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Evaluation of the Top-level Research Initiative

Final report

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Executive summary

In the autumn of 2008, the Nordic countries joined forces on the largest joint Nordic research and innovation initiative to date: the Top-level Research Initiative (TRI). The initiative aimed to involve the very best agencies and institutions in the Nordic region, and to promote research and innovation of the highest level to make a Nordic contribution towards solving the global climate crisis. The budget of the programme was DKK400m over five years.

The focus for this ex-post evaluation of TRI is on the results and impact that the programme has had, and on the Nordic added value it has brought. Data were collected from a wide range of sources: documents from existing databases and other sources, interviews with client representatives and central stakeholders, self-assessments from project leaders of the funded projects, e-surveys of project participants (research organisations and companies), in-depth case studies of selected projects and bibliometric analyses of research output. As part of the evaluation process, an intervention logic for the programme was constructed, and an advisory group of three domain experts supported the evaluation team with insights and critical observations. At an interpretation seminar in Copenhagen a selection of observations and tentative conclusions were presented to stimulate discussion on their relative merits, and possible alternative conclusions.

Good goal fulfilment, but not excellent

The TRI addressed issues of climate, energy and the environment with the overarching idea to strengthen the Nordic competitive advantage in science and innovation in these areas. The TRI aimed to contribute to establishing a Nordic research arena that increases the level and ambition of collaboration among Nordic research. This would be achieved through the funding of activities in six sub-programmes and the collaboration in programme committees, all involving a large number of researchers from universities, research institutions and companies from all Nordic countries.

As an overall observation it can be stated that the fulfilment of the TRI's overall goals is good, but somewhat uneven. The TRI has certainly performed notably well on three of the six goals; TRI has strengthened national research and innovation systems and ensured the highest quality in research and innovation by combining the strongest Nordic communities. It can also be argued that the TRI has delivered well on the goal of profiling the Nordic region as a leader within certain areas of the energy and climate sectors. As for the remaining three goals, to provide a platform for increased international cooperation both within the EU and beyond, to enhance Nordic participation in EU programmes, and to strengthen Nordic competitiveness by using research and innovation to counter economic downturns, the goal fulfilment is considered to be less than complete.

The evaluation work has been guided by a set of evaluation questions, organised under four headings: Societal and scientific impact of the TRI, Nordic added value of the TRI, Societal readiness for innovation and research and Applicability and utilisation of the innovation and research outcome.

Societal and scientific impact of the TRI

The evaluation confirms that excellent research has been carried out, involving agencies and institutions in the five Nordic countries. The projects funded by the TRI have published frequently, and publications tend to appear in journals with high impact. The share of highly-cited papers is notably greater than the comparable field average. The general quality of the publications is equal between Integrated Projects and Nordic Centres of Excellence.

The projects have attracted a large amount of additional funding. The self-assessments show additional research funding to an amount of at least €73.5m, which is close to 150 per cent of the total budget of the programme. A large part of the additional funding comes from national public sources, whereas Nordic institutions provide only some 10 per cent of the total additional funding. This suggests that subsequent/additional Nordic funding opportunities have been rather scarce.

The TRI largely funded already-established research and researchers, and this was also the purpose from the start. This enabled research collaborations that would otherwise not have been possible. The empirical data also indicate that existing cross-border research collaborations were strengthened, and in several cases included research partners formerly not part of the network.

The TRI enabled research collaborations that would otherwise not have been possible, and enabled projects that would otherwise not have existed. Some of the project ideas would obviously have found other means of funding, but they would then in most cases have been more national in scope.

The TRI has contributed to providing academia and industry with highly qualified professionals (and future policymakers). The evaluation shows that at least 81 PhDs have been (co)funded by TRI. Roughly half the number of these have remained in the university sector, and the remainder are currently employed by companies, research institutes and in public administration. There are at least 19 cases of international mobility amongst these former PhD students. The Nordic Centres of Excellence have generated strong Nordic research teams and there is evidence of lasting Nordic collaboration. Evidence of policy impact, however, is limited.

Nordic added value

The evaluation provides evidence of real collaborative efforts and network building in practically all projects. The TRI encouraged expanding actors' Nordic networks, which form a basis for continued collaboration. To a large degree, parts of the networks were already in place, but these core relations were amplified and strengthened with the inclusion of project participants connected to only one or a few of the 'core team(s)'. This created opportunities for further added value by making it possible for researchers and industry from several Nordic countries to actually work together. In several cases it was pointed out that the funding created an opportunity to include crucial expertise, competence, R&D infrastructure and facilities from a neighbouring country that may not have existed at the same top-level in a single country. The TRI has contributed to increased and sustainable Nordic research collaboration. However, the sustainability of these collaborations depends on availability of continued and relevant funding opportunities.

The TRI favoured enhanced Nordic unity in research and a developed Nordic research profile. Climate and ecology issues do not know borders and the TRI was an opportunity to address (Nordic) cross-border issues, ideal for collaboration between researchers from various countries. Co-funding a large number of PhD students in these areas and enabling a presupposed Nordic orientation of these researchers continued professional careers also helps to create Nordic added value, as does the mobility of these individuals.

Although active collaboration has not been sustained in many of the former project consortia, there is a certain level of readiness to reawaken the research networks should an opportunity arise. This could be understood as the creation of a Nordic critical mass, which could be called upon.

Societal readiness for innovation and research

The concept of 'societal readiness' addresses the level of societal adaptation of, for instance, a particular social project, a technology, a product, a process, an intervention, or an innovation to be integrated into society, and all seven were on levels 5–7 on a nine-grade scale, thus relatively well underway for integration into society. The projects are well past the initial stages of identifying and formulating the problem, and address validating proposed solution(s) by relevant stakeholders in the area or demonstrating these solutions in relevant environment and in cooperation with relevant stakeholders to gain initial feedback on potential impact.

Applicability and utilisation of the innovation and research outcome

Participation in the TRI projects clearly contributed to value creation and new contacts and partnerships for the company partners. For these companies, the TRI contributed to increased R&D cooperation, mainly within the Nordic countries. Altogether, however, fewer companies than expected participated in the TRI: the programme's contribution to strengthening the competitiveness of the business sector is thus less clear.

Utilisation of results from the TRI projects to policy or in society remains limited. There are some examples of societal impact, where TRI-funded projects have reached out and influenced stakeholders outside the scientific community. The results from the NCoE are clearly useful for public policy actors, although there are yet few signs of direct policy impact. In any case, experience shows that it tends to take rather long time before knowledge produced in research projects in these areas is taken up by policymaking.

TRI was an ambitious effort that produced important results

No doubt, the TRI has been a successful programme. It has delivered in accordance with the expectations – and in some cases more. The programme has performed well on its overall objectives.

The programme's impact ought to be put in some perspective. It was indeed the largest Nordic research programme in history, but the total budget was still modest compared to what the Nordic countries invest individually in research in these areas. While the TRI was a unique effort with strong political backing, it was not enough to radically change the Nordic research landscape in its target research area. That would have required a long-term commitment with subsequent programmes or funding opportunities at Nordic level. Neither was the creation of Nordic collaboration as a platform for increased international cooperation within the EU and beyond a central aim for most of the projects and their participants. There is evidence from some projects that this was after all achieved, but it was not necessarily a key driving force or motivation for the researchers when applying for and carrying out research collaboration with funding from the TRI.

The TRI still had a clear Nordic added value. Through the TRI, real cross-border collaboration between researchers and some companies did take place, including networking of importance for PhDs and senior researchers, resulting in several examples of continued collaboration/contacts. It is likely that the training of the (at least) 81 PhDs will have long-term impact on joint Nordic research, 'marinated' in Nordic collaboration as they are.

The Nordic organisations have an obligation to nurture the investment made. A large number of highly qualified and internationally competitive researchers have created and/or developed networks with researchers in the other Nordic countries, and the evaluation testifies that most of these researchers are interested in ways to continue Nordic collaboration. There are plenty of examples of areas and topics that researchers wish to explore further in a Nordic context, and where preconditions for cooperation and successful outcomes, and thus Nordic added value, are generally promising.

1 Introduction

1.1 Assignment and scope

In the autumn of 2008, the Nordic countries joined forces on the largest joint Nordic research and innovation initiative to date: the Top-level Research Initiative (TRI). The initiative aimed to involve the very best agencies and institutions in the Nordic region, and to promote research and innovation of the highest level, in order to make a Nordic contribution towards solving the global climate crisis. The budget of the programme was DKK400m over five years.

Parallel to the implementation of the programme, an ongoing evaluation started in the spring 2010 to contribute to the execution of the TRI and to gain knowledge to improve future similar programmes. The ongoing evaluation resulted in several interim reports, and a final report delivered in October 2014.

The Terms of Reference state that the objective is to do an ex post evaluation of the six sub programmes in the TRI. This evaluation differs from the ongoing evaluation in some fundamental respects. This report does not discuss in detail the implementation of the programme and its activities, as this was central to and well covered in the ongoing evaluation. Instead, the focus is on the results of the programme efforts, and what effects these have brought to different sets of participants and stakeholders. Some four years after the ongoing evaluation final report, we believe enough time has gone by in order to detect some results and effects, and also to discuss the sustainability of the efforts carried out through the programme. What lasting effects can be detected, and how can any lack of such effects be explained?

1.2 Evaluation questions

A set of evaluation questions has guided the work with the evaluation. There are twelve evaluation questions, organised under four headings:

Societal and scientific impact of the TRI

- How has the TRI contributed to societal and scientific impact?
- In what ways have the TRI funded projects reached out and influenced stakeholders outside the scientific community?
- In which areas has the TRI been most successful in reaching out?

Nordic added value of the TRI

- In what ways have visibility and attractiveness of Nordic research increased in a European and global context?
- In what ways has the TRI facilitated appropriate division of work and specialisation between the Nordic countries?
- To what extent have the TRI projects been integrated and fed back into the national research systems?
- How has the efficient and flexible use of the Nordic resources been ensured?

Societal readiness for innovation and research

- How are TRI-funded projects distributed on the Societal Readiness Level scale?

Applicability and utilisation of the innovation and research outcome

- In what ways have the activities supported by the TRI contributed to innovation?
- How has the TRI contributed to knowledge and innovation that serves the needs of business and society?

- How has the TRI contributed to increased international cooperation in research?
- How has the TRI contributed to strengthened Nordic international competitiveness?

The focus for this evaluation, thus, is on the results and impact TRI has had, and on the Nordic added value the programme has brought. The concept of Nordic added value is rather vague, but commonly agreed to exist where initiatives or activities are best and most efficiently carried out in a Nordic context rather than at national or EU level. We return to the concept of Nordic added value in chapter 4.

1.3 Data acquisition and methods used

Data used in the evaluation have been collected from a wide range of sources:

1.3.1 Document studies

Documents from existing databases and evidence sources were analysed; policy documents, programme documents and descriptions, minutes from programme committee meetings, project descriptions, reports and final reports, previous evaluations, etc.

1.3.2 Interviews

A total of 33 interviews were carried out with client representatives and central stakeholders drawn from the TRI Managing Board, the Boards of NordForsk, Nordic Innovation and Nordic Energy Research, researchers and project leaders and industrial participants and stakeholders. The initial interviews were of a more open-ended, scoping character, allowing us to reach a deeper initial understanding of the context and expectations of the evaluation and to fine-tune further interviews and data collection. Additional e-mail correspondence with interviewees and other stakeholders also took place.

1.3.3 Self-assessments

Project leaders from 17 of the funded projects filled in and returned a self-assessment template developed by the evaluation team, containing information about staff (incl. mobility of individuals), sources of funding, postgraduate education, peer-reviewed publications, the most influential publications, patent applications and granted patents, descriptions of impact cases and partners in business and academia. Three project leaders did not fill in the template since their projects were pre-studies that did not lead to any of the results the self-assessment asked about. One project leader refused to participate.

The information provided in the self-assessments was also used as input to the eSurveys, the bibliometric analysis, stakeholder interviews and cases studies.

1.3.4 eSurveys

Two surveys were sent to project participants; one to the research organisations and one to the companies involved in the projects. The surveys focused on effects and developments that resulted from participation in the project (in quantitative and qualitative terms), and the value or worth of the Nordic scope of the programme and its fit with national programmes and opportunities. Contact information was retrieved from the documentation provided by NordForsk and complemented through the self-assessments from project leaders. Additional e-mail addresses and phone numbers were obtained through desk research.

177 researchers were initially invited to answer the survey; after two rounds of reminders 54 responses were obtained. To further increase the response rate, those who had not answered the surveys were contacted by phone. This increased the response rate to 75 respondents (42%). The survey of companies was sent to 53 addresses and received 18 responses (a response rate of 34%) after complementary phone calls.

One aspect that most likely had a negative effect on the response rate is the amount of time that has passed since the end of the programme and the initiation of this evaluation. There were outdated e-mails due to participants changing employer, going into retirement, or due to reorganisation of businesses. At the same time, contacting project participants by phone enabled us to further substantiate our response analysis by conducting 'miniature interviews' with the respondents. The most recurring reasons given for not answering the survey were the number of surveys received in general, that the survey was received at a very busy time of the year, and that the respondents felt that they were not sufficiently involved in the project administration to provide meaningful responses.

1.3.5 Case studies

Seven in-depth case studies of selected projects were carried out in order to study effects on national or regional innovation systems. The case studies were based on desk research, the self-assessments from the project leaders, respondent results from the eSurvey and interviews with relevant stakeholders. Projects from all six sub-programmes were chosen for case studies, and the selection was carried out in consultation with the client.

1.3.6 Bibliometric analyses

Bibliometric analyses of research output from the funded research projects were made, targeting research production, impact and collaboration. The bibliometric analyses were based on the self-assessments and publication data from Web of Science. The analyses investigated the journal impact factor and analysed the publications' citation impact, to describe the researchers' international visibility and contribution to scientific development, comparing their development with field normalised indicators. The bibliometric analyses also showed which organisations the funded groups had co-published with, and this was used as an indicator of the intensity in the collaboration.

1.3.7 Intervention logic

An intervention logic for the programme was elaborated as a representation of how and why a complex change process will succeed under specific circumstances. This helped to examine the concept and logic of Nordic added value as well as what the drivers and barriers to innovation in projects of this nature and research are. A tentative intervention logic to describe how TRI works, based on desk research and early scoping interviews, was tested and refined during the evaluation work.

1.3.8 Advisory group

An advisory group of three highly qualified domain experts supported the evaluation team with insights and critical observations: Erik Arnold, Jerker Moodysson and Johan Nylander. The advisory group followed the evaluation and supported the project managers regarding methodological issues, and actively contributed to the conclusions and interpretations. The expertise of the members of the advisory group helped us to critically examine Nordic added value and discuss in what areas and under what conditions Nordic added value can thrive. It also allowed us to discuss the TRI in relation to the national arenas and its feedback into them, and analyse whether and how the TRI has favoured societal readiness for innovation and research.

1.3.9 Interpretation seminar

An interpretation seminar was held in Copenhagen on March 5th, 2018, where we presented a selection of our observations and tentative conclusions to stimulate discussion on their relative merits, and possible alternative conclusions. The seminar was a valuable data-acquisition opportunity as regards all evaluation questions, served quality control purposes (to sort out any misunderstandings), and simultaneously prepared the client for the main findings of the evaluation. Representatives from NordForsk, Nordic Innovation, Nordic Energy Research and public research funding agencies from several Nordic countries attended the seminar (a list of the participants is found in Appendix B).

1.4 Duration and contribution

The evaluation ran between September 2017 and May 2018. Dissemination of the results continued during 2018. Göran Melin functioned as overall project director, while Tommy Jansson was responsible for day to day project management. Anders Håkansson, Julia Synnelius, and Sebastian Eriksson Berggren made substantial contributions to the empirical work with the evaluation. Alexander Buitenhuis contributed with case studies, and Rickard Danell made the bibliometric analysis.

The evaluation team wishes to thank all informants for answering our questions in surveys or interviews, and for submitting self-assessments; participants at the interpretation seminar for valuable insights and discussion; the advisory group; and contributing colleagues external to Technopolis Group's office in Stockholm.

2 Description of the Top-level Research Initiative

2.1 Political background, objectives, implementation

The TRI is the largest joint Nordic research and innovation initiative to date. The initiative, created in 2008 by the prime ministers of the five Nordic countries and launched in 2009, addressed issues of climate, energy and the environment with the overarching idea to strengthen the Nordic competitive advantage in science and innovation in these areas. The initiative involved the very best agencies and institutions in the Nordic region, and some 200 researchers from universities and research institutions and 63 companies participated. Multi-disciplinary coordination was emphasised, including sciences and social sciences as well as business and industry.[1]

Budgetary funding was divided among the Nordic countries in proportion to their GDP. On top of this, the Nordic Council of Ministers, as well as the Nordic organisations NordForsk, Nordic Energy Research and Nordic Innovation, all contributed to the financing of the TRI. The TRI was organised as a true common pot, with none of the financially contributing partners being guaranteed an equal share of the research grants. Administration of sub-programmes and projects was however split between NordForsk, Nordic Energy Research and Nordic Innovation. 50 per cent of the total budget of DKK400m was allocated to NordForsk, 25 per cent was allocated to Nordic Energy Research and 25 per cent was allocated to Nordic Innovation.

The TRI was a result of an ambition in the Nordic Council to establish a Nordic research arena that would increase the level and ambition of collaboration among Nordic research as well as creating a basis for enhanced Nordic participation in EU framework programmes. Whereas today it can be concluded that several of the programmes of the TRI not only had the potential to enhance collaboration and to support innovation in key future technology areas, TRI was tightly coupled with the climate change agenda. Although the aim of TRI was threefold – climate, energy and the environment – accounts of achievements of TRI seem to stress the fight against global warming.

