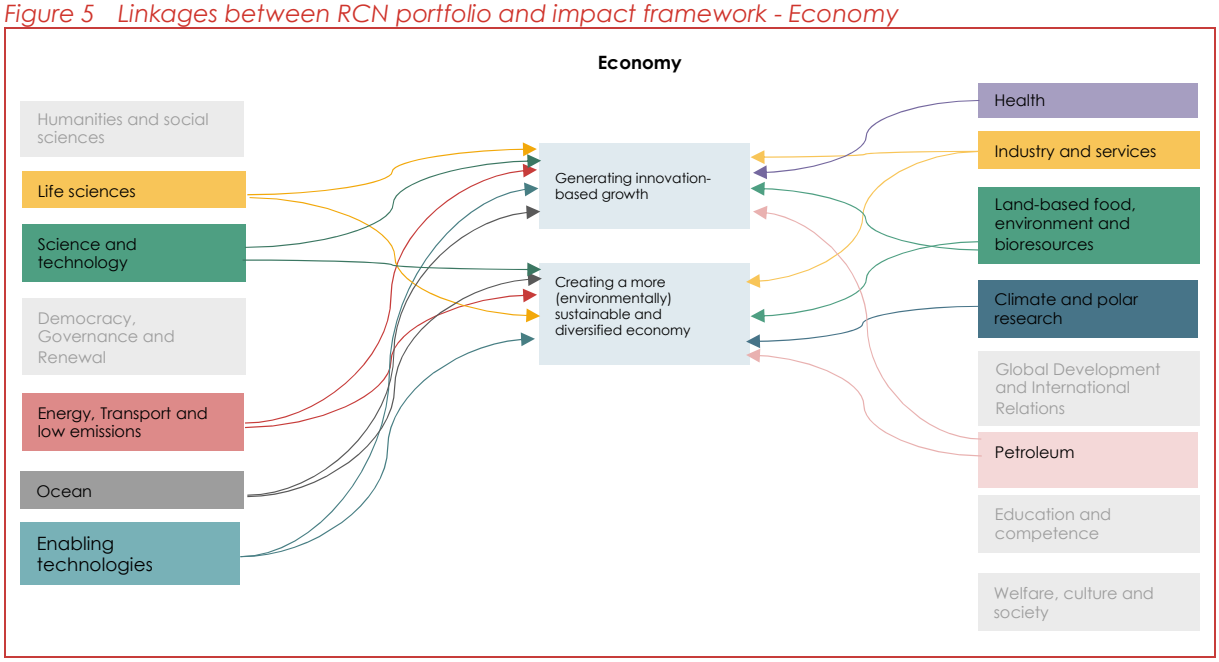


Figure 5 Linkages between RCN portfolio and impact framework - Economy



3 Overall conceptual approach

This section provides conceptual considerations that justified our approach to testing the impact framework in the context of this study (and in the pilot exercise).

We first provide an overview of the evolution of thinking around the measurement of the impacts of research and innovation activities Section 3.1. We then locate RCN within a conceptual framework of system transformation (Section 3.2), discusses the main characteristics of research and how that influenced our current recommendation on developing the impact pathways further (Section 3.3), and provides two conceptual approaches (Section 3.4).

3.1 Measuring impact of research and innovation activities

The way we think about, and try to describe or measure, impact is rooted in ideas about the links between science and society. These ideas evolve, partly because our understanding improves and partly because both science and society change over time. The links between science and practice have always been complex, for example with improved lens-grinding enabling better telescopes for naval use connecting to astronomy and cosmology, leading Galileo to get into all sorts of trouble with the church. Or 200 years of experimentation and engineering with steam engines triggering Carnot's equations that effectively created the science of thermodynamics (Carnot, 1824).

The 'linear model' of innovation – the idea that basic science ultimately causes applied research, production and wealth creation, is largely an invention of the period following World War II and Vannevar Bush's manifesto "Science, the Endless Frontier" (1945). It was also encouraged by the growth of state-organised 'missions' (defence, health, the moon shot, etc), together leading to the idea that research causes changes in society ('impact'). That supply-driven idea of impact stays with us, in part because it provides a powerful political narrative for funders to justify research funding in terms of societal returns.

Mainstream economics traditionally treated technology as 'exogenous' to the economy: it investigates how technology affects production and productivity through various kinds of 'production functions' (Sollow, 1964), but then evolved to assume that the long-run rate of growth is primarily determined by endogenous variables that are internal to the system, such as human capital, innovation and investment capital (Romer, 1986), although in many cases technological progress is assumed constant. Wider economic analysis is becoming increasingly sophisticated in assessing the economic impact of research, both directly on firms and industries and indirectly through spillovers among different parts of the economy.

Modern thinking about research and innovation systems builds on this economic tradition by trying to look inside the 'black box' of change to understand the role of people, institutions and learning with evolutionary economists like Nelson and Winter (1982) playing central roles. Research in the 1970s on the importance of the demand side in innovation (Rothwell, et al., 1974) (Shimshoni, 1970) (von Hippel, 1975) led to a revolution in thinking about impact, with innovation reconceptualised from 'science push' to interactive, 'coupling', spanning push and pull (Mowery & Rosenberg, 1979) and recognition of the importance of the stock of existing knowledge as well (sometimes) as new knowledge in innovation. These ideas underpin the national innovation systems heuristic (Freeman, 1987) (Lundvall, 1992) (Nelson, National Innovation Systems, 1993) that regards innovation as being coproduced in networks of actors and as potentially being stimulated from anywhere in the innovation system. Thus, research can have impact by satisfying needs, but can itself also be triggered by the identification of need, especially by organisations that have "absorptive capacity" (Cohen & Levinthal, 1990)

or the ability – based on their internal R&D capabilities – to specify scientific and technological problems, seek solutions and apply them to business opportunities.

Continuing research both on innovation and the broader interaction between science and society has been uncovering a lengthening list of channels through which research has societal impact. These include increase in the stock of useful knowledge; supply of skilled graduates and researchers; creation of new scientific instrumentation and methodologies; development of networks and stimulation of social interaction; enhancement of problem-solving capacity; creation of new firms; provision of social knowledge (Martin & Tang, 2007). Other categories include provision of public goods and improving professional skills (Arnold, Assessing the Impact of State Interventions in Research – Techniques, Issues and Solutions, 2015); health, well-being and sustainability (Harland & O'Connor, 2015); public understanding of science (Hansen & Pedersen, 2018).

We owe the systemic view of innovation and the impact of research mostly to people influenced by the OECD's focus on economic growth and industrial innovation. In parallel, the wider evaluation community has been trying to understand the impact of research on policymaking. The iconic figure here is Carol Weiss, who became rather fed up with the predominantly linear views of her contemporaries and introduced a focus on the absorptive capacity and behaviour of the 'demand side' in the shape of policymakers to help explain when and how research impacts policy (Weiss C. , 1979). Weiss was central in the adoption of theories of change (Weiss C. , 1987) (Chen, 1990) (Chen & Rossi, 1989) in evaluation, involving rather detailed tracing of successive cause-and-effect steps in order to open the 'black box' and investigate the mechanisms that lead from policy interventions to societal impact. Like the innovation researchers, the evaluation community increasingly looks at theories of change from a systemic perspective: rather than anticipating simple, linear paths to impact, it sees impact as the combined result of interventions and the (systemic) contexts in which they are made (Pawson & Tilley, 1997). The systems involved are increasingly seen as complex. As we move into a 'third generation' of innovation policy that tackles societal challenges (including the SDGs) and socio-technical transitions via large interventions with broad societal scope (Arnold, Åström, Glass, & de Scalzi, 2018), this concern with systemic aspects and complexity is becoming more and more important.

The systemic perspective introduces a complication in the form of the 'attribution problem': if the impact of an intervention (including doing research) results from the interaction between the intervention and its context, it is no longer possible to attribute the entire impact to the intervention. How much of the impact to attribute to the intervention and how much to other factors becomes a central – and in practice very difficult – evaluation problem.

Studying impact is complicated by the fact that it is often indirect or non-linear, 'percolating' through media or passing into the general stock of knowledge and being retrieved later (Benneworth & Olmos-Peñuela, 2018), achieving societal impact only after stimulating new research (Jonkers & Sachwald, 2018) or being mediated by knowledge intermediaries such as research institutes (Thune, 2019) or simply not measurable or amenable to use of indicators (Donovan, 2011) (Wilsdon, 2015).

A key consideration will be the extent to which quantitative versus qualitative methods are appropriate. (In much of our wider evaluation practice, we find it useful to combine both.) Quantitative (metrics or indicator-based) techniques need to be robust, have a meaningful relation to the phenomena they depict and should preferably be understandable to end-users. They enable aggregation and generalisation of impacts, but at best give a partial view of mechanisms of impact. Qualitative techniques can more directly explore impact mechanisms, especially direct impacts, especially in the short-medium term. They can generate persuasive

impact stories to publicise successes, but they are not able to aggregate or compare different impact achievements.

3.2 A conceptual framework for understanding (systemic) change

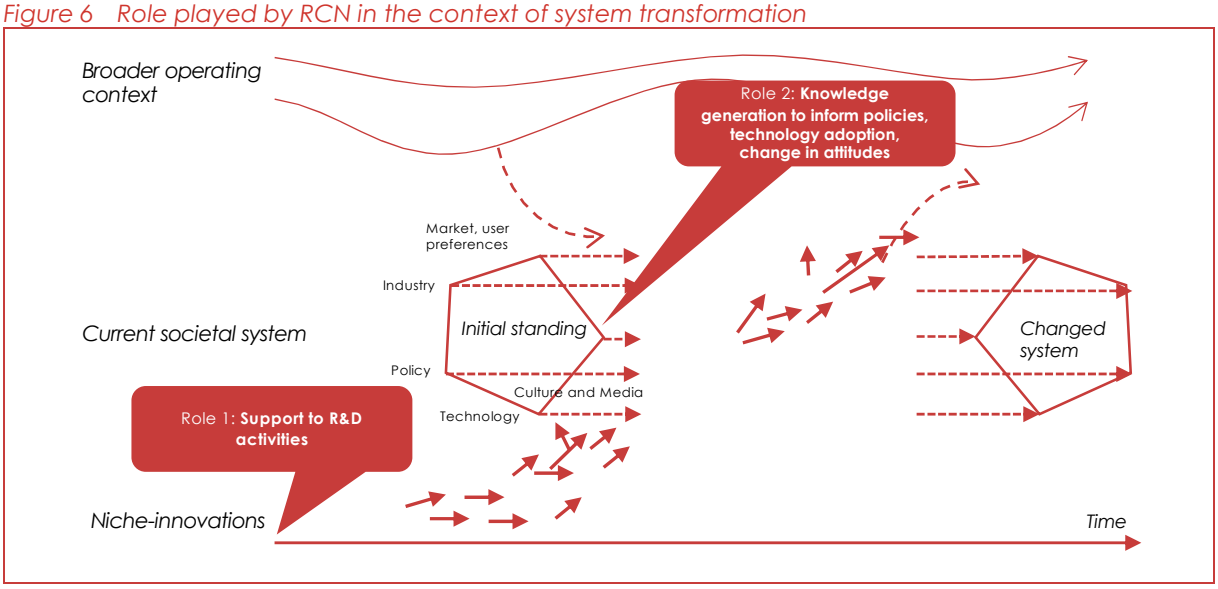
To address societal challenges in the broader sense, a *system transformation* might be necessary. Unlike specific technological challenges - where a clearly specified end goal is seen as a requirement - Kuhlmann and Rip (2014) see societal challenges as *open-ended* in nature. In the long run, addressing grand challenges through innovation requires not only working within the existing research and innovation system but also possibly *transforming* the system. This constitutes 'another grand challenge' in itself (p. 3).

Literature on systems transformation is increasingly used to analyse societal challenges. Frank Geels (2004), among others, has developed models to describe 'socio-technical systems', which encompass a broad set of actors including both producers and users of R&D and the interaction between them. He also describes different 'pathways' to transformation, such as 'rapid breakthroughs' caused by an external shock to the system, or a process of 'gradual transformation' with a prolonged period of search for new solutions and experimentation (Geels and Schot, 2007).

Geels also makes a distinction between historic transitions (e.g. the transition from horse-drawn carriages to automobiles) and 'sustainability transitions' (which tend to be goal-oriented or 'purposive' and may call for the need to generate incentives to promote uptake among users and strategic reorientation of incumbents in sectors dominated by large traditional companies). This distinction provides justification for Government intervention and the need for concerted actions (as opposed to market-driven solutions) and highlights the need for a shared vision, collective coordination, and an appropriate portfolio of policy instruments to ensure implementation (Weber and Rohracher, 2012, pp. 1042–1043).

This framework of analysis is useful to identify (and visualise – see Figure 3) the role that an organisation like RCN may have in supporting the system level transformation that is necessary to tackle societal challenges and achieve societal impact. It also highlights the fact that RCN support plays a key role in 'sustainability transitions' (as it moves forward the initial standing), but that uptake and ultimately change in the system would be outside the remit of researchers and research funders. It has informed our recommendations on the two conceptual approaches discussed below.

Figure 6 Role played by RCN in the context of system transformation



Source: Adapted from: Geels, F.W. (2002), Technological transitions as evolutionary reconfiguration processes: a multi-level perspective and a case-study. Research Policy, Vol. 31, 1257–1274; Geels, F.W. and Schot, J. (2007), Typology of sociotechnical transition pathways. Research Policy, Vol. 36, 399–417.

3.3 Addressing the distinct nature of the relationship between research and impact

Our literature review (presented in Section 3.1 above) provides a reflection on the characteristics of research. We highlighted that the links between science and impact have always been complex, non-linear and cumulative in nature (with, for instance, 200 years of experimentation and engineering with steam engines triggering Carnot's equations that effectively created the science of thermodynamics (Carnot, 1824)).

Impacts are also discipline specific. The contribution made from different disciplines and portfolios towards the different impact pathways (described in the framework) are expected to be materially different, with some contributing in terms of technological advances or new solutions, and others contributing through influencing policy decisions or informing the direction of travel. This also means that the contribution of different areas of research needs to be measured differently. Broadly speaking areas such as health, engineering, or natural sciences can measure their contribution to a set of objectives by demonstrating the progress toward solutions using widely accepted metrics (such as technology readiness level, or the conclusions emerging from experimentation and demonstration). This is more challenging for the social sciences, arts and humanities, where research and research outcomes play different roles and could be instrumental (feeding directly into decision making for policy and practice), conceptual (providing new ways of thinking or new insights), or act as a mobilisation tool (to provide legitimacy to a course of action or political decision)(Nutley et al, 2002)[5]. In both cases, however, uptake and, ultimately, change would be outside the remit of researchers and research funders.

These characteristics need to be considered when further unpacking the impact framework to account for intermediate outcomes. To do this, there are three approaches that could be considered:

- **Logic models:** Logic models (LM) are graphic (static) representations that attempt to capture a chain of events, from inputs to outcomes, that ultimately lead to impact. They are an extremely helpful device to test the rationale of interventions (and check alignment with strategic objectives) and, subsequently, measure progress towards impact. They are less effective, however, as a tool to capture the myriad mechanisms that could lead to societal challenges. They run the risk of being reductive, inviting a linear perspective of the innovation process, or diverting attention towards counting outputs and outcomes. The European Commission (EC), for instance, has recently established a framework to identify Key Impact Pathways, not too disimilar to the framework proposed here, albeit sometimes mixing mechanims and intermediate outcomes with impacts. The EC is in the process of operationalising that framework with a logic model style structure as a starting point, which places too much emphasis on counting things like number of publications or number of innovations (due in part to an ambition to automate the evidence collection process as as much as possible and embed it into internal monitoring systems). As such, the framework does not necessarily reveal the contribution of research and research-based activities to the ultimate goals.

[5] Nutley, S., Davies, H., Walter, I. (2002) Evidence Based Policy and Practice: Cross Sector Lessons From the UK. Research Unit for Research Utilisation Department of Management University of St Andrewshttps://www.kcl.ac.uk/sspp/departments/politicaleconomy/research/cep/pubs/papers/assets/wp9b.pdf

- **Theories of change:** A logic model can be expanded to produce a theory of change (ToC) which takes the LM as starting point to develop a narrative on the mechanisms at play in explaining the journey from inputs to final impacts. The ToC is also more explicit about the external factors that could have played a role in attaining those impacts. This however, does not fully solve many of the shortcomings of the LM (in the context of this study). Additionally, we would need to build a dedicated ToC for each objective and even each portfolio, which we understood is not the aim of the study . This could be done, however, on case by case basis, and as part of the methodological toolbox (mostly when implementing methods such as contribution analysis).
- **REF approach:** The REF impact case studies implement a historical tracing approach, whereby researchers are expected to provide evidence linking excellent research and bodies of work (within the submitting Unit of Assessment), developed over 20 years, to impacts on the economy, society, culture, public policy or services, health, the environment or quality of life, recognising that this relationship can be indirect or non-linear. They are also expected to provide evidence of the *reach and significance* of the impact. Within their narrative account in the case study, submitting units are expected to provide the indicators and evidence most appropriate to support the impact(s) claimed. To this end, REF provides researchers and panel reviewers with a long list of potential supporting evidence, making the process more flexible, less prescriptive, and more in line with what the research community will recognise as contributions towards impact in their respective areas.

  Despite criticism of this approach (its focus on a narrow and instrumental sub-set of impact (Meagher & Martin, 2017), and "extraordinary" rather than "normal" impact (Sivertsen and Meijer (2018)), this framework seems to be better suited to deal with the non-linear nature of the relationship between research and (non-academic) impact.

3.4 The two overall approaches

Against the backdrop of conceptual and practical /methodological considerations discussed above, a decision could be made to focus on 'normal' impact, versus 'extraordinary impact' (or both) - following the terminology used by Sivertsen and Meijer (2018) when reflecting on the focus of a UK REF approach - and this can be pursued by applying two approaches to historical or longitudinal tracing: forward tracing and backward tracing, which have been commonly used as an overall approach to measure the impact of research[6]. **Due to RCNs need to monitor impact of the research it funds on a permanent basis, it was decided that forward tracing was most useful approach to explore in the pilot exercise.** We present in Section 5.2 a description of methodologies that could help to implement a backward tracing as this is useful for developing deeper insights into selected cases, especially cases of extraordinary impact.

Both approaches provide a starting point for the analysis of impact (as described below and show in Figure 7), and in both cases a toolbox of different methods or data gathering exercises could be used to develop the analysis.

1. **Approach 1: Forward tracing**. Under this approach 'RCN support' acts as a starting point to showcase contributions/ progress towards key objectives, understanding that final change and uptake is outside the remit of RCN and its beneficiaries (knowledge/ technology producers, broadly speaking). Under this approach, greater emphasis is placed on 'mining' the portfolio of projects funded (project database), to explore key areas of development supported overtime (and account for the cumulative nature of knowledge). This approach

[6] Newson, R., King, L., Rychetnik, L. et al. Looking both ways: a review of methods for assessing research impacts on policy and the policy utilisation of research. Health Res Policy Sys 16, 54 (2018). https://doi.org/10.1186/s12961-018-0310-4

allows covering a wide range of activities, focusing first on the initial objectives of projects, and subsequently exploring (tracing) if that led to intermediate outcomes and, ultimately, to an actual change or uptake (which may or not may have happened)[7]. As such, this approach focuses on 'normal' impact.

For instance, the extent of the dissemination to / uptake by users and policy makers could be demonstrated via citation within patents of knowledge funded by RCN to inform technological landscapes, or citation within policy documents of knowledge funded by RCN, or an increase in the sustainability focus of companies taking part in relevant projects, or testimonials from key stakeholders on the difference made by Norwegian research. Furthermore, forward tracing can be complemented with summative methods such as econometric and statistical analysis to test the effect of the support in a particular outcome or area of interest (e.g. effect of R&D support on firms' performance in a particular economic sector). In sum, this approach makes maximum use of data linkage (and existing databases) but can also be complemented with additional primary data collection (especially qualitative data).

This approach was also used, to some extent, in Technopolis' 2011 analysis of the Long Term Impact of the Framework Programme [8], where initial analysis of the FP4 and FP5 portfolio, bibliometric data and expert interviews led to identification of six potential 'breakthroughs' that were subsequently further developed via (qualitative) case studies. New developments in the application of 'data science for policy' allow taking one step forward in terms of linking more resources, however, it is fair to say that a degree of qualitative analysis will be needed to complete the narrative and RCN's 'contribution story'.

2. **Approach 2: Backward tracing.** Under this approach changes/uptake experienced in Norway in the past 5 years (across the main impact pathways) act as the starting point to trace the extent to which RCN support has contributed to any of those observed changes. This may require initial *consultation* with key industrial and government "end-users" to identify key changes/uptake in the past 5 years. Under this approach, greater emphasis would be placed on the narrow set of projects/research agendas that may have contributed to those changes. As such, it is narrower and focuses on 'extraordinary' impact. If taken forward on a regular basis, it would also require substantial investments and workload if it were to be used as a regular methodology to map impacts of RCN funding.

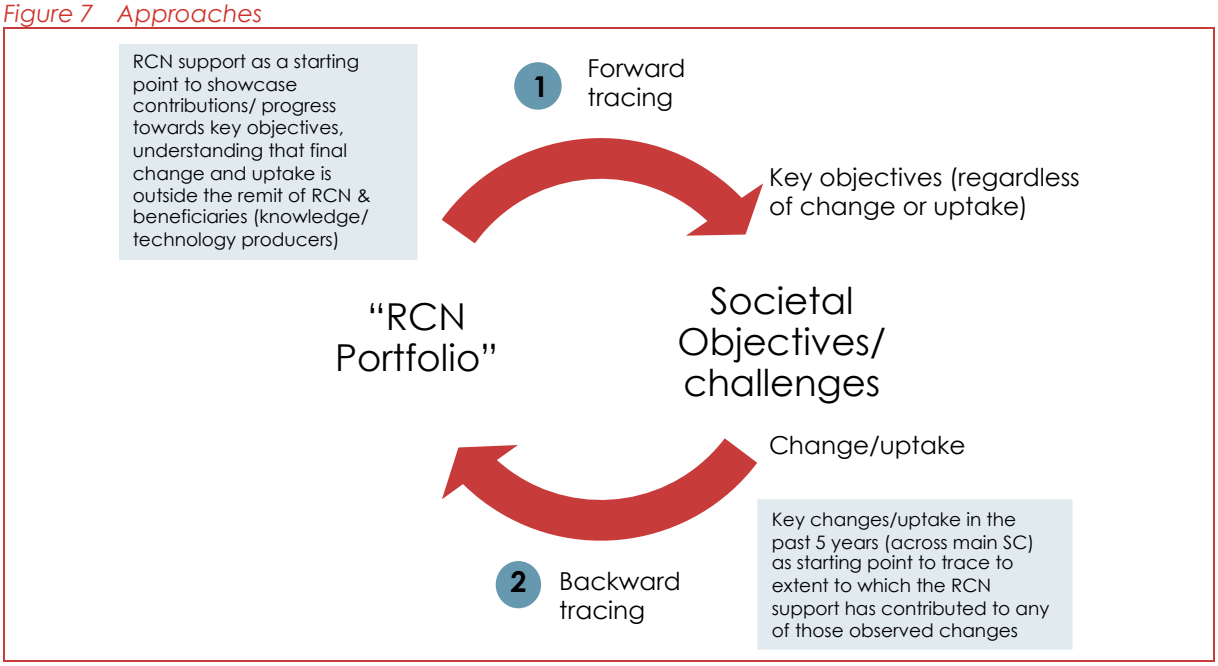
   To some extent this approach has been used by NIFU in their "Pathways to impact" studies. As indicated above, this approach has not been selected for the purpose of this study (and pilot). However, this does not imply that backward tracing is to be excluded entirely; it could be maintained as part of the toolbox for undertaking closer examination of impact in specific areas or to document the results of the RCN portfolio in cases of extraordinary impact.

[7] This approach could also focus on "final results" as reported in project completion report. However, we understand that these project reports do not yet include enough information to give evidence of the uptake of knowledge or societal impact (actual change). The methodology report and pilot will help to formulate recommendations regarding potential future if the requirements.

[8] Technopolis (2011). Understanding the Long Term Impact of the Framework Programme. Final report for the European Commission DG Research https://ec.europa.eu/research/evaluations/pdf/archive/other_reports_studies_and_documents/long_term_impact_of_the_fp.pdf

The selected approach (*Forward tracing*) has influenced the specific methodological choices and assessment of findings[9], presented in Section 4 below.

Figure 7 Approaches



[9] Newson, R., King, L., Rychetnik, L. et al. Looking both ways: a review of methods for assessing research impacts on policy and the policy utilisation of research. Health Res Policy Sys 16, 54 (2018). https://doi.org/10.1186/s12961-018-0310-4

4 A data-driven pilot exercise

As described above the pilot exercise have tested the implementation of impact framework using **forward tracing approach**. Additionally, the pilots follow a **data driven approach**, with a focus of maximising the use of available secondary sources, and minimising duplication of efforts with regards to other RCN monitoring and evaluation activities (e.g. econometric analysis at firm level to measure the effect of RCN support on firms' turnover and growth)[10].