2.2 Objectives of the Top-level Research Initiative

The overall goals of the programme as specified by the Nordic Council of Ministers were the following:

- Profile the Nordic region as a leader within certain areas of the energy and climate sectors
- Strengthen national research and innovation systems
- Ensure the highest quality in research and innovation by combining the strongest Nordic communities
- Provide a platform for increased international cooperation both within the EU and beyond
- Enhance Nordic participation in EU programmes
- Strengthen Nordic competitiveness by using research and innovation to counter economic downturns

2.3 Project portfolio and participation patterns

The TRI consisted of six sub-programmes:

1) **Effect studies and adaptation to climate change**, to improve knowledge about (1) the effects of climate change, (2) the adaptation capacities of society (3) the risks and opportunities that the effects of climate change may bring to the Nordic region. The sub-programme consisted of 10 networks and 3 Nordic Centres of Excellence.

[1] For a more detailed description and discussion of the background and implementation of the TRI, see Arnold E and Eriksson M (2009): Experience from the first Nordic Top Level Research Initiative. See e.g. http://www.toppforskningsinitiativet.org/filer/TRI_brochure_spread.pdf-en

2) **Interaction between climate change and the cryosphere**, to reinforce Arctic research cooperation in the Nordic region and internationally, to improve modelling of the climate change interactions with the cryosphere, and provide results for infrastructure risk assessments and possibilities. The sub-programme consisted of three Nordic Centres of Excellence including funding of Nordic/Russian collaboration.

3) **Energy efficiency with nanotechnology**, to improve the efficiency of future sustainable energy systems by applying nanotechnology to the transport sector, energy conversion and energy use.

4) **Integration of large-scale wind power**, to promote the development of new, innovative and sustainable forms of wind energy and the integrational aspects connected to wind energy. The sub-programme supported the development of innovative and sustainable forms of wind energy and its better integration with energy systems.

5) **Sustainable bio-fuels**, to promote the development of new, innovative and sustainable forms of bio-energy, as well as to enhance the development of Nordic R&D institutions and businesses within the bio-energy field. The project activities were organised in three categories: (1) integrating activities, (2) spreading excellence, (3) joint R&D activities.

6) **CO2 – capture and storage**, to contribute in boosting the deployment of CCS in the Nordic countries by creating a durable network of excellence integrating R&D capacities and relevant industry.

In each of the sub-programmes, projects were carried out. Table 1 lists the respective projects under each sub-programme, including details about project leader, budget, and duration.

Table 1 Projects in the Top-level Research Initiative covered by the evaluation

Project	*Project type*	*Project leader*	*Budget (m€)*	*Duration*
Sub-programme: Effect studies and adaptation to climate change				
Tundra	NCoE	University of Turku	1.9	2011–2016
NorMER	NCoE	University of Oslo	3.2	2011–2016
NORD-STAR	NCoE	University of Southern Denmark	3.6	2011–2016
Sub-programme: Interaction between climate change and the cryosphere				
SVALI	NCoE	University of Oslo	3.8	2010–2016
CRAICC	NCoE	University of Helsinki	3.7	2010–2017
DEFROST	NCoE	Lund University	2.6	2010–2016
Sub-programme: Energy efficiency with nanotechnology				
Enesca	Integrated Project	Uppsala University	1.6	2010–2013
SOFC	Integrated Project	Chalmers University of Technology	0.8	2011–2014
TopNANO	Integrated Project	SP Chemistry, Materials and Surfaces, Sweden	1.6	2010–2013
NANORDSUN	Integrated Project	NTNU	1	2010–2013

Sub-programme: Integration of large-scale wind power				
ICEWIND	Integrated Project	Technical University of Denmark	1.3	2010–2014
Offshore DC	Integrated Project	Technical University of Denmark	1.1	2011–2016
OSR Nordic	Integrated Project	Aalborg University	0.4	2010–2013
Sub-programme: Sustainable bio-fuels				
BioEng	Integrated Project	NTNU	0.5	2010–2013
SusBioFuel	Integrated Project	SINTEF, Norway	1	2010–2014
HG Biofuels	Integrated Project	Chalmers University of Technology	0.6	2010–2015
NORD-SYNGAS	Integrated Project	VTT Technical Research Centre of Finland	1	2010–2013
Sub-programme: CO2 – capture and storage				
NORDICCS	Integrated Project	SINTEF, Norway	3.6	2011–2015
Potential for Carbon Capture and Storage (CCS) in the Nordic Region	Study	VTT Technical Research Centre of Finland	0.2	2010
CSS in a Nordic Renewable Energy Scenario	Study	Sund Energy, Norway	0.1	2010

Source: Self-assessments and final report

2.4 Types of projects

NCoE (Nordic Centres of Excellence) were large centres for existing Nordic research communities with participants from at least three Nordic countries. The NCoE aim to increase and facilitate cooperation between excellent researchers, research groups or institutions in the Nordic countries to strengthen the communities and enhance the international profile in prioritised areas in the Nordic countries through joint research and researcher training, joint management and leadership, and shared infrastructure.

Integrated Projects were research projects involving research partners from the Nordic countries and more decidedly involving business partners. These projects focused on involving non-academic partners and thus facilitating ties to business and end-users. The IPs included industry partners and operated under four of the six sub-programmes: Energy Efficiency with Nanotechnology, Integration of large-scale wind power, Sustainable biofuels, and CCS.

2.5 Previous studies and evaluations of the TRI

The TRI has, as mentioned, been subject to previous studies.

In the report "Experience from the first Nordic Top Level Research Initiative" (2009), Erik Arnold and Marie-Louise Eriksson tell the story of the background and implementation of the TRI. The report offers an analysis of what happened and makes some suggestions for the future. It concludes that the problems encountered are more matters of principle than of administration. The result of the process was establishing and beginning to implement the TRI in a way that largely rearranged existing funding rather than providing the deepening of Nordic cooperation originally intended by the Prime Ministers. Nonetheless, the initiative had the effect of focusing and structuring Nordic research cooperation to an extent not achieved before and it demonstrated a practical form of governance for such a more focused effort. It showed the way to a more effective way of working together, as well as providing a practice that can serve as a platform for Nordic states' participation in future joint programming at the European level.

Between 2010–2014, the Danish consulting company DAMVAD carried out an ongoing evaluation of the Top-level Research, to document the results and contribute to the further development of the TRI. During the course of the ongoing evaluation, several reports were presented.

The initial evaluation (2010) concluded that the TRI organisation was operationally well-functioning, but that is was both large and complex relative to the funds allocated. Despite this, the stakeholders (both national and Nordic) were generally satisfied with the operational running of the programme.

The Interim Report (2011) concluded that the initial phases of setting up the TRI was seen as a turbulent and difficult process by stakeholders. However, TRI contributed to building the trust required for a true common-pot initiative involving the Nordic countries. The report established that the programme was well functioning with a balanced portfolio of relevant projects and that the progress of the individual projects was on track. The interim report further concluded that businesses did not serve as project leaders but were nevertheless engaged in the project and considered their participation strategically important. The TRI was well on its way to realising its stated goals, but challenges also remained: the efficiency of the programme organisation, in terms of size, complexity and division of resources, and the degree of international collaboration.

The final report evaluated early result outputs from the TRI programme and portfolio, summed up the findings of the initial and interim evaluations and offered points of learning for similar programmes in the future. The evaluation concluded that TRI contributed more than initially expected, and provided the following main findings:

- The TRI is a central part of the Nordic research effort in the field of climate, energy and the environment
- The TRI is a cross-institutional Nordic research and innovation programme
- The TRI contributes to developing good framework conditions in the Nordic countries for cooperation in top research
- The TRI contributes to increased coordination and professional leadership of Nordic research
- Participation in TRI projects generates increased international visibility
- There are supplementary effects of the TRI

2.6 An intervention logic for TRI

Based on our understanding of the TRI, an intervention logic was developed for the programme. This intervention logic describes relationships between the expected outputs and impact of the programme and its objectives. This is a useful tool to favour the understanding of a programme operating in a complex system, and it is a way to illustrate the concept and logic of Nordic added value. The intervention logic of the TRI looks like this:

Figure 1 Intervention logic of the Top-level Research Initiative

In chapter 4, we return to the intervention logic to discuss its relevance and how well the programme has delivered on the first-order and second-order effects.

2.7 TRI and Nordic Added Value

The concept of Nordic added value has been discussed since the 1990s. In the wake of Denmark, Sweden and Finland all joining the EU, the discussion arose concerning what the value of continued Nordic regional cooperation would be, and if it still had a role to play. Answers in the affirmative to these questions gave birth to the term *Nordisk Nytte*, and to Nordic added value (NAV).

There is no clear definition of the concept, but it is commonly agreed that this NAV somehow exists in the mid-range between national and EU competences and can be brought about through initiatives or activities that are best and most efficiently carried out in a Nordic context. A Policy Brief to NordForsk from Technopolis Group showed that international networks are beneficial both in terms of cost sharing and knowledge production.[2] Certain research topics are too complex and wide-ranging for a single country to address on its own and well-functioning infrastructure is a major driver of research cooperation. Such cooperation may create added value in the long term, although this is not always visible from a short-term perspective. The final report of the ongoing evaluation of TRI derived NAV from the empirical evidence collected.[3]

Technopolis Group has described and elaborated on the concept of NAV before in reports to Nordic funding organisations. NAV is a core criterion against which the relevance, efficiency, effectiveness, impact and sustainability of Nordic Innovation's activities is judged. Added value is often used to justify the need for an intervention at European, Nordic, transnational, inter-regional and cross-border levels.

At European level, the concept of European added value (EAV) is routinely mentioned in policy texts and used as an evaluation criterion.[4] According to the European Commission,[5] added value "*is best defined as the value resulting from an EU intervention which is additional to the value that would have been otherwise created by member states alone*". The Commission tests the added value of proposed expenditure in all policy areas when making its proposals for the EU budget.

A strict economic interpretation of EAV should be avoided; instead "operational added value or enhanced visibility of the EU as well as increased support for the European integration project that provides 'political added value'" should be considered.[6] In the framework of the EU's Cohesion Policy, several types of added value were identified.[7] These include:

- Cohesion added value: with regard to the net macroeconomic effect on Europe
- Political added value: in terms of making a territory more politically visible
- Policy added value: for integrating a strategic dimension in programme outcomes
- Operational added value: through vertical and horizontal governance linkages
- Learning added value: promoting learning and innovation via programmes

[2] Arnold, E, Melin, G, Jansson, T et al. (2011): Enhancing the Effectiveness of Nordic Research Cooperation.

[3] DAMVAD (2014): Final Report from the Ongoing Evaluation of the Top-level Research Initiative.

[4] See also Rand Europe (2013) The European Added Value of EU Spending: Can the EU Help its Member States to Save Money? Exploratory Study. Bertelsmann Stiftung: Gütersloh

[5] European Commission Staff Working Paper: The added value of the EU budget SEC(2011) 867 final (29.6.2011) http://ec.europa.eu/budget/library/biblio/documents/fin_fwk1420/working_paper_added_value_EU_budget_SEC-867_en.pdf

[6] Rubio, E. The "Added Value" in the EU Budgetary Debates: One Concept, Four Meanings, Policy Brief: Notre Europe 28, 1 – 6, 2011

[7] Bachtler J. and Taylor, S. (2003), "The Added Value of the Structural Funds: A Regional Perspective", IQ-Net Thematic Paper on the Future of the Structural Funds, Glasgow.

A sixth type can be added, territorial added value, which targets the territorial specificities of the programme area (e.g. the Nordic countries) and contributing to a greater territorial cohesion.[8] In the context of European territorial cooperation addressing common problems together allows for a more efficient use of public resources and circulation of ideas and good practices. The added value lies in the fact that it offers possibilities for joint action which are needed to address challenges that increasingly cut across national/regional boundaries. The EAV concept is very similar to the NAV concept. NAV is present in:[9]

- activities that otherwise could be undertaken at the national level, but where concrete positive effects are achieved through common Nordic solutions
- activities that demonstrate and develop Nordic solidarity
- activities that increase Nordic capabilities and competitiveness

In addition, the expected results of Nordic initiatives should not be more efficiently achievable via national or European-level action.[10] In the case of TRI, NAV *is created when cross-border cooperation between organisations generates more value than would be the case by only working nationally*.

The background to the TRI in itself created clear opportunities for NAV. It was a top-down initiative championed by the Prime Ministers of the five Nordic countries and had thus very strong political backing. The size and scope of the initiative (heralded as “the largest joint Nordic research and innovation initiative to date”) gave reasons to expect good harvests in several scientific areas of joint Nordic strength and interest – thus, NAV could be identified and hoped for.

The NAV of the TRI could be described the following way. By combining expertise and resources and giving support to outstanding researchers, the projects funded through the programme strengthen top level research groups, innovation ability and competitiveness in key areas for the Nordic countries. This would lead to added values such as

- Network building
- Cost sharing
- Knowledge production
- Enhanced Nordic unity in research and a developed Nordic research profile
- Reduced fragmentation of the Nordic research system

The realisation of these NAVs would open the doors for opportunities to develop a platform on which Nordic stakeholders could achieve a more visible profile on the European and global markets. These added values would obviously not all appear in all projects being funded, but in different configurations and degrees depending on the type of project and its implementation. Closer coordination and collaboration between the three Nordic organisations NordForsk, Nordic Innovation and Nordic Energy Research would constitute another added value, and a sustainable side effect of the initiative.

The respective sub-programmes in TRI do not specify what NAV they aim to achieve. However, given what is specified in call texts and on the sub-programmes’ websites, it is possible to formulate what NAV can be expected. This must be done with respect to what type of projects each sub-programme supports; sub-programmes that support Integrated Projects can be expected to result in NAV of a more market-oriented character compared with sub-programmes that support NCoE. The expected NAV is specified in Figure 2 for each sub-programme.

[8] Hörnström L., Smed Olsen L. & Van Well L. (2012) Added Value of Cross-Border and Transnational Cooperation in Nordic Regions, Nordregio Working Paper 2012:14

[9] Nordiska Rådet och Nordiska ministerrådet, Nordiskt samarbete i en ny tid. Det nordiska samarbetet i ljuset av folkomröstningarna om EU-medlemskap för Finland, Norge och Sverige, Copenhagen: Nordiska Rådet och Nordiska ministerrådet, 1995

[10] NordForsk Policy Briefs 3–2011, Rethinking Nordic Added Value in Research

Figure 2 Nordic added value by evaluated sub-programme

Sub-programme	Objective (from call text, website, etc.)	What type of NAV is this sub-programme expected to generate
Effect studies and adaptation to climate change	• To improve knowledge about society's capacities for adaptation, and the risks and opportunities that the effects of climate change may bring the Nordic region	• Increased scientific quality, efficiency, competitiveness and visibility of Nordic research in the area through enhanced collaboration between Nordic countries: – Network building – Cost sharing – Knowledge production – Enhanced Nordic unity in research, a developed Nordic research profile – Reduced fragmentation of the Nordic research system
Interaction between climate change and the cryosphere	• To strengthen the international competitiveness of Nordic climate research and increase cooperation between academia, industry and public authorities to meet future climate change	• Increased scientific quality, efficiency, competitiveness and visibility of Nordic research in the area through enhanced collaboration between Nordic countries – Network building – Cost sharing – Knowledge production – Enhanced Nordic unity in research, a developed Nordic research profile – Reduced fragmentation of the Nordic research system
Energy efficiency with nanotechnology	• To improve the efficiency of future sustainable energy systems by applying nanotechnology to the transport sector, energy conversion and energy use	• User-driven development of sustainable energy solutions enabled by nanotechnology approaches for commercialisation • Enhanced Nordic cooperation and augmented society – industry - academia interaction and international involvement: – Network building – Knowledge production – Enhanced Nordic unity in research, a developed Nordic research profile
Integration of large-scale wind power	• To promote the development of new, innovative and sustainable forms of wind energy and improve the integration of wind power • To enhance the development of Nordic R&D institutions and business within the wind energy field. • To contribute to promoting the Nordic countries in a global context	• Consolidated and developed Nordic knowledge base in wind energy technologies • Nordic user-driven research projects with strong user involvement in the knowledge creation and diffusion throughout the project cycle: – Network building – Knowledge production – Enhanced Nordic unity in research, a developed Nordic research profile
Sustainable bio-fuels	• To promote the development of new, innovative and sustainable forms of bio-energy • To enhance the development of Nordic R&D institutions and business within the bio-energy field	• Collaborative integrated research projects focusing on technological bottlenecks and exploring new opportunities leading to innovative breakthrough technologies: – Network building – Knowledge production – Enhanced Nordic unity in research, a developed Nordic research profile
CO2 – capture and storage	• Create synergies and efficiency through an overview of ongoing national activities and priorities • Facilitate cooperation between stakeholders; industry, researchers and policymakers	• Network building • Enhanced Nordic unity in the field • Reduced fragmentation of the Nordic research system

Source: Technopolis Group, based on TRI sub-programme documents and website.