As presented in Section 2, impact framework developed in this study identifies three main impact dimensions (on the Economy, Society and Environment) and nine main impact pathways (all relevant to RCN's research and research-based innovation activities). For the purpose of the pilot, two areas where selected, in coordination with the RCN study team:

- **Environment:** Achieving better protection / enhancement of natural ecosystems
- **Society:** Supporting change in behaviour and attitudes geared towards more inclusive societies

Section 4.1 presents the methodology for tracing effects, while Section 4.2 presents the methodology for classifying data and evidence into societal challenges.

4.1 Methodology for tracing effects

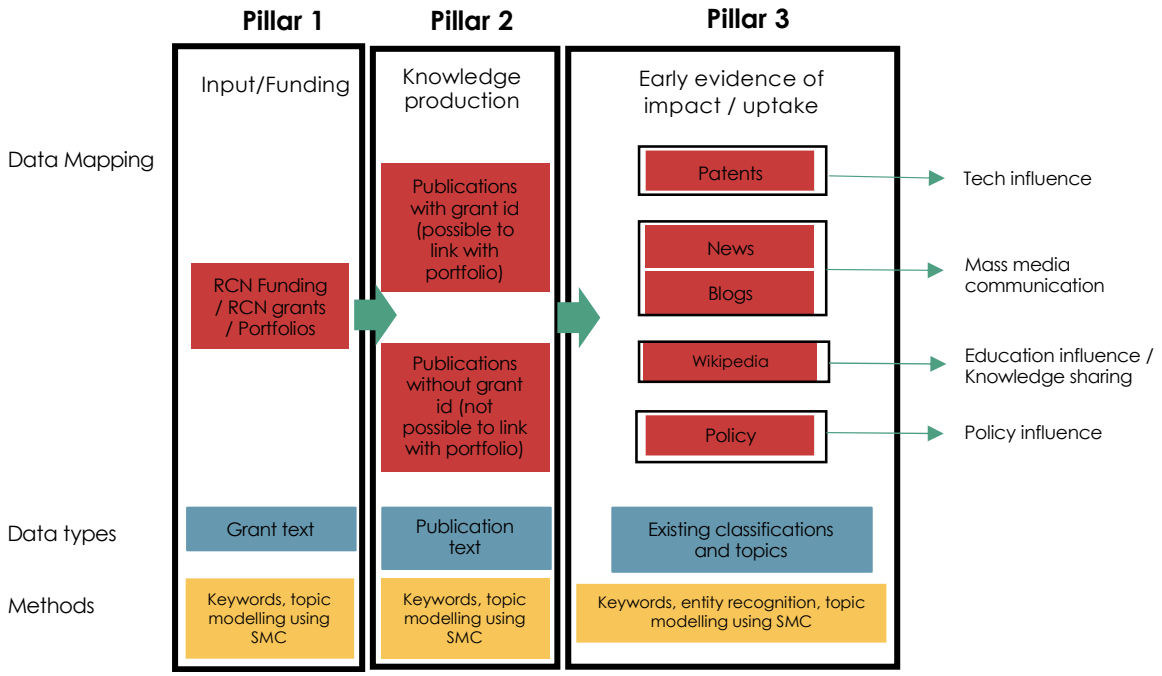
Our methodology attempts **to trace the journey of research and research-based innovation from funding to early evidence of impact / uptake**. We defined 3 pillars denoting 3 different stages:

- **Pillar 1** corresponds to the input or funding element of research
- **Pillar 2** represents the knowledge production/knowledge outputs that result from the funding
- **Pillar 3** track early evidence of impact and uptake through the dimensions of technological influence, mass media communication and education, social media and policy influence.

As such our methodology follows a logic model approach linking 'inputs', 'outputs' and 'outcomes/impacts'. We focus on collecting and linking data that exists within secondary data sources as such the method even though powerful in its ability to trace the journey from funding to impact *at scale*, has inherited limitations. Figure 8 provides an overview of our methodological strategy, data linking and examples of methods we applied under each pillar, while further explanation (including limitations) is provided in the sub-sections below. Further discussion on lessons learned from the pilot are presented in Section 5.

[10] Including for example: Statistics Norway (2020). R&D subsidies from Research Council of Norway and firm performance in the period 2006-2018. https://www.ssb.no/en/teknologi-og-innovasjon/artikler-og-publikasjoner/_attachment/415049?_ts=170cd794228

Figure 8 Overall methodological strategy and data mapping



Source: Technopolis-group 2020

In this exercise, we have linked data across all three pillars, then proceed to 'mine' the resulting body of evidence in order to assess the contributions made by RCN-funded research.

In order to identify which grants, publications and evidence of uptake (Pillar 3) might be relevant for a given impact pathway, the latter need to be operationalised. For the purposes of the pilot as well as the overall study, we have opted to use a text classification approach based on machine learning. The operationalisation of the impact pathways by means of text classification is discussed in more detail in Section 4.2.

The implementation of the methodology has meant making use of four proprietary platforms and implementing 36 scripts/coded that have been shared with RCN. The subsections below attempt explain, in a didactic manner, how the different data sources (including RCN project database) have been compiled, link together, and classified while Appendix B presents this in a diagrammatic form and calls attention to the structure of the scripts.

4.1.1 Pillar 1

RCN grants represent the input/funding dimensions of our analysis and will be considered under the present pillar. RCN funding is organised by thematic portfolios which are linked with different funding programmes. Each portfolio is also aligned with different dimensions of the government's Long-term plan for Research and Higher Education and the strategic areas of the 2020-2024 RCN Strategy. In our approach, we categorise all the grants regardless of their thematic portfolio and analyse the alignment with the societal challenges under considerations across the different funding dimensions (grant, portfolio and funding programme, and respective strategic areas).

4.1.1.1 Approach

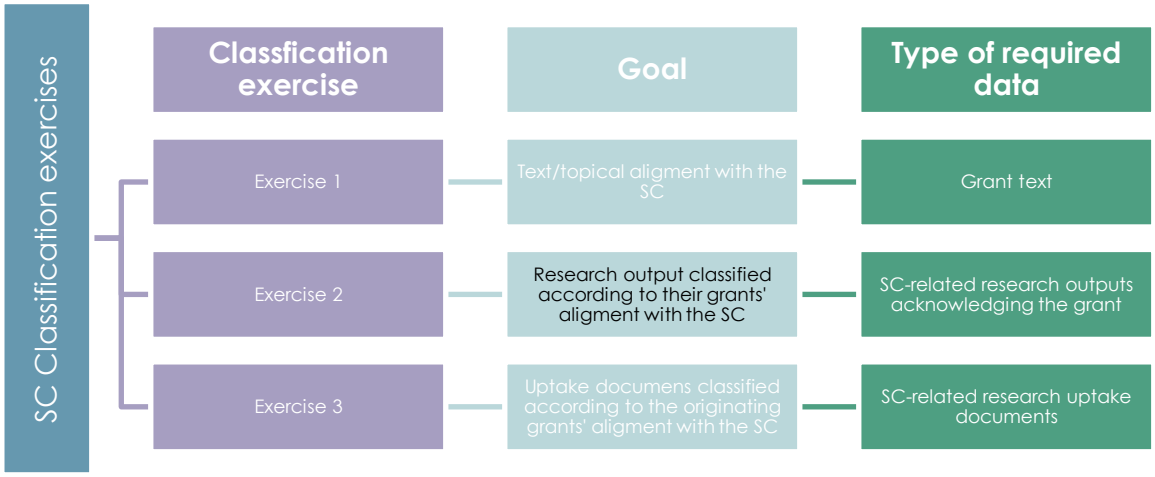
We classify RCN-grants and portfolios according to their alignment with each societal challenge under consideration. To do so, we perform three types of classification exercises.

- First, we classify all RCN grants according to their topical alignment with each societal challenge. At this stage, we do not explore alignment of knowledge outputs, nor evidence of uptake or impact in these areas, instead, we classify each grant in terms of textual alignment with the two societal challenges being piloted.

  This classification exercise is based on an external Natural Language Processing tool (TextRazor), which is described in Section 4.2.

- The second exercise consists in classifying the resulting publications of RCN grants according to the classification of the respective grants. (Note that in Pillar 2 we ran a similar classification exercise, but using text from the publications).
- Finally, the third exercise entails classifying the uptake documents which cite RCN-funded publications according to the classification of the originating grant. The aforementioned classification exercises are summarised in Figure 9.

Figure 9 Overview of the classification exercise types under Pillar 1



Note that our approach allows detecting results in Pillar 2 and / or 3 (that align with the pathways of interest) and look back to test the origin of those results (which may or may not link to grants – or publications – produced in the same areas of interest). **This acknowledges the fact that research produced with an initial focus could then feed into other (unanticipated) areas of application.**

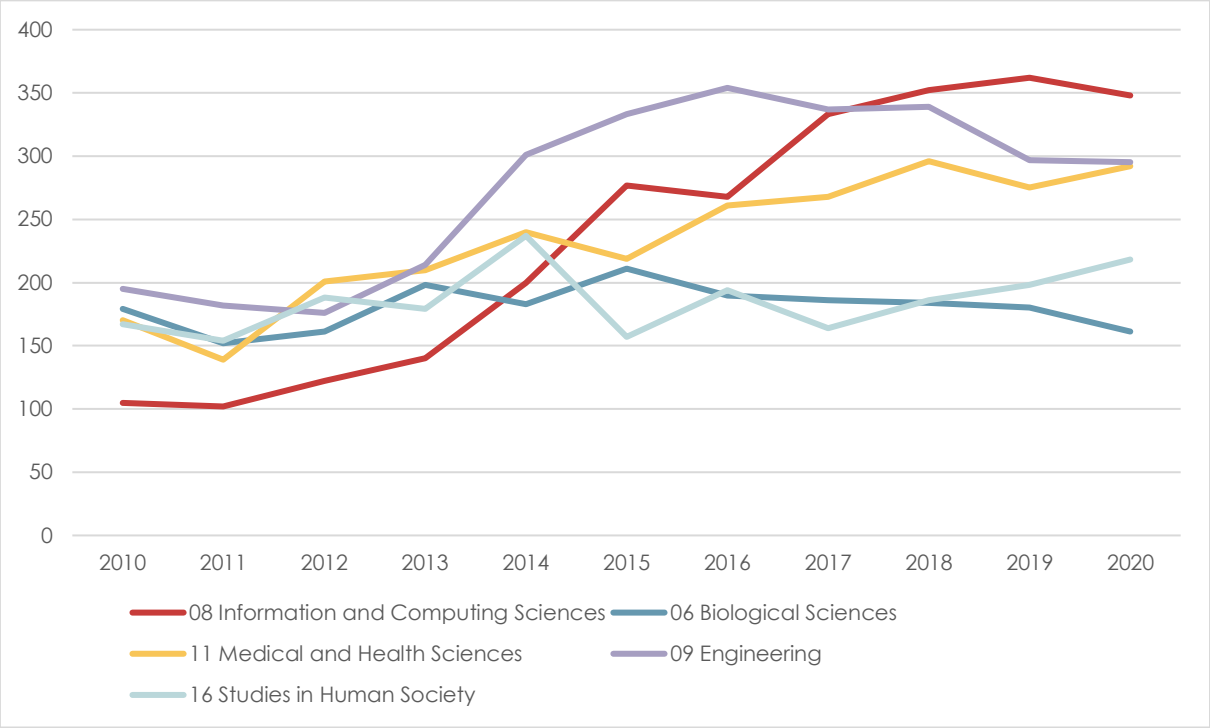
4.1.1.2 Data sources

Description – The main data source we use under Pillar 1 is RCN's internal project database containing information about RCN grants. The project database contains grant identifiers and years, the titles, descriptions and topics/categories of each project, as well as the total budgets. In addition to the project database, we also use Dimensions (data source described in Section 4.1.2) to link Pillars 1 and 2.

Coverage – The RCN project database contains information about 38,665 projects spawning the years of 2004 to 2030 (a minor percentage of grants included a future date). About 55% of the projects contain project summaries in English, while 32% only contain descriptions in Norwegian and 12% do not have any textual summary. These data are relevant for the

classification exercise 1 to measure topical alignment with the societal challenges under consideration. Figure 10 depicts the number of RCN grants per starting year for the 5 fields of research with the largest number of RCN grants.

Figure 10 Number of RCN grants per starting year in the top 5 fields of research



Source: Technopolis-group based on the RCN project database and Dimensions

Data linking – We link Pillar 1 and Pillar 2 by exploring the text of publications' acknowledgements and identifying references to RCN funding and to the grant number from which the publication results. Figure 11 provides three examples of research outputs and their full acknowledgements text from where we identify the relevant information for the linking exercise.

Figure 11 Examples of parsed text to link RCN funding/grants to research outputs

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4.1.1.3 Indicators

Each of the three approaches detailed above (in Section 4.1.1.1) will result in different sets of possible indicators. These are summarised in Table 2.

Table 2 Examples of possible indicators under Pillar 1

Approach / exercise	#	Indicator
Exercise 1.a – topical alignment	1.	• % of grants addressing the societal challenge "Achieving better protection / enhancement of natural ecosystems"
Exercise 1.a – topical alignment	2.	• % of grants addressing the societal challenge "Supporting change in behaviour and attitudes geared towards more inclusive societies"
Exercise 1.b – topical alignment per research area	3.	• % of grants addressing the societal challenge "Achieving better protection / enhancement of natural ecosystems", per research area of the grants
Exercise 1.b – topical alignment per research area	4.	• % of grants addressing the societal challenge "Supporting change in behaviour and attitudes geared towards more inclusive societies" per research area of the grants
Exercise 2 – direct output alignment	5.	• % of publications resulting from grants addressing the societal challenge "Achieving better protection / enhancement of natural ecosystems"
Exercise 2 – direct output alignment	6.	• % of publications resulting from grants addressing the societal challenge "Supporting change in behaviour and attitudes geared towards more inclusive societies"
Exercise 3 – indirect uptake alignment	7.	• # of uptake documents citing publications resulting from grants addressing the societal challenge "Achieving better protection / enhancement of natural ecosystems"
Exercise 3 – indirect uptake alignment	8.	• # of uptake documents citing publications resulting from grants addressing the societal challenge "Supporting change in behaviour and attitudes geared towards more inclusive societies"

4.1.1.4 Limitations

While over half of the available project descriptions were in English, another 30% were available in Norwegian alone. We have incorporated the Norwegian descriptions by translating them into English to be able to carry out the text analysis on a single collection of texts. However, there is still the risk of inconsistency between terminology written in English and Norwegian terminology translated into English. However, we do not consider this risk a serious threat to the study for the following reasons.

Translation was automated using Google's translation service. Research[11] on the accuracy of Google Translate for 108 different languages formulated the several conditions for proper use and accuracy of results. One of these is that results are generally best when translating to or from English, which is the case. Moreover, results are also considered best when the input text is structured and has sufficient context (i.e. complete sentences rather than loose words or phrases), and relates to formal topics. Both of these are clearly applicable to the project descriptions in the RCN database.

Moreover, while accepting that there may be inaccuracies in the translation of Norwegian to English, this does not automatically pose a significant threat to the integrity of the classification exercises. Since we use Natural Language Processing for the classification of documents, the focus is on the extraction of semantic meanings from their texts and considers words in context rather than in isolation. This ultimately means that the impact of any inaccurate or incorrect translations is largely circumvented by our classification methodology.

4.1.2 Pillar 2

Knowledge outputs that can be traced back to RCN funding will be considered under Pillar 2. The types of documents that can be included are journal article publications, conference proceeding papers, books and books chapters, preprints and monographs.

4.1.2.1 Approach

We undertake the three classification exercises described above with the overarching goal of mapping the alignment between RCN-funded research outputs and societal challenges. The exercises consist on the text-classification of RCN-funded research publications, link these publications to uptake documents and identifying cases where the text-classification of publications are misaligned with the text-classification of their originating grants.

In the first exercise, we classify all RCN-funded research publications according to their relevance to each societal challenge. At this stage, we do not explore evidence of uptake or impact, instead, we classify each output in terms of topical alignment with the two societal challenges being piloted.

For each societal challenge (and corresponding subtopics), the exercise consists of applying a text classification model in which the topics relevant to the individual impact pathways have been identified. The process of classifying documents across all three pillars per societal challenge is described in Section 4.2.

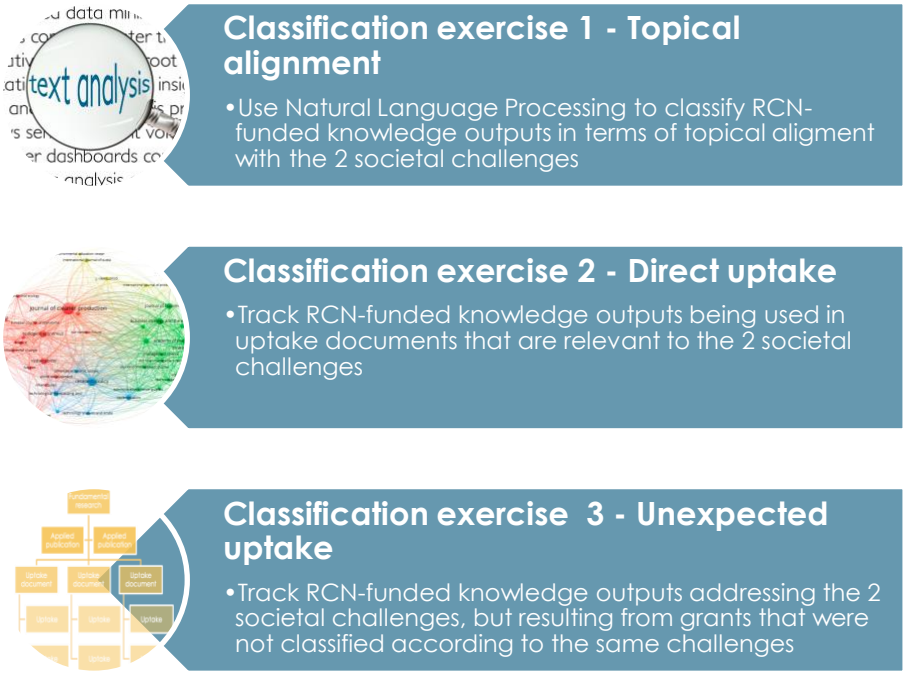
The second exercise is interdependent to Pillar 3 because it is based on the classification of uptake documents. That said, the second exercise consists in identifying the knowledge outputs that are used on uptake documents when the latter are classified as relevant to each societal

[11] Benjamin, M. (2019). Teach You Backwards: An In-Depth Study of Google Translate for 108 Languages, Kamusi Project International, https://teachyoubackwards.com.

challenge. We identify this link and count the number of times each RCN-funded research publications is used per type of uptake document. In pillar 3, as it will be explained in section 4.1.2, we explore uptake documents in-depth, whilst this second exercise under pillar 2 refers to the linking of RCN-funded research publications and uptake documents. This direct uptake linkage is visualised with Sankey diagrams.

Finally, in the third exercise, we identify cases where publications are classified as aligned with the two societal challenges of interest, but their initial grants are not. The goal was to capture the extent to which research intended to explore a specific subject can end up evolving to address other related, sometimes initially unexpected, topic. Such "surprises" can also represent potential measurement errors of our text-classification strategy, classifying text according to their alignment with the societal challenges under consideration (with the classifier 'missing out' on relevant grants).

Figure 12 Overview of the classification exercise types under Pillar 2



4.1.2.2 Data sources

Description – The main data source for Pillar 2 is the bibliometric repository Dimensions.[12] At the time of writing, the Dimensions database included over 110 million publications and their citations, along with content types that illustrate the larger information life cycle: from funding of an idea (via grants data for more than 5 million funded projects), to the eventual publications that result from such support, to the impact of the publications (illustrated through the 1.1 billion citations to 100 million research outputs and Altmetrics for 11 million research outputs, respectively). Dimensions sources data from a number of organisations. Indices such as Crossref and PubMed Central serve as a "backbone" for publication data to which is added

[12] Hook, D. W., Porter, S. J., & Herzog, C. (2018). Dimensions: building context for search and evaluation. Frontiers in Research Metrics and Analytics, 3, 23.

data derived from full-text access to more than 75 million books and articles. These full-text publications are mined to enhance metadata, citations and funding acknowledgements.[13]

Coverage – At the time of writing, more than 46k+ publications associated with RCN funding are indexed on Dimensions with publication year spanning from 1979 to 2020. Most publications are in the form of peer-reviewed scientific articles (42k+). In addition to publications, the repository also includes 2397 conference proceedings, 882 chapters, 401 preprints, 3 edited books and 2 monographs. Figure 13 presents the top 15 fields of research of RCN-funded publications and Figure 14 the number of publications in the top 5 fields of research per year from 2000 to 2020.

Box 1 Fields of Research (FOR) used in Dimensions

The Fields of Research (FOR) classification is a component of the Australian and New Zealand Standard Research Classification (ANZSRC) system, developed in 2008. Dimensions used a reverse engineering technique, based on artificial intelligence, where a corpus of manually coded grants were examined and reproduced by the algorithm.

The ANZSRC system categorises all R&D activity using a single system. The system is hierarchical, with major fields subdivided into minor fields. The ANZSRC is used in all areas of research and education in Australia and New Zealand. It is used to classify research projects, research outputs, staff-skills and course content (including PhDs). There are three inter-linked classification types: Type of Activity (TOA), Fields of Research (FOR), and Socio-economic Objective (SEO). Only FOR is present in Dimensions.

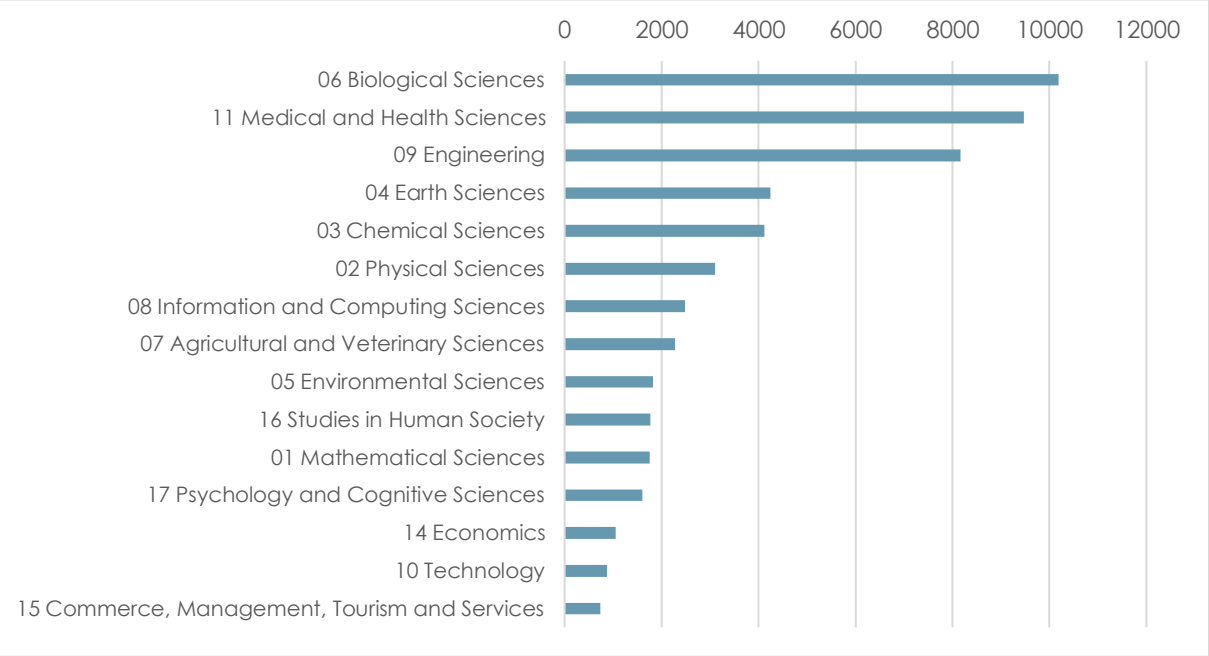
The FOR has three hierarchical levels: Divisions, Groups and Fields. Division represents a broad subject area or research discipline, while Groups and Fields represent increasingly detailed subsets of these categories. There are 22 Divisions, 157 Groups and 1238 Fields.

FOR cover all areas of academic research at a high level, so it works well for non-granular investigations into funding by broad subject areas. Therefore, FOR is good for comparative analyses across all academia at a fairly high level.