3 Results and impact

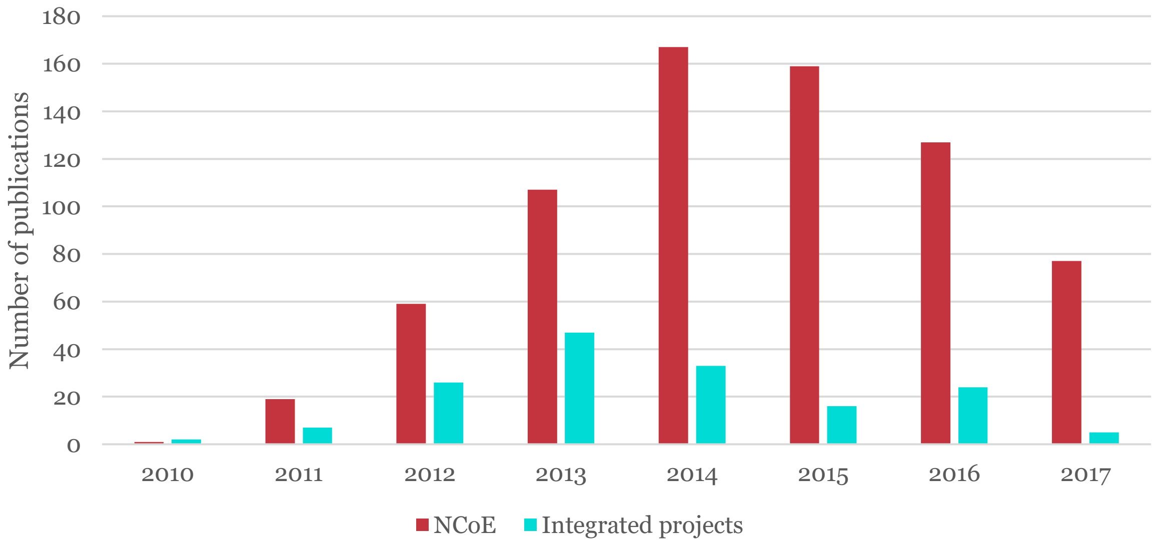
This chapter presents the empirical material which reflects the results and impact of the TRI. At the outset of the chapter, the bibliometric analysis, an estimation of related research grants, and an estimate of the mobility of former PhDs are presented. The remaining data and findings on impact are presented in separate headings depending on the type of impact; *The impact of the TRI for Nordic industry, The impact of TRI for Nordic research organisations, Impact of the TRI for Nordic society* and *Impact in Nordic countries*. The indicators used to identify impact of the TRI are based on the Nordic Added Value intervention logic; lasting Nordic collaboration, value creation, visibility and competitiveness of Nordic research organisations for international consortia, and influence on stakeholders outside the scientific community. The data underpinning the sections are mainly derived from the survey results, self-assessments and case studies.

3.1 Scientific quality and impact

Some 747 publications were identified from the projects' own reporting, spanning the period from 2010 to 2017. The number of publications varies considerably between the different projects. For example, the CRAICC project reports 158 publications, and the BioENG project only three publications. There is a considerable lag in the process of publishing scientific papers; researchers continue to publish results several years after the project has ended and the final report has been submitted. We were also not able to retrieve complete publication lists for all projects. These two factors called for additional measures to identify TRI publications. In order to retrieve additional publications linked to the various projects the Web of Science database was searched for both the publications reported by the projects and publications in which projects are listed according to funding sources. This procedure increased the number of publications attributed to the various projects from 747 to 880. The annual distribution of retrieved publications can be viewed in Figure 3. It should be noted that some of the publications are shared by two or more projects. Especially CRAICC and DEFROST have several publications in which authors are funded by both projects.

Figure 3 clearly shows the difference in publication patterns between projects funded through the NCoE instrument and the Integrated Projects. As mentioned above, researchers continued to publish scientific results derived from TRI projects in 2016 and 2017 although all projects were terminated, thus illustrating the time lag in the publishing process.

Figure 3 Annual distribution of publications from TRI projects.



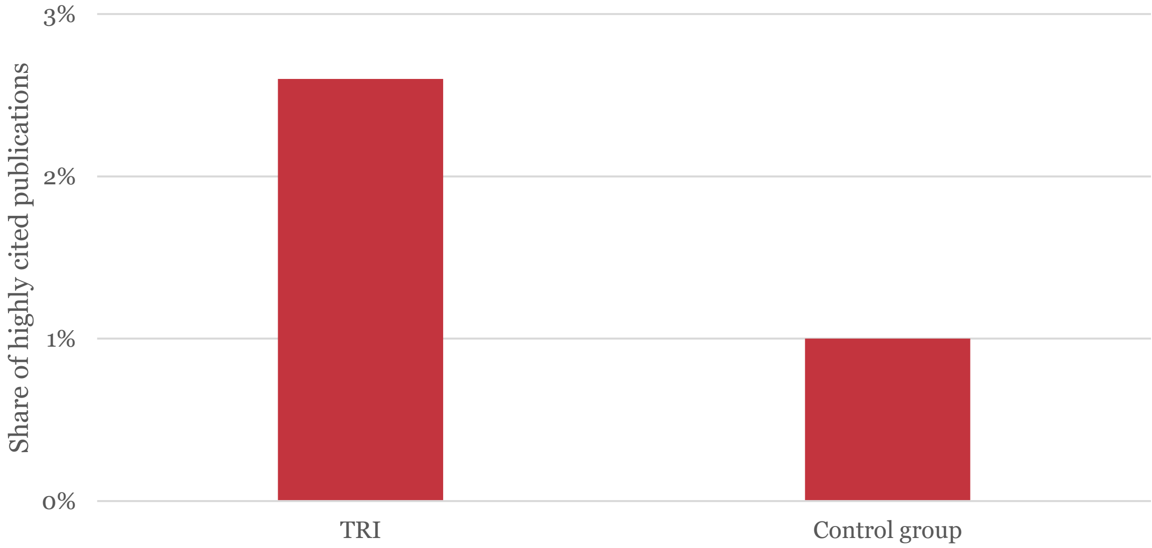
Source: Web of Science

3.1.1 Impact of publications

Two types of indicators were used to investigate the impact of research. Articles with very high impact were identified using the so-called top 1 per cent indicator. The highly cited threshold is the minimum number of citations received by the top 1 per cent of papers in a specified year and in a specific research area. The second indicator is the Source Normalised Impact per paper (SNIP) indicator, which represents the state of the art among journal indicators. The SNIP value was calculated for not only journals, but also for conference series and some book series covered by Web of Science. The SNIP indicator adjusts for differences in publication behaviour in different research fields, thus enabling comparisons of impact of journals in different fields. These two indicators complement each other in describing the quality of both the top performers and in general across the entire population of publications.

To measure the impact of research produced in the TRI projects, the TRI publications were compared to a control group. For the highly cited indicator the control group was a set of publications published the same year within the same research area. The 1 per cent indicator for highly cited papers has an expected value of 1 per cent, i.e. the performance of TRI publications in terms of "citedness" is compared to the "citedness" in the research area in general, to investigate if more or less than 1 per cent of the TRI publications belong to the top 1 per cent highly cited group in the research area. Out of all TRI papers there are 23 highly cited papers (cited more than the top 1% in the control group) for the period 2010–2017. Since 23 publications in a set of 880 publications is approximately 2.6 per cent, the share of TRI papers in the top 1 per cent highly cited papers is 2.6 times higher than the expected value, see Figure 4.

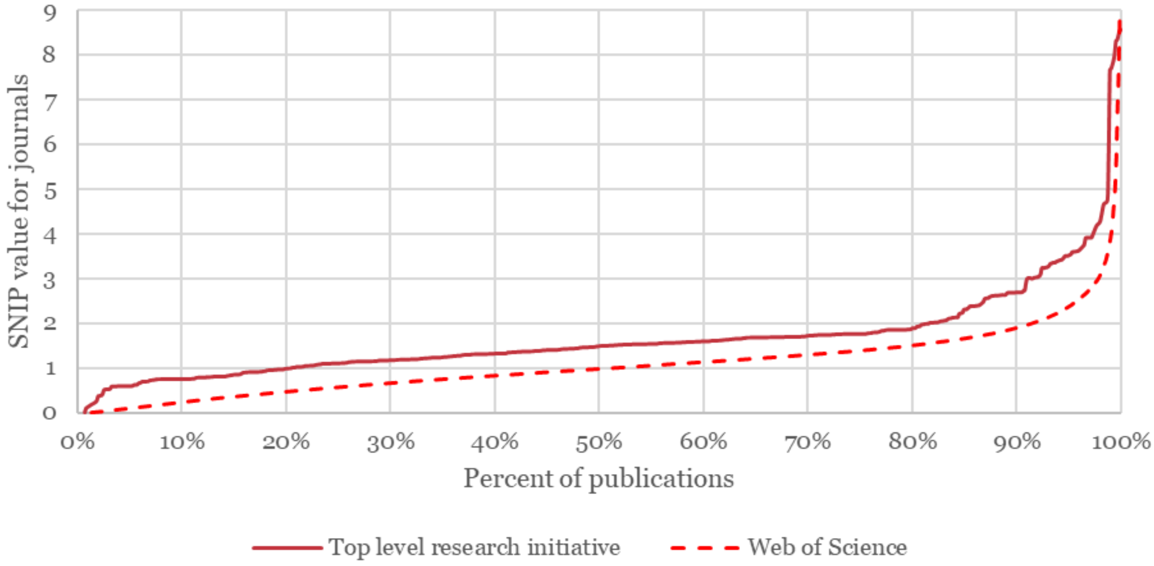
Figure 4 Share of highly cited publications among publications deduced to TRI compared to the control group.



Source: Web of Science

Figure 5 displays depicts a line of all TRI publications' SNIP values, compared with all publications in that research area in Web of Science (the control group). The x-axis represents share of publications and the y-axis represents their SNIP values. If drawing an imagined vertical line straight up from the 50 per cent point to the point where this vertical line meets the lines for TRI and Web of Science respectively, the value on the y-axis is the median SNIP value. The conclusion is that publications from TRI tend to be published in journals with higher impact than the average publication within the research area. The average TRI publication has a significantly higher SNIP value compared with the control group (all publications in Web of Science). In the control group, 50 per cent of the publications have a SNIP-value below 1, and 50 per cent a value above 1. Among the TRI publications, the SNIP value of 1 is achieved already at the 20 percentile, meaning that 80 per cent of all TRI publications have a higher SNIP value than 1.

Figure 5 Distribution of TRI publications (journals or proceedings) with respect to the SNIP value, compared to the control group.



Source: Web of Science

In short: The bibliometric analysis shows that TRI projects have produced scientific publications that are more cited in high-end journals than would be expected from a statistical viewpoint. The TRI projects produced more high-end scientific publications, and also a broader base of high-end publications.

There is considerable variation in publication volume between the projects. Publications from the most productive groups constitute a substantial part of all publications, and NCoE projects account for the overwhelming majority of publications. The average number of citations per publication is however higher in Integrated Projects compared to NCoE. At the same time, the share of top 1 per cent publications is equal among publications from NCoE and Integrated Projects. The average SNIP value is the same for Integrated Projects and NCoE.

The two most productive projects have produced 13 of the 23 highly cited publications. The DEFROST project stands out, with a particularly large number of highly cited publications.

3.2 Related additional research funding

Another indicator of the impact of the TRI is the amount of related additional funding for subsequent projects. In the self-assessments, the project leaders were asked to report all new research grants (exceeding €40,000 in total project budget) which were enabled by the TRI project. The results are displayed in Table 2.

Table 2 Additional funding of TRI-projects, by sub-programme

Sub-programme	*Total TRI funding (m€)*	*National related research grants (m€)*	*Nordic related research grants (m€)*	*EU related research grants (m€)*	*International related research grants (m€)*	*Total related research grants (m€)*
Effect Studies and adaption to climate change	14	7	5.1	4	-	16.1
Interaction between climate change and the cryosphere	14	21.7	2.6	9.2	0.2	33.7
Energy efficiency with nanotechnology	7.3	8.6	-	2	-	10.6
Integration of large-scale wind power	4.2	0.3	-	4.8	-	5.1
Sustainable bio-fuels	4.2	5.8	-	1.7	-	7.5
CO2 – capture and storage	5.6	0.5	-	-	-	0.5
Total	**49.3**	**43.9**	**7.7**	**21.7**	**0.2**	**73.5**

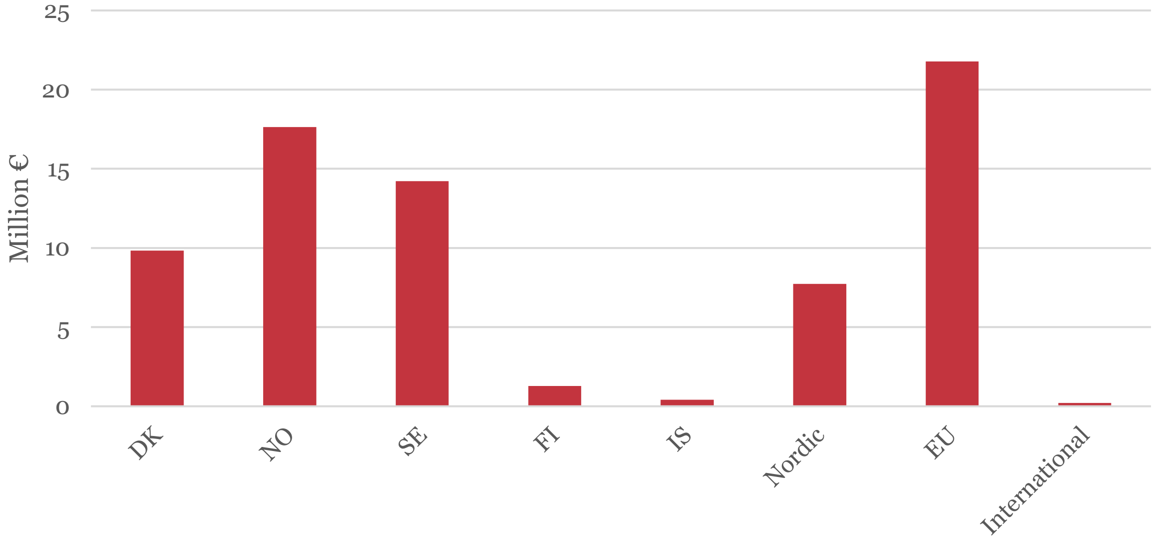
Source: "Riktlinjer för utformning och implementering av toppforskningsinitiativet inom klimat, energi och miljö" and self-assessments.

The information on additional funding resulting from the projects include several caveats. Firstly, it is of course difficult to determine the additionality of the TRI to these subsequent research grants, in terms of the extent to which the TRI project enabled the researchers to secure the additional grants, and which grants that would have been awarded to them anyway. It is also difficult to determine how the TRI influenced researchers to continue to apply for funding of projects further exploring the topics of TRI, perhaps in a Nordic or international project, instead of choosing an alternative path of another topic. The second caveat is that the self-assessments were completed by the project managers. In some cases, the project managers asked for information from other project participants, but we are aware of several cases where we are restricted to the (limited) knowledge of the project manager on what happened after the TRI project was terminated. We can therefore assume that the information in the self-assessments (and especially regarding additional funding) is incomplete and somewhat biased towards the research environments that led the TRI projects.

In any case, the self-assessments show additional research funding reaching an amount of at least €73.5m, which is close to 150 per cent of the total budget of the programme. A large part of the additional funding comes from national public sources. Some of the case studies and the interviews indicate that additional funding opportunities from Nordic institutions were few or difficult to get; the fact that additional research funding from Nordic institutions represents only some 10 per cent of the total additional funding – and is present in projects from only two of six sub-programmes – suggests that additional Nordic funding opportunities were rather scarce.

TRI largely funded already established research and researchers, and this was also the purpose from the start. This enabled research collaborations that would otherwise not have been possible. The empirical data also indicate that existing cross-border research collaborations were strengthened, and in several cases included research partners formerly not part of the network. Figure 6 shows the distribution of additional funding per Nordic country of origin, plus from the Nordic countries and from the EU.

Figure 6 Source of additional funding reported in TRI project self-assessments.



Source: TRI projects' self-assessments.

3.3 Education of PhDs

The TRI contributed to the training of at least 81 PhDs. The PhDs were identified through project reports (when this information was available). The project leaders were asked to confirm/supplement the list of PhDs, as well as to provide information about their current employer. As discussed previously, the self-assessments should not be considered a comprehensive data source – there are several cases where the project leader is the only informant. This means that the number of PhDs identified is a minimum – the TRI contributed to the education of *at least* 81 PhDs. Table 3 presents the number of PhDs per sub-programme.

Table 3 Identified PhDs trained within a TRI project, per sub-programme.

Sub-programme	***Same faculty***	***New faculty***	***Institute***	***Company***	***Public administration***	***Other/unknown***	***Total***
Interaction between climate change and the cryosphere	9	7	8	1	4	8	37
Sustainable biofuel	1	1	0	3	0	1	6
Integration of large-scale wind power	2	0	0	5	0	0	7
Effect Studies and adaption to climate change	9	5	3	0	3	1	21
Energy Efficiency with Nanotechnology	3	2	0	2	0	3	10
CCS	0	0	0	0	0	0	0
Total	**24**	**15**	**11**	**11**	**7**	**13**	**81**

Source: Self-assessments.

An additional scanning of ResearchGate, LinkedIn and university websites was carried out in order to obtain a fuller picture of where the former PhD students are today. In 3.6.1 we return to the question of mobility.

3.4 The impact of the TRI for Nordic industry

This section discusses the impact of the programme on industry. It distinguishes between impact in terms of lasting collaborations for industry partners and value creation. As mentioned before, the Integrated Projects included industry partners. The Integrated Projects operated under four of the six sub-programmes: *Energy Efficiency with Nanotechnology, Integration of large-scale wind power, Sustainable biofuels,* and *CCS*. The projects with industry partners were *Enesca, SOFC, TopNANO, NANORDSUN, IceWind, Offshore DC, OSR Nordic, SusBioFuel, HG Biofuels, NORD-SYNGAS, BioEng*, and *NORDICCS*.