Source
[1] Dimensions' web site: https://plus.dimensions.ai/support/solutions/articles/23000018826-what-is-the-background-behind-the-fields-of-research-for-classification-system-

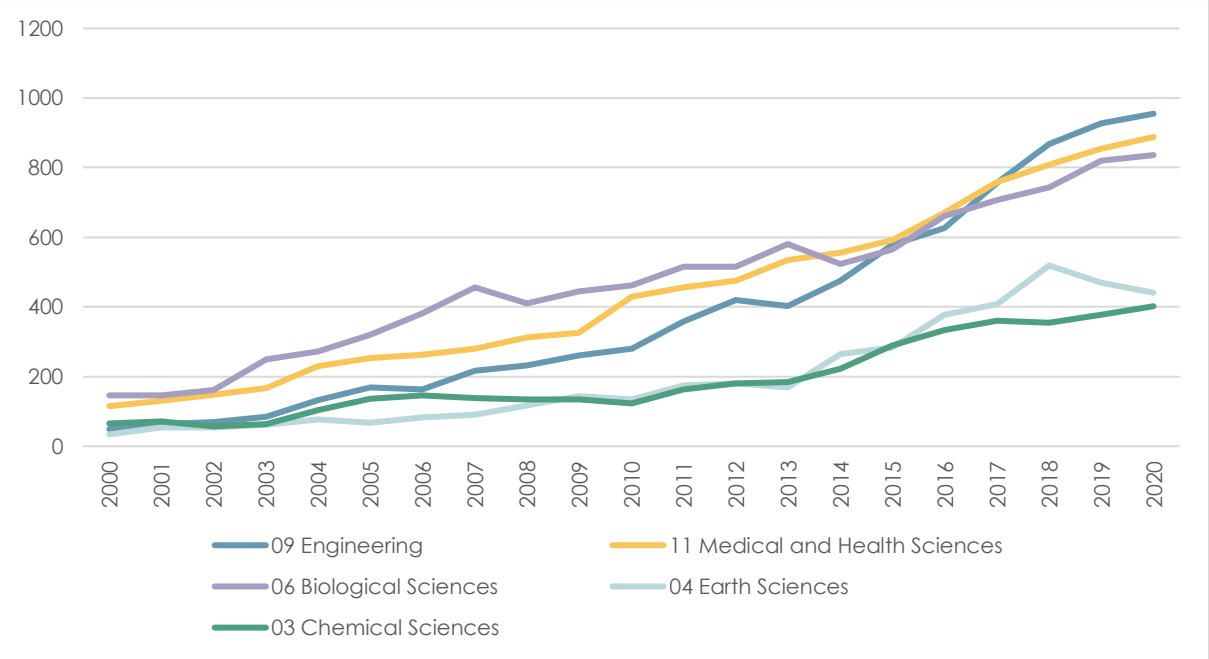
[13] Herzog, C., Hook, D., & Konkiel, S. (2020). Dimensions: Bringing down barriers between scientometricians and data. Quantitative Science Studies, 1(1), 387-395.

Figure 13 Number of RCN-funded publications per field of research



Source: Technopolis-group based on Dimensions

Figure 14 Number of RCN-funded publications per year in the top 5 fields of research



Source: Technopolis-group based on Dimensions

Data linking – All the knowledge outputs we identify that acknowledge RCN funding have been included in the analysis and thus linked to Pillar 1. To this end, we explore the text of publications' acknowledgements in order to identify those that received RCN funding. Some publications only acknowledge funding in general terms, such as "The specific analysis for the present study were funded by the Norwegian Research Council funding", while others are more specific and also acknowledge their grant, for example "This work was funded by the

Norwegian Research Council (Grant No. 280511)". As a result, in the cases where the acknowledgements include references to a grant identifier, we are able to link them back to the specific portfolio. Otherwise, for the publications without references to their specific grants, we only consider them in a broad "unspecified RCN funding" category.

The strategy to link RCN-funded research outputs with uptake documents varies per type of database. For example, in terms of patents and policy documents we rely mostly in digital object identifiers (DOIs) to do the matching, while in the case of news, blogs or social media, we mostly rely in a web crawling functionality that searches the web for references that explicitly use the online uniform resource locators (URLs) of the research outputs.

4.1.2.3 Indicators

Each of the three approaches detailed above (in Section 4.1.2.1) will result in different sets of possible indicators. These are summarised in Table 3.

Table 3 Examples of possible indicators under Pillar 2

Approach / exercise	#	Indicator
Exercise 1.a – topical alignment	1.	• % of publications addressing the societal challenge "Achieving better protection / enhancement of natural ecosystems"
Exercise 1.a – topical alignment	2.	• % of publications addressing the societal challenge "Supporting change in behaviour and attitudes geared towards more inclusive societies"
Exercise 1.b – topical alignment per research area	3.	• % of publications addressing the societal challenge "Achieving better protection / enhancement of natural ecosystems", per field of research of the publications
Exercise 1.b – topical alignment per research area	4.	• % of publications addressing the societal challenge "Supporting change in behaviour and attitudes geared towards more inclusive societies", per field of research of the publications of the publications
Exercise 2 – direct uptake	5.	• % of publications cited in uptake documents which were classified as relevant for "Achieving better protection / enhancement of natural ecosystems" (used to produce sankey diagrams for each uptake document type)
Exercise 2 – direct uptake	6.	• % of publications cited in uptake documents which were classified as relevant for "Supporting change in behaviour and attitudes geared towards more inclusive societies" (used to produce sankey diagrams for each uptake document type)
Exercise 3 – direct input misalignment	7.	• # of cases where a publication is aligned with the societal challenge "Achieving better protection / enhancement of natural ecosystems", but its originating grant is not
Exercise 3 – direct input misalignment	8.	• # of cases where a publication is aligned with the societal challenge "Supporting change in behaviour and attitudes geared towards more inclusive societies", but its originating grant is not

4.1.2.4 Limitations

The proposed approach limits the analysis to RCN's science funding efforts since it uses scientific publications as its core knowledge output. This means that the impact of RCN grants that do not generate any scientific publication will not be captured under this pillar. Notwithstanding, at the time of writing, more than 60% of RCN open and recently closed calls

for proposals have "research organisations" as key target group.[14] Many of these grants should be associated with scientific publications along with other outputs. Moreover, as long as the uptake of other outputs is cross-referenced together with the respective scientific publications, we are able to track their uptake / early evidence of impact. For example, if a grant funds an international conference where researchers present research publications, the grant itself will not have research publications as direct output. However, if the conference receives media attention being mentioned in the news, this uptake can be tracked as long as the news articles also mention RCN-funded research publications presented in the conference.

The type of impact which stems from grants that do not generate a single scientific publication will not be captured under our proposed approach. This type of funding is likely to be related with innovation grants, involving private firms and being closer to the development and demonstration side of R&D. This said, RCN already undertakes other monitoring and evaluation efforts on the business-related impact of their funding. Therefore, our approach does not imply a duplication of efforts and contributes to enrich the arsenal of evaluation methodologies available to the RCN in the areas that are more in need of evidence-based impact evaluation tools.

Finally, given the need to rely on a platform that already linked up information for Pillar 1, 2 and 3, the study team has not use CRISTIN as a starting point. CRISTIN is the Norwegian Research Information System. CRISTIN includes bibliometric data with a larger coverage than WoS and Scopus, especially monographs, edited volumes and publications in Norwegian. However, we can confirm that the study team tested the coverage of the datasets used in the pilot by identifying the percentage of publications included in CRISTIN that are also present in our data sources (using a list DOIs shared by RCN). The conclusions are presented in Section 5.1.2.

4.1.3 Pillar 3

In this pillar we capture documents that reflect potential uptake of RCN-funded knowledge outputs. Our goal is to identify and classify these documents according to whether they address the societal challenges under consideration. These "uptake documents" make use and cite knowledge that stems from RCN-funded projects and represent an early evidence of impact in the context of the societal challenges. The types of uptake dimensions we initially considered include technological influence, mass media communication and coverage, education and knowledge sharing, social media influence/discussion and policy influence. All these dimensions were explored in the final analysis with the exception of social media influence/discussion for which we encountered data accessibility and methodological concerns, since mentions in social media channels (e.g. tweets or Facebook posts) are very easily corrupted by anyone with enough time on their hands to artificially inflate the metric.

4.1.3.1 Approach

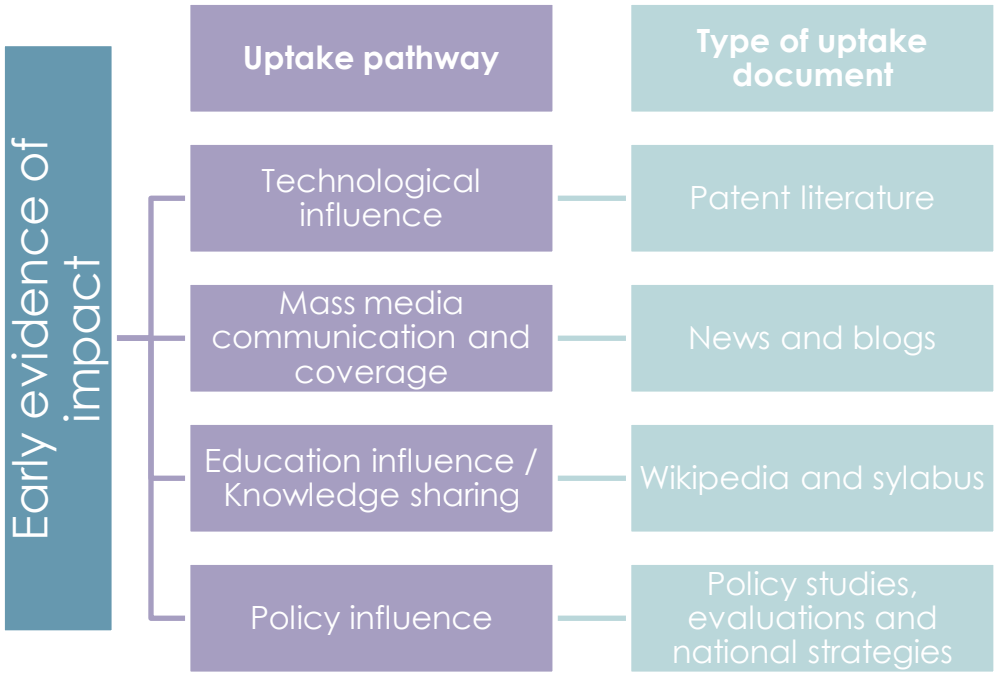
We classify according to their alignment with each societal challenge under consideration. For each societal challenge, we use a machine learning technique to extract topics and entities from the full text of each uptake document, and then link them to the societal challenge under consideration. To this end, we analyse the text in the documents and compare them to data derived from articles on Wikipedia in order to find which ones have the most in common. The titles and categories of Wikipedia articles that have a lot of overlap in language with the uptake documents are chosen as topics. We then identify uptake documents addressing topics that are associated with the societal challenges under consideration.

[14] https://www.forskningsradet.no/en/call-for-proposals (accessed in November 2020)

The uptake pathways act as proxies to the different channels of impact of RCN-funded knowledge outputs. Moreover, each pathway is represented by different types of uptake documents from various databases (summarised in Figure 15). The type of pathways we are considering include:

- Technological influence: knowledge embedding new or improved technologies and products (measured by number of patents citing the knowledge)
- Mass media communication and coverage: knowledge covered by journalists and media commentators contributing to, for example, public discussions, consultations or judgements (measured by number of news and blogs mentioning the knowledge)
- Education influence / knowledge sharing: knowledge uptake through education and learning (measured by number of Wikipedia articles citing the knowledge)
- Policy influence: knowledge contributing to sustain, for example, changes in regulations, public funding decisions or strategic policy priorities (measured by number of policy documents citing the knowledge)

Figure 15 Uptake pathways and respective types of uptake documents



4.1.3.2 Data sources

Description – No single database merges together all the pathways we propose exploring in this study. Therefore, we link at least four different databases to cover the uptake pathways from pillar 3. These include Lens.org, Dimensions, Altmetrics, and Overton, which are further described below. [15]

[15] We also considered using Pitchbook data of Venture Capital investments in order to identify innovative firms raising capital and being co-cited in news articles and blogs posts alongside with RCN-funded research findings. However, this option was dropped because references to RCN-funded publications often represent just the backing of an argument or idea in a larger context of issues being raised, so it was hard to directly relate mentions to firms to the RCN-funded publication being co-cited.

The first proposed uptake pathway is **technological influence**, for which we use patents as impact measurement proxy. In order to be granted a patent, inventors are required to prove that their invention embeds a true inventive step in regard to the prior art. In this process, inventors provide patent examiners with a list of references of prior knowledge on which the new invention builds upon. The list of references is typically composed by prior patents, but also contains other documents known as non-patent literature (NPL), which are typically academic publications. That said, we identify all the patents that cite RCN-funded publications as an indication that those publications were relevant for the new or improved technological development that is represented by a patent. Moreover, we planned to distinguish between patents from Norwegian organisations (local technological influence) and non-Norwegian (international technological influence). However, only about 6% of the patents had at least one associated Norwegian organisation, thus we did not compute the breakdown per nationality. We use Lens.org as well as Dimensions to link patents to RCN-funded publications. Lens.org is a repository of bibliometric and patent data matched through NPL citations. It is particularly well suited to measure science to technology knowledge spillovers. The main source of bibliometric data used by Lens is Microsoft Academic, while for patents, Lens contains data from nearly 100 jurisdictions, sourcing its data from the EPO, USPTO, WIPO and IP Australia.

Mass media communication and coverage is proxied by news and blogs that mention RCN-funded knowledge outputs. We identify these using the database Altmetrics. We also use Altmetrics for **education influence and knowledge sharing** proxied by academic references in Wikipedia pages. If possible, we perform this analysis distinguishing between documents in Norwegian and documents in other languages. Altmetrics is a database of metrics and qualitative data that are complementary to traditional, citation-based metrics. These metrics are sourced from the Web, tracking over 2,000 mainstream media outlets around the world and 9,000+ academic and non-academic blogs, Wikipedia citations to published research, as well as mentions of research outputs in a range of social networks. Altmetrics is a relatively new and unexplored database, thus it needs to be used and interpreted carefully. In the context of the present study, we have used Altmetrics as an indication of alignment/early evidence of contribution in regard to the societal challenges under consideration and not as ultimate evidence of direct impact.

Policy influence is measured by identifying policy documents from Norway that mention RCN-funded publications. When possible and relevant, we also track policy documents from international or foreign sources. To do this, we use the database Overton. Overton is a searchable index of policy literature including government documents and guidelines, IGO and NGO reports, think tank policy research, central bank working papers, etc. Collected policy documents are parsed to extract topics and references to scholarly documents which are then explored to link the policy documents to RCN-funded publications. We interpret citations in policy documents as contribution to a policy discussion, policy recommendation or even, potentially, to actual policy decision-making, but as in the case with Altmetrics, we use policy citations as an indication of alignment with the societal challenge under consideration and not as ultimate evidence of direct impact.

In addition to the aforementioned databases, we also use Dimensions (described in section 4.1.2.2) to link Pillar 2 and 3.

Complete coverage – We combine multiple data sources in this pillar and therefore the coverage varies by type of data under consideration. Table 4 summarises all the uptake documents we were able to track per type of data and data source.

Table 4 Coverage per type of data source

Type of data	Data source	Uptake documents

Patents	Lens and Dimensions	• ~4000 patents citing RCN publications in their NPL references
News and blogs	Altmetrics	• ~15000 news articles and ~5000 blog posts mentioning RCN-funded publications
Wikipedia and Syllabuses	Altmetrics	• ~1700 Wikipedia pages mentioning RCN-funded publications
Twitter, Facebook and Reddit (dropped due to data access and methodological concerns)	Altmetrics	• ~20000 RCN funded publications with Altmetric scores, which include number of posts from social media sources
Policy documents	Overton	• ~16000 policy documents from Norway, ~1900 documents citing RCN knowledge outputs

Data linking [mechanism by which we can link this back to publications and or grants] – Each uptake pathway under Pillar 3 will be linked to the knowledge outputs under pillar 2, and, through that channel, linked to grants under pillar 1. The strategy to link uptake documents to the corresponding RCN-funded research outputs varies per type of uptake document. In terms of patents, Wikipedia articles and policy documents we rely mostly on digital object identifiers (DOIs) or other unique identifiers. Patents, Wikipedia articles and policy documents cite scholarly research outputs in their references with bibliographic styles similar to scientific studies. Therefore, we are able to parse unique identifiers from their references and match them to the Dimensions bibliometric database. In the case of news, blogs or social media, these uptake documents do not always mention scholarly articles in the same citation or bibliographic formats. Hence, in these cases we used Altmetrics data, which implements matching techniques with a web crawling functionality that searches the web for references that explicitly refer to the online uniform resource locators (URLs) of the research outputs.

4.1.3.3 Indicators

Each impact pathway detailed above (in Section 4.1.3.1) will result in different sets of possible indicators. These are summarised in Table 5.

Table 5 Examples of possible indicators under Pillar 3

Approach / impact pathway	#	Indicator
Technological influence	1.	• % of patents citing RCN-funded outputs that are aligned with each SC topic
Technological influence	2.	• # patents citing RCN-funded outputs per year of application
Mass media communication and coverage	3.	• % of news and blogs using RCN-funded outputs that address each SC topic
Mass media communication and coverage	4.	• # of news and blogs using RCN-funded outputs per year and classification according to SC topic
Education influence / knowledge sharing	5.	• % of Wikipedia articles citing RCN-funded outputs that address each SC topic and subtopic
Education influence / knowledge sharing	6.	• # of Wikipedia articles citing RCN-funded outputs per year and classification according to SC topic

Policy influence	7.	• % of policy documents citing RCN-funded outputs that address with each SC topic and subtopic
Policy influence	8.	• # of policy documents citing RCN-funded outputs per year and classification according to SC topic
Policy influence	9.	• % of policy documents citing RCN-funded outputs per type of policy organisation and classification according to SC topic
Policy influence	10.	• % of policy documents citing RCN-funded outputs per language and classification according to SC topic

4.1.3.4 Limitations

Many of the applications and datasets under consideration in this pillar are extremely new and thus not yet completely studied and understood. Thus, this is an opportunity to move impact evaluation methodologies forward and test novel applications with high potential value-added. However, the novel aspect of these datasets also requires interpreting our quantitative results with caution and with an appropriate complementary qualitative assessment.

Even traditional indicators of scientific impact are not free of limitations, exceptions and of potential abuse and misuse. The use of scientific citations as a representation of scientific influence and quality is a good example. The consensus is that, in general, the larger the number of citations a publication receives the larger is its impact, both in terms of being a positive and meaningful contribution.[16] Moreover, citations from a broader set of disciplines represent a wider range of impact. However, several inconsistencies can arise, such as time inconsistencies (for example discoveries that take time to be properly recognised and cited), citations in a context of criticism and negative reviews, or the potential to "game" the metric leading to an artificial inflation of citation impact.

New data sources and novel indicators will embed similar limitations to traditional indicators, with the additional shortcoming of being still relatively unexplored. All the aforementioned limitations of traditional bibliometric data sources and indicators are likely to be present in the proposed uptake documents to an extent that is still undetermined. For example, in the case of Altmetrics, a publication may be cited and used incorrectly by a news outlet, which would represent an unclear demonstration of impact. Or even worse, a publication can be cited incorrectly to sustain "fake news" arguments in a social media post, which would represent a potential negative impact pathway. Therefore, the indicators we derive from these novel data sources need to be put in context and combined with qualitative checks. But more importantly, the impact pathways we are able to establish need to be interpreted as early signs of uptake / contribution, rather than interpreted as an explicit and causal impact attribution. Table 6 provides a summary of reach and possible limitations associated with each data source.

Table 6 Summary of the approach, reach and limitations per impact pathway

Pathway	Document type (data sources)	Reach	Examples of potential limitations
Technological influence	• Patent documents (Lens.org, Dimensions	• New or improved technologies and products citing knowledge outputs	• Not all technologies are patentable and even when they are inventors can choose other IP strategies

[16] Garfield, E. (1979). Is citation analysis a legitimate evaluation tool?. Scientometrics, 1(4), 359-375.

Pathway	Document type (data sources)	Reach	Examples of potential limitations
	and Pitchbook)		• Inventors can attempt to strategically add or hide prior art, artificially inflating or deflating NPL citations
Mass media communication and coverage	• News and blogs (Altmetrics & Pitchbook)	• Coverage by journalists and media commentators contributing to e.g., public discussions, consultations or judgements	• Potential misuse of the knowledge since news/blog documents are not peer-reviewed • As in traditional indicators, it is difficult to distinguish between positive and negative references
Education influence / knowledge sharing	• Wikipedia and syllabuses (Altmetrics)	• Knowledge uptake through education and learning	• Potential to artificially inflate the metric by anyone with enough time on their hands
Social media influence / discussion (dropped due to data access and methodological concerns)	• Twitter, Facebook and Reddit (Altmetrics & Pitchbook)	• Debate among practitioners sharing and discussing new evidence and engaging with other stakeholders such as civil society organizations	• Potential misuse of the knowledge since social media posts are not peer-reviewed • Potential to artificially inflate the metric by anyone with enough time on their hands • As in traditional indicators, it is difficult to distinguish between positive and negative references
Policy influence	• Government papers and guidelines, IGO and NGO reports, think tank policy research and central bank papers (Overton)	• Knowledge contributing to sustain e.g., changes in regulations, public funding decisions or strategic policy priorities	• Relatively unexplored dimension. For example, we do not know about potential biases stemming from incomplete coverage of policy documents in different years (the population of policy documents is unknown), or from different citation styles (research publications cited in policy documents may not be captured due to the lack of a common citation framework across policy documents) [17]

4.2 Methodology for operationalising the impact pathways

This section presents the approach followed by the study team to classify all projects in the RCN database (i), all publications linked to RCN grants (ii), and all uptake documents connected to these grants (ii), according to the impact pathways that were selected for the study's pilot. Specifically, this refers to the pathways on "supporting change in behaviour and attitudes geared towards more inclusive societies" and "achieving better protection / enhancement of natural ecosystems". To conduct the classification exercises, an external machine learning-based classifier provided by TextRazor was used, which is described in more detail below.

As noted above our approach can be implemented to:

[17] Examples of analysis exploring policy documents include the Contextual Response Analysis developed by Ad Prins. See https://adprins.nl/projecten/analyses-for-pbl-cpb-scp-zonmw-and-the-health-council/ and Spaapen, J., & Van Drooge, L. (2011). Introducing 'productive interactions' in social impact assessment. *Research evaluation*, *20*(3), 211-218.

- Classify RCN project database according to the selected pathways, to identify original intent and then analyse the results produced (in Pillar 2 and 3)
- Classify results as detected in Pillar 2 and / or 3 and look back to test the origin of those results (which may or may not link to grants – or publications- produced in the same areas on interest). This acknowledges the fact that research produced with an initial focus could then feed into other (unanticipated) areas of application.

Approach to the classification exercises

The classification of RCN grants, publications and uptake documents relied on an external classification tool, provided by TextRazor[18]. The latter is a Natural Language Processing (NLP) platform that uses Artificial Intelligence to offer a range of text analysis services such as entity recognition, topic tagging, and indeed document classification. With regards to the latter, TextRazor offers out of the box classification models but also allows for custom models. The out-of-the-box models are based on publicly available taxonomies while the classifier itself is derived from a training set of textual elements from Wikipedia[19], DBPedia[20] and Wikidata[2122]. Currently, TextRazor offers classifiers according to the following public taxonomies, considered media industry standards:

- Interactive Advertising Bureau (IAB) Content Taxonomy[23]: used by publishers to organise website content. Currently, this consists of around 400 high level categories.
- International Press Telecommunications Council (IPTC) NewsCodes[24]: This is a set of news metadata concepts developed to consistently code news media. NewsCodes has around 1,400 high level categories.
- International Press Telecommunications Council (IPTC) Media Topics[25]: this is a public taxonomy primarily designed for text classification. Currently this consists of around 1,100 terms.

For the purposes of the pilot, we opted for the IPTC Media Topics taxonomy as this was deemed most appropriate for the types of documents and content to be classified.

Before applying the classifier to the documents across all three pillars, two more steps were required. First of all, the categories within the IPTC Media Topics taxonomy that were relevant to the two impact pathways of interest had to be identified. Table 11 and Table 12 in Appendix B provide an overview of all media topics that were connected to "achieving better protection / enhancement of natural ecosystems" and "supporting change in behaviour and attitudes geared towards more inclusive societies" respectively. The selection of relevant media topics was in part informed by the portfolio mapping exercise (see Section 2.3) as well as an analysis of key words and phrases extracted from project descriptions available in the RCN database, carried out as a background task.

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[18] TextRazor website: https://www.textrazor.com

[19] See: https://www.wikipedia.org

[20] See: https://www.dbpedia.org

[21] See: https://www.wikidata.org

[22] For more details on TextRazor's classification technique, please see: https://www.textrazor.com/classification

[23] IAB Content Taxonomy: https://www.iab.com/guidelines/content-taxonomy/

[24] IPTC NewsCodes: http://cv.iptc.org/newscodes/

[25] IPTC Media Topics: http://cv.iptc.org/newscodes/mediatopic/

Finally, some translation of project descriptions and summaries was necessary as Norwegian is not one of the classifier's supported languages. The overall RCN database consists of 38,665 projects with end dates ranging from 2004 to 2030 of which:

- 21,373 projects had descriptions in English (55%)
- 12,461 additional projects only had Norwegian descriptions (32%)
- 4,831 projects did not have any description (13%)

The descriptions in Norwegian were translated into English through automated translation based on Google's multilingual neural machine translation service (Google Translate). Naturally, some limitations are associated with the translation of Norwegian text into English, such as the potential loss of discipline-specific terminology. These limitations and their mitigation are discussed in section 4.1.1.4.

The resulting classification served as the starting point for closer analysis of the two pathways and three pillars, as well as the relationships between them. Furthermore, it also determined the process of data linking for analyses where the full chain of grants, publications, and uptake documents was traced. Lastly, it is worth noting that the classification of documents across all pillars was portfolio-agnostic meaning that RCN grants and their respective outputs could be classified under a certain pathway even if the corresponding portfolio was not initially mapped to said pathway.

4.3 Results

This section presents the results from our analysis. All the relevant documents, from grants to uptake documents, are classified individually according to how their text is aligned with the two societal challenges of interest. This includes each individual RCN-grant, all publications acknowledging RCN funding (regardless of mentioning the specific grant number) and all the uptake documents citing those publications.

Overall, the results show an upward trend regarding the alignment with the two societal challenges under consideration measured by the total percentage of grants and publications classified under each societal challenge.

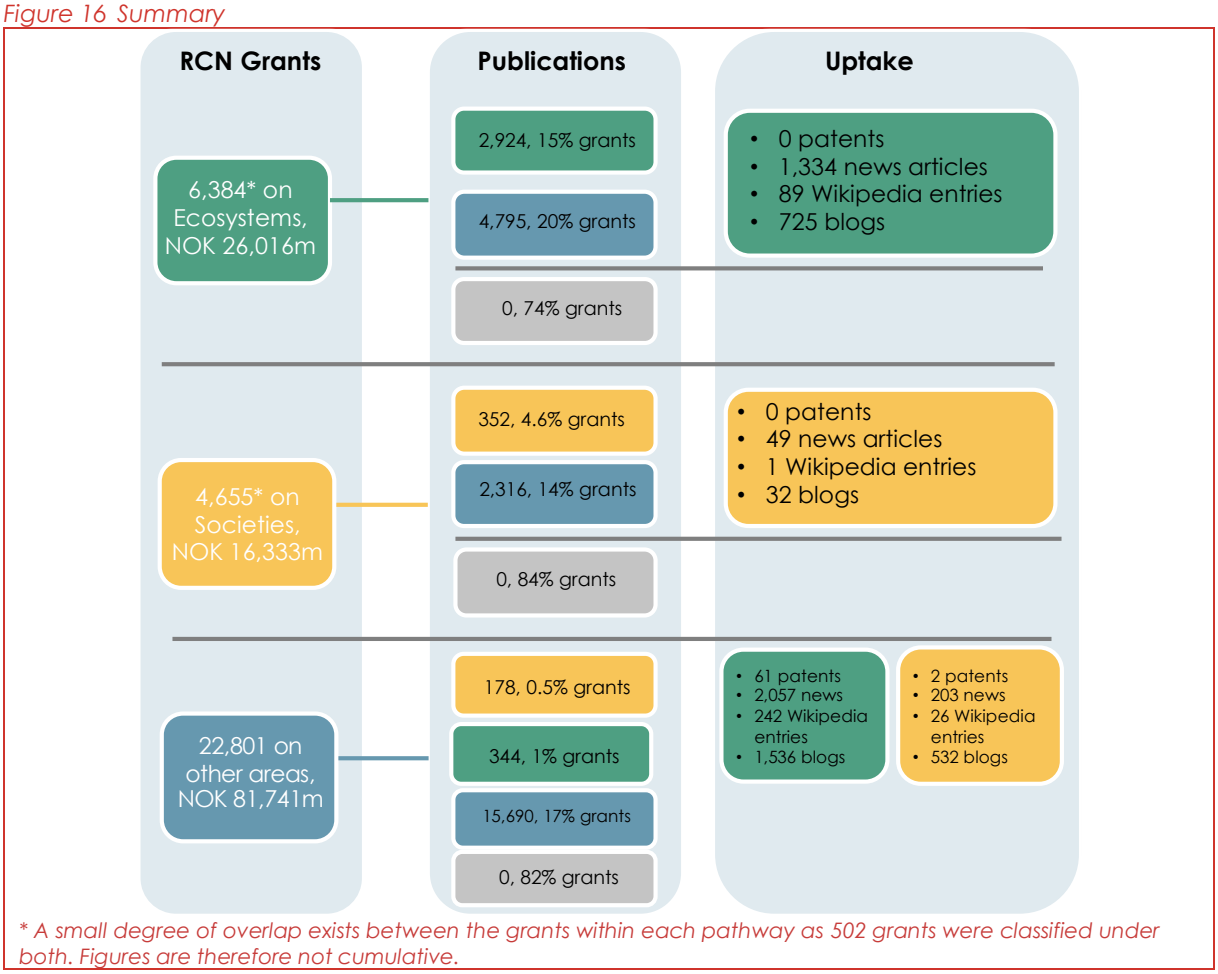
As explained in the prior section, the data linking exercise consisted in matching grants (Pillar 1) to resulting publications (Pillar 2) and to the respective uptake documents mentioning the publications (Pillar 3). However, the text-classification was applied regardless of establishing a direct link between pillars. This is particularly relevant because authors often mention RCN funding in broad terms without specifying grant numbers in their publications. Therefore, we were not able to link those publications to their originating grants. Additionally, authors may not acknowledge RCN funding at all in their publications. [26] These two sources of irregularities contribute to deflate the total number of grants we identify with resulting publications, therefore the values we achieve for share of grants with resulting publications are certainly an underestimation of the real values.

Given the underestimation of the total number of grants with direct links with publications, the final linked dataset needs to be interpreted as a representation of the links between pillars. Figure 16 summarises the results of the data linking exercise. It presents in green those statistics related to either grants, publications or other documents which have been classified as being related to "Protecting Ecosystems"; in yellow those related to "Inclusive Societies" and in blue those that do not fall in those categories. It shows for instance, that 6,384 RCN grants have

[26] These elements are a result of identifying RCN-funded publications based on acknowledgements. We discuss the limitations and pros and cons of potential alternatives in Section 5.

been classified as "Protecting Ecosystems". Of that total about 15% have led to publications related to that area (and a total of 2,924 publications). 20% grants have led to publications in 'other areas", while for 74% we were not able to track resulting publications. As explained above, not finding a publication match does not necessarily mean that the grant resulted in zero publications, instead, it is probably the case that the resulting publications did not mention the specific grant number and therefore we were not able to match them. The 2,924 publications in the area of ecosystems have then been cited in various outlets. The figure also shows that a series of patents, Wikipedia and new articles, and blogs related to "Protecting Ecosystems" cite grants not initially classified under that category (and we discuss this in more detail below).

Figure 16 Summary



** A small degree of overlap exists between the grants within each pathway as 502 grants were classified under both. Figures are therefore not cumulative.*

4.3.1 RCN portfolio (Pillar 1)

Our analysis reveals the alignment of the RCN portfolio with the two areas of interest. We find that:

- **19% of all RCN grants** (1994 - 2020[27]) had (as an initial objective) to develop or advance knowledge, understanding, and / or solutions geared towards achieving **better protection / enhancement of natural ecosystems. They represent a value of NOK 26,016m**.

[27] Grant starting years.

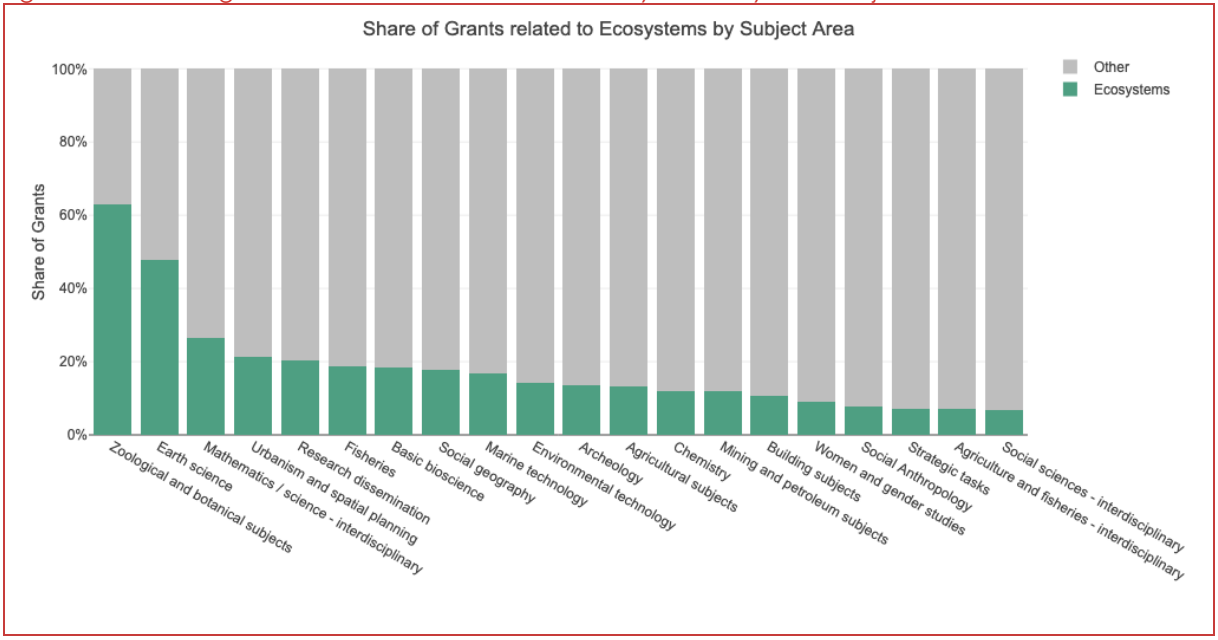
- **14% of all RCN grants** (1994 - 2020) had (as an initial objective) to develop or advance knowledge, understanding, solutions linked geared towards supporting **changes in behaviour and attitudes geared towards more inclusive societies. They represent a value of NOK 16,333m.**

Those grants related to multiple thematic areas (based on RCN grant classification), denoting how different areas of research can ultimately (seek to) contribute to a wider societal impact.

In the case of "Ecosystems", a high percentage of grants classified under this area relate to Zoological and botanical subjects, Earth Science, Mathematics/science-interdisciplinary, Urbanism and spatial planning, Research dissemination and Fisheries (see Figure 17)[28].

Additionally, a high percentage of grants in the area of "Inclusive societies" relate to Demographics, Social work, Sociology, Social Anthropology, and Folklore/ethnology (see Figure 18).

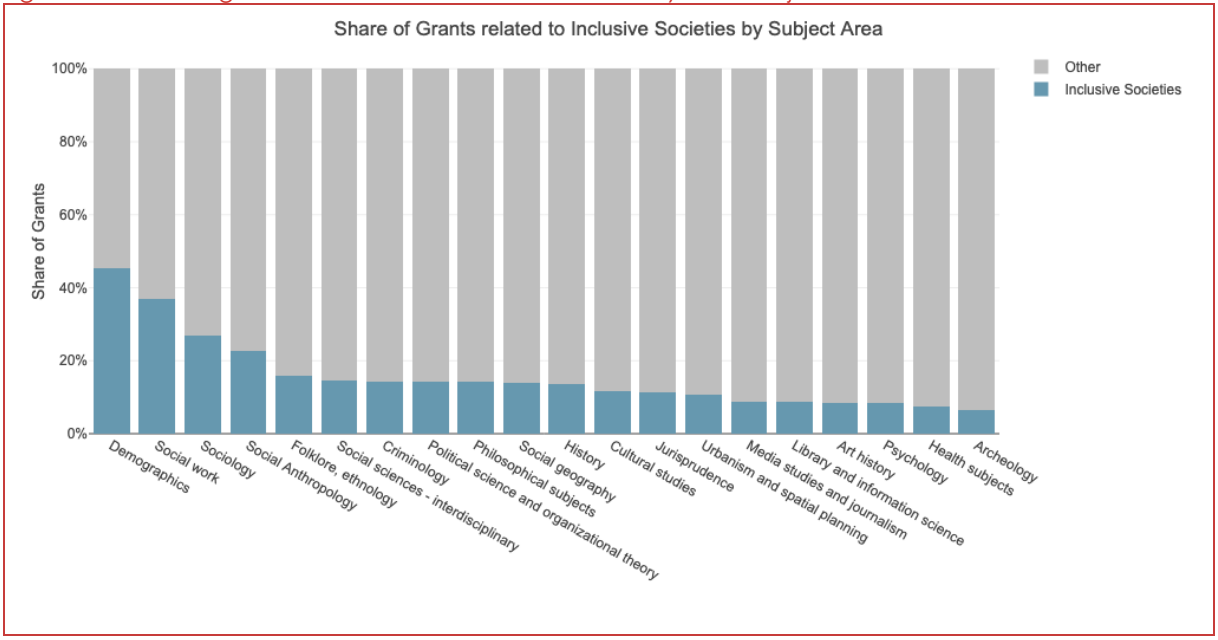
Figure 17 Share of grants related to "Protection of Ecosystems" by RCN Subject area



Source: Technopolis (2020)

[28] Note that one publication can have multiple classifications.

Figure 18 Share of grants related to 'Inclusive Societies" by RCN Subject area



Source: Technopolis (2020)

4.3.2 Publications (Pillar 2)

Our analysis also shed light on the production of codified knowledge that aligns with the two areas of interest. The analysis focuses only on publications published in peer review journals, as well as book chapters and conference proceedings, as captured in Dimension[29], since this is the body of work that we are able to identify via this secondary data source. This means, in turn, that the analysis does not capture the flow of knowledge that is transferred by other means, including tacit or implicit knowledge, which will undoubtedly also influence the achievement of impact.

We find that:

- **5,302 publications funded by the RCN are geared towards achieving better protection / enhancement of natural ecosystems (about 12% of all RCN funded publications). 60% of the 5,302 publications explicitly mention the specific grant number. Based on this information, we found that 1,295 RCN grants (2000 - 2019[30]) have led to the development of new /enhanced knowledge geared towards this societal challenge. They represent a value of NOK 16,795m.**

This includes 303 grants that were not initially classified under this impact area (based on their project description). This captures, to some extent, the fact that research intended to explore a specific subject could evolve to address other related, sometimes initially unexpected, issues. However, the result also captures potential measurement errors (with the classifier 'missing out' on relevant grants), and we expect to find this 'misalignment' in 10-15% of the cases.

[29] At the time of writing, more than 46k+ publications associated with RCN funding are indexed on Dimensions with publication year spanning from 1979 to 2020. Most publications are in the form of peer-reviewed scientific articles (42k+). In addition to publications, the repository also includes 2397 conference proceedings, 882 chapters, 401 preprints, 3 edited books and 2 monographs. The link between publications and RCN funding is established by exploring the text of publications' acknowledgements which provides references to RCN funding.

[30] Grant start years.

For instance, research from the Centre for Early Sapiens Behaviour (SapienCE) on the origins of early Homo sapiens behaviour in southern Africa between 120-50 ka was not classified under "Protection ecosystems" but one of the publications associated to the grant discusses how human footprints provide a snapshot of the last interglacial ecology in the Arabian interior, the type of research that informs our understanding of climate change, (and was correctly - classified under this area). Whether or not the grant should also be classified under "Protection ecosystems" could be open to debate. Positively, the classifier did pick up its relevance, based on the information on publications.

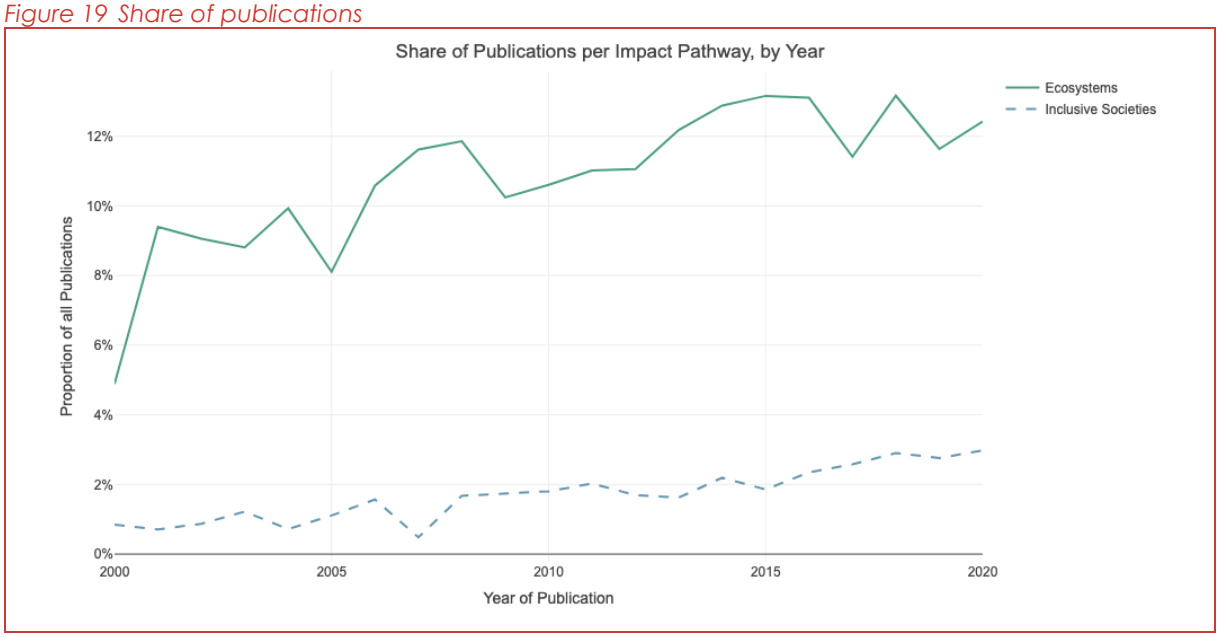
We also find that 74% of RCN grants classified as "Protection ecosystems" are not associated with specific publications in our databases. It is most likely the case that many resulting publications did not mention the specific grant number in their acknowledgements, and we therefore could not match them.

- **972 publications with RCN funding are linked to supporting changes in behaviour and attitudes geared towards more inclusive societies (about 2% of all RCN funded publications). About 57% of the 972 publications acknowledge the specific RCN grant number associated with RCN funding. Based on this link, we found 386 RCN grants (2000 - 2019) that have led to the development or advancement of knowledge and understanding linked to the topic of more inclusive societies. They represent a value of NOK 5,124m.**

As above, this includes 168 grants that were not initially classified under this impact area. We also find that 84% of RCN grants classified as "Inclusive societies" are not explicitly cited in publications. As explained above, that does not necessarily mean that these grants have no publication output, instead, it is probably the case that many resulting publications did not explicitly cite the specific project number.

We also find that publications related to both areas (as a percentage of total publications linked to RCN grants) has increased overtime, with a steeper increase in the case of 'new /enhance knowledge geared towards achieving better protection / enhancement of natural ecosystems', as shown in Figure 19, denoting an increased focus on knowledge production that contributes towards advances in this area among the research community over the past 20 years.

Figure 19 Share of publications



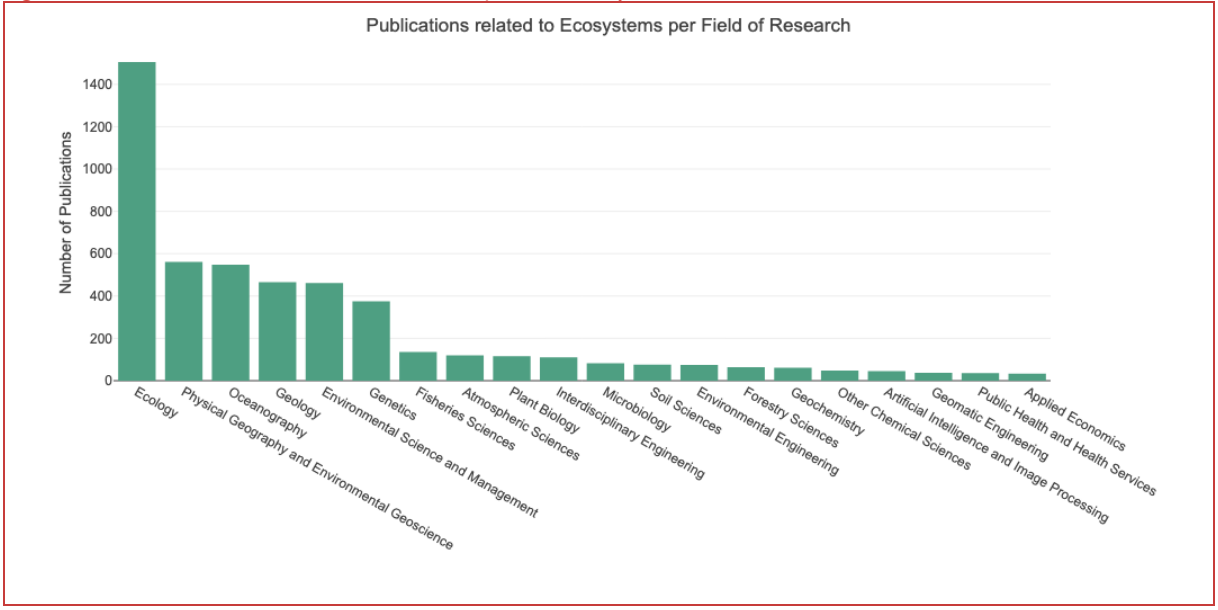
Source: Technopolis (2020)

In the case of publications related to 'new /enhanced knowledge linked to achieving better protection / enhancement of natural ecosystems', the key subject areas (as reported in Scopus classification based on Journals) include Ecology, Physical Geography, Oceanography, Geology, and Environmental Science and Management, among others (see Figure 20)

In the case of publications related to 'supporting changes in behaviour and attitudes geared towards more inclusive societies', the key subject areas include Public Health and Health Services, Sociology, Applied Economics, Political Sciences, Phycology, Policy and Administration and Demography, among others (see Figure 21).

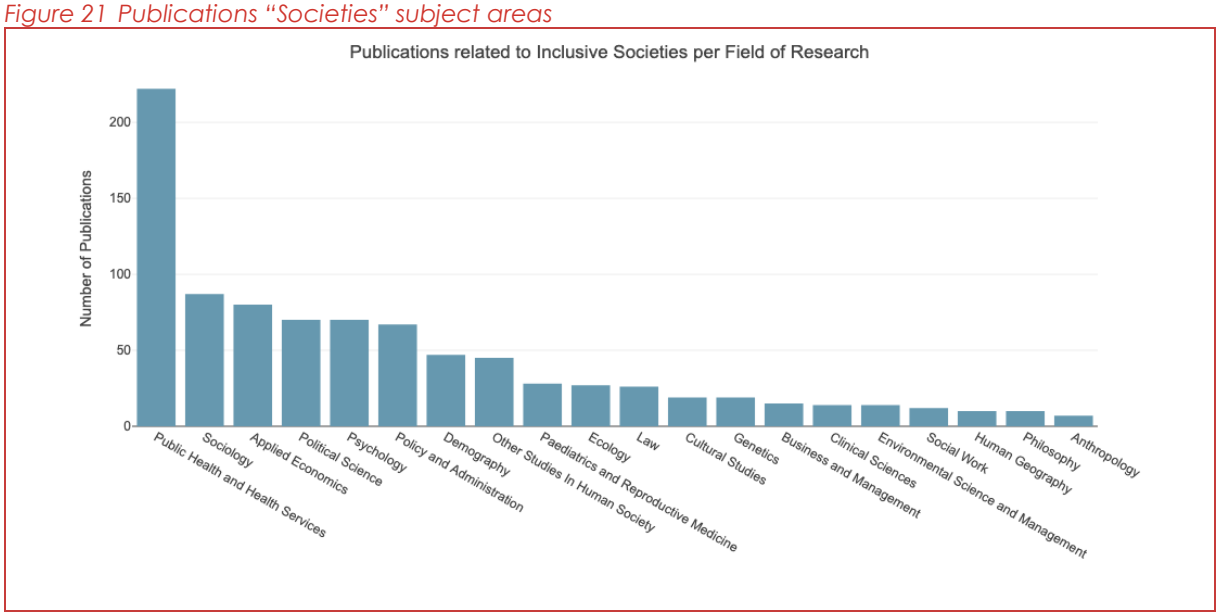
Examples of those publications and how their uptake across different outlets is presented in the following subsections.