3.4.1 Increased and sustainable collaborations

Results from the survey of company participants indicate that the TRI contributed to increased R&D cooperation, mainly within the Nordics.[11] The increase is most evident regarding cooperation with Nordic research organisations. Fourteen of the eighteen respondents agree or strongly agree that participation in the TRI project established or strengthened cooperation with Nordic research organisations. The TRI projects contributed to a more limited extent to increased cooperation with other Nordic companies. Some respondents agree that the TRI contributed to cooperation with research organisations or companies outside of the Nordics, whereas about as many disagree. One respondent mentioned that the TRI project increased their network, and others think that the TRI project improved their communication, collaboration, and discussion – for example through participation in PhD dissertation committees.

The self-assessments and case studies of Integrated Projects reveal more in-depth information about the impact of the TRI on collaboration for company partners, about its level of intensity and sustainability. Participation in the TRI project clearly contributed to new contacts and partnerships for the company partners. These are some examples:

- Through the IceWind project, company partners (as well as research partners) became involved in the international expert group IEA task 19. The value of the partners' knowledge of wind energy in cold climates was confirmed by a Canadian research partner from the expert group.
- The Enesca project contributed to new contacts, through the uptake and use of the research results by the external company BillerudKorsnäs, which is now developing the research results in collaboration with the project partner Uppsala University.
- The results of HG Biofuels attracted external actors and were the basis for new contacts and collaborations; one of the Swedish company partners, SEKAB, is currently developing the project results in a plant together with the Swedish research institute RISE. HG Biofuels also enabled SEKAB to participate in an EU project where they potentially got opportunities to establish new contacts with other companies and research organisations.
- The NANORDSUN project enabled one of the company partners to participate in an EU-funded project with new French and Dutch partners.
- The NORDICCS project enabled several crucial contacts by bringing the Nordic CCS actors (industry and research organisations) together.

Regarding the sustainability of collaboration for company partners, it seems that lasting collaborations between industry and academic partners occur where there is potential for further value creation. For example, the IceWind project produced a model for icing forecasts which was implemented in the company partners' daily operations, and according to an interviewee from Vestas, the project was a role model example of value creation. The contact between the partners in IceWind is still live.

[11] The survey was sent out to 54 contacts and generated 18 responses. Response rate: 33%.

Although the partners have not been able to secure funding for a new collaborative project, they keep in contact and await potential funding opportunities for more joint projects, as both research and industry see potential to further develop the forecast model jointly.

The partners from NORDICCS are also motivated to continue their collaboration. The members of the consortium keep in contact in wait of an opportunity to continue joint R&D projects. The partners in the project see clear benefits with sustaining the Nordic team. In Sweden and Iceland, CCS technologies had been low on the public agenda for several years, but as interest is currently rising regarding CCS technologies for industrial processes (iron, steel, cement, refineries), the CCS network created in the project creates a potentially important platform for participating industry partners.

The industry partners in HG Biofuels and NANORDSUN have had incentives to continue working at national level. In NANORDSUN, the project results opened up new interesting fields of R&D for company/research organisations separately, in their respective countries. The academic partners continued working on Nanotech-based light, and the industry partners pursued the research results related to nano solar technology. In HG Biofuels, the research results have mainly been pursued by the Swedish industry partner SEKAB, in collaboration with the Swedish research institute RISE (from outside the project).

The Danish industry partner in HG Biofuels was not able to pursue the R&D due to lack of profitability. Similarly, the project leader from TopNANO explained that the TRI project did not enable technological advancements sufficient for further Nordic collaboration; due to the complexity of the area and the small-sized industry actors, solutions must be highly profitable in order to attract further investments.

3.4.2 Value creation

There are examples where the Integrated Projects had an impact on the development and application of scientific methods for participating and external companies:

- The NANORDSUN project enabled the Swedish industry partner Sol Voltaics to patent technologies based on the TRI project. Two patents on nanowired solar cells have been registered by the solar power company, although the technology has not yet been commercialised. However, an interviewee from the project explained that the technology is used to improve industry processes. Sol Voltaics has been able to use results relating to aerotaxy growth of nanowires, which is a new method for growing semiconductor nanowires without involving a substrate.
- The NANORDSUN project also enabled the establishment of a spin-off company, located in Trondheim. The company has eleven employees and a revenue of €183,000. It uses the NANORDSUN research results on nanowire growth on graphene substrates.
- The Enesca project created results with potential for commercialisation. The project rationale was to develop and industrialise a salt-and-paper battery, using a new organic material for energy storage devices, based on organic materials, polypyrrole and cellulose, operating in salt containing aqueous electrolytes. Uppsala University has been granted a patent for a technology called *A composite material in the form of a continuous structure comprises an intrinsically conducting polymer (ICP) layer coated on a substrate.* Moreover, a Swedish company focused on development of materials and packaging solutions picked up the research results and is now cooperating with Uppsala University to develop energy storing materials, which the company hopes to commercialise. A possible usage would be to equip packaging products with sensors, in order to enable consumers access to relevant information on their goods.
- The Finnish academic partner from TopNANO is in the process of applying for a patent regarding a two-mode ice adhesion tester based on scientific results from the project. The complexity of the research area and the lack of highly profitable solutions, however, limit the possibility for investments, because the industries in the field are not large actors.
- The IceWind project embarked on a relatively unexplored area of research with high potential for value creation: the effectiveness of wind power in cold climates. Before the project, there was no

solution for predicting ice formation on wind turbines. One of the PhD projects developed a state of the art forecasting model based on metrological data, as well as an open code for estimating production loss from wind farms. The model, called IceBlade, is now used in everyday operations by the company partner, which continues to invest in R&D related to wind power in cold climates. According to interviewees from the project, all major actors in the industry are using the model, and some additional companies are in contact with the former PhD candidate for consultations on how they can implement it.

- The profitability of the IceWind research results is also proven by the establishment in 2014 of a spin-off company by two researchers from IceWind's academic partner. The company provides wind turbine ice prevention systems to customers worldwide. It had two employees and €469,000 in revenue in 2015.

The survey distributed to the companies participating in the TRI also addressed the perceived effects of the programme on the respondents' respective organisations. Thirteen of the eighteen respondents agreed that the TRI contributed to improved scientific or technical skills of employees, and implementation of new knowledge, methods or technology in internal processes in their organisation. When asked about contribution to commercialisation of new or improved products or services, however, only four respondents agreed and six found the statement not to be applicable to their organisation. Other examples of impact that the TRI project has had on the companies include increased awareness of the Nordic region, sharpened internal R&D strategy in the area, strategic decision making and awareness of new technology and application.

There is a clear difference in how the respondents assessed the impact of projects with mainly private funding and projects including public funding. Eleven respondents agreed or strongly agreed that the TRI contributed to participation in a subsequent R&D project co-funded by a public funding body. When the same question was posed regarding internal R&D project with mainly private funding, eight of eleven respondents disagreed or strongly disagreed that TRI contributed to this.

3.5 The impact of TRI for Nordic research organisations

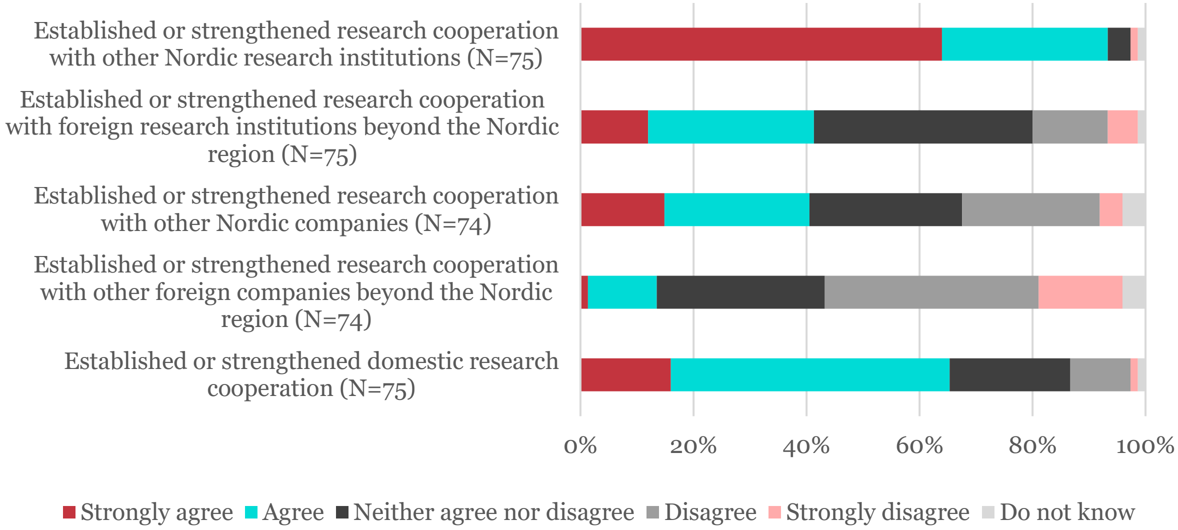
This section deals with the impact of the TRI for Nordic research organisations. The section distinguishes between impact in terms of lasting collaborations for research partners and visibility and competitiveness of Nordic research organisations in international consortia.

3.5.1 Increased and sustainable Nordic research collaboration

As Figure 7 shows, a clear majority of the surveyed researchers participating in the TRI indicate that the programme contributed to establish or strengthen research cooperation with other Nordic research institutions; 64 per cent of the respondents strongly agreed while 29 per cent agreed.[12] The view concerning cooperation with companies is in great part explained by the fact that a large share of the respondents were involved in NCoE, which did not have industry partners. Many respondents (49 respondents; 65%) agreed or strongly agreed that the programme contributed to domestic research cooperation. Only ten respondents (13%) agreed or strongly agreed that the TRI contributed to research cooperation with foreign companies beyond the Nordic region.

[12] The survey was sent out to 180 contacts and generated 75 responses. Response rate: 42%.

Figure 7 To what extent participation in The TRI project contributed to increased R&D for your organisation.



Source: Survey of project participants from research institutions.

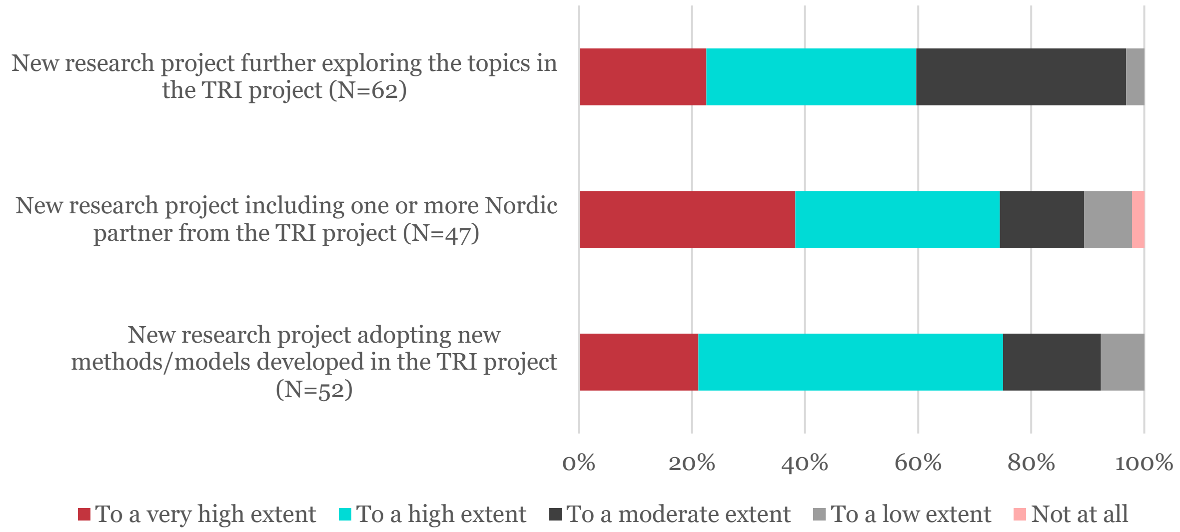
The indication of an increased cooperation in general and between the Nordic research institutions in particular is further corroborated by the examples given in the open questions. Many respondents perceived the TRI to have a positive effect on Nordic cooperation within their field. One of the respondents wrote:

> *We have established better connections to our Nordic partners and this has improved our research environment so that we are more international and more easily make joint activity and joint discussions about future projects. We have also established closer links in the PhD education and established courses that can be used in the years to come at several Nordic universities.*

Other examples of increased Nordic research collaboration include increased data sharing, researcher mobility, increased communication and, although less frequent, sustained cooperation with industry actors.

Some 65 per cent of respondents said that TRI contributed to a new research project further exploring the topics of the TRI project, and 49 per cent said that methods or models developed in the TRI project were adapted in subsequent projects. Furthermore, 45 per cent said that TRI contributed to a new project including one or more of the Nordic partners from the prior TRI project. The extent of the TRI projects' contribution to these outcomes and results is shown in Figure 8. A convincing majority of the project participants believed that their TRI project was important in order to achieve these outcomes.

Figure 8 To what extent TRI enabled new research and research collaboration in subsequent projects.



Source: Survey of project participants from research institutions.

The bibliometric analysis shows clear differences between NCoE projects and Integrated Projects. As shown in Table 4, there are differences with respect to the number of publications, the number of authors per paper, the number of organisations per paper, the number of countries per paper, and the share of internationally co-authored papers.

Table 4 Differences between NCoE projects and Integrated Projects.

Instrument	*Publications per project*	*Authors per paper*	*Organisations per paper*	*Countries per paper*	*Percent internationally co-authored*
NCoE	119.3	7.2	4.2	2.7	71 %
Integrated Projects	13.8	4.8	2.2	1.6	46 %

Source: Web of Science

The analysis also revealed two distinct collaboration formations, both referring to NCoE:

- Aarhus University and Stockholm University
- Technical University of Denmark and University of Oslo

The self-assessments and case studies show that the intensity and sustainability of collaboration based on the TRI vary between projects. Some consortia (full or parts) had cooperated prior to the TRI project (e.g. SVALI, Tundra), while for some, the TRI project enabled a new composition of actors (e.g. NorMER, IceWind, NORDICCS). None of the projects has been able to secure funding for subsequent projects with the full consortia, although several have submitted joint proposals, e.g. NORDICCS and IceWind. The partners from NORDICCS applied to the Nordic Energy Research for a Flagship Projects grant, which reached the final stage but was ultimately not successful. The IceWind partners have not had success with subsequent funding either, although they have applied for EU funding for several projects.

The research organisations involved in NORDICCS as well as IceWind and SVALI have submitted proposals for new joint research projects but have not been successful. The project teams do not have any current joint activities, but they are ready to gather the consortia if or when a funding opportunity arises.

The project leaders and interviewed researchers indicate that difficulties with obtaining funding for international projects mean that it is at national level (includes academy-academy and academy-industry) that the more intensive and deep collaborations exist. This is also clear from Table 2, on additional funding – the majority of related research grants come from national sources. An example of strengthened national collaboration is found in NORD-STAR. The project results enabled continued collaboration between the partners Chalmers and Stockholm Environmental Institute (SEI), through a grant from the Swedish research council Formas. The Swedish partners in HG Biofuels have also secured funding from Formas, which strengthened their continued collaboration.

However, there are several examples of *potential* international collaborations between research organisations. For example, a survey respondent from NTNU said that the CRAICC project enabled collaboration between researchers from University of Helsinki and NTNU, and that they are currently trying to find ways to continue their joint efforts. Participants from Chalmers and University of Copenhagen collaborated for the first time in the project HG Biofuels, and they have also applied for several new projects to continue their collaboration.

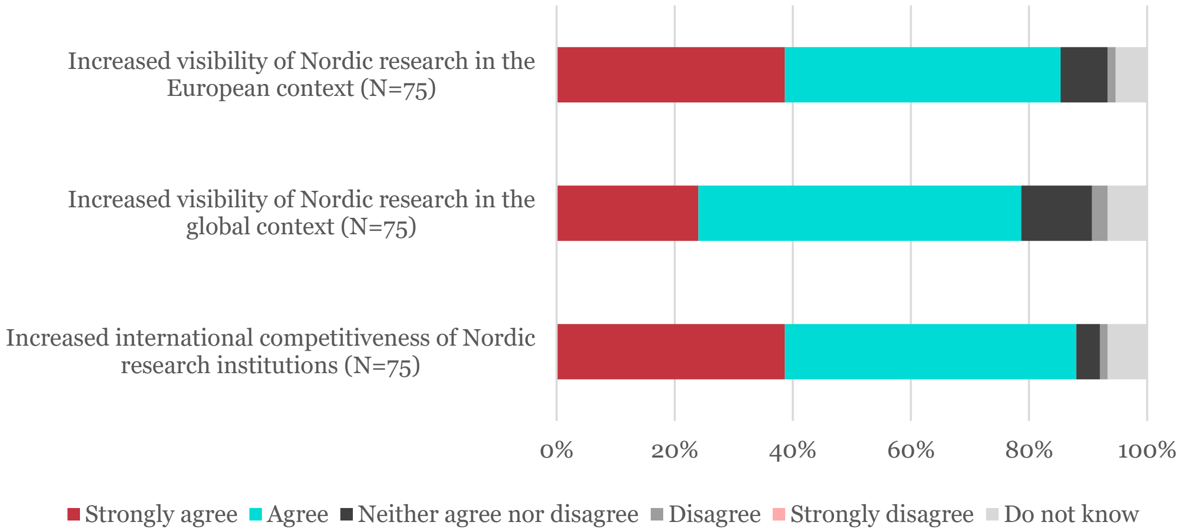
Some de facto international collaborations are also identified. These collaborations have been able to secure funding for subsequent projects, mainly funded by Nordic or EU sources. An example is Offshore DC, which enabled the participation (and coordination) of EU-funded projects including both academic and industry partners from different Nordic countries. Tundra is an example of a project where postdoc researchers from several Nordic countries continued their cooperation with Nordic funding in the NCoE ReiGN.

There are three examples of collaboration between universities through PhD training. Within the scope of the projects SVALI and NORDICCS, graduate schools were established. In SVALI, courses were established and are currently ongoing at the partner universities. In NORDICCS, a summer school was established which will continue if the partners find ways to fund it. In HG Biofuels, the researchers lecture at PhD courses at each other's universities.

3.5.2 Visibility and competitiveness of Nordic research organisations

A large majority of the respondents (66 answers, 88%) agreed or strongly agreed that the TRI contributed to increased international competitiveness of Nordic research institutions. Most of the respondents agreed or strongly agreed that the TRI contributed to increased visibility, both in a European and a global context (86% and 79% respectively) (Figure 9).

Figure 9 Question: To what extent do the following statements reflect the contribution of the TRI?



Source: Survey of project participants from research institutions.

The self-assessments and case studies describe several examples of related research projects in EU consortia, which were enabled through the TRI. Some projects have been especially successful regarding participation in EU-funded activities, e.g. Offshore DC, SusBioFuel and DEFROST. The project leader of SusBioFuel reported four related research grants within the FP7, and the project leader of DEFROST confirmed that there are at least two grants which have been enabled by the project (also within FP7).[13] The project leader of Offshore DC (at DTU) reported three EU projects which were enabled by the TRI; two Marie Skłodowska-Curie Initial Training Networks about multi-terminal DC grids where DTU is a participant organisation, and Cardiff University is the coordinating partner. One is ongoing; MEDOW, including other European and non-European universities, as well as an industry partner. The other training network – InnoDC – is still open for applications. The third EU project, PROMOTioN, is funded through Horizon 2020. It focuses on advancing innovation and technologies relevant to the deployment of meshed HVDC offshore grids. Several project participant organisations from Offshore DC participates; ABB, DTU, Energinet, and Dong. The project also includes other Nordic companies and research organisations; KTH, Svenska Kraftnät, Statoil, Vestas and Scibreak.[14] PROMOTioN is a project involving a total of 30 partners in 11 European countries – 11 academic partners, 16 company partners, one public body partner and three "other".

The research results from the TRI have also been the basis for involvement in global initiatives. Academic partners from IceWind (Sweden and Denmark) contributed with knowledge, especially regarding the earlier-mentioned model for wind turbine icing forecasts, to the international expert group IEA task 19, on cold climate and wind power. Participation in the expert group also involved presentation at the IEA conference, with participants from all over the world. The NORDICCS project results were picked up by and used in Mission Innovation (MI), a global initiative of 22 countries and the EU, to dramatically accelerate global clean energy innovation. In particular, the collaborative constellation and how it was carried out have attracted interest.

As described earlier, the NCoE had substantial scientific impact and have contributed to Nordic competitiveness, an enhanced unity in research, and development of a Nordic research profile. Especially DEFROST stands out with strong production of high impact publications. Another example of how the TRI has raised the competitiveness of Nordic research organisations is that as a result of the

[13] The project leader explains that he does not have a full overview of related research grants, and that it is likely that individual WP leaders have been able to secure even more funding based on the project results.

[14] https://cordis.europa.eu/project/rcn/199016_en.html

TRI project SOFC, Chalmers has become world leading in the area of Co/Ce Nano coating, in terms of publications and output.

However, several interviewees mention that more Nordic programmes like TRI are needed in order to further develop the research results and consolidate the collaborations.

3.6 Impact of the TRI for Nordic society

Impact can be distinguished as first-order effects and second-order effects. First-order effects are defined as such effects that could be expected to appear in the short to mid-long term (2–5 years). Second-order effects are defined as such effects that could be expected to appear in the long term (five years or more).

The TRI addressed societal challenges through its focus on climate and energy related issues. Evidence of societal impact is, however, relatively limited. The indicators *PhD mobility* and *influence on stakeholders outside of the scientific community* cover what is found in terms of societal impact – in its general and potential form. Second-order effects, such as substantial policy impact and development of a platform for Nordic stakeholders (on which they can achieve a more visible profile on European and global markets), are not evident at this point in time.

3.6.1 Mobility of researchers

The mobility of researchers – PhDs in particular – implies sharing of knowledge and networks between Nordic actors. The value and impact of the mobility component is emphasised by the survey respondents:[15]

> *The opportunity for PhD students to visit other research groups outside of their country was a particularly valuable training component. The collaborative projects led by the PhD students was an excellent practice in international cooperation and research.*
>
> *Essential collaboration between our university and a partner university in Sweden; part of the experimental research was carried out in Finland and part in Sweden, but by the same PhD student.*
>
> *Workshops, co-publication, exchange of students, also after the end of TRI project.*

As mentioned in 3.3, at least 81 PhDs have had their training (co)funded by the TRI. Over 70 per cent of the recorded PhDs originate from the NCoE projects. Nearly half of all PhDs remained in the university sector after finishing their PhD training, and 15 of them changed university. The data suggest that four of these have moved to a university in another country. There are in total at least 19 cases of international mobility. Although a relatively large share of the PhDs remained at the home university, the TRI project enabled contacts and networks at a Nordic level. One of the interviewed PhDs from IceWind who stayed at the home university (DTU) described that TRI enabled what is now his professional network, and that it includes contacts with research organisations and companies in all of the Nordic countries.

Eleven of the PhDs are currently employed by companies; six are employed by companies that were involved in a TRI project, and five by external companies. These external companies are in most cases related to the project's activities, but in some cases, a certain connection is observed. One of the PhDs from Enesca is currently employed by the external company BillerudKorsnäs, which develops innovative materials for packaging. The company uses the results from Enesca on the salt and paper battery to develop material for goods packaging using nanotechnology. Another example is the mobility of a PhD from SusBioFuel, who is now working with product development at Ferring Pharmaceuticals.

[15] Open answers in survey of researchers.

Nine of the PhDs who finished their training within the NCoE CRAICC, NorMER and SVALI, are currently at research institutes in the Nordics and beyond, including institutes in Norway, Finland and Iceland, Japan, the U.S and Germany. The institutes are oriented towards meteorological research, polar research, and oceanographic research – the fields correspond to the NCoE in which the PhDs finished their training.

Eight of the PhDs who finished their training within SVALI, NorMER, NORD-STAR and CRAICC are currently employed at public administration organisations:

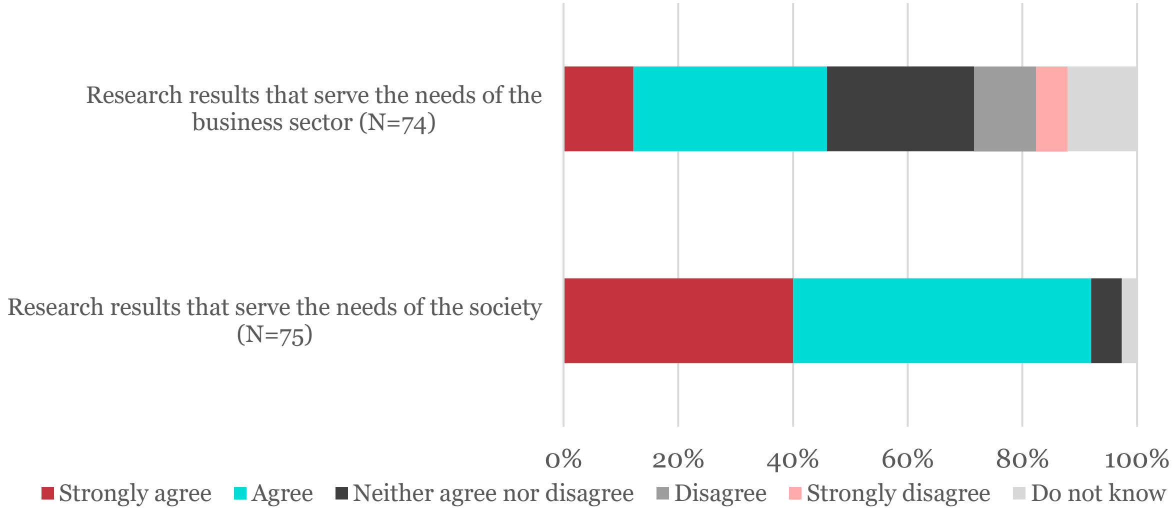
- The Finnish Environmental Administration
- The Italian National Research Council
- The Norwegian Environment Agency
- GTK geological survey of Finland – an expert organisation under Finland's Ministry of Economic Affairs and Employment
- NVE (Norwegian Water Resources and Energy Directorate)
- IMO (International Maritime Organisation)
- The Geological Survey of Denmark and Greenland (GEUS) – a research and advisory institution in the Danish Ministry of Energy, Utilities and Climate
- Environmental and Climate Change Canada

All the PhDs who continued in public administration organisations did so within the same field as their TRI project focused on. The PhDs stayed in the same country in which they finished their training, with the exception of the PhD who is currently employed by the Italian National Research Council, and the PhD employed by the International Maritime Organisation (headquarters in London). Data suggest that the mobility is concentrated to Finland and Norway, with no identified mobility to public administration in Sweden or Iceland.

3.6.2 Influence on stakeholders outside academia

When the surveyed researchers from the TRI were asked to indicate to what extent they perceive that the TRI contributed to research results that serve the needs of the business sector and society as a whole, respectively, there was an apparent bias towards the needs of society. Sixty-nine (92%) of the respondents either agreed or strongly agreed that the TRI had contributed to research results that serve the needs of society while the corresponding number for the business sector was 34 (46%) (Figure 10).

Figure 10 Question: To what extent does the following statement reflect the contribution of the TRI?



Source: Survey of project participants from research institutions.

When the same questions were posed to the participants from the companies, the same pattern between the answers can be distinguished but with a less optimistic overall view of the effects of the research results.

Several TRI projects, especially in the NCoE, had a substantial focus on dissemination activities. These were aimed at public policy actors as well as the general public. The activities have potential impact in terms of raised awareness. The Tundra produced several accessible reports in all Nordic languages with concrete advice for policymakers regarding the issue of reindeer grazing as a means to prevent shrub encroachment and woodland expansion. The project also organised many workshops, presentations (including participation at the Paris climate conference 2015), and media articles. SVALI arranged their final conference in Greenland 2015, in cooperation with the European Space Agency (ESA). Their outreach activities also included an interactive web-portal for elementary school students.[16] The activities of DEFROST were shared with public administration and politicians through frequent visits at the Greenland research centre site. However, project leaders described the complexity of environmental policy as an obstacle to impact – because it is a long-term policy issue, politicians are reluctant to prioritise it. Some interviewed researchers from the Tundra project were still optimistic; future regional policymakers around the arctic circle may take findings into account, maybe in a time frame of approximately fifteen years.

The TRI projects also created information platforms aimed at a wider audience. Two projects have web pages which are frequently used by policy actors, in public discussions, by companies and NGOs. NORD-STAR enabled the TRASE platform, which is a model to track supply chains of agricultural commodities at greater detail than was possible before – it is a supply chain transparency initiative.[17] It provides information on how companies, governments and other actors involved in the trade of agricultural commodities are linked to impact and opportunities for more sustainable production. It was developed and is supported by a research group of around ten people and is steadily growing. The platform is used by research groups, private companies and NGOs. Within the IceWind project, a wind atlas for Iceland was developed and is displayed as an interactive web tool at the web page of the meteorological office of Iceland.[18] The web tool has been important for policy discussions on wind power in Iceland, and it was used by the Icelandic national power company Landsvirkjun (partner in

[16] www.Isskolen.dk

[17] www.trase.earth

[18] http://en.vindatlas.vedur.is/

the IceWind project) as the basis for their plans on wind power regarding site selection and preselection/preliminary design criteria.

The NORDICCS project produced an atlas of the CO_2 storage potential of Nordic region. This has been used, as mentioned by Mission Innovation, and in EU projects. It also gave important input to the Icelandic project CarbFix, a collaborative research project led by the public utility Reykjavik Energy that aims at developing safe, simple, and economical methods and technology for permanent CO_2 mineral storage in basalts.

As part of the IceWind project, two experimental wind turbines were established. Due to their high level of efficiency, there are currently plans to establish wind farms in Iceland. However, the process has been stalled, mainly due to legality issues.

3.7 Impact in Nordic countries

As displayed in Table 2, the greater part of additional related research grants is awarded at national level. The majority of PhDs have stayed in the Nordics and in their countries of origin, hence there is an impact on the national research and innovation systems. The dominant national impact of the TRI on national research organisations was also evident in the case studies and self-assessments.

At national level, the TRI enabled an amount of €44m in related research grants. This evaluation has identified a total of 57 PhDs from the TRI projects who are active in the Nordic countries and in their present positions share their knowledge and networks from the TRI projects.

3.7.1 Denmark

The TRI enabled related research grants of at least €10m for Denmark. Eleven PhDs from the TRI projects have been identified who are now working in Denmark, nine in academia and two in companies. An example of a project with Danish oriented impact is the IceWind project. The project embarked on a relatively unexplored area of research, which was new to the Danish academic partner DTU – as well as the Danish company partner Vestas. As a result of the project, DTU established a new area of research – wind power in cold climate (where one of the PhD students work). The university has been able to establish collaboration with the company FORCE regarding experimental research facilities, which enables the use of the company's wind tunnel for master's candidates' thesis work. DTU was granted €300,000 from the Defence Agency of South Korea (collaborative project with Seoul National University) to develop numerical simulation code for airworthiness certification on fixed and rotary wing aircraft in aircraft icing conditions. Vestas has continued to invest in development of the area of ice prevention systems and wind energy in cold climates. The interviewee from the company argued that this was due to the profitable solutions developed in IceWind.

3.7.2 Finland

The TRI enabled related research grants in Finland to an amount of €1m. This evaluation has identified 14 PhDs who are currently working in the country, most of them at the university where they carried out their PhD studies or at another Finnish university. The only example of cross-border mobility is the one former PhD from the NorMER project who is now carrying out her scientific work at the Danish Technological University. One PhD from the NorMER project is now at the Finnish Environmental Administration, one from the SVALI project is now at the Finnish Meteorological Institute and one from the NORD-STAR project at the expert organisation under Finland's Ministry of Economic Affairs and Employment, GTK. research organisations and research institutes. There is, however, no TRI project which is identified to have had a wider impact for Finland.

3.7.3 Iceland

As for Iceland, the TRI enabled one national level research grant. The NCoE SVALI led to a €410,000 grant for the University of Iceland, from the Icelandic Ministry of Environment. The evaluation has identified three TRI PhDs who are working in the country, two in research organisations and one at the national power company. Despite these modest numbers, the TRI has been important for Iceland.

As discussed earlier, the wind atlas of Iceland and CO2 storage atlas exercise may have great importance for future energy supply. An interviewee from the national power company stated that due to the country's hydro and geothermal power resources, alternative energy sources are not explored. On the same note, the country's legal system which regulated the establishment of power plants (the master plan[19]) is unclear about the establishment of wind farms, which is currently stalling Landsvirkjun's plan to start to establish windfarms.

3.7.4 Norway

In Norway, a total of €18m was awarded in research grants for projects which, according to the project leaders, are enabled by the TRI. This evaluation has identified seven PhDs from TRI projects now working in Norway; six in research organisations, and one at a public agency. The NORDICCS project heavily influenced the existence of the NCCS – the Norwegian CCS centre. This is a centre funded by the Research Council of Norway (RCN), with a budget of €42m. Though it would be incorrect to see NCCS as a direct effect of NORDICCS, the project was a contributing factor. Other related research grants consist of the funding from Norwegian sources (RCN, CLIMIT/GASSNOVA) of two summer schools to a total value of €477,000. NANORDSUN enabled a research grant from the RCN to NTNU, on *Low cost, ultra-high efficiency graphene nanowire solar cells* (€1m). It also influenced the establishment of the Norwegian company CrayNano. The company operates in the UV LED industry, and uses the results from the project to develop a method to grow nanowires on graphene. The company has 11 employees and revenue of €183,000. The NCoE CRAICC enabled the project *EVA – Earth system modelling of climate Variations in the Anthropocene* for the Norwegian Centre for International Climate Research (CICERO), which is the country's foremost institute for interdisciplinary climate research. The project was awarded a total of €1.5m from the RCN. One of the PhDs from the project is now employed by the Norwegian Institute for Air Research (NILU).

3.7.5 Sweden

TRI enabled related research grants in Sweden amounting to €14m, and there are currently 15 PhDs who are active in the country. Some projects seem to have had impact primarily in one of the Nordic countries. The Enesca project has had impact in Sweden, but less so in the other Nordic countries. It enabled two research grants to Uppsala University, one from the Foundation of Strategic Research on lightweight polymer composites for durable batteries (€3.1m), and one from Vinnova, to fund an innovative outreach activity; *The Enesca competition,* where Swedish high school and college students proposed different applications for the paper battery (€29,000). The Enesca project strengthened cross disciplinary research at Uppsala University and enabled new PhD courses in the area of industrial engineering. BillerudKorsnäs, the company developing the results from the Enesca project in cooperation with Uppsala University, has been able to hire more employees, one of these an alumnus from the Enesca project.