Figure 20 Publications "Protection of Ecosystems" subject areas



Source: Technopolis (2020)

Figure 21 Publications "Societies" subject areas



Source: Technopolis (2020)

4.3.3 Uptake of knowledge outputs (Pillar 3)

4.3.3.1 Overview

In this pillar we have considered documents that reflect potential uptake of RCN-funded knowledge outputs. Our goal has been to identify and classify these documents according to whether they address the societal challenges under consideration. These "uptake documents" make use of and cite knowledge that stems from RCN-funded projects and represent an early evidence of impact in the context of the societal challenges. The types of uptake dimensions we consider include technological influence, mass media communication and coverage, education and knowledge sharing, social media influence/discussion and policy influence.

The uptake pathways act as proxies to the different channels of impact of RCN-funded knowledge outputs. Moreover, each pathway is represented by different types of uptake documents from various databases (as described in the section above). The type of pathways we are considering include:

- Technological influence: knowledge embedding new or improved technologies and products (measured by number of patents citing the knowledge)
- Mass media communication and coverage: knowledge covered by journalists and media commentators contributing to, for example, public discussions, consultations or judgements (measured by number of news and blogs mentioning the knowledge)
- Education influence / knowledge sharing: knowledge uptake through education and learning (measured by number of Wikipedia articles citing the knowledge)
- Policy influence: knowledge contributing to sustain, for example, changes in regulations, public funding decisions or strategic policy priorities (measured by number of policy documents citing the knowledge)

The results are presented in turn in the subsections below.

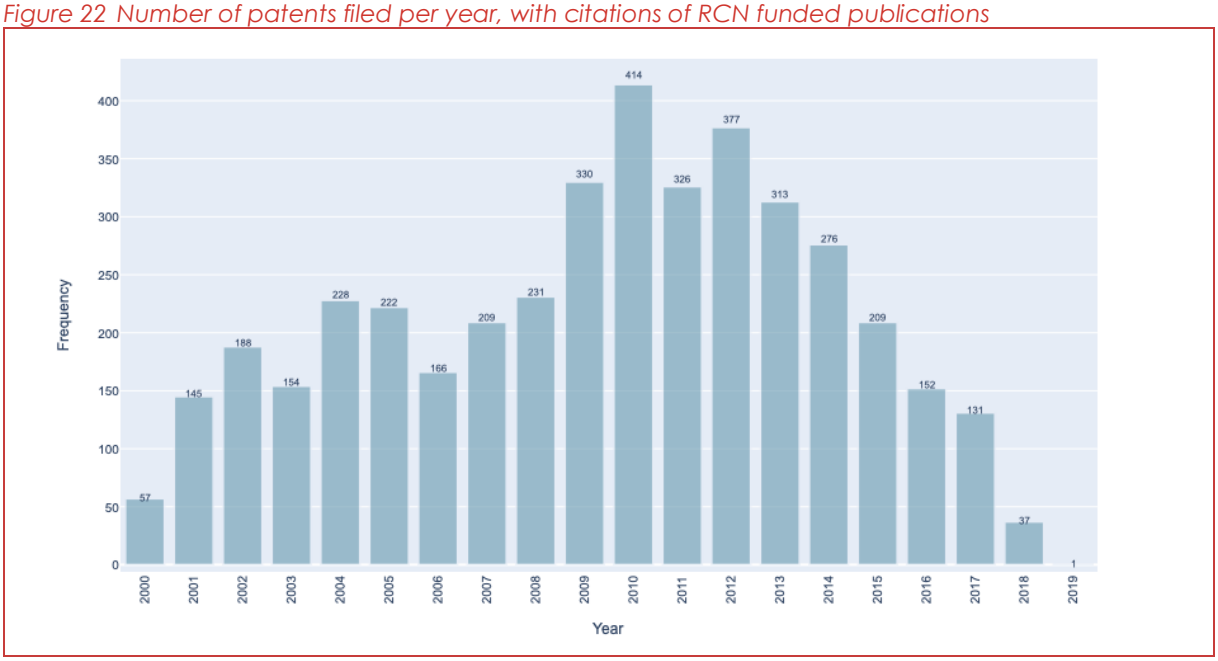
4.3.3.2 Technological influence

As mentioned above, the analysis of citations of publications linked to RCN grants, provides a proxy for the knowledge embedding new or improved technologies and products. We find that:

- 4,310 patents (in the period) include at least one citation to an RCN funded publication. About 6 % of these patents included a Norwegian organization.
- 34 patents related to the "Protection of Ecosystems" cite publications linked to RCN grants, with 6% citing publications in this area, and 94% citing other publications linked to RCN grants.

In the last years (from 2012-2017), and as shown in Figure 22, we see a decline on the number of patents that cite a publication linked to RCN grants, which could signal a slight decline in the number of publications that could inform new (patentable) products and technologies.

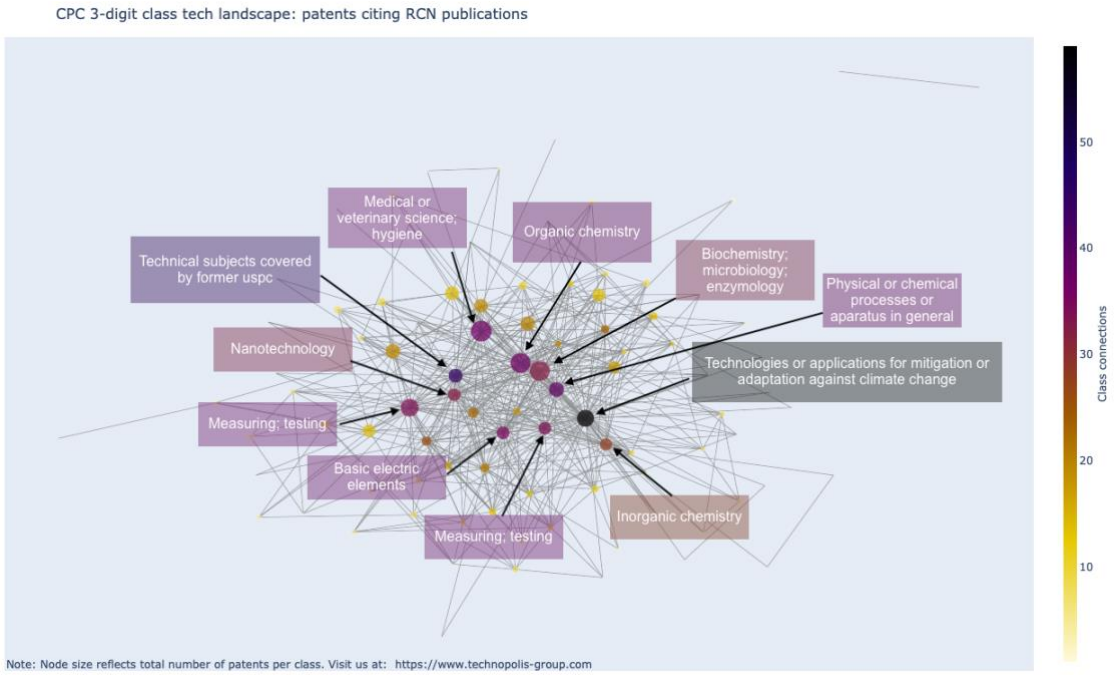
Figure 22 Number of patents filed per year, with citations of RCN funded publications



Source: Technopolis (2020)

In terms of contribution to the technological landscape, patents related to the "Protection of Ecosystems" (that cite publications linked to RCN grants) tend to be clustered around nine areas (shown in Figure 23 below), which include Medical or veterinary science, organic chemistry, Biochemistry and Measuring & testing, among others.

Figure 23 Technological landscape - Ecosystems



Source: Technopolis (2020)

The Box below presents an example of the 'journey' and links between grants, publications and patents. It is a unique example in terms the speed of 'uptake'.

In fact, based on the information linked in the context of this study, we estimate that it takes on average 11.6 years, between the start of the grant and the filing of a patent.

Box 2 ***Better protection/enhancement of natural ecosystem***

One of the patents identified via our analysis related to a method and system for underwater hyperspectral imaging of seabed impact, environmental state or environmental footprint from natural or man-made sedimentation.

The inventors belonged to the Norwegian University of Science and Technology (NTNU), working in collaboration with Ecotone (a Norwegian company) (a spin off from NTNU).

One of 3 papers cited in the patent was funded by RCN through the MarMine project focused on the exploitation technologies for marine minerals on the extended Norwegian continental shelf (as part of the User-driven Research based Innovation – BIA). The project has a funding for NOK 24.9mill. It started in 2015 and concluded in 2020.

Among other activities, the project funded an expedition to the Atlantic Mid-Ocean ridge in August 2016, where an underwater hyperspectral imager (UHI) was utilised to investigate its applicability to exploration for marine minerals. The results were presented via a conference proceeding published in 2017, which subsequently informed the patent, filed in 2018 and submitted by Ecotone.

The company (Ecotone) now offers its technology to scientists and commercial customers, for purposes such as the monitoring coral and sponge habitats. A number of new applications are soon ready for launch as research and development progresses.

Sources

[1] https://prosjektbanken.forskningsradet.no/#/project/NFR/247626
[2] https://ieeexplore.ieee.org/document/8084995
[3] https://patentscope.wipo.int/search/en/detail.jsf?docId=WO2019088847
[4] https://ecotone.com/om-oss/?lang=en

4.3.3.3 Mass media communication and coverage and knowledge sharing

We also explored the extent to which publications linked to RCN grants are picked up by news outlets and knowledge sharing platforms.

This includes knowledge covered by journalists and media commentators contributing to, for example, public discussions, consultations or judgements (measured by the number of news articles and blogs mentioning the knowledge); and knowledge uptake through platforms such a Wikipedia which provides educational information with a wide outreach to society at large.

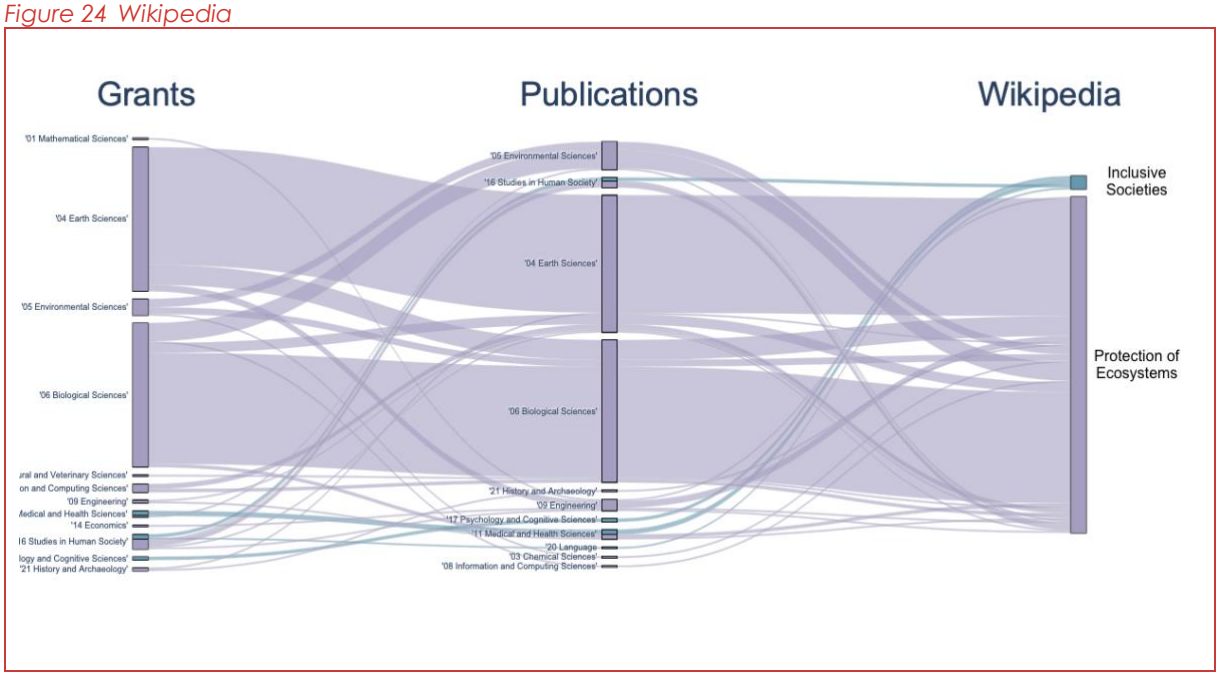
4.3.3.3.1 Wikipedia

We find a total of 26 and 242 Wikipedia articles, addressing or concerned with supporting changes in behaviour and attitudes geared towards more inclusive societies; and achieving better protection / enhancement of natural ecosystems, respectively, that cite publications funded by the RCN.

Figure 24 showcases how a diverse set of topics covered by RCN grants, and the publications (linked to those grants), then feed into articles published that relate to "Protection of ecosystems" and "Inclusive societies".

The boxes below provide examples of the research linked to RCN grants, the publication, and its uptake in these articles.

Figure 24 Wikipedia



Source: Technopolis (2020)

Box 3 ***Better protection/enhancement of natural ecosystem***

Publication: Chytrid fungi distribution and co-occurrence with diatoms correlate with sea ice melt in the Arctic Ocean. (DOI:10.1038/s42003-020-0891-7)

Global warming is rapidly altering the attributes of Arctic Waters. These changes are predicted to alter microbial networks which could upset wider functions resulting in parasite infections. In this paper, the researchers investigate diversity and distribution patterns of fungi during one record sea ice minimum in 2012. The research shows that chytrid fungi (fungi with swimming tails) are primarily encountered at sites influenced by sea ice melt. The findings identify a potential future scenario in which chytrid

representation within these communities increases because of ice retreat and further altering community structure through upsetting of parasitic interaction networks.

The project received grants from *NANSEN - Arven etter Nansen,* a joint Norwegian research platform funded by RCN, that intends to bring an integrated Arctic perspective on climate and ecosystem change, from physical processes to living resources, and from understanding the past to predicting the future. The project, which has a budget of NOK360mill started in 2018 and will last until 2023.

One of the papers that have emerged from this initiative (and published in Nature in 2020) is cited in several Wikipedia articles. In the Wikipedia articles "Marine Protiststst", "Marine food web" and "Marine Fungi", an example from the research paper is used of how fungi infests Pennate diatom (major group of algae) in an Arctic meltpond.

The authors (affiliated to institutions based in Norway, Germany, and the UK) also acknowledge funding from European Union's Horizon 2020 (under the Marie Sklodowska-Curie Fellowship) and Innovate UK.

Sources

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[4] Wikipedia, 2020, "Marine protists", Last modified: 2020-12-07, https://en.wikipedia.org/?curid=63933276
[5] Wikipedia, 2020, "Marine food web", Last modified: 2020-12-16, https://en.wikipedia.org/?curid=60927729
[6] Wikipedia, 2020, "Marine fungi", Last modified: 2020-11-26, https://en.wikipedia.org/?curid=34635084

Box 4 ***More inclusive societies***

Publication: Interorganizational complexity and organizational accident risk: A literature review. (DOI: 10.1016/j.ssci.2015.08.010)

Due to increased outsourcing in many industries, organizations are becoming larger and more interorganizationally complex and numerous operations now require cooperation among employees from different organizations. This paper presents a review of empirical literature addressing safety issues in complex interorganizational systems wherein the potential for major organizational accidents is present. The findings suggest that issues due to interorganizational complexity can hinder efficient safety management and thereby elevate the risk of organizational accidents.

The paper (published in 2016) is cited in four different Wikipedia articles, amongst them are the articles "Blame", "Blame in organizations" and "Workplace bullying". The paper is cited in a different amount in all the articles, but the main reference is how several issues identified in organizations with a blame culture contradicts high reliability organizations best practices.

Note

The paper acknowledges contribution from RCN, but it does cite grant.

Sources

[1] Vibeke Milch, Karin Laumann, 2016, "*Interorganizational complexity and organizational accident risk: A literature review*", ScienceDirect, DOI: 10.1016/j.ssci.2015.08.010
[2] Wikipedia, 2020, "Blame", Last modified: 2020-12-02, http://en.wikipedia.org/?curid=319888
[3] Wikipedia, 2020, "Blame in organizations", Last modified: 2020-11-19, http://en.wikipedia.org/?curid=32297502
[4] Wikipedia, 2020, "Workplace bullying", Last modified: 2020-11-29, http://en.wikipedia.org/?curid=4082874

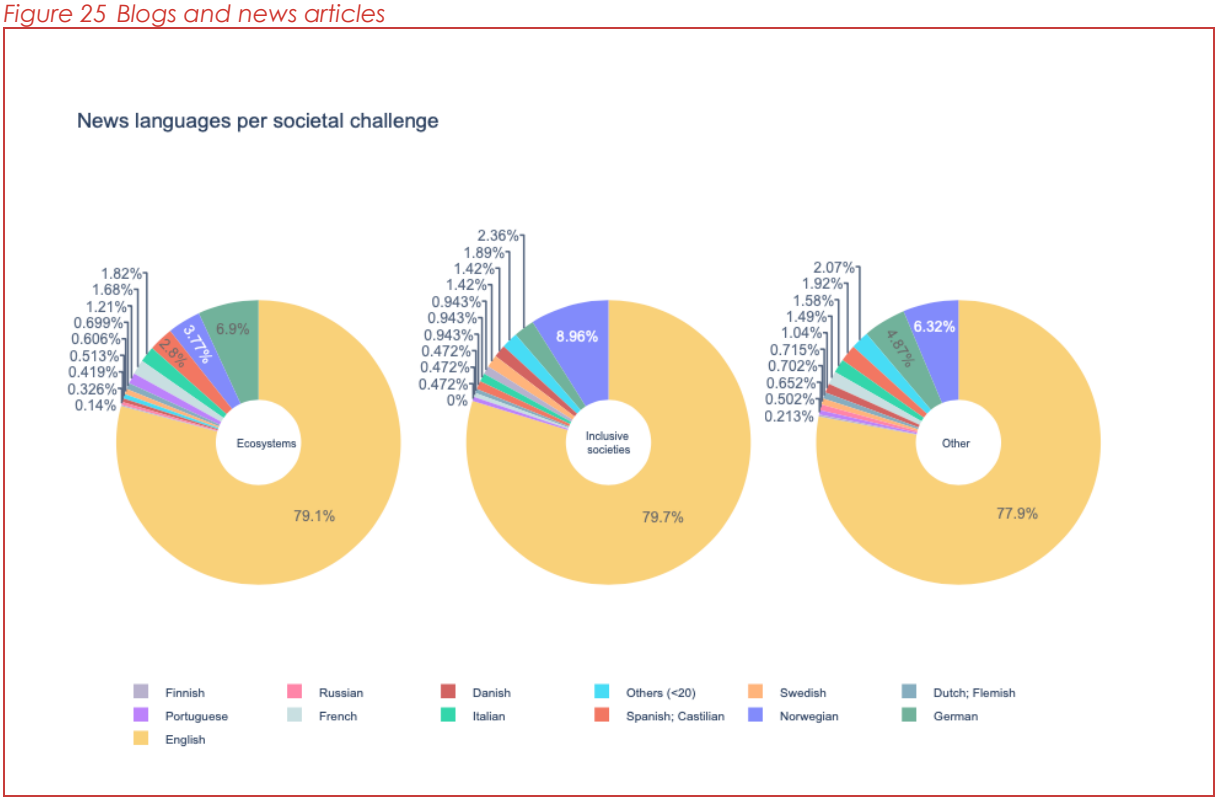
4.3.3.3.2 Blogs and news

We ran a similar exercise for blogs and news articles. We find a total of 735 and 3,596 blogs and news articles addressing or concerned with supporting changes in behaviour and attitudes geared towards more inclusive societies; and achieving better protection / enhancement of natural ecosystems, respectively, that cite RCN funded publications.

Most publications are in English; however, we also see some interesting patterns in terms of other languages. We find for instance a higher proportion of blogs and news articles in Norwegian picking up (citing) publications funded by RCN grants in the area of 'Inclusive

societies' (9%) in comparison with 'Protection of ecosystems' (4%). This reflects in part the fact that research related to 'Inclusive societies' is likely to be of higher relevance to the Norwegian society and the challenges it faces in areas such as migration or social mobility.

Figure 25 Blogs and news articles



Source: Technopolis (2020)

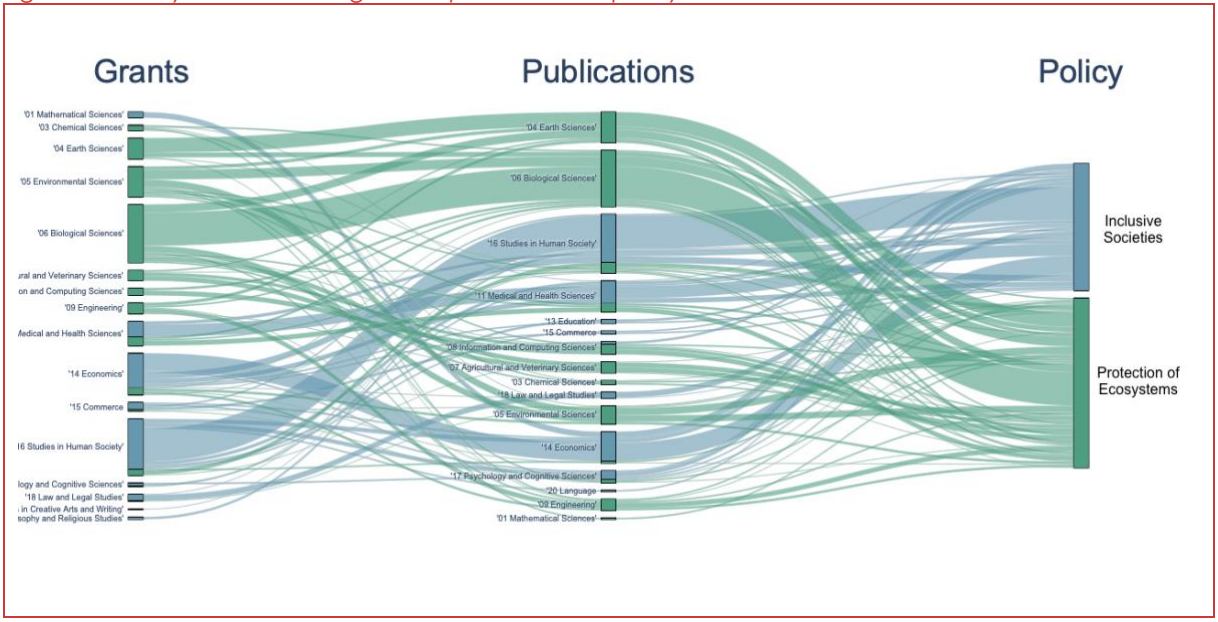
4.3.3.4 Policy influence

We also explored the uptake of publications linked to RCN grants in policy documents. This provides a proxy for understanding how this knowledge influences policy decisions and contributes to sustained, for example, changes in regulations, public funding decisions or strategic policy priorities.

We find a total of 165 and 124 policy documents, addressing or concerned with supporting changes in behaviour and attitudes geared towards more inclusive societies; and achieving better protection / enhancement of natural ecosystems, respectively, that cite RCN funded publications.

Similarly to what we present above, Figure 26 showcases how a diverse set of topics covered by RCN grants and publications (linked to those grants) then feed into policy documents related to "Protection of ecosystems" and "Inclusive societies".

Figure 26 Policy documents – grants > publications> policy documents



Source: Technopolis (2020)

In terms of type of organisations that make use of / cite the publications, we find that there are clear differences depending on the area of interest.

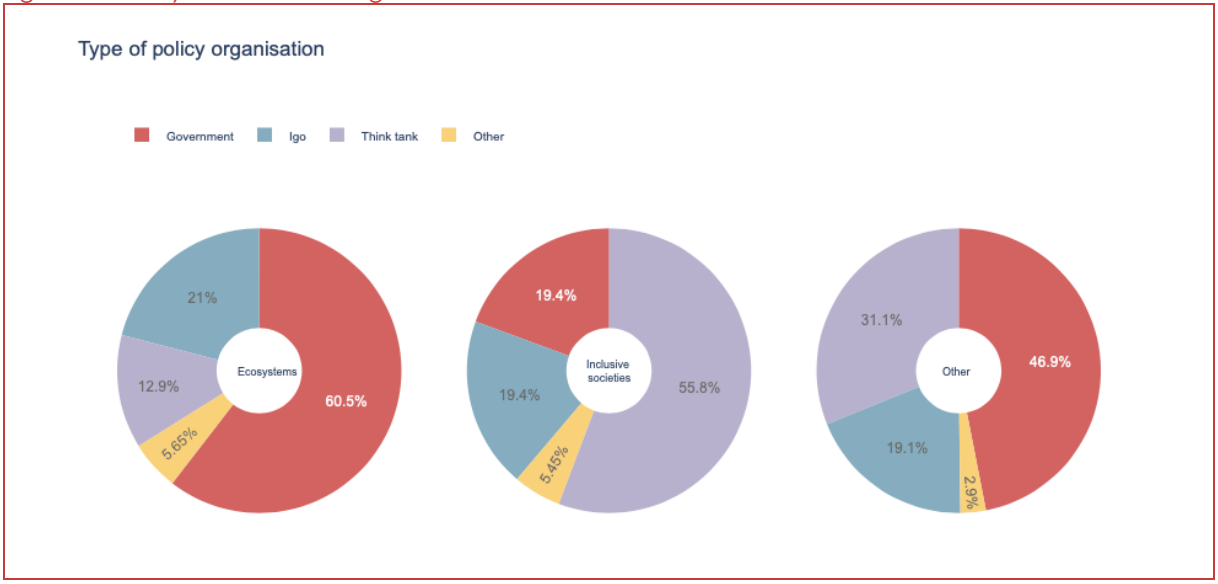
Publications related to 'Protection of Ecosystems' tend to be cited mostly by government institutions (60.5% of policy documents that cite those publications), followed by international organisations (21%) (see Figure 27).