HG Biofuels is another project with specific impact in Sweden. The project results heavily influenced the existence of the biorefinery demo plant, run by SEKAB (project partner) in collaboration with the Swedish research institute RISE. The project enabled three research grants to Chalmers, two from the Energy Agency of Sweden and one from Formas, to a total amount of €366,000. Two PhD alumni from the project are now employed at two Swedish energy companies; Taurus energy and SEKAB.

[19] https://nea.is/geothermal/master-plan/

4 Relevance and objective fulfilment

4.1 Outcomes

The TRI addressed issues of climate, energy and the environment with the overarching idea to strengthen the Nordic competitive advantage in science and innovation in these areas. The broader objective of the programme was to promote excellent research and innovation to make a Nordic contribution towards solving the global climate crisis, by involving the very best agencies and institutions in processes of the highest quality. The TRI aimed to contribute to establishing a Nordic research arena that increases the level and ambition of collaboration among Nordic research. These objectives would be achieved through the funding of activities in six sub-programmes, involving a large number of researchers from universities and research institutions and companies from all Nordic countries. The active collaboration in six programme committees between representatives from these sectors from all Nordic countries was another important output which would favour good fulfilment of the objectives.

The evaluation shows that to a large degree the programme has fulfilled these over-arching objectives. Excellent research has been carried out, involving agencies and institutions in the five Nordic countries. With reference to the intervention logic (section 2.6) the programme has performed well on all expected outcomes:

- a large number of PhDs in areas of relevance and priority for the Nordic countries
- scientific publications of high quality and quantity
- internationally competitive Nordic research collaborations
- application and utilisation of research results (through close partnership with public sector and industry)
- knowledge of relevance for policymaking
- new technical knowledge and competence
- innovative solutions

Climate change has been tied to global development since the UN Framework Convention on Climate Change but has recently come to be an integral part of policymaking in most countries. Given this, the TRI should be highly relevant in terms of societal as well as scientific impact. The six sub-programmes each cover key aspects of issues that are high on the agenda for policymakers as well as for other societal actors.

The intervention logic for the TRI shows the 'mechanism' of the programme, and what types of results and impact can be expected and when.

The question then is: How well has the programme performed? The short answer is that the TRI has delivered well on most of the expected results and effects; in many cases, the programme can be considered a success, in other cases a little bit less so.

First, we turn to **first-order effects**, defined as such effects that can be expected to appear in the short to mid-long term (2–5 years). Following that, **second-order effects**, defined as such effects that could be expected to appear in the long term (five years or more) are discussed.

4.2 First-order effects

The evaluation shows that the programme has delivered well on the first-order effects:

- **Application of developed scientific methods**

The programme has contributed to this. There are incremental improvements of methods in several research areas.

- **Increased visibility, attractiveness and competitiveness of Nordic researchers**

The programme has contributed to this. Researchers have become more visible and competitive, and attracted subsequent funding. At the same time, the programme addressed already strong and competitive researchers who presumably in any case would have been able to further their research and secure funding opportunities. It is thus difficult to determine the additionality of the TRI, but stronger project consortia through collaboration between top-level researchers in several Nordic countries is an added value.

- **Lasting networks, collaboration and knowledge sharing**

The programme has contributed to this. There are several examples of parts of project consortia continuing their collaboration and knowledge sharing. In many cases there is potential for the networks to last, but the sustainability depends on relevant subsequent funding opportunities.

- **New contacts and partnerships created for companies**

This has been achieved to some degree, particularly in several Integrated Projects where companies that were brought into the project by a researcher from the same country have come into contact with researchers (and sometimes companies) from other Nordic countries. The overall involvement in the programme of the business sector, however, has been limited.

- **New products or technologies developed**

The programme has contributed to this. There are several examples of results that have reached application in industry or are about to do so.

4.3 Second-order effects

The evaluation shows that second-order effects thus far have been achieved to some extent:

- **International top-level research and research groups in areas of Nordic strength**

The programme has certainly contributed to top-level research in areas of strength, as it was indeed a condition for funding. The bibliometric analyses show that the research in the programme is of a high international level, and there are also examples of additional funding from EU sources.

- **Nordic cooperation is an integrated part of research in the fields of climate, energy and environmental research**

It could well be argued that the programme has contributed to make Nordic cooperation an integrated part of research in these fields. However, this will probably not be fully achieved – meaning that it lasts for five years and beyond – without continued substantial funding opportunities for Nordic research collaboration.

- **More prominent Nordic participation in EU framework programmes**

There are examples of participation in EU framework programmes as a direct or indirect result of TRI projects, but whether this qualifies as more prominent participation cannot be ascertained. Performance of Nordic actors in relevant thematic areas in EU framework programmes has not been analysed.

- **New products or technologies on the market**

The programme has contributed to this, and it has to some extent already been achieved. Given the relatively modest participation from companies in the programme, the results are perhaps not on par with the size of the investment in the TRI.

In brief, the TRI has delivered on its overall objectives and contributed well to most of the results and effects that the intervention logic prescribed. It can be argued that a Nordic research arena has been established in research areas of high relevance to Nordic society. This is clearly an important and positive achievement. The next section further elaborates on the Nordic added value of the programme.

4.4 The TRI and Nordic added value

A Policy Brief to NordForsk from Technopolis Group concluded that Nordic cooperation can help to enhance Nordic unity in research and develop a Nordic research profile, reduce fragmentation of the Nordic research system and provide opportunities to support outstanding researchers and develop a platform on which Nordic stakeholders can achieve a more visible profile on the European and global markets.[20] NAV is created when cross-border cooperation between organisations generates more value than would be the case by only working nationally.

This is something confirmed by the empirical evidence from this evaluation. By combining expertise and resources, the projects funded by the TRI strengthen top-level research groups, innovation and competitiveness in key areas for the Nordic countries. The TRI offered opportunities to support outstanding researchers and develop a platform on which Nordic stakeholders can achieve a more visible profile on the European and global markets.

The discussion in section 2.7 suggests that Nordic added value of the TRI consists of:

- Network building
- Cost sharing
- Knowledge production
- Enhanced Nordic unity in research and a developed Nordic research profile
- Reduced fragmentation of the Nordic research system

This evaluation provides evidence of real **network building** from practically all projects. Importantly, this networking included a large number of PhD candidates: in particular, graduate schools could enjoy long-term benefits (as evidenced from other programmes). The programme encouraged expanding actors' Nordic networks, which form a basis for continued collaboration. To a large degree, parts of the networks were already in place, but these core relations were amplified and strengthened with the inclusion of project participants connected to only one or a few of the 'core team(s)'. This dynamic is obviously not unique to the TRI, but it created opportunities for further NAV by making it possible for researchers and industry from several Nordic countries to actually work together. It is also clear that the projects in general were indeed collaborative efforts. In several cases it was pointed out that the funding created an opportunity to include crucial expertise and competence from a neighbouring country that may not have existed at the same top level in a single country. This also encompassed R&D infrastructure and facilities; the evaluation shows that several projects benefited from data sharing and an efficient use of research infrastructure. This has given rise to efficient and **cost-sharing** projects. Clearly, research projects in themselves lead to **knowledge production**, but it could well be argued that the factors mentioned above have enhanced this further. The bibliometric analyses showed that the projects produced scientific publications of a quality well above what could be expected. Table 4 also showed a relatively high share of internationally co-authored papers.

The programme focused on thematic areas in the field of climate and energy research that are of common interest to the Nordic countries, and where the region can contribute with solutions at international level. The TRI from the outset favoured enhanced **Nordic unity in research and a developed Nordic research profile**. The programme, with a management board consisting of members from public funding bodies for research and innovation as well as the private sector, and programme committees for the sub-programmes, was organised to facilitate this. The activity in the programme committees also provided the representatives from the national funding bodies with opportunities to discuss common issues with colleagues from the other countries and created stronger personal ties that favoured an increased unity around these issues between the Nordic countries. Furthermore, climate and ecology issues do not know borders and the TRI was an opportunity to address (Nordic) cross-border issues, ideal for collaboration between researchers from various

[20] Arnold, E, Melin, G, Jansson, T et al. (2011): Enhancing the Effectiveness of Nordic Research Cooperation.

countries. All these factors enabled (but not necessarily led to) **reduced fragmentation of the Nordic research system**, and ultimately to increased Nordic competitiveness.

As mentioned before, there are no descriptions of what specific NAV the sub-programmes in the TRI were expected to achieve. Based on call texts and on the sub-programmes' websites, the evaluation team formulated what NAV could be expected from the different sub-programmes. The conclusion is that the sub-programmes overall delivered well on the NAV that could be expected.

4.5 Would the projects have existed without Nordic funding?

A conclusion of the discussion above is that the projects and programme areas supported by the TRI did have a NAV. Had these projects been strictly national, an important dimension would have been lost. The question which then arises is: Would these projects have been carried out if the TRI opportunity had not existed?

Evidence from the surveys, interviews and case studies shows that very few projects would have started without this funding opportunity. The TRI enabled projects and project consortia that would otherwise not have come into being. Researchers indicated that European or national funding would not have been a suitable alternative; European funding demands too many 'artificial' partnerships and national funding lacks capacity or does not allow funding of non-national research institutions.

In several cases, lack of follow-up Nordic funding is seen as an obstacle. There are examples of additional funding from Nordic organisations, but also of project ideas surged from TRI projects where Nordic funding opportunities did not exist. The greater part of secured subsequent additional funding is national; thus projects live on mainly in a national context and lasting impact on intra-Nordic level is less clear. In any case, researchers continue working together in a variety of different projects and collaboration constellations. However, active collaboration has not been sustained in many of the former project consortia. Some case studies indicate a 'snooze mode'; there may be no actual collaboration at present, but if/when an opportunity arises it is close at hand to reawaken the research network. This could be understood as creation of Nordic critical mass, which could be called upon when opportunities arise.

4.6 Societal readiness for innovation and research

Societal Readiness Levels (SRL) is a way of assessing the level of societal adaptation of, for instance, a particular social project, a technology, a product, a process, an intervention, or an innovation (whether social or technical) to be integrated into society.[21] If the societal readiness for the social or technical solution is expected to be low, suggestions for a realistic transition towards societal adaptation are required. The lower the societal readiness is, the better the plan must be for transition. These are the SRL levels:

- SRL 1 – identifying problem and identifying societal readiness
- SRL 2 – formulation of problem, proposed solution(s) and potential impact, expected societal readiness; identifying relevant stakeholders for the project
- SRL 3 – initial testing of proposed solution(s) together with relevant stakeholders
- SRL 4 – problem validated through pilot testing in relevant environment to substantiate proposed impact and societal readiness
- SRL 5 – proposed solution(s) validated, now by relevant stakeholders in the area
- SRL 6 – solution(s) demonstrated in relevant environment and in cooperation with relevant stakeholders to gain initial feedback on potential impact

SRL 7 – refinement of project and/or solution and, if needed, retesting in relevant environment with relevant stakeholders

[21] Societal Readiness Levels (SRL) defined according to Innovation Fund Denmark.

- SRL 8 – proposed solution(s) as well as a plan for societal adaptation complete and qualified
- SRL 9 – actual project solution(s) proven in relevant environment

The SRL scale is still not a broadly recognised concept, and it was indeed difficult for interviewees to assess projects according to this scale. We therefore chose to focus this assessment on the projects that were selected as case studies. Also, the SRL scale has several features in common with the more broadly recognised Technology Readiness Level concept. The former, to some extent, mirrors the latter.

Technology Readiness Levels (TRL) are used to assess the maturity level of a particular technology. Each technology project is evaluated against the parameters for each technology level and is then assigned a TRL rating based on the projects progress. There are nine technology readiness levels. TRL 1 is the lowest and TRL 9 is the highest. The TRL levels are as follows:[22]

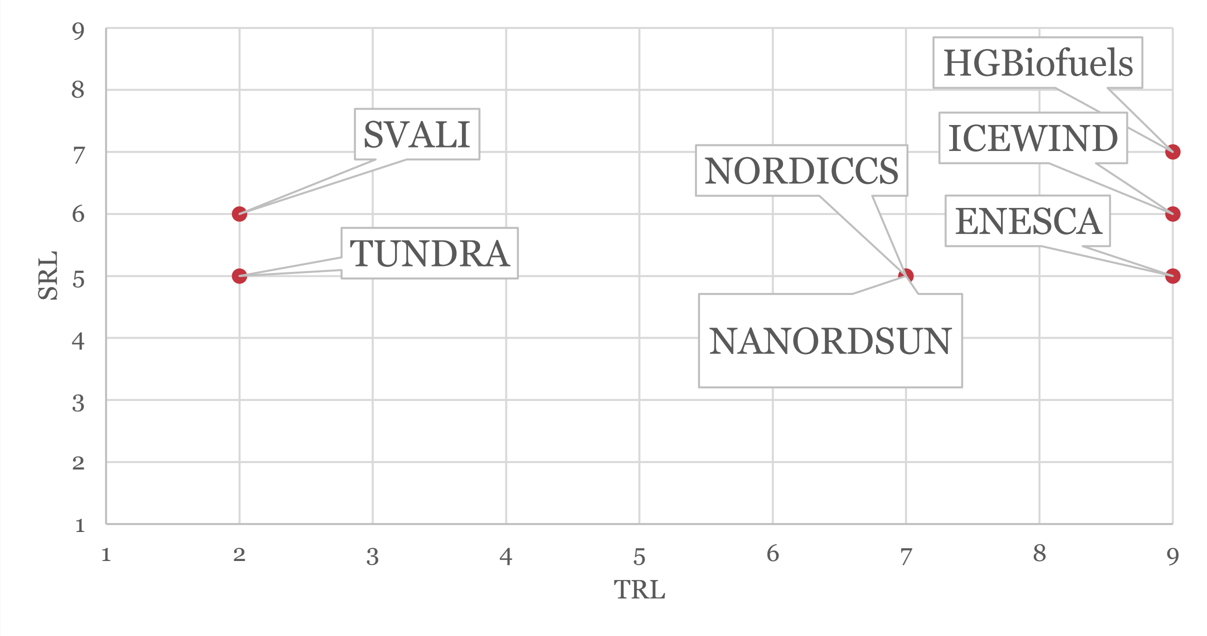
- TRL 1 – basic principles observed
- TRL 2 – technology concept formulated
- TRL 3 – experimental proof of concept
- TRL 4 – technology validated in lab
- TRL 5 – technology validated in relevant environment (industrially relevant environment in the case of key enabling technologies)
- TRL 6 – technology demonstrated in relevant environment (industrially relevant environment in
- the case of key enabling technologies)
- TRL 7 – system prototype demonstration in operational environment
- TRL 8 – system complete and qualified
- TRL 9 – actual system proven in operational environment (competitive manufacturing in the case of key enabling technologies; or in space)

Given the difficulties in assessing the projects on the SRL scale, we have chosen to map the projects on both levels. A comparison of how the projects perform on the TRL scale provides better possibilities to assess how they are positioned on the SRL scale.

Figure 11 depicts the projects' positions on the SRL and TRL scales.

[22] HORIZON 2020 – WORK PROGRAMME 2014–2015. General annexes.

Figure 11 The projects' positions on the SRL and TRL scales.



Source: Technopolis Group

The mapping of the projects on the two levels shows that six of the seven are at SRL levels 5 and 6. They are well past the initial stages of identifying and formulating the problem, and address validating proposed solution(s) by relevant stakeholders in the area or demonstrating these solutions in relevant environment and in cooperation with relevant stakeholders to gain initial feedback on potential impact. One project – HG Biofuels – is at the stage of refinement of project and/or solution. This suggests that these projects (the solutions) have come a relatively long way to be integrated into society.

The span is larger on the TRL scale. The Integrated Projects are, not surprisingly, at higher levels. Some of them have actual systems proven in operational environments and products on the market. Two NCoE – SVALI and Tundra – are, as is logical, at the other extreme of the TRL scale.

5 Conclusions and reflection

5.1 Conclusions

The TRI was ambitious, and several important results and effects can be observed. This was already a conclusion from the final report of the ongoing evaluation, presented in 2014. Now, four years later, the following can be concluded:

- The research funded by TRI is generally of high or very high scientific quality

The TRI projects have produced scientific publications that are more cited in high-end journals than would be expected from a statistical viewpoint. The TRI projects produced more high-end scientific publications, and also a broader base of high-end publications. In recent years there continues to be a steady stream of publications.

- The NCoE have had larger scientific impact than the Integrated Projects

This is, of course, to be expected. The Integrated Projects have had more industry-oriented impact, and at the same time attracted a large portion of additional research funding. Some of the Integrated Projects have been able to produce profitable solutions – some of which have been commercialised.

- The TRI projects have attracted a large amount of additional funding

The research carried out in TRI projects in total have attracted at least €73.5m in additional funding, or close to 150 per cent of the total budget of the programme. Subsequent projects based on research carried out in the NCoE have attracted €49.8m from national, Nordic, EU and international sources. This shows that the research was of high quality, and also highly relevant. The additional funding stems to a large extent from national funding sources, but there are several examples of related research projects in EU consortia enabled through the TRI. Among several researchers, there is an impression that additional funding opportunities from Nordic institutions have been few.

- The TRI largely funded already established research and researchers

This was the purpose from the start, and this also partly explains the much better-than-average scientific quality and citing rates.

- The TRI has contributed to increased and sustainable Nordic research collaboration

The NCoE have been able to more firmly consolidate their collaborations through additional funding from Nordic and EU sources. Due to the fact that the additional funding for Integrated Projects is secured mainly from national funding sources, there is less international cooperation, although some is enabled through EU funding. However, the sustainability of these collaborations depends on availability of continued and relevant funding opportunities. There are several examples of *potential* international collaborations between research organisations.