Publications related to 'Inclusive Societies', in turn, tend to be cited mostly by think thanks (55.8% of policy documents that cite those publications), followed by government and international organisations (both 19.4% of the total) (see Figure 27).

In terms of geography, 'Protection of Ecosystems', 24.2% and 21% of those policy documents have been prepared by EU and International organisations, respectively, indicating the transnational nature of the topics covered from protection of oceans, to better management of forests, and their relationship with current global concerns related to climate change mitigation (see Figure 28).

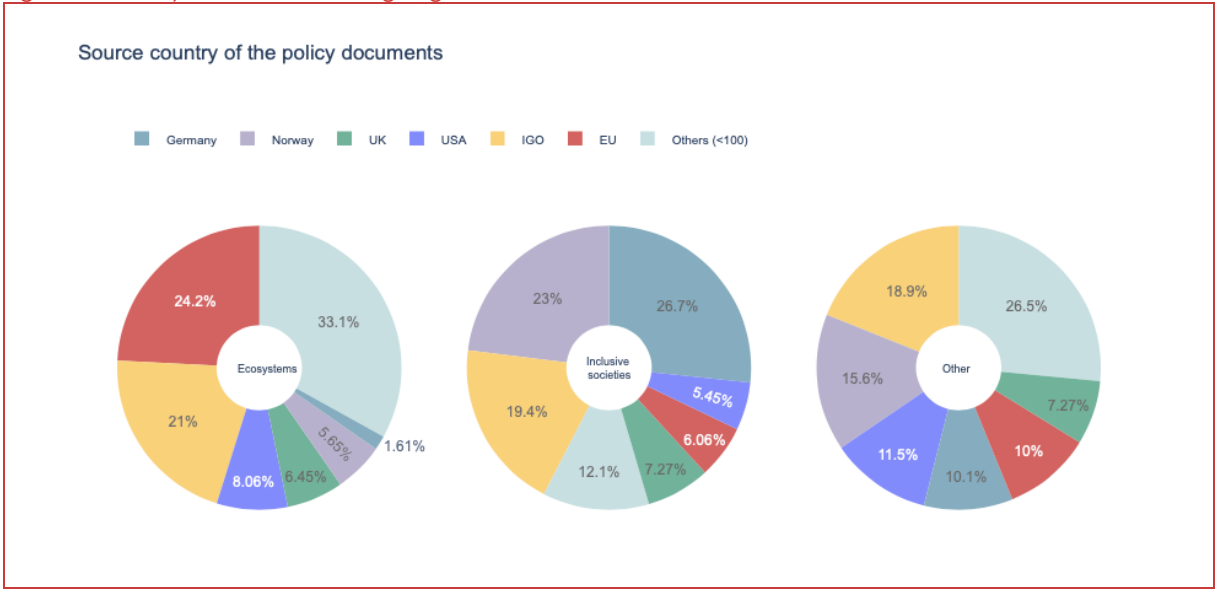
In contrast, in the case of 'Inclusive Societies' publications linked to RCN grants, are mostly picked up (cited) by organisations based in Norway 23% reflecting the more 'local'/regional nature of the topics covered, closely link to the characteristics of the societal make in the country. There is also a high uptake in Germany (see Figure 28). This is mostly explained by a high uptake from IZA Institute of Labor Economics (a private, independent economic research institute and academic network focused on the analysis of global labor markets and headquartered in Bonn, Germany). The papers cited have provided insights into reviews of evidence related to migration and integration, gender pay gap, and social assistance programmes among others.

Figure 27 Policy documents - organisations



Source: Technopolis (2020)

Figure 28 Policy documents - language



Source: Technopolis (2020)

The boxes below provide examples of the research funded by RCN, the publication, and its uptake on policy documents.

Box 5 ***Better protection/enhancement of natural ecosystem***

Publication: Widespread genetic introgression of escaped farmed Atlantic salmon in wild salmon populations (DOI: 10.1093/icesjms/fsw121)

Farmed Atlantic salmon escape from net pens and enter into rivers to spawn, which could result in genetic introgression (the transfer of genetic material between species)of farmed salmon to wild salmon. In this project, the researchers used molecular genetic markers in populations from 147 salmon rivers.

Around one third of these rivers found significant farmed introgression and average proportion of escaped farmed salmon. The researchers found a generally lower level of introgression in National Salmon Rivers and National Salmon Fjords protected by parliament. The researchers further conclude that farmed to wild genetic introgression is high in a large proportion of Norwegian salmon rivers, with the highest levels found in the most intensive areas of salmon farming. This poses a serious challenge to the management of farmed and wild Atlantic salmon in Norway, and most likely in other regions where farmed-salmon escape.

The project linked to this publication (QuantEscape) received funding from *HAVBRUKS*. It lasted from 2012-2016 and had a budget of NOK 20mill. QuantEscape combined the expertise from four central research institutions that study interactions between escaped farmed and wild Atlantic salmon Salmo salar from different perspectives: population genetics, ecology, genomics, and quantitative genetics.

The paper was published in 2016 and the authors (from the Norwegian Institute for Nature Research) also acknowledge funding from the Norwegian Environment Agency, and by Norwegian hydropower companies and county fishery offices.

It is cited in several different policy documents:

- By the Norwegian Institute for Nature Research and their report *Gene drives in nature: Mathematical models to understand their effects on target organisms and ecosystems*. In the report the paper is cited as a reference for empirical studies of gene flow and ecological effects from domesticated to wild populations.
- The Norwegian Scientific Committee for Food and Environments (VKM) *Assessment of the risk to Norwegian biodiversity and aquaculture from pink salmon*. In this assessment the paper is cited for the statement that expected climate change, where increased run-off, warmer temperatures, and longer growing season will reinforce the negative consequences of man-made eutrophication (excessive plant and algal growth) and make it more difficult to improve the water quality.

Sources

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[2] Sten Karlsson, Ola H. Diserud, Peder Fiske, and Kjetil Hindar, 2016, "*Widespread genetic introgression of escaped farmed Atlantic salmon in wild salmon populations*", ICES Journal of Marine Science
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[4] Melle, W., Runge, J.A., Head, E., Plourde, S., Castellani, C., Licandro, P., Pierson, J., Jonasdottir, S.H., Johnson, C., Broms, C., Debes, H., Falkenhaug, T., Gaard, E., Gislason, A., Heath, M.R., Niehoff, B., Nielsen, T.G., Pepin, P., Stenevik, E.K., Chust, G., "*The North Atlantic Ocean as habitat for Calanus finmarchicus: environmental factors and life history traits*", *Progress in Oceanography* (2014), doi: http://dx.doi.org/10.1016/j.pocean.2014.04.026

Box 6 ***More inclusive societies***

Publication: Return Migration Intentions in the Integration–Transnationalism Matrix (DOI: 10.1111/imig.12161)

The article asks how return migration intentions are shaped by ties to the country of residence on the one hand, and ties to the country of origin on the other. It discusses these two sets of ties in terms of immigrant integration and transnationalism, respectively. A central tenet of the study is that, at the individual level, integration and transnationalism are neither related in a predictable way nor independent of each other. The analysis is based on methodological steps that reflect this argument and introduces an integration–transnationalism matrix. The article found that it is the *relative strength* of integration and transnationalism that is decisive for return migration intentions.

The project linked to this publication received funding from *VAM — Velferd, arbeid og migrasjon,* had a budget of NOK 19.9mil, and lasted between 2011 and 2017.

The paper (published in 2014) is cited in at least two policy documents:

- "*Trust across Borders: A Review of the Literature on Trust, Migration and Child Welfare Services*" (The Peace Research Institute Oslo (PRIO)) as an important research insight due to its claim that simultaneous integration and transnational ties are fully possible, but also, individuals might neither be well-integrated nor much transnationally active.

- "*Research on Migration: Facing Realities and Maximising Opportunities (A Policy Review)*" (EC DG RTD) as to help explain the various processes through which return migration can occur, as they in that paper try to explain how return migration is not necessarily a case of failure or rejection, but instead can be a case of success and achieved goals.

Sources:

[1] Jørgen Carling, Silje Vatne Pettersen, 2014, "*Return Migration Intentions in the Integration–Transnationalism Matrix*", Wiley Online Library, DOI: 10.1111/imig.12161

[2] Lubomiła Korzeniewska, Marta Bivand Erdal; Natasza Kosakowska-Berezecka, Magdalena Żadkowska, 2019, "*Trust across Borders: A Review of the Literature on Trust, Migration and Child Welfare*", Services Gdańsk, https://www.prio.org/publications/publication/?x=11335

[3] 2016, "*Research on Migration: Facing Realities and Maximising Opportunities (A Policy Review)*" Publications Office of the European Union, DOI:10.2777/414370, https://op.europa.eu/en/publication-detail/-/publication/1db10988-c97b-11e5-a4b5-01aa75ed71a1/language-en/format-pdf

5 Lessons learned and recommendations

5.1 Lessons learned from pilot

This section covers the key lessons learned in the development of this pilot, describing the steps taken to produce the analysis, as well as the main limitation and caveats. The section concludes with a set of recommendations for future monitoring and evaluation activities pursuing the proposed approach.

5.1.1 Recommended steps for reproducing the analysis

The pilot undertaken in this project pursued a 'data-driven' approach (to produce main indicators), which has been complemented with desk research (to produce short case studies to exemplify the uptake of knowledge produced with RCN support). The analysis focused on two societal challenges ("Achieving better protection / enhancement of natural ecosystems" and "Supporting change in behaviour and attitudes geared towards more inclusive societies"), however, due to its quantitative nature and methodical approach, other societal challenges can be analysed using this same approach by following the same steps. In order to enable the reproduction of the method and applications to other societal challenges, each step is described below.

The key steps involved in the implementation of the pilot were:

1. Mapping of RCN portfolios to define objectives and societal goals
2. Identification of societal challenges and impact pathways
3. Categorisation according to societal challenges
4. Data linking

The operationalisation of the pilot started with an in-depth **mapping of RCN portfolios** and respective funding programmes. This stage involved assessing the content and descriptions of RCN portfolios and link them to the government's Long-term plan for Research and Higher Education and the strategic areas of the 2020-2024 RCN Strategy. The mapping exercise, which qualitative in nature, enabled the **identification of societal challenges and impact pathways** of interest. This initial qualitative groundwork set the direction of the following steps with a solid theoretical background, which allowed to identify relevant datasets that provided proxies or illustrations of the different pathways.

The following step consisted in operationalising the association between societal challenges and impact pathways. After the identification of datasets illustrating the different impact pathways, those datasets required a **categorisation according to societal challenges**. This step consisted in the application of text classification techniques using natural language processing. That said, two parallel approaches were pursued. The first approach for text classification consisted in exploring the text from RCN grants in portfolios that were qualitatively classified as relevant for the societal challenges in question and using their text as "inspiration" for the text classification. This approach resulted in various keywords and key phrases that represented each societal challenge.

These keywords and phrases were then used to classify the texts of the documents across the three pillars (i.e. publications, patents, news, etc.) according to the respective societal challenges. The second approach involved implementing a topic modelling technique using a predefined training set containing textual elements from Wikipedia pages, classified per Wikipedia categories and Media topics. This approach required first identifying the categories and topics embodied in the societal challenges of interest and then extrapolating the text

classification of the training set to each element of all the datasets under consideration (see section 4.1.1.2 for an overview of the different data sources used).

When comparing the two approaches for text categorisation, the second one leveraging the Wikipedia-based training set and media topics proved to be more flexible. It provided more accurate classification results for all types of documents. In contrast, the model implemented in the first approach produced good results for the classification of RCN grants and resulting publications, but not so accurate results for the remaining datasets. The first approach was developed using the text from grants, therefore it produced good results when applied to the same type of documents (other grants) or documents with similar textual styles (publications). However, it did not perform as well when applied to documents of different nature, such as blog posts, news or policy documents. Therefore, for the sake of consistency, the Wikipedia-based method was ultimately used to classify all documents across all three pillars.

The final step in the process consisted of connecting all the dots through **data linking**. The first type of linkage consisted in connecting grants to resulting publications. This was done exploring RCN's project database and the bibliometric repository Dimensions. The linkage consisted of identifying references to RCN in publications' acknowledgement sections and link the publications to the respective grant(s) when the grant number is acknowledged. Many publications only acknowledged RCN funding without mentioning the grant number, therefore those were kept and classified, but not linked to any grant. The remaining linkages consisted of connecting academic publications to mentions in patents, news articles, blog posts, Wikipedia articles and policy documents. In the case of patents, the linkage consisted of exploring patents' non-patent literature citations using Dimensions and Lens.org. For news, blogs and Wikipedia pages, Altmetrics data was used, and Overton was the data source to identify policy documents citing academic publications.

5.1.2 Limitations and caveats

The proposed methodology has limitations and caveats that need to be considered when interpreting results. The first element to consider is that this methodology was heavily centred on scholarly publications and thus limited to RCN's research (rather than innovation) funding efforts. Therefore, the uptake and early signs of societal impact of RCN grants without scientific publications are not directly captured under this pilot. Nevertheless, most RCN calls (more than 60%) have "research organisations" as key target group and these should be related with the production of scholarly articles, thus this methodology covers the bulk of RCN activities and explores signs of impact using dimensions that are currently underexplored. Moreover, the RCN already runs multiple impact evaluation activities focused on its business funding arm — activities resulting in no or in a lower number of scholarly articles. That said, the proposed methodology does not duplicate efforts attempting to directly measure the impact of business funding activities.

A thorough understanding of the limitations and caveats associated with the use of each data source is an essential exercise to correctly interpret results. With this pilot being focused on scholarly publications, it is important to understand the consequences of using different bibliometric sources. In this pilot, relevant scholarly articles were identified using the bibliometric repository Dimensions and associated to RCN funding by exploring articles' references to RCN in their acknowledgement sections. This approach presents potential setbacks. For example, authors do not always acknowledge funding and when they do so, a systematic approach is not always followed. This means that this approach may be missing potential RCN-funded publications because authors did not acknowledge funding from the RCN.

At the time of this analysis, the Dimensions database presented the most comprehensive commercial dataset connecting scholarly publications and respective grants/funding bodies. Different data sources can produce slightly different results, especially if linking grants and

publications through different means other than exploring acknowledgment sections. In order to assess the coverage of different data sources, the connection between grants and publications in Dimensions was compared with a sample of Cristin. Cristin is a public repository of Norwegian bibliometric data filled mostly by authors themselves who link their publications to the RCN-grants they received.

By comparing Dimensions and Cristin, it was found that the later includes several publications linked to RCN grants that were not linked in Dimensions. 192 grants in Cristin were associated with 1209 publications with DOIs, while the same 192 grants in Dimensions were associated with only 497 publications with DOIs.

In order to assess the source of the gap between Dimensions and Cristin, a random sample of 118 publications linked to RCN funding in Cristin but not in Dimensions was individually analysed.

The analysis of this sample found that:

- 75% of the publications assigned to RCN grants in Cristin but not in Dimensions did not acknowledge RCN funding at all.
- 92% of these publications (i.e. 69% of the total) did acknowledge other funding agencies and grant numbers, but not RCN's.

In some cases, authors even specified that their work received no specific grant/funding, but still assigned the publication to an RCN grant in Cristin. In 25% of these publications RCN funding was acknowledged but Dimensions did not capture it because the mention was not in acknowledgement sections. The mentions were hidden in other documents (e.g. online supplements, etc…) or under alternative headings such as "Funding".

The key conclusion from this comparison was that reproducing the methodology of this pilot is not neutral to the type of bibliometric data that is used, largely because of differences on how publications are assigned to RCN funding. Having a clear understanding how accurately publications are linked to grants is an essential step in order to choose the source of bibliometric data to be used in this approach. By comparing Dimensions and Cristin, this analysis found that using Dimensions proved to be a more conservative approach, while Cristin provided a broader coverage, but including several potential false links.

The remaining data sources that represent early signs of uptake do also present several caveats of relevant acknowledgement. The main common consideration to most of these data sources is that their linkage with academic publications is relatively recent and thus not yet completely understood. The only exception are patents where the exploration of non-patent literature citations and the corresponding academic publications is becoming of more mainstream exploration in the academic literature. The main consequence from these datasets still being rather unexplored, is the need to be extremely cautious in how to interpret the nature of societal impact embodied by these datasets. This pilot uses the term "early signs of uptake" instead of actual "impact" because more research is needed in order to understand the quality and size of the impact that these data sources represent. That said, this is also why a qualitative assessment was included in this pilot, producing small case-studies exploring the full journey of RCN funding, from the grant dataset to each of the early signs of impact datasets. More examples of limitations and other considerations specific to each dataset are presented in Table 7.

Table 7 Examples of relevant caveats per uptake related database

Type of document	Database(s)	Caveats
Patents	Lens, Dimensions	• Not all technologies are patentable and even when they are inventors can choose other IP strategies • Inventors can strategically add or hide prior art, artificially inflating or deflating NPL citations
News articles, blogs posts and Wikipedia pages	Altmetrics	• Potential misuse of the knowledge since news/blog documents are not peer-reviewed • Potential to artificially inflate the metric by anyone with enough time on their hands • As in traditional indicators (e.g. citations in bibliometric data), it is difficult to distinguish between positive and negative references
Policy documents	Overton	• Lack of understanding regarding the whole population of policy documents. The documents that are recorded and parsed to identify academic citations are not necessarily a representative sample of the full population. We lack knowledge of potential biased towards particular topics or periods • As in traditional indicators (e.g. citations in bibliometric data), it is difficult to distinguish between positive and negative references

Finally, while the pilot expanded the scope of impact measurement, some relevant dimensions were still not captured. The pilot did not address a number of dimensions which are still hard to analyse with a quantitative approach due to lack of relevant data. Examples of gaps in dimensions not addressed in this pilot include the impact of knowledge produced with RCN funding on training and skills, or even on business performance.

5.2 Recommendations for future M&E

5.2.1 Building upon this data driven approach

The key advantage of pursuing a quantitative approach, as demonstrated in the pilot, is its **scalability and automation**. Once established, the methodology can now be scaled and replicated to future grants and different societal challenges. The most relevant decision is concerning the integration the methodology of the pilot as a permanent tool for monitoring and evaluation is deciding what data source to use when linking RCN grants to scholarly output publications. As reviewed in section 5.1.2, using the Dimensions database provides conservatives results, by only linking publications that explicitly refer to RCN funding in their acknowledgement section, but excluding potential cases where authors do not acknowledge the funder of their research. In the other hand, Norway's bibliometric repository Cristin provides a broader coverage beyond what is explicitly acknowledged in the publications. However, Cristin may also include cases of false positives, where authors link publications to RCN grants in situations where those grants did not fund the underlying research.

For future exercises, it will be valuable to compare RCN's alignment with societal challenges in comparison with other funding organisations. The pilot presented evidence of an upward trend regarding RCN's alignment with the two societal challenges under consideration, with an increasing share of all articles funded by the RCN being classified as addressing these challenges. However, are science funding agencies from other countries presenting even higher upward trends, or is the RCN leading this transition? Likewise, are RCN-funded publications more heavily cited in uptake documents in comparison with other agencies? The goal of the pilot was to classify and link all the documents according to the two societal challenges under consideration and provide a snapshot of RCN's influence. Benchmarking

that level of influence in comparison with other science funding agencies was out of scope of the pilot. However, the pilot contributed with the first and most relevant initial step to enable the benchmarking by producing a standardised and automated approach to measure initial signs of alignment, that can be easily reproduced across different agencies. For future projects benchmarking would be an interesting exercise in order to evaluate how over or underperforming the RCN is in comparison with peers.

A final consideration in terms of recommendations for future work is the potential to leverage this methodology with complementary methods. The pilot mapped channels of uptake and early signs of impact without providing causal assessments. However, the methodology builds the necessary data infrastructure to undertake a causal analysis. Different complementary methodologies are proposed in following sections. With the implementation of methods such as contribution analysis, process tracing, or with comparative case studies, it is possible to assess the degree to which RCN-funded knowledge, through the documented signs of uptake, contributed to effectively fight a societal challenge. For example, one application would be to trace the grants resulting in publications that were cited in a policy document known to have been instrumental for an important policy change. A more detailed explanation of a theory-based approach is provided in section 5.2.2.1. Moreover, with the implementation of econometric methods, such as propensity score matching, differences-in-differences or regression discontinuity design, the data developed in this methodology can be explored to produce causal quantitative estimates of societal impact. These methods are further explained in section 5.2.2.5. An example of application would be to compare the long-term career consequences of young researchers who were awarded an RCN-grant with a targeted societal challenge goal and others who applied to the same grant but were unsuccessful. Econometric methods can be implemented to measure the causal impact of such targeted grant in steering researchers' careers into topics related with societal challenges and in producing publications with higher levels of uptake.

5.2.2 Other approaches to measuring impact on societal challenges

In this section we provide further detail of a set of methodologies that RCN could consider taking forward to assess how RCN- funded activities contribute to addressing societal challenges, and included as part of a toolbox for assessing impact.

The sub-sections below present a summary of five types of overarching approaches that are relevant to assessing impacts on societal challenges. For each approach we provide an overview of:

- Type (Qualitative / Quantitative)
- Methods/tools
- Range of impacts and time frames
- Robustness
- Unit of analysis
- Relevance to societal challenges and portfolio analysis, relevant to RCN
- Pros and cons

The list of reference used to map these approaches is presented in Appendix E.

5.2.2.1 Theory-based evaluation

Type	Qualitative

Methods/tools	Range of qualitative methods used to build or test theories about cause and effect in the context of single or comparative case studies. Tools and methods include: • Theories of change • Contribution analysis • Process tracing • Comparative case study	
Range of impacts and time frames	• **Range of impacts:** Academic, Economic, Societal • **Timeframes:** Short and medium-term impacts (limited by the ability to trace back to intervention) • **Type of impact:** Will tend to focus on (theoretically) expected impacts	
Robustness	Relies on the skills and knowledge of the evaluator	
Unit of analysis	Projects or programmes	
Relevance to societal challenges and portfolio analysis, relevant to RCN	• Relevant to all challenges • Relative strength in societal (non-economic) domains without standardised measures	
Pros and cons	**Pros** • Helps improve understanding of programme mechanisms. • Applicable to complex programmes and contexts	**Cons** • Resource-intensive • Requires subject expertise • No estimate of size effects

Theory-based evaluation methods aim to explain *how* programme impacts are produced and thereby why a programme may or may not have been successful – as opposed to simply looking for the magnitude of attributable impact. This typically involves developing a programme logic model or 'theory of change', identifying the logical steps required for the intervention to produce the desired impact, as well the assumptions and contextual factors influencing outcomes (Arnold et al. 2018).

A series of increasingly formalised methodological tools have been developed to investigate the chain of 'causal mechanisms' on which the programme logic is based. By way of example, these include:

- **Contribution analysis (CA)** involves developing and testing the theory of change or 'contribution story' of how a programme has contributed to observed impacts. The approach does not attempt to solve the attribution problem but instead to establish a 'good enough' (Riley et al. 2017) or 'plausible association' (Hendricks 1996) between the programme and impacts as compared to alternative explanations.
- **Process Tracing (PT)** involves tracing the pathway towards impact through a series of steps, applying formal tests to assess the strength of evidence of a given causal claim (see e.g. Collier 2011, Beach and Pedersen 2019).
- **Comparative case studies**: Most theory-based approaches focus on an understanding of the specific case, but where a number of similar cases (e.g. projects) exist, a comparative approach can be deployed to explain variations in outcomes and potentially generate knowledge of more general applicability (external validity). (Ragin 2014)

It has long been argued that evaluations of science and innovation programmes should be shaped by theoretical understanding of the field (see e.g. Arnold 2004, Molas-Gallart and Davis 2006), and the advent of 'societal challenges' and 'missions' adds further complexity to the

landscape with implications for programme evaluation (Wittmann et al. 2020). Theory-based evaluation is particularly well placed to assess impacts in a complex landscape where multiple policies and other events influence outcomes and thus is suited to investigate the research impact in the context of societal challenges.