- There are no clear differences in impact between the sub-programmes

There are high-impact projects in all sub-programmes, as well as projects with less impact. That said, it is difficult to label projects with less impact, as this in several cases may still be too early to fully appraise.

- TRI enabled research collaborations that would otherwise not have been possible

Existing cross-border research collaborations were strengthened, and in several cases included research partners (and in some cases companies) formerly not part of the network.

- TRI enabled to carry out projects that would otherwise not have existed

Some of the project ideas would obviously have found other means of funding, but they would then in most cases have been more national in scope.

- The TRI contributed to the training of at least 81 PhD students

This is an important contribution to national and Nordic strengths in these areas. The presupposed Nordic orientation of these researchers' continued professional careers also helps to create Nordic added value, as does the mobility of these individuals.

- Participation in the TRI projects clearly contributed to value creation and new contacts and partnerships for the company partners

For the companies, TRI contributed to increased R&D cooperation, mainly within the Nordic countries. There are examples where the Integrated Projects had an impact on the development and application of scientific methods for participating and external companies.

- There are some examples of clear societal impact

The results from the NCoE are clearly useful for public policy actors, although there are yet few clear signs of direct policy impact. The results from Integrated Projects have had some influence on public actors, especially in Iceland regarding the country's potential for wind power and for CO_2 storage. When discussing potential societal impact, the future and potential importance of the large number of PhDs co-funded by the programme, and who thus have received a Nordic perspective and grown a Nordic network, should be noted.

- The TRI clearly contributed to Nordic added value

All the points above indicate this direction.

5.2 How well has the TRI fulfilled its objectives?

The TRI had six overall objectives. The empirical evidence of the evaluation point to the following fulfilment of those objectives:

- **Profile the Nordic region as a leader within certain areas of the energy and climate sectors**

  The TRI programme has fulfilled this objective well.

- **Strengthen national research and innovation systems**

  The programme has certainly contributed to this goal.

- **Ensure the highest quality in research and innovation by combining the strongest Nordic communities**

  This has been central to the programme, and it has certainly delivered.

- **Provide a platform for increased international cooperation both within the EU and beyond**

  There is evidence from some projects that this has been achieved, but the impression is that this has not been a central aim for many other projects.

- **Enhance Nordic participation in EU programmes**

  Same as the point above.

- **Strengthen Nordic competitiveness by using research and innovation to counter economic downturns**

  There is little doubt that the TRI has contributed to strengthening Nordic competitiveness by using research and innovation, but the evidence from this evaluation does not make it possible to value the latter part of the goal.

5.3 Final reflections

No doubt, the TRI has been a successful programme. As has been shown above, it has delivered in accordance with the expectations – and in some cases more. The programme has performed well on its overall objectives, in particular those addressing "the highest quality in research and innovation by combining the strongest Nordic communities" and "strengthen national research and innovation systems".

The programme's impact still ought to be put in some perspective. It was indeed the largest Nordic research programme in history, but the total budget was still modest compared with what the Nordic countries invest individually in research in these areas. Just to take one example, the Swedish Energy Agency has an annual budget of around SEK1.6b (close to €160m) for research and innovation in the field of energy for ecological sustainability, competitiveness and security of supply.[23] The Agency's mandate and area of support reflect a much larger commitment and a much larger area than that of the TRI, but budget figure does give a perspective on the relative weight of national and Nordic investment in research and innovation, in related research areas. Results and impact that came out of the TRI need to be regarded in this perspective.

While the TRI was a unique effort with strong political backing, it was not enough to radically change the Nordic research landscape in its target research area. That would have required a long-term commitment with subsequent programmes or funding opportunities at Nordic level. It would probably also have required a closer alignment with national priorities and funding schemes. This is an insight that could be taken into account if launching similarly ambitious initiatives in the future.

Neither was the creation of Nordic collaboration as a platform for increased international cooperation within the EU and beyond a central aim for most of the projects and their participants. There is evidence from some projects that this was after all achieved, but it was not necessarily a key driving force or motivation for the researchers when applying for and carrying out research collaboration with funding from the TRI.

The TRI still had a clear Nordic added value. Through the TRI, real cross-border collaboration between researchers and some companies did take place, including networking of importance for PhDs and senior researchers, resulting in several examples of continued collaboration/contacts. It is likely that the training of the (at least) 81 PhDs will have long-term impact on joint Nordic research, 'marinated' in Nordic collaboration as they are.

Nordic cooperation has a certain political dimension. It builds on the idea that these five countries have some shared communalities and characteristics, compared with other countries. Still, respect for each country's specificities and independent will is at the heart of Nordic collaboration as well. The balance is delicate, and friction is as common as enthusiasm. Each part wants something from the collaboration; Nordic collaboration is a means to achieve something, not the end goal in itself. National priorities are always superior to a joint Nordic perspective. The TRI is in fact really special in this light. When negotiating and deciding about the TRI, attention to such national interests was surely paid. But once it was launched, it was truly super-national in character. Most other Nordic projects, programmes or initiatives are so to say guarded by national representatives throughout their execution. In this respect, the TRI was quite unique.

Perhaps friction was instead unintentionally placed on another level. The TRI was administered by three Nordic organisations. They did not get the same 'share' however; 50 per cent of the funding was allocated to projects that NordForsk administered, while Nordic Innovation and Nordic Energy Research each got to administer 25 per cent. Despite the shared overall objectives of the TRI, each organisation has had its own ambitions and goals with the projects, which naturally originate in their respective mandate and area of interest. One important circumstance to bear in mind is that it is not reasonable to expect the same volume of output from projects under the auspices of Nordic Innovation and Nordic Energy Research, as from those administered by NordForsk. As in most administrations, projects within their own respective sphere quickly become "their" projects. And not all of the projects' achievements are valued equally at the three administering organisations. Consequently, the degree of satisfaction differs somewhat between them. While one (or two) are happy with the strong scientific

[23] Prop. 2016/17:66 Forskning och innovation på energiområdet för ekologisk hållbarhet, konkurrenskraft och försörjningstrygghet.

publication record, for example, one (or two) are less impressed by this. And similarly, not all three share the same enthusiasm regarding the projects' positioning on the TRL and SRL scale. The evaluation team has occasionally heard rather harsh comments of the other organisations' focus and management of the TRI.

So, while the TRI design as such was indeed most successful in order to boost Nordic added value, the decision to split the administration among three organisations was at least in part a source of friction between them, and to split it unevenly may have underpinned this even more. But was it negative for the programme? Given how successful the projects have been, there is little evidence that they suffered in any significant way from the administrative setup. Although it is beyond the mandate of the evaluation, we would advise a relatively similar administrative arrangement if a future large research programme would be launched.

The Nordic organisations have an obligation to nurture the investment made. By investment, we refer to the money put in by the Nordic organisations into the programme, as well as the efforts made by all participants. The Nordic organisations should also have a self-interest to build on what has been created. A large number of highly qualified and internationally competitive researchers have created and/or developed networks with researchers in the other Nordic countries, and the evaluation testifies that most of these researchers are interested in ways to continue Nordic collaboration. There are plenty of examples of areas and topics that researchers wish to explore further in a Nordic context.

If funding for continued Nordic collaboration cannot be allocated one way or the other, the researchers are of course likely to look for other funding, which probably will be more national in scope and participation. With this funding, they will carry out the research that they wanted, and the findings will be equally important as the findings from the TRI. They will just not be as 'Nordic' as they were in the TRI.

In this presumption, which may seem as a weakness with joint Nordic funding and an initiative like the TRI, lies after all perhaps an opportunity for those who advocate the importance of Nordic collaboration and joint Nordic forces. When national funding organisations fund research of high quality, some good research will surely be undertaken. If the funding is channelled through Nordic funding organisations and in accordance to the terms of the TRI, the same good research will be undertaken but in addition, networks of Nordic researchers and companies will be supported. There is really no minus in doing it from a Nordic funding platform. In the light of the budget volume of the TRI compared with investments by national funding organisations, the funding set aside for Nordic joint research is not dramatic. Following this line of thought, there seems to be a rather strong added value in setting aside funding for future initiatives similar to the TRI, besides the regular national funding. The target research area, the participation, and the goals overall, may all be revisited and changed, but this evaluation of the TRI has anyway shown the added value of complimentary funding of research and innovation on a Nordic level, in addition to such funding on national level.

Appendix A Case studies

Case study: IceWind

Executive summary

The IceWind project is an integrated project focused on the issue of wind energy in cold climates. The project had academic and industry partners in Sweden, Denmark, Norway Finland and Iceland. The most important project outputs are a model for wind turbine icing forecasting and production loss, and a wind atlas of Iceland. The project contributed to the education of three PhDs and enabled three related research grants, two from the international expert group IEA task 19 (on wind energy in cold climates), and one from the South Korean Defence Agency.

Through the involvement in the IEA task 19 group, the partners have been able to communicate their results on a global scale.

In terms of impact, the project contributed to value creation for the industry partners involved, a new area of research for DTU, and a spin-off company in Finland. The wind atlas of Iceland has been an important basis for future development and future establishment of wind farms in the country.

The partners find that there are still topics within the field that they want to continue to research, but they have not been able to secure funding for international consortia. However, the project results live on and are further developed in academia and industry respectively. At the same time, the partners are in contact with each other and await a suitable funding opportunity.

Project background

Brief description of the project

The project's objective was to investigate some of the main barriers for large-scale integration of wind energy in the Nordic countries – wind energy in cold climates. The main issues identified were icing on wind turbines, forecasts for distributed offshore wind farms, and the wind energy potential in Iceland. IceWind consisted of four work packages (WPs): WP1 Icing, WP2 Iceland, WP3 Offshore forecast, operation and maintenance and WP4 Power and energy aspects. The project was implemented during September 2010–August 2014. The project had a budget of 20.80 MNOK, out of which TRI contributed with 12.34 MNOK (59.3% of the total budget).

The academic partners of the project were DTU Wind Energy – Technical University of Denmark, VTT Technical Research Centre of Finland and the University of Iceland. The project had five industry partners: Vestas Wind Systems A/S, Kjeller Vindteknikk, Statoil AS, Oceaneering Asset Management AS, and Offshore Windservice Aps. Weathertech Scandinavia AB is also an industry partner, but it subcontracted under Uppsala University, Campus Gotland (HGO). The remaining partners were nationally owned institutes and power companies: the Icelandic Meteorological Office (IMO), Meteorologisk Institutt met.no, Landsnet, and Landvirkjun.

Background and rationale of the project

The IceWind project was based on the results from a prior project called *Climate and Energy systems*, which was part of the Nordic Energy Research's strategy and action plan between 2007–2010.[24] The Technical University of Denmark (DTU), Technical Research Centre of Finland (VTT) and the Icelandic Meteorological Office (IMO) were involved in this prior project, the results of which had pointed to the importance of wind energy. DTU, with major competence and influence in the field, came to be the leader for the IceWind project.

[24] http://www.nordicenergy.org/wp-content/uploads/2011/12/Climate-Change-and-Energy-Systems-CES-project.pdf

DTU's rationale in applying for TRI funding was influenced by advantageous timing; the orientation of the project fits well with the priorities and objectives of the TRI. In addition, the TRI would enable crucial knowledge sharing with other Nordic countries – DTU had no prior involvement with cold climates and wind, and the project was considered a way into the field. According to the interviewed researchers, the field is relatively new and unexplored in general, and especially for the Danish research environment.

The interviewed industry partner, Vestas Wind Systems, was motivated to participate in the project mainly because of the perceived importance of WP1 – icing on wind turbines. At the time, the partner had not invested in the subject in terms of competence or R&D, but they anticipated that the ability to predict icing and to estimate production loss would become important for the wind turbine industry in the future. Because there were no existing means to aid the problem, the potential for value creation was high, and being close to the research was expected to facilitate the implementation of any new technology.

Results and effects

Outputs and results

The most important scientific outputs of the IceWind project include the development of an engineering tool for production loss calculation of large wind turbine installations in the northern latitudes, an icing atlas for Sweden and Iceland based on long term meteorological statistics, and a method for estimating power production of offshore wind turbines. Three PhD students graduated within the project. These are all now employed by partners from the project; one at DTU, one at Kjeller Vindteknikk partner, and one at Iceland's nationally-owned power company Landsvirkjun. Furthermore, the project enabled three related research grants.

IceBlade

A PhD project within WP1 (led by DTU), focused on designing a model for icing forecasts, based on meteorological data. The resulting model, IceBlade, is a model for predicting icing on the blades of wind turbines, and for calculating associated production loss. Vestas Wind Systems uses the model in everyday operations and finds it highly valuable as it has unprecedented accuracy.

Wind Atlas for Iceland

The wind atlas for Iceland is identified by the project leader as an especially important result of the project. Historically, Iceland has depended heavily on hydropower, and the potential for wind power has not been investigated. The IceWind project had the output of a wind atlas of Iceland, and a scientific article called *The wind energy potential of Iceland* (2014). The publication is identified by the project leader as the most important written dissemination.

Related research grants

The research results from IceWind have successfully enabled new research grants within wind energy, cold climate and ice. Two of these grants were related to the participation in the IEA task 19 – an expert group for gathering and sharing information and knowledge on wind energy in cold climates, which runs between 2016–2018 and is funded by the International Energy Agency Wind Technology Collaboration Programme (IEA). Three of the partners (VTT, DTU, Kjeller VindTeknikk) were invited to participate in phase I (2012) and II (2016). The partners were awarded €120,000 for phase 1, and €160,000 for phase 2.

The third related research grant concerns the collaboration between DTU and Seoul National University, who jointly were awarded €300,000 from the Agency for Defence Development in South Korea to develop numerical simulation code for airworthiness certification on fixed and rotary wing aircraft in aircraft icing conditions.

Spin-off company

In connection with the IceWind project, a company was established by two researchers from VTT (one of them had been involved in the IceWind project). The company, called Wicetec Oy, provides wind turbine ice prevention systems to customers, and was positively influenced by the IceWind project, the IceBlade model in particular.

Impact

Scientific impact

IceWind has been a catalyst establishing the research area of icing forecasting at DTU. Prior to the project, DTU was not involved in the topic at all. The team of WP1 advanced the state of the art predicting model, which fed back to DTU. The project also enabled the identification of future issues to be dealt with, topics for research and ways which the model could be improved. These include the issue of ice removing: whether it is more efficient to remove ice from turbine blades manually or let nature take its course.

For the Icelandic research partners, the project enabled groundbreaking research regarding the potential of wind power. The wind resource assessment in WP2 resulted in the wind atlas for Iceland, which was a major step towards gaining an overview of the wind resource in Iceland.

Furthermore, the interviewed partners find that the project feeds back to the wider community of model development, which includes national services in the Nordic countries, the US centre for Atmospheric Research and the European Centre for Medium-Range Weather Forecasts (ECMWF). The results of the IceWind project helped these actors update their agendas and identify potential challenges.

Societal impact

The project has stimulated the discussion of wind energy in the Icelandic energy mix. The project results caught the attention of the Icelandic government, as evident by the participation of the responsible Minister of Energy and representatives for science and energy planning at the launch event for the wind atlas in Reykjavik in November 2014. Furthermore, the Icelandic meteorological office (IMO) has used the wind atlas and set up an interactive tool.[25] According to the Icelandic partner, the tool has been an important base for public discussion on wind power in Iceland.

During the course of the project, two experimental wind turbines were built on sites in Iceland. These reached a capacity factor of 44 per cent in their first calendar year of operations, which is remarkably high – even by global comparison. This result confirmed the potential of wind power in Iceland, and the partner Landsvirkjun – the Icelandic national power company – is trying to establish wind farms, with potentially a 50–60 wind turbine farm at the site of the experimental wind turbines. A representative from Landsvirkjun indicates they have used the wind turbine icing atlas for both site selection and preselection/preliminary design criteria. Other results from the project have also been of interest to the company but have not influenced any operations.

However, the general development of wind power in Iceland has stalled for various reasons. Icelandic legislation is not very clear about wind farms. The establishment of power plants by government-owned Landsvirkjun must go through the Master Plan, which is a national framework for comparing economic feasibility and the environmental impact of proposed power development projects[26] – but the Master Plan is unclear about windfarms. An interviewed researcher who participated in the IceWind project and who now works at Landsvirkjun confirms that Landsvirkjun applied to the Master Plan for two wind farms. One of the applications was turned down because of the location – the farm would have too much impact on mountain tourism. The other application was approved, but the establishment of a windfarm has been delayed due to difficulties with transmission systems at that

[25] See vindatlas.vedur.is

[26] https://nea.is/geothermal/master-plan/

particular site. Landsvirkjun continues to scope for potential sites for windfarms and with integration of windfarm energy into the energy system.

Nordic collaboration

IceWind facilitated a network of partners, some of whom had no prior experience of working together. In particular, WP1 brought the actors together as they embarked on a relatively new area of research. The issue of icing on wind turbine blades requires a combination of skills and experience in the field of wind power, manufacturing, and meteorological forecasting. DTU provided competence in wind energy, while the partners from the northern parts of the Nordics (Finland, Sweden and Iceland) contributed with crucial forecasting competence. The project sparked some new collaboration and deepened the one that was already existing.

The PhD student who led the project on the IceBlade model created his professional network through the project and is now working with the same partner universities and companies, plus a few contacts in the field of wind energy, such as students and other companies.

The project results also enabled a new collaboration between DTU Department of civil engineering and Force Technology. Force is a consultancy company within energy, oil and gas, the maritime sector and infrastructure. The company has a climate wind tunnel which DTU master's candidates use as experimental research facility for their thesis work.