5.2.2.2 'Packaged' approaches

Type	Mixed / Qualitative	
Methods/tools	• Payback method • SIAMPI framework • Research Contribution Framework • Linkage and Exchange Model • RAPID Outcome Mapping, • Contribution Mapping	
Range of impacts and time frames	• **Range of impacts** *(E.g.):* Behavioural change; Uptake, use; Collaboration • **Timeframes:** Tends to focus on near-term effects • **Type of impact** Impacts within pre-defined categories	
Robustness	Needs well document description of qualitative assesstments	
Unit of analysis	Project or programme	
Relevance to societal challenges and portfolio analysis, relevant to RCN	Applied for multiple subject areas, incl • Health, • nanotechnology • Environment • Urban development	
Pros and cons	**Pros** • Practically oriented • Standardised procedures	**Cons** • Often limited in scope • Linear conception of innovation process

Impact assessment methods used by the evaluation community tend to focus on direct paths to impact because they are amenable to observation, especially in the social sciences and humanities where indicators tend not to work well.

- **HERG Payback Framework**: A research tool providing a common structure to ensure comparable data collection and facilitate cross-case analysis. The framework has two main elements: a logical model of the research process and a series of categories to classify 'paybacks' from research It uses series of categories to classify the individual paybacks from research ranging from research outputs to wider benefits (Donovan and Hanney, 2011). It was originally developed by Health economists but has since been adapted to look at humanities research (Levitt et al. 2010)
- The Social Impact Assessment Methods through **Productive Interactions (SIAMPI)** model[31] focusses on 'productive interactions' between researchers and social stakeholders. This guides the identification of indicators. (SIAMPI 2011, Boshoff & Sefatsa, 2019, Esko and Tuunainen, 2018)

[31] See e.g. Molas-Gallart, J. & Tang, P. (2011); Spaapen, J. & van Drooge, L. (2011); SIAMPI (2011).

Other examples include IMPACT-EV, Research Contribution Framework, Linkage and Exchange Model, RAPID Outcome Mapping, Contribution Mapping and the AHRD Engagement Model. These methods tend to be interview- and survey-based or use wider mixed methods, largely dealing with direct rather than indirect impacts. All effectively assume linear impact processes; some of them even use linear impact scales or stages.

5.2.2.3 Meta-evaluation

Type	Mixed	
Methods/tools	• Statistical meta-analysis • Qualitative aggregation of findings	
Range of impacts and time frames	• **Range of impacts**: Any, depends on the evaluation record. • **Timeframes**: Medium to long-term (cannot capture recent impacts) • **Types of impacts:** Any, depends on the valuation record.	
Robustness	• Depends on completeness and homogeneity of data	
Unit of analysis	• Programme, Thematic area, portfolio	
Relevance to societal challenges and portfolio analysis, relevant to RCN	• Relevant to RCN's portfolio	
Pros and cons	**Pros** • Makes use of existing evidence • Provides a longer-term and/or aggregated	**Cons:** • Evidence-based likely to be incomplete and varied in quality

Meta-evaluations are systematic reviews of existing evaluations, including their methods and findings. Where a record of existing evaluations is available, it can be a useful tool as part of the scoping phase of an evaluation to identify areas of interest for further investigation. The meta-analysis involves a *systematic* analysis of evaluation documents and will typically cover the following dimensions as a minimum:[32]

- Evaluation focus (topic area, scope)
- Methods used (and possibly an assessment thereof)
- Types of data
- Findings (outcomes and impacts)
- Synthesis

Meta-evaluations can take the form of statistical meta-analysis of quantitative findings - although this is more demanding in terms of data availability and methods used – or a more qualitative aggregation of findings (Magro and Wilson, 2013)

Meta-analysis of evaluations is particularly useful the context of complex systems where evaluation at different levels is needed (Arnold 2004),[33] or as a way to track impacts over a long period of time (Arnold et al. 2011). Meta-analysis of R&I evaluations has been used

[32] Formal methods for meta-evaluation often involves a systematic search and selection of sources, but that would be unnecessary in an evaluation of the Research Councils own programmes. See for example the Cochrane handbook for Systematic Reviews of Interventions: https://training.cochrane.org/handbook/current/chapter-04

[33] See also RCN's evaluation policy for 2013-2017 (p. 10)

regularly at EU-level to aggregate findings from evaluations of sub-programmes (2005, 2009) or establish long-term effects (Arnold et al.), but also to analysis national programmes (e.g. Good 2012).

5.2.2.4 Impact case studies

Type	Mix methods	
Methods/tools	Submitted using a standard template but no specific methods prescribed. Could be based on: • Interviews • Desk research • Accompany statistics (when possible) All combined to produce case studies that capture the cumulative 'history' of research developments (including breakthroughs and contributions from different funding sources & accumulative knowledge) (backward tracing)	
Range of impacts and time frames	• **Range of impacts:** Captures a wide range of impacts (social, economic, environmental, political) • **Timeframes:** Impacts occurring in the last "X" number years (e.g. 5) based on underpinning research published in the prior two or three decades. • **Type of impact:** Detects 'extraordinary' impact (best examples of achievement in an area)	
Robustness	Non-standardised judgement	
Unit of analysis	• Disciplines/Themes • Can also be applied to portfolios or 'bodies of work'	
Relevance to societal challenges and portfolio analysis, relevant to RCN	Any / all	
Pros and cons	**Pros** • Flexible; can cover a variety of types of impacts	**Cons** • Non-standard assessment • Risk of bias from peer review

Impact evaluation is increasingly deployed by national policy makers and some national systems have come to define their approach. The UK's Research Excellence Framework (REF) is one such example.

Impact case studies provide a qualitative narrative account of how research, as published in high-quality peer-reviewed journals, have societal impacts beyond academia. The international standard for this approach is the UK for the Research Excellence Framework, first used in 2014 and planned again for 2021. Each department (or Unit of Assessment) will choose the best examples from the preceding years.

Case studies follow a standard template with five main sections: 1) Summary of impact, 2) Underpinning research, 3) References to the research 4) Details for the impact, 5) Sources to corroborate the impact. Within the template, the authors can deploy whatever methods they believe is most likely to convince the reviewers, including quantitative evidence where available. As universities are preparing the submission for REF2021, there is now a substantial literature providing advice on 'how to' write a four star case study (e.g. Reed et al., 2019, Wall and Grey 2018)

The use of impact statements and peer judgements, made popular by REF2014, is felt to overcome (or evade) many of the difficulties involved (Donovan, 2011) but in practice rely on

non-standardised judgements (Derrick & Samuel, 2016) and involve a narrow and instrumental sub-set of impact (Meagher & Martin, 2017), focusing on what Sivertsen and Meijer (2018) call "extraordinary" rather than "normal" impact.

Impact case studies inspired by the UK REF have also been produced in Sweden (Elg & Håkansson 2012) and Norway (reviews of social sciences and humanities) although not as an integrated part of the funding process. Further, REF case studies have been used as a resource for secondary analysis to learn more the impact of UK research in aggregate.

In Appendix B we provide a suggested analytical approach that identifies the different routes through which research and research-based activities supported by RCN could contribute to each of the nine impact pathways identified in our framework and could be used in the development of impact case studies. It provides suggestions on the supporting evidence that could be collected to understand the significance of the impact (reach and influence). The analytical approach is an adaption of the REF framework of types of impact and understanding reach and influence. In contrast with REF, is takes the impact pathway as starting point (not the discipline) and it is fed from the results achieve across various portfolios / disciplines. Table 7 - Table 9 cover each of the impact dimensions. Some impact routes are covered in more than one impact area/pathway.

5.2.2.5 Econometric methods

Type	Quantitative	
Methods/tools	• Difference in difference • Propensity score matching • Regression discontinuity • Synthetic control group	
Range of impacts and time frames	• **Range of impacts** – Economic (including business, regional and national performance) – Social (including indicators around education, income, inequality) – Environmental – Academic Bibliometric/Research excellence • **Timeframes:** Allows capturing medium term impacts (2-3 years after developments supported by RCN, depending on thematic area) • **Type of impact:** Detects 'average' impact	
Robustness	High robustness when data available	
Unit of analysis	(individuals, business, projects, themes, portfolios) • Individuals/Households, businesses, regions - with possible aggregations at portfolio level	
Relevance to societal challenges and portfolio analysis, relevant to RCN	• Improved business performance / competitiveness (among those involved) • Improve inclusion / reduced inequality (at regional/country level) • Reduction in carbon emissions (at regional/country level) • Higher production of knowledge in areas related to societal challenges • Steer researchers' careers towards areas related with societal challenges	
Pros and cons	**Pros** • Considered a robust method to address a counterfactual scenario	**Cons** • Depends on data availability • Tends to rely on a linear view of the innovation process

		• It is circumscribed to outcomes / impacts that can be quantified

Econometrics is the application of statistical methods to economics with the goal of measuring relationships between variables in quantitative way. In most cases econometrics is used for causal inference, attempting to measure how a given variable causes a positive or negative variation in another variable, instead of two just moving together for any other reason.

The fundamental statistical method used by econometricians is typically regression analysis. The golden standard to estimate causal effects is through running a Randomised Control Trial as in Pharmaceutical testing, randomly choosing between treatment and control to isolate and measure the causal effect of the treatment. Regression methods are important in econometrics because economists in most cases cannot use RCTS. Econometricians often seek conceptually replicate RCTs by exploring exogenous variations in a dataset as a source of random variations between treated and control. Examples of strategies like these include:

- **Propensity score matching (PSM)** consists of identifying plausible control groups based on observable characteristics. Suppose a group of researchers receive an innovate grant with different features in terms of e.g. length, funding amount and directionality. In order to evaluate the effectiveness of that intervention we can compare the post-grant performance of the researchers who received that innovative grant against others that have not. However, the selected researchers can have characteristics that make them inherently different from other researchers who did not receive the grant and hence potentially perform differently in the post-grant period not because of the innovate grant features but because they have different abilities. The PSM consists of identifying a group of researchers that did not receive the grant (control group) with comparable observable characteristics to the researchers who received the grant.
- **Difference-in-differences (DiD)** involves examining the differences between beneficiaries and non-beneficiaries of an intervention before and after such intervention. This approach enables measuring the causal impact of an intervention with no need to randomise the selection process. The methodology follows a two step-approach: First, it takes the difference across time within participants and non-participants. This eliminates any group specific unobserved factors which are fixed in time. Second, it takes the difference of the differences to remove any time trends in the results.
- **Regression discontinuity design (RDD)** measures the impact of an intervention by comparing the performance of beneficiaries that almost did not meet the intervention's selection criteria, with a group of non-beneficiaries that almost met the selection criteria. The idea is that groups just below and just above the selection threshold have comparable characteristics and therefore their differences post-intervention can be attributed to the intervention.

There is still too little reliable evidence on how to best design science and innovation policy despite their proven importance for productivity growth and for improving standards of living. A more evidence-based approach to science, innovation, and growth policy with the implementation of econometric tools for causal inference will enable evaluating interventions more rigorously to measure impact and to understand what works and what does not in science, innovation and growth policy.

Appendix A Analysis of RCN portfolio and links to societal challenges

As part of the process of developing an impact framework for this study we have linked the different portfolios to high-level objectives and relevant societal challenges/objectives to inform the impact categories selected. This exercise is shown in Table 8. For completeness, we have also mapped the portfolios based on their own stated links with the RCN strategy's strategic areas and objectives (as presented in their portfolio plans), as shown Table 9 below.

Table 8 Portfolio and link to societal challenges

<table>
<tr><th>Portfolio</th><th>Funding programme</th><th>Aims linked to societal challenges / objectives (portfolio level)</th><th>Impact pathways</th><th>Impact dimension</th></tr>
<tr><td>Humanities and social sciences</td><td rowspan="3">FRIPRO</td><td rowspan="3">Basic research – no direct link to SC
(noting, however, that Societal Challenges such as reduced demand on petroleum, an ageing population and climate and environmental challenges are all addressed through interdisciplinary research, with contributions from the life sciences)</td><td>• Reducing inequalities of opportunity (health, education, economic)
• Producing more effective and /or better designed policies geared towards improving quality of life (health, safety, security, etc.)
• Generating improved and more inclusive public administration and services
• Supporting change in behaviour and attitudes geared towards more inclusive societies</td><td rowspan="3">• Society
• Economy</td></tr>
<tr><td>Life sciences</td><td>• Reducing inequalities of opportunity (health, education, economic)
• Producing more effective and /or better designed policies geared towards improving quality of life (health, safety, security, etc.)
• Generating innovation-based growth
• Creating a more (environmentally) sustainable and diversified economy</td></tr>
<tr><td rowspan="3">Science and technology</td><td></td></tr>
<tr><td>CERN</td><td>Basic research – no direct link to SC</td><td></td><td></td></tr>
<tr><td>ROMFORSKNING – Programme on Space research</td><td>• More secure navigation and communication, and less vulnerable infrastructure on the ground
• Better understanding of processes that affect the Earth as a planet</td><td>• Achieving better protection / enhancement of natural ecosystems
• Generating innovation-based growth
• Creating a more (environmentally) sustainable and diversified economy</td><td>• Environment
• Economy</td></tr>
</table>

Portfolio	Funding programme	Aims linked to societal challenges / objectives (portfolio level)	Impact pathways	Impact dimension
Democracy, Governance and Renewal	DEMOS – Democratic and effective governance, planning and administration FORKOMMUNE – Research and innovation in the municipal sector SAMRISK II – Social Security SKATT – Tax economics research FORSTAT – Research and innovation programme for public sector	• Support more democratic and effective governance, planning and administration in the public sector. • Support a knowledge-based administration and more innovative public sector • Increase ability to change and address unforeseen events to safeguard citizens' lives, health and basic needs • Increase quality and effectiveness of municipal services, organisation and participation processes	• Reducing inequalities of opportunity (health, education, economy) • Generating improved and more inclusive public administration and services • Producing more effective and /or better designed policies geared towards improving quality of life (health, safety, security, etc.)	• **Society**
Energy, Transport and low emissions	ENERGIX CLIMIT – Research, development and demonstration of CO2 management technology FME – Research centres for environmentally friendly energy TRANSPORT – Transport 2025 BYFORSK	• Promote a society that is climate neutral and preserves natural diversity • Contribute to the transition to the low-emission society and to promote a competitive Norwegian business community. • Support the revolution of the energy system and minimise climate effects from energy consumption/production • Ensure that Norwegian renewable energy resources are used sustainably. • Ensure that transport and mobility are conducted safely, efficiently and environmentally friendly • Ensure that cities and urban areas are smart, sustainable and safe • Promote a competitive and adaptable business community in areas which Norway has or can develop advantages in • Support scientific environments in energy, transport and cities/urban areas that are relevant and outstanding	• Reducing of pollution and waste in production and consumption • Increasing production and use of energy from renewable sources • Achieving better protection / enhancement of natural ecosystems • Generating of more effective and / or better design policies geared towards improving quality of life (health, safety, security, etc.) • Generating innovation-based growth • Creating a more (environmentally) sustainable and diversified economy	• **Environment** • **Society** • **Economy**

Portfolio	Funding programme	Aims linked to societal challenges / objectives (portfolio level)	Impact pathways	Impact dimension
Global Development and International Relations	UTENRIKS – International relations, foreign policy and Norwegian interests NORGLOBAL – Norway Global Partner GLOBVAC – Global health and vaccination research VISJON2030	• Support knowledge in areas related to demographic trends, democracy, inequality, religion, migration and climate change, to inform Norwegian policymaking • Search for solutions to poverty related neglected diseases. • Support sustainable development in the areas of sea, ocean, environment and renewable energy (with focus in specific geographies)	• Reducing inequalities of opportunity (health, education, economic)	• **Society**
Ocean	MARINFORSK – Marine resources and environment HAVBRUK – Large programme for aquaculture research MAROFF – Maritime operations and offshore operations	• Support sustainable exploitation of marine resources (including fisheries & aquaculture) • Improve competitiveness or marine and maritime sectors to further support sustainable diversification of the economy • Support clean and rich oceans • Support sustainable use of ocean and coastal areas • Support safe and healthy sea food	• Reducing of pollution and waste in production and consumption • Achieving better protection / enhancement of natural ecosystems • Generating innovation-based growth • Creating a more (environmentally) sustainable and diversified economy	• **Environment** • **Economy**
Health	BEDREHELSE – Better health and quality of life BEHANDLING – Good and accurate diagnosis, treatment and rehabilitation HELSEVEL – Good and effective health, care and welfare services *(also part of welfare board)* FKB – Research centres for clinical treatment KVINNEHELSE – women's health and gender perspectives	• Improve public health, improve quality of life and reduce social inequalities in health. • Address challenges faced by the health and welfare services, such as aging population or antibiotic resistance, as a result of demographic change, increased social and cultural inequalities, decreased national finances, higher expectations, and new medical and technological opportunities.	• Reducing inequalities of opportunity (health, education, economic) • Generating improved and more inclusive public administration and services • Producing more effective and /or better designed policies geared towards improving quality of life (health, safety, security, etc.) • Generating innovation-based growth	• **Society** • **Economy**

Portfolio	Funding programme	Aims linked to societal challenges / objectives (portfolio level)	Impact pathways	Impact dimension
Industry and services	BIA – User-driven innovation arena EUROSTARS FORNY2020 – Research-based innovation FORREGION – Research-based innovation in the regions	• Improve business competitiveness and create new businesses via increased research and innovation activities • Improve regional competitiveness via increased research and innovation activities • Ensure building of competence in areas important for Norwegian industry, e.g. process, manufacturing, health, ICT and services	• Generating innovation-based growth • Creating a more (environmentally) sustainable and diversified economy	• **Economy**
Land-based food, environment and bioresources	BIONÆR – Sustainable value creation in food and bio-based industries MILJØFORSK – Environmental research for a green social change	• Support Norwegian bio-based industries and greater knowledge about key environmental challenges. • Support solutions for the green transition in society and industry.	• Achieving better protection / enhancement of natural ecosystems • Reducing of pollution and waste in production and consumption • Generating innovation-based growth • Creating a more (environmentally) sustainable and diversified economy	• ***Environment*** • ***Economy***
Climate and polar research	KLIMAFORSK – Large programme for climate POLARPROG – The Polar Research Programme	• Advance knowledge on climate systems and climate change to mitigate effects and make use of new possibilities • Understand effects on society and nature, and climate adaptation. • Support the development of environmentally sustainable business in the polar regions	• Creating a more (environmentally) sustainable and diversified economy • Producing more effective and / or better design policies geared towards improving quality of life (health, safety, security, etc.) • Achieving better protection / enhancement of natural ecosystems	• **Environment** • **Society**
Enabling technologies	IKTPLUSS – ICT and digital innovation NANO2021 – Nanotechnology and advanced materials BIOTEK2021 – Biotechnology for value creation SAMANSVAR – Responsible innovation and corporate social responsibility	• Improve competitiveness along the supply chain by the use of nanotechnology, microtechnology and advanced materials • Support renewable energy, reduced negative effects on environment and climate, improved health and medical technology, better utilisation of national raw materials. • Help to achieve a socially responsible regulatory regime for use of nanotechnology and nanomaterials and in general for technology development in relevant areas. • Address societal challenges related to health, the oceans, agriculture and industrial processes via biotechnological advances.	• Generating innovation-based growth • Creating a more (environmentally) sustainable and diversified economy	• **Economy**

Portfolio	Funding programme	Aims linked to societal challenges / objectives (portfolio level)	Impact pathways	Impact dimension
		• Support the development of a bioeconomy in Norway. • Support the digitalisation of the society with improved cyber security.		
Petroleum	PETROMAKS2 – Large programme for petroleum research DEMO2000 – demonstration of new technology PETROSENTER – Research centres for petroleum	• Ensure responsible administration of "Norwegian resources", including minimizing environmental impact and CO2 emissions • Support societal objectives in existing strategies, including the Council's overall strategy, Oceans Strategy, EU's Green New Deal and OG21 • Support sustainable use of marine and coastal areas	• Reducing of pollution and waste in production and consumption • Increasing production and use of energy from renewable sources • Achieving better protection / enhancement of natural ecosystem • Generating innovation-based growth • Creating a more (environmentally) sustainable and diversified economy	• **Environment** • **Economy**
Education and competence	FINNUT – Research and innovation in the education sector LÆREEFFEKT – Teacher density and learning effect PROFESJON –Research competence for selected professional education	• Provide good and attractive education and for the whole population • Reduce alienation and a secure a high level of professional participation • Inform a sustainable welfare system adapted to changed demographics • Contribute to a robust democratic system with high trust and legitimacy • Contribute to an inclulding, diverse and equal society	• Reducing inequalities of opportunity (health, education, economic) • Producing more effective and /or better designed policies geared towards improving quality of life (health, safety, security, etc.)	• **Society**
Welfare, culture and society	HELSEVEL – Good and effective health, care and welfare services *(also part of Health board)* VAM – Welfare, working life and migration SAMKUL – The cultural preconditions of social development KULMEDIA – The culture and media sector	• Support an inclusive and robust democracy with high trust and legitimacy • Support cultural and media life for equal society • Support a health-promoting work life • Ensure good adjustment to demographical changes • Support integration across society and active citizenship	• Reducing inequalities of opportunity (health, education, economic) • Generating improved and more inclusive public administration and services • Producing more effective and /or better designed policies geared towards improving quality of life (health, safety, security, etc.) • Supporting change in behaviour and attitudes geared towards more inclusive societies	• **Society**

The table below shows are mapping of RCN portfolios based on their own stated links with the RCN strategy's strategic areas and objectives (as presented in their portfolio plans). The numbering (1-3) indicates the suggested importance or centrality of the Portfolio to the areas of the RCN strategy referenced (i.e. 1 = Primary areas that the portfolio will contribute to, 2 = Areas where the portfolio will contribute to a lesser extent; and 3 = Other areas of potential (limited) contribution). At the time of writing, we do not have access to the portfolio plan for the Industry and Service portfolio.

Table 9 Mapping of portfolios and RCN strategic objectives

RCN Strategy		Climate and polar research	Democracy, governance & renewal	Enabling technologies	Energy, transport and low emissions	Humanities and social sciences	Life sciences	Global development and international	Science and technology	Welfare, culture and society	Oceans	Health	Petroleum	Land-based food, environment and	Education and competence	Industry and services
Headline objectives																
Sustainable development		1					2		1		2			1	2	
Ground-breaking research and radical innovation						1	1				2			1	2	
Restructuring of the business and public sectors			1							2	2				1	
Strategic areas	**RCN will invest in R&I to promote...**															
Oceans	Clean, rich oceans		3		1				2		1				3	
	Sustainable management of oceans and coastal areas		3		2				2		1		1		3	
	Safe and healthy seafood		3		2				2		1				3	
	Competitive Norwegian ocean and seafood industries		3		1				2		1		1		3	
Green transition	A rapid transition to a zero-emissions society and effective adaptation to climate change	1	3				2		2		3		1	1	3	
	A circular economy based on sustainable production, services and consumption	2	3				2		2		3			1	3	
	A sustainable bioeconomy and responsible management of the environment, natural resources, nature and land areas	1	3				2		2		3			1	3	
	A competitive business sector that delivers green energy, climate and environmental solutions to global markets	2	3				2		2		3			1	3	
Health and welfare	Satisfactory and sustainable health care for all segments of the population		3				2					1		1	2	
	Strong, competitive health industries		3				2					1		1	2	

RCN Strategy		Climate and polar research	Democracy, governance & renewal	Enabling technologies	Energy, transport and low emissions	Humanities and social sciences	Life sciences	Global development and international	Science and technology	Welfare, culture and society	Oceans	Health	Petroleum	Land-based food, environment and	Education and competence	Industry and services
	Reduced exclusion and high participation in the labour force		3				2			1		1		1	1	
	A sustainable welfare system adapted to demographic changes		3				2			1		1		1	1	
Technology and digitisation	Value creation and restructuring based on IT, nanotechnology and biotechnology		3	1			2		2		3	2		1	3	
	Technology development aimed at solving global societal challenges		3	1			2		2		3	2		1	3	
	Industrial development and restructuring of the public sector based on linking technology to domain knowledge and designing new business models		2	1			2		2		3	2		1	3	
	Research-based digital transformation and technology development		2	1			2		2		3	2	1	1	3	
Cohesion and globalisation	Good insight into crucial global change processes and Norway's influence on these		1			1		1		1		2		1	2	
	A robust democracy that enjoys a high level of trust and legitimacy		1			1		1		1		2		1	1	
	An inclusive, diverse and equal society		1			1		1		1		2		1	1	
	Societal security based on effective preparedness and risk prevention		1			1		1				2		1	2	
Cross-cutting																
A well-functioning research and innovation system	Productive interaction between education, research and innovation					1	1		1	2	2	1			1	
	High participation in international research cooperation					1	1		1	2	2	1			1	
	Ethical and socially responsible research and innovation			2		1	1		1	2	2	1			2	
	Open research and innovation processes that facilitate broad-based access to and verification of results					1	1		1	2	2	1			2	
	Relevant, up-to-date and widely accessible research infrastructure					1	1		1	2	2	1			2	

Appendix B Pipeline of analysis

B.1 Data sources

Four platforms were to conduct the pilot analysis, which are described in Table 10. The study team relied on these existing data sources to be able to conduct the analysis within the time and resources provided. Each platform has been developed over a number of years and with substantial capital investment and reproducing them for a single study would not have been possible.

Even when relying on existing platforms, the study team had to implement multiple scripts (codes) to access, clean, link and analyse the data (see below).

Table 10 Data sources

Data source	Description	Access	Links
Dimensions	Dimensions covers millions of research publications connected by more than 1.4 billion citations, supporting grants, datasets, clinical trials, patents and policy documents. It allows linking RCN grants to the outputs listed above (using the references to RCN or RCN grants contained in Dimensions). The coverage of policy documents for Norway was limited in Dimensions and another database (Overton) has been used to cover this aspect.	Subscription/ API to access data	https://www.digital-science.com/product/dimensions/
Almetrics	Altmetrics is a database of metrics and qualitative data that are complementary to traditional, citation-based metrics. These metrics are sourced from the Web, tracking over 2,000 mainstream media outlets around the world and 9,000+ academic and non-academic blogs, Wikipedia citations to published research, as well as mentions of research outputs in a range of social networks. Accessed via subscription to Dimensions	Subscription/ API to access data	
Lens.org	Lens contains information on 130 million patents and identifies scholarly documentation cited in those patents. It allows linking RCN publications cited in patents (with publications being identified via Dimensions)	Subscription/ API to access data	https://www.lens.org/
Overton	Overton is the world's largest searchable index of policy documents, guidelines, think tank publications and working papers. It collects data from 182 countries and over a thousand sources worldwide with more being added all the time. Overton parses each document, finding references, people and key concepts, and then link them to the relevant news stories, academic research, think tank output and other policy.	Subscription/ API to access data	https://www.overton.io

Data source	Description	Access	Links
	It allows linking RCN grants to policy documents (using RCN publications identified via Dimensions)		
TextRazor	The classifier used is explained in 4.2	API to access data based on number of requests (i.e. grants / text)	https://www.textrazor.com/

B.2 Codes and pipeline

The pilot includes 36 scripts (combination of Python and R codes) to implement different subprocesses, which have been provided to RCN.

The tile of each script represents the subprocess it represents (e.g., 0_dimensions_publications_text.py is a Python script to retrieve the text of relevant publications from Dimensions).

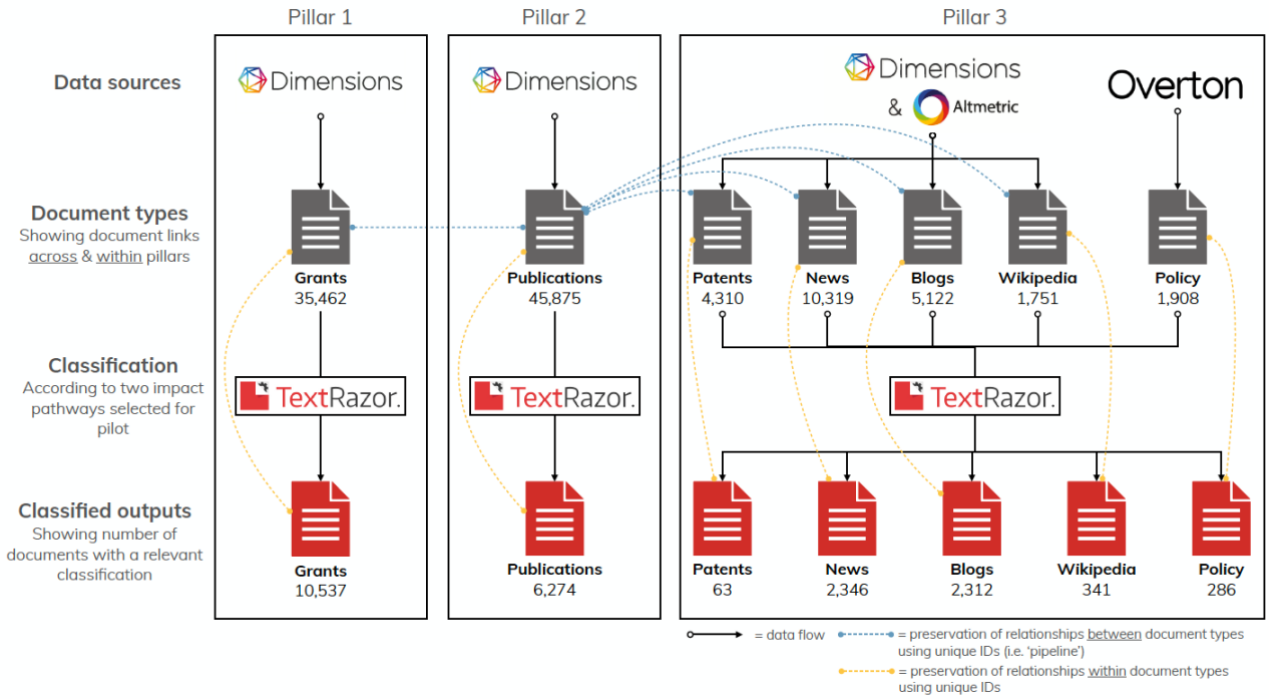
The number preceding each title represents the overall stage:

- 0 for data retrieval
- 1 for matching and classification exercises
- 2 for visualisations outputs

Each script starts with a 1-line description of the task it implements, and it denotes when changes to the parameters can be made.

The diagram below provides a visual representation of the pipeline followed for the analysis. In sum, it illustrates how, in each pillar, the documents of interest were retrieved primarily from Dimensions as well as Overton in the case of policy documents. All but the policy documents could be linked 'horizontally' (marked with blue arrows in the figure below) to a previous cited document (e.g. Wikipedia articles citing publications resulting from an RCN-funded grant). This linking was possible through unique document IDs retrieved from Dimensions.

Furthermore, the documents in each pillar were classified using TextRazor resulting in a subset of documents with a classification that was relevant to the impact pathways included in the pilot. For each pillar, 'vertical' document links (yellow arrows in figure below) between original documents and classified documents were also maintained, also based on unique document IDs. The combination of these horizontal and vertical links is crucial for large parts of the analysis as it allows the impact of a given grants to be traced fully up to the types of documents included in pillar 3.


Pillar 1
Pillar 2
Pillar 3
Data sources
Document types
Showing document links across & within pillars
Classification
According to two impact pathways selected for pilot
Classified outputs
Showing number of documents with a relevant classification
Dimensions
Dimensions
Dimensions & Altmetric
Overton
Grants 35,462
Publications 45,875
Patents 4,310
News 10,319
Blogs 5,122
Wikipedia 1,751
Policy 1,908
TextRazor.
TextRazor.
TextRazor.
Grants 10,537
Publications 6,274
Patents 63
News 2,346
Blogs 2,312
Wikipedia 341
Policy 286
= data flow
= preservation of relationships between document types using unique IDs (i.e. 'pipeline')
= preservation of relationships within document types using unique IDs

Appendix C **Classification - media topics**

Table 11 and Table 12 below presents for the full list of media topics used for each societal challenge (to inform the analysis in Pillar 3). Under both approaches, the goal was to classify all documents according to their alignment with the societal challenges of interest regardless of that being their original intent. For example, under this approach, RCN grants and respective outputs were categorised as aligned with a societal challenge even if the corresponding portfolio was not qualitatively categorised as aligned with that challenge.

Table 11 Media topics classified according to a Wikipedia-based training set: "Achieving better protection / enhancement of natural ecosystems"

Media topic	Description
Environment	All aspects of protection, damage, and condition of the ecosystem of the planet earth and its surroundings.
Conservation	Preservation of wilderness areas, flora and fauna, including species extinction
Energy Saving	Conservation of electrical, and other power sources
Parks	Areas set aside for preservation
Environmental Clean-up	Processes whereby contaminated areas are cleaned of hazardous materials so they can be inhabited again by either people or animals.
Hazardous Materials	Materials that are harmful to humans or animals if they are exposed to them. Includes radiation, poison gases, chemicals, heavy metals, PCBs, and certain plant products
Land Resources	That portion of a nation or state that is above water and available for development either for profit or for the general good of the public
Forests	Open areas of trees either available for public enjoyment, or for commercial purposes
Mountains	Elevated land masses formed over the ages either by erosion, volcanic eruption, or movement of massive geographical formations called plates
Water	Environmental issues about bodies of water, including oceans, lakes, streams and reservoirs, as well as ice, glaciers and forms of precipitation
Oceans	Salt water masses separating continents or other major geographical masses. smaller forms are seas or lakes or ponds
Rivers	Moving water areas bounded by land that extend from earth sources and meander through land areas to join with other water areas. In smaller forms they are creeks, rivulets, streams etc
Wetlands	Areas generally marshy and not either under water or dry land. Often related to aquifers for water quality and/or wildlife
Nature	The natural world in its entirety
Ecosystem	A system of plants, animals and bacteria interrelated in its physical/chemical environment
Endangered Species	Those species in danger of disappearing, largely because of changes in environment, hunting, or weather
Invasive Species	Non-native plants, animals and other organisms that tend to take over native species

Table 12 Media topics classified according to a Wikipedia-based training set: "Supporting change in behaviour and attitudes geared towards more inclusive societies"

Media topic	Description
Society	The concerns, issues, affairs and institutions relevant to human social interactions, problems and welfare, such as poverty, human rights and family planning
Communities	A group of individuals actively sharing a common value or interest
Demographics	The study of human populations and their characteristics, for example statistics or trends around aging populations in a particular geographic region
Discrimination	Unfair treatment of, or policies or practices against, individuals or groups of people on the basis of real or perceived membership in a group, such as race, sexual orientation, political or religious beliefs, age or height
Ageism	Discrimination against individuals or groups of people on the basis of age
Racism	Discrimination against individuals or groups of people on the basis of race
Religious Discrimination	Unfair treatment of individuals or groups of people on the basis of their religious belief
Sexism	Discrimination against individuals or groups of people, usually women, on the basis of gender
Emigration	Leaving one's country of residence to settle permanently elsewhere
Family	A group of people related genetically or by a legal bond, or who consider themselves part of a familial unit regardless of genetic or legal status
Dating And Relationships	The development of an intimate connection between individuals, through various forms of activities enjoyed together, often leading to a legal or permanent union such as marriage
Adoption	The legal process of transferring parental rights to someone other than a person's birth parents, that person usually being a child
Divorce	The process by which a marriage is legally dissolved
Family Planning	Services and education aimed at informing individual decisions about reproduction, such as contraception, fertility or abortion
Abortion	The intentional termination of a pregnancy for elective or medical reasons
Contraception	A method or device used to prevent pregnancy
Marriage	The legal or socially recognised union of individuals, which establishes rights and obligations between them
Parenting	The caring for and support of a child's physical, emotional, developmental and social needs from birth to adulthood
Immigration	The movement of individuals or groups of people from one country to another
Illegal Immigration	The movement of individuals or groups of people from one country to another without legal authorisation from the destination country
Mankind	Human beings taken as a whole, or described as members of particular groups such as teenagers, women, or people with disabilities
LGBTQ	People who identify as lesbian, gay, bisexual, transgender or queer
Disabilities	Physical or mental conditions that limits a person's movements, senses, or activities
Gender	The classification of individuals as male, female, or a non-binary designation

Indigenous People	People who are the original owners and caretakers of a given region, also known as native peoples, first peoples or aboriginal peoples, in contrast to groups that have settled, occupied or colonised the area more recently
National Or Ethnic Minority	Groups of people that form a minority on an ethnic or national basis, and their status or issues relating to the majority
Nuclear Radiation Victims	Includes antinuclear movements and compensation for atomic blast victims.
Social Condition	The circumstances or state of affairs affecting a person's life, welfare and relations with others in a society
Homelessness	The social condition defined by lack of permanent residence, living in shelters or on streets, and the issues and problems associated with it
Poverty	The lack of sufficient resources and means to provide basic needs such as food, clothing or shelter for oneself and one's family
Social Problem	Issues related to human rights, human welfare and other areas of societal concern
Abusive Behaviour	Actions that intentionally harm another person or people, often on an ongoing basis, such as psychological or mental abuse, negligence, physical or sexual abuse and torture
Addiction	The habitual and compulsive use of substances such as alcohol or drugs, or behavior such as gambling, gaming or sex, often causing detrimental effects on the body, brain, and relationships with others
Bullying	Taking actions meant to harm, coerce and intimidate another person perceived as vulnerable. These actions can be taken in person or online.
Juvenile Delinquency	Unlawful conduct perpetrated by minors, often on a repeated basis
Prostitution	The business of engaging in sexual activity in exchange for payment
Sexual Misconduct	Unwanted behavior of a sexual nature that is of lesser offense than felony sexual assault, particularly when behavior occurs in a normally non-sexual situation, or where there is some aspect of personal power or authority involved
Slavery	The ownership of people as property, and the involuntary servitude of those people to their owners, which includes unpaid labor and coerced actions
Values	A person's or group's principles or standards of behaviour, which guide their way of living and choices made
Corrupt Practices	Any action which is harmful to others
Death And Dying	Social, medical and mental health issues relating to people at the end of their lives
Euthanasia	The practice of humanely ending the life of a person suffering from a terminal illness
Assisted Suicide	The practice of assisting a person suffering from a terminal illness in the process of suicide, often with a physician's oversight
Suicide	The intentional taking of one's own life
Ethics	The moral values and standards that define right and wrong actions or decisions
Pornography	The depiction of sexually explicit acts in various media renditions, such as video or photos, often considered obscene or immoral
Sexual Behaviour	The manner in which people express their sexuality in physical acts
Welfare	Help for those in need of food, housing, health and other services

Charity	The voluntary giving of money, food or other necessities to those in need
Elderly Care	The long-term care of the elderly provided by residential institutions or by paid daily help in the home
Long Term Care	Services provided on an extended and ongoing basis to patients suffering from chronic illness or disability
Public Housing	Housing that is owned or managed by a government or non-profit organisation and rented to tenants with the aim of making housing affordable. Eligibility for such housing arrangements varies country to country.
Social Services	Social programmes, usually publicly sponsored, aimed at promoting people's welfare, such as housing, health care or education services

Appendix D Analytical framework for impact case studies

In this Appendix we provide an suggested analytical approach that identifies the different routes through which research and research-based activities supported by RCN could contribute to each of the nine impact pathways identified in our framework.

The tables provide suggestions on the supporting evidence that could be collected to understand the significance of the impact (reach and influence). This suggested approach is an adaption of the REF framework of types of impact, and understanding reach and influence. In contrast with REF, is takes the impact pathway as starting point (not the discipline) and it is fed from the results achieve across various portfolios / disciplines. Table 13 to Table 15 cover each of the impact dimensions. Some impact routes are covered in more than one impact area/pathway.

Table 13 Analytical approach for impact cases studies. Impact dimension: Environment

Impact Pathways Type of impacts	**Supporting evidence** (Indicators of reach and influence) [PRELIMINARY]
• The environment has been improved through the introduction of new products, processes or services; the improvement of existing products, processes or services; or the enhancement of strategy, operations or management practices. • New methods, models, monitoring or techniques have been developed that have led to changes or benefits. • The management or conservation of natural resources, including energy, water and food, has changed. • The management of an environmental risk or hazard has changed.	• Sales of new products, or improvements in existing products, that bring quantifiable environmental benefits, related to the protection of ecosystems • Verifiable influence on particular projects or processes which bring environmental benefits, related to the protection of ecosystems • Evidence of generic environmental impact across a sector, confirmed by independent authoritative evidence. • Documented case-specific improvements to environment-related issues
Reducing pollution and waste in production and consumption	
• Direct intervention, based on research evidence, has led to a reduction in carbon dioxide or other environmentally damaging emissions. • The management or conservation of natural resources, including energy, water and food, has changed. • Production, yields or quality have been enhanced or the level of waste has been reduced.	• Sales of new products, or improvements in existing products, that bring quantifiable benefits, in terms of reduction in carbon dioxide or other environmentally damaging emissions. • Verifiable influence on particular projects or processes which bring benefits, in terms of reduction in carbon dioxide or other environmentally damaging emissions. • Verifiable influence on particular projects or processes which bring benefits, in terms of reduction in waste. • Statistics on pollution and waste • Testimonials from experts/practitioners/industrialists

Increasing production and use of energy from renewable sources	
• New or improved products, processes or services have been introduced that improve the cost-effectiveness of renewable energy.	• Sales of new products, or improvements in existing products, in areas such as wind farms, solar panels, etc. • Testimonials from experts/practitioners/industrialists

Table 14 Analytical approach for impact cases studies. Impact dimension: Society

Impact Pathways Type of impacts	**Supporting evidence** (Indicators of reach and influence) [PRELIMINARY]
Reducing inequalities of opportunity (health, education, economic)	
• Contributions have been made to continuing personal and professional development. • Workforce planning has been influenced by research. • Educational or pedagogical practices and methods have changed in primary, secondary, further or higher education • The development of expert systems has been influenced in areas such as medicine, human resources, accounting, and financial services. • Research into the languages and cultures of minority linguistic, ethnic, religious, immigrant, cultures and communities has been used by government, NGOs, charities or the private sector to understand and respond to their needs. • The costs of treatment, health or social care have changed as a result of research-led changes in practice. • Better access to finance opportunities has been enabled. • Research-led engagement with marginalised, under-engaged and/or diverse audiences has led to increased cultural participation. • There have been improvements to social welfare, equality and social inclusion, or to access to justice and other opportunities (including employment and education). • Engagement with research has enhanced policy and practice for securing poverty alleviation. • Changes to social policy have led to improved social welfare, equality or social inclusion. • Research has contributed to community regeneration or development. • Social and educational inclusion of marginalised groups in any given context has been improved • There has been more effective integration of immigrants or refugees into host communities.	• Change to professional standards, performance or behaviour, underpinned by research • Evidence of adoption of best practice (e.g. by educators or law enforcement personnel), underpinned by research • New or modified professional standards and codes of practice, underpinned by research • New or modified technical standards or protocols, underpinned by research • Traceable reference to inclusion of research in national or international industry standards or authoritative guidance. • Traceable references by practitioners to research papers that describe their use and the impact of the research. • Evidence of use of education materials arising from the research. • Evidence on the increase access to, or reduce cost of public services by socioeconomic groups • Evidence of engagement with campaign and pressure groups and other civil organisations (including membership and activities of those organisations and campaigns) geared towards reducing inequalities as a result of research.

Producing more effective and /or better designed policies geared towards improving quality of life (health, safety, security, etc.)	
• Policy debate in areas of health, safety, security, etc. has been influenced by research evidence, which may have led to confirmation of policy, change in policy direction, implementation or withdrawal of policy. • Policymakers make use of research-based critical evidence synthesis in developing policy. • Policy decisions or changes to legislation, regulations or guidelines have been informed by research evidence. • Policies have been introduced which have had an impact on economic growth or incentivising productivity. [->Economy] • Changes have been made in design standards or general practice areas of health, safety, security, etc. • Research stimulates critical public debate that leads to the non-adoption of policy. • Professional bodies and learned societies have used research to define best practice, formulate policy, or to lobby government or other stakeholders. • Law enforcement and security practices have changed. • Practices have ceased where these were shown by research to be ineffective. • The quality, accessibility, acceptability or cost-effectiveness of a public service has been improved. • Risks to the security of nation states have been reduced. • Forms of dispute resolution or access to justice have been influenced. • There have been improvements to legal and other frameworks for securing intellectual property rights. • Changes to social policy have led to improved social welfare, equality or social inclusion.	• Traceable reference to inclusion of research into government policy papers, legislation and industry guidance. • Traceable reference to the influence of research in planning decision outcomes. • Literature/web information from practitioners and advisers, including the research findings and how they are applied in practice. • Evidence on the increase access to, or reduce cost of public services by socioeconomic groups • Documented evidence of policy debate (e.g. in Parliament, the media, material produced by NGOs) that takes into account research findings
Generating improved and more inclusive public administration and services	
• A public service has improved based on research evidence • In delivering a public service, a new technology or process has been adopted or an existing technology or process improved. • The quality, accessibility, acceptability or cost-effectiveness of a public service has been improved. • Research has been used to change current processes or services, or identify new services to be provided. • (Sections of) the public have benefited from public service improvements. • Practices have ceased where these were shown by research to be ineffective. • More effective dispute resolution has been enabled. • Government analysts have adopted innovative methodological or approach-based advice from researchers.	• Traceable reference to inclusion of research into government policy papers, legislation and industry guidance. • Traceable reference to the influence of research in planning decision outcomes. • Literature/web information from practitioners and advisers, including the research findings and how they are applied in practice. • Evidence on the increase access to, or reduce cost of public services by socioeconomic groups • Documented evidence of policy debate (e.g. in Parliament, the media, material produced by NGOs) that takes into account research findings
Supporting change in behaviour and attitudes geared towards more inclusive societies	

• Research into the languages and cultures of minority linguistic, ethnic, religious, immigrant, cultures and communities has been used by government, NGOs, charities or private sector to understand and respond to their needs. • International policy development has been influenced by research. • The allocation and/or distribution of Official Development Assistance (ODA) has been influenced by research. • Policy and practice of international agencies or institutions have been influenced by research.	• Evidence of debate among practitioners, leading to developments in attitudes or behaviours, underpinned by research • Documented shift in public attitude (e.g. to sexual behaviour, or social factors in health). • Citation in a public discussion, consultation document or judgement. • Citation by journalists, broadcasters or social media. • Evidence of engagement with campaign and pressure groups and other civil organisations (including membership and activities of those organisations and campaigns) as a result of research.

Table 15 Analytical approach for impact cases studies. Impact dimension: Economy

Impact Pathways Type of impacts	**Supporting evidence** (Indicators of reach and influence) [PRELIMINARY]
Generating innovation-based growth	
• Contributions have been made to innovation and entrepreneurial activity through the design and delivery of new products or services. • Decisions have been made not to introduce a new process or product as a result of research. • Gains in productivity have been realised as a result of research-led changes in practice. • Research has helped to stimulate foreign direct investment (FDI). • The performance of an existing business has been improved through the introduction of new, or the improvement of existing, products, processes or services; the adoption of new, updated or enhanced technical standards and/or protocols; or the enhancement of strategy, operations or management practices. • Performance has been improved, or new or changed technologies or processes adopted, in companies or other organisations through highly skilled people having taken up specialist roles that draw on their research, or through the provision of consultancy or training that draws on their research. • There has been improved support for the development of 'small scale' technologies.	• Evidence of improved cost-effectiveness of new products /services / Quantitative data relating, for example, to cost-effectiveness or organisational performance. • Sales of new products/services. • Commercial adoption of a new technology, process, knowledge or concept. • Business performance measures, for example sales, turnover, profits or employment associated with new or improved products, processes or services. • Jobs created or protected. • Investment funding raised from Norwegian and/or non-Norwegian agencies (venture capital/Business Angel, and so on) for start-up businesses and new activities of existing businesses. • Priority shifts in expenditure profiles or quantifiable reallocation of corporate, non-profit or public budgets. • Evidence of critical impact on particular projects, products and processes confirmed by independent authoritative

	evidence, which should be financial where possible. • Evidence of research leading to avoidance of negative outcomes.
Creating a more (environmentally) sustainable and inclusive economy	
• Corporate social responsibility policies have been enhanced • Alternative economic models (such as fair trade) have been developed and adopted. • There have been improvements in legal frameworks, regulatory environment or governance of business entities. • Potential future losses have been mitigated by improved methods of risk assessment and management in safety- or security-critical situations. • The strategy, operations or workplace practices of a business have changed. • Social enterprise initiatives have been created. • Contributions have been made to innovation and entrepreneurial activity (in environmentally sustainable businesses) through the design and delivery of new products or services • Gains in productivity have been realised (in environmentally sustainable businesses) as a result of research-led changes in practice, • The performance of an existing (environmentally sustainable) business has been improved through the introduction of new, or the improvement of existing, products, processes or services; the adoption of new, updated or enhanced technical standards and/or protocols; or the enhancement of strategy, operations or management practices.	• Evidence of improved cost-effectiveness of new products /services that improve environmentally sustainable practices • Sales of new products/services geared towards environmentally sustainable practices • Commercial adoption of a new technology, process, knowledge or concept, geared towards environmentally sustainable practices. • Business performance measures, for example sales, turnover, profits or employment associated with new or improved products, processes or services geared towards environmentally sustainable practices • Jobs created or protected, in environmentally sustainable businesses • Investment funding raised from Norwegian and/or non-Norwegian agencies (venture capital/Business Angel, and so on) for start-up businesses and new activities of existing businesses, to support 'green economy" • Priority shifts in expenditure profiles or quantifiable reallocation of corporate, non-profit or public budgets, towards environmentally sustainable practices • Evidence of critical impact on particular projects, products and processes that support environmentally sustainable businesses, confirmed by independent authoritative evidence, which should be financial where possible. • Evidence of research leading to avoidance of negative outcomes.

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