Competitiveness of Nordic research institutions

The issue of cold climate for wind power is a typically Nordic phenomenon, important also for other regions. The IceWind project has enabled the partners to take a globally-leading position in the field. At the IWAIS (International Workshop on Atmospheric Icing of Structures) conference in Sweden in 2015 the project's results were presented; nearly 300 individuals from all over the world attended. In the IEA task 19, the knowledge from the IceWind project enabled DTU to contribute substantially regarding available technologies and recommended practices for icing forecasting, which is acknowledged by an industry-leading expert in wind power in cold climates from Canada.

Some of the interviewees and survey respondents mention difficulties in further developing the IceWind project results. The interviewed Danish researchers identify difficulties with national funding, due to political priorities. The consortia have applied for further funding but have so far not been successful. The researchers anticipate that future Nordic or EU funding would be needed to take the research further.

Value creation

Vestas Wind Systems find the IceBlade model from WP1 highly useful and one of their best examples of value creation. The project opened up the area of icing, which the company has continued to invest in. Since the end of the project, the technology has been implemented into company processes, and is used in everyday operations. Business and research projects rely on it, for example wind farm operation strategies and a number of products. Vestas found that closeness to the development of the new technology simplified the implementation and gave the company a leading edge. Because there are not that many large manufacturing companies within the wind power industry, the interviewed partners anticipate that all actors will want to use the model from the project at some point. An interviewed researcher from DTU states that other companies, for example the Swedish energy company Vattenfall, have approached the WP1 team to investigate the potential use of the icing forecast model.

Furthermore, the WP1 results have created value for companies and enriched industry through consultancy work by the project partners at DTU regarding meteorological modelling of icing of wind turbines blades and loss of wind turbine production. Another impact is the contribution of IceWind to the education of six master's degree candidates, who have completed their MSc projects within the field of wind turbines and icing. These candidates now have a deep knowledge within this area and are ready to serve in the wind industry.

The Icelandic company Biocraft was influenced by the project and has set up small windfarm in south Iceland, and on the basis of two years of running it they are now planning expansion. This company does not go through the earlier-mentioned Master Plan for financing.

Goal fulfilment and relevance

The project leader finds that the project has had good goal fulfilment regarding ice and wind, and the development of a wind atlas for Iceland (WP1, WP2 and WP4). The results from these WPs have since the project ended been used and developed by the different partners. However, WP3 *Offshore forecast, operation and maintenance,* did not reach the same level of success. The researcher who was going to take the lead for the WP resigned at the last minute, and it was difficult to find a replacement. In the end, an engineering company was recruited to take the lead and the situation was solved. However, the project leader finds that the scientific results from the WP did not reach the same standard as the other WPs.

Alignment with TRI objectives

The results of IceWind align well with the objectives of TRI, as was already scoped out at the beginning and part of the rationale for the application. Regarding the WP on icing, a researcher from DTU points out that IceWind significantly has helped establish the Nordic leading position within the field, which is evident from the international attention the different parts of the project have received. The researcher argues that the success was enabled by the novelty of the research, combined with unique Nordic competence around cold climates and wind energy.

The project has also contributed to strengthening national research and innovation systems. Advancement is found at national level, concerning both academia and industry. DTU has established a new research field, wind power and cold climate, with a leading edge in ice forecasting model development. Vestas Wind Systems has continued to invest in the business area, and more companies will eventually use the knowledge created in the project, because it has greater accuracy than previous forecasting models. For Iceland, the project has enabled development of expertise in wind energy assessment, and the Icelandic partners have since the end of the project participated in assessments of the wind energy potential of specific sites. Additionally, by producing the first wind-atlas of Iceland, the project has helped initiate public discussion on wind power, as well as strengthening research on the issue.

The project has also contributed to larger professional communities. Due to the novelty of the research on icing, the partners from the project still find it important to work together on the issue. Although there are no current projects ongoing, they have frequent contact. An interviewee from DTU points out that the knowledge is spreading, other actors in industry and research have reached out to get advice on the IceBlade model.

The project has raised considerable international interest, mainly through the IEA task 19 and the IWAIS conference. The issue of icing on surfaces is important for several regions in the world, and interviewees indicate that there has been widespread interest in the research. One of the interviewees mentions that the partners are interested in applying for more Nordic – or EU – funding, as there are difficulties in gaining national funding.

A researcher from DTU explains that because of the novelty of the research field and the technology, it was expected that the project would encounter new scientific findings – and it did, for example regarding the usefulness of different statistical methods for calculating the icing forecasts and production loss, or on the issue of calculating ice-removal – whether it is more efficient to remove ice manually or let nature take its course.

Vestas Wind Systems finds the scientific quality, scope and technological advancement of the PhD thesis on IceBlade unexpectedly high. IceBlade had far more accuracy than was scoped.

The earlier-mentioned spin-off company was also an unexpected result. Spin-off companies were not sought from the start, but arose from the value creation potential of the research.

Indirect beneficiaries

Vestas Wind Systems finds that the project enriches the wider community of forecast modelling, with indirect beneficiaries such as: national services, US centre for Atmospheric Research, European centre for medium-range weather forecasts, and other actors in the field, not least the wide research community through IEA task 19. Other potential indirect beneficiaries are, for example, business managers and consumers.

Sustainability

Many of the results of IceWind have been successfully sustained – at DTU through the establishment of a new area of research, and at Vestas through continued investments in solutions for wind power in cold climates. The interviewees point out that the main reason for this is the usefulness of the results: there is a real need within the topic of cold climate and wind. Vestas Wind Systems continues to invest, as the company finds business potential in the area. The timing of the project was important; the research around icing aimed at fixing a problem for which there was no prior solution.

Regarding cooperation, the partners have submitted applications for further funding but have not yet been successful. The interviewees indicate that they keep in contact with each other and await a suitable funding opportunity.

Communication

The results from the projects have been made visible in several ways. The project partners identify that the launch of the Icelandic wind atlas was a particularly important event. This public event in Reykjavik in November 2014 marked the start of wind power at a commercial level in Iceland. The event involved government representatives, as the wind atlas was officially opened by the responsible Minister of Energy and representatives for science and energy planning in Iceland.

Other events which have been accentuated by the partners are presentations at the international workshop on atmospheric icing on structures (IWAIS) conference. The project's results have been the topic of two presentations at IWAIS: once when the conference was held in Sweden, and the second when it was held in Canada. As mentioned, the project has also been made visible through more informal channels for communication. The project partners have disseminated the results to national, European and global actors in the field.

Scientific publications have been important for communicating the results. Apart from the aforementioned article on the wind energy potential of Iceland, the results from the PhD project on icing has been substantially communicated – the thesis has had many downloads and the papers have received much attention.

Summary, lessons learnt

Nordic added value

All the interviewees indicate that the success of the project would not have been been possible without the Nordic funding and the associated Nordic added value. Through the project, the Nordic countries established an arena where their competences and assets complemented each other. DTU, being world leading in wind energy, benefited from knowledge share with more northern countries (Iceland, Finland and Sweden) on cold climates and forecasting. Denmark's world leading position in wind turbine industry enabled the successful industry involvement.

The interviewees at DTU find that they could not have implemented the project with national funding, as it would be difficult to attract the interest from other countries. Nordic projects are more appealing in this respect. Additionally, the researchers identify that political priorities in Denmark limit the potential to obtain Danish funding – research on icing is not prioritised because it is not an extensive problem in Denmark.

According to the project leader, the project has enabled the development of Nordic expertise, especially regarding application of wind energy in areas with icing. The markets for wind turbines in Sweden, Norway and Finland are important, even on a global scale. The project has made it possible to transfer this knowledge to other regions with similar problems, such as Canada, Japan, Alpine areas, but also for example Turkey and Greece.

The interviewees also find that the ease of cooperating with other Nordic countries is another Nordic added value. To have Nordic partners simplifies the cooperation and coordination of the project – one of the interviewees mentions experience of a European project which is much more challenging with regard to cooperation and coordination. Vestas Wind Systems mentions that, in a Nordic project, all partners speak the same language, and refers to the similarities of the Scandinavian languages particularly regarding technology and knowledge. The partners work in similar fields, in similar contexts and have similar goals. The project's success was influenced by the open climate and sharing of practices and knowledge.

Recommendations

All of the interviewees are content with the project and the design of TRI. One of the interviewed researchers especially points out the importance of business involvement. The fact that TRI has strong industry involvement is considered to be a key dimension which enables Nordic collaboration. It is also important in order to generate knowledge sharing, as the potential of value creation is easily picked up by the industry.

Case study: NORDICCS

Executive summary

The Nordic CCS competence centre NORDICCS ran between 2011–2014, addressing Pan-Nordic issues in CCS. The issues in focus for the project were: where can CO2 be stored in the Nordic countries, what is the most efficient way of transporting CO2 in the region and which capture technologies are best suited to the oil and gas, power and industrial processes that can be found in these five countries? What is the business case for CCS in the Nordic region and what are the opportunities for technology development and innovation, what are the barriers – not only the technical barriers but also the legal and civic society barriers?

The following are some key results of the project:

- The NORDICCS storage atlas, a web-based storage atlas for the region providing a comprehensive view of where storage is possible as well as estimated capacities. Thanks to close cooperation with the state authorities to access data and to use an agreed methodology, the atlas is fully transparent in assessing the storage capacities. Surprisingly, Iceland has vast envisaged capacity to store CO2 in young basalts, and this capacity could be of the same magnitude as the North Sea basin.
- Clusters of transportation showing that a mix of "trunklines" and ship transport is the best way of doing this. The project identified where the important hubs could be located, and which source sink combinations can be foreseen. Ship transport will be the preferred choice of transport for many plants in the Nordics, due to large distances and volumes too low to justify pipelines.
- Capture technologies, and combined capture and storage. The Icelandic case, storing CO2 from geothermal wells, is a groundbreaking project.
- Understanding what role CCS could play in the Nordic region energy and climate policy. This is embedded in the Nordic CCS roadmap, which binds everything together: where we can capture, how we can transport and where we can store and to what cost. This will be a reference document for the shaping of the Nordic energy and climate policy.
- Team and capacity building and dissemination. The project has created a Nordic team of excellence in CCS that will have long lasting effects. It has embedded PhD studies and two NORDIC Summer Schools, which have educated more than 60 young researchers, PhD and Post Docs in CCS. The Summer Schools have not continued, but the networks and know-how remain an asset to be used when funding for a continuation can be secured.
- NORDICCS results are requested in major European programmes to understand how Europe can establish transport and storage for CO2. The results are used in Mission Innovation (MI, a global initiative of 22 countries and the European Union to accelerate global clean energy innovation) where the collaborative constellation of the project and how it was carried out have caused interest. The storage atlas is also used in EU projects, as well as in the Norwegian full-scale project (funded by Gassnova). NORDICCS was presented at the COP21 in Paris. Nordic cooperation is also embraced by the IEA as an example of how regions can play a role in the climate mitigation issues.

The NORDICCS project fully met its goals and has created a solid basis for further work and policymaking. The team succeeded in building a Nordic team of excellence in CCS, with committed academic and industrial partners from the five Nordic countries. Even though there is no direct continuation of this cooperation – a proposal to Nordic Energy Research for a Nordic Flagships project did not get funding – continued collaboration will take place when appropriate funding allows for this to happen. A recent invitation from the Research Council of Norway to SINTEF to submit a proposal for a continuation of the project may not prosper, but has set in motion activities among the former project partners to probe how a pan-Nordic project could be brought about.

Project background

Brief description of the project

The NORDICCS project was a Nordic CCS platform involving major CCS stakeholders in the five Nordic countries. The project ran from 2011 until 2014, with a total budget of 47 MNOK.

The main objective was to boost the deployment of CCS in the Nordic countries by creating a durable network of excellence integrating R&D capacities and relevant industry with the purpose to:

- Provide Nordic industry-driven leadership within CCS innovation and realisation
- Demonstrate how CCS can contribute to the Nordic portfolio of climate change mitigation options
- Enable the Nordic countries to join forces to become pioneers in large-scale implementation of CCS
- Multi-contextual focus to utilise Nordic differences for broad stakeholder and global relevance
- Strengthen the competitive power of the region by combining capacities of the Nordic countries

The project involved a large number of project partners from all Nordic countries. Chalmers University of Technology, University of Oslo, University of Iceland, and the Norwegian University of Science and Technology were academic partners, the participating research institutes were the Geological Survey of Denmark and Greenland, Geological Survey of Sweden, Swedish Environmental Research Institute IVL, SINTEF Energy Research, SINTEF Petroleum Research, Tel-Tek, VTT Technical Research Centre of Finland. Gassco, Norcem, Reykjavik Energy, Statoil, Technology Centre Mongstad, and Vattenfall were the industrial partners. SINTEF Energy Research was project coordinator.

Project activities were organised in three categories: integrating activities, spreading excellence, and joint R&D activities. Each category included one or more of the six work packages: The Integrating Activities consisted of Assumptions and Premises (WP 1), Spreading Excellence consisted of Communication (WP 2), and the Joint R&D consisted of: Feasibility studies of Industry Cases (WP 3), CO2 Capture (WP 4), CO2 Transport (WP 5), and CO2 Storage (WP 6).

Background and rationale of the project

The project was preceded by a pre-study, funded by TRI and stakeholders such as SINTEF, which studied what type of project instruments could be used in this area. Based on an initiative by SINTEF, a large project team was put together for the main project. The ambition was high from the start: the aim was one big project covering all Nordic countries and different types of stakeholders, not several small projects. The pre-study served to scan for suitable project participants, even though those in charge of setting the team together already had a good network.

This was seen as an appropriate area for Nordic collaboration. A meeting with the Nordic Council of Ministers served to get responsible politicians on board.

For the research organisations, the opportunity to establish or strengthen cooperation with other companies in the Nordic region was a particularly strong motive to take part in the project. They were also motivated by the possibilities to increase value creation through the development of products, processes or services and to contribute to tackling societal challenges. The industrial partners' main motives to participate were to establish or strengthen cooperation with Nordic research institutions and to contribute to tackling societal challenges. A minority of the industrial partners also claim getting access specific research expertise as a motive for participation.

Results and effects

Outputs and results

The project has resulted in one PhD graduate. She was not funded by the NORDICCS project but was one of the key researchers in the project. Related research grants consist of the funding from

Norwegian sources (Research Council of Norway, CLIMIT/Gassnova) of two Summer Schools to a total value of €477,000. In 2016, the large Norwegian CCS Research Centre (NCCS) was granted €42m by the Research Council of Norway. The project leader of NORDICCS describes the project's relation to the NCCS in the following way: "It is not correct to say that NCCS is a DIRECT effect of, NORDICCS, but it could have been a contributing factor". The project did not lead to any spin-off companies or patent applications, and neither was this expected to happen.

Important dissemination results

The publications list from the NORDICCS project contains a total of 113 contributions. An informative website was created at the start of the project (http://www.sintef.no/projectweb/nordiccs/), Some of the most prominent dissemination results are the following:

- Nordic CCS Roadmap (peer-reviewed journal publication) by Marit Mazzetti et al., in Elsevier, Energy Procedia, 2013
- Norden kan fjerne CO2 (Newspaper chronicle) by Marit Mazzetti et.al, in Dagens Næringsliv, 2016-02-19
- CO2-rensing koster minst på sokkelen (Popular science publication) by Nils Røkke et.al, in Teknisk Ukeblad, 2013-11-11
- Local acceptance and communication as crucial elements for realising CCS in the Nordic region (peer-reviewed journal publication), in Elsevier, Energy Procedia, 2016
- Nordic Storage Atlas, https://data.geus.dk/nordiccs/map.xhtml
- Building Nordic Excellence in CCS – NORDICCS, The Nordic CCS Competence centre (final report) by Kielland Haug et.al, ISSN 1504-8640

Impact

Scientific impact

The NORDICCS project has clearly established or strengthened research cooperation with Nordic research institutions – all project partners stress this. For the research organisations, the NORDICCS project above all made it possible to start an internal R&D project with mainly private funding. The project has also contributed to their participation in a subsequent R&D project co-funded by a public funding body.

The summer schools were academic courses which also yield credits. Clearly this is a lasting footprint, and they have also contributed to the Roadmap activity in NORDICCS. The summer schools will be maintained in the future, if financial support can be found.

A Swedish researcher emphasises the value of a multidisciplinary group of experts with different backgrounds. Through this, the project obtained a "highly broad-spectrum palette of results which could not be possible in a national research group". A Danish researcher concludes that their Nordic research network has been significantly increased, and that they now have new projects including some of the NORDICCS partners. One interviewee sums up the project like this: "I have been at SINTEF for 30 years – I have never received so much positive feedback about any project before!".

Societal impact

As is well known, CCS technologies are high on the agenda in Norway. The country invests in large research and demonstration programmes (such as CLIMIT research and CLIMIT demo) and demonstration facilities such as NCCS and the Mongstad facility. Norway is, and has always been, the leading country in the area in the Nordic region. The Sleipner CO2 Storage facility in Norway began in 1996 as the first in the world to inject CO2 into a dedicated geological storage setting. The captured CO2 is directly injected into an offshore sandstone reservoir at the gas development area. Approximately 0.85 million tonnes of CO2 are injected per annum and over 17 million tonnes have been injected since inception to date.

The NORDICCS project contributed notably to put CCS on the public agenda, also in Sweden and Iceland. In Sweden, the interest in CCS went down after a first period of interest furthered by the commitment from Vattenfall when it was believed that prices on allowances in the EU emissions trading scheme would continue to be high. This did not happen, and the prices of emission allowances have become far too low, and other subsidy schemes have led to electricity prices going down. For several years after this, there was little movement in Sweden in the CCS field. Due to lack of commercial interest, the EU Commission established a specific fund based on funding through the sales of allowances, NER 300 for the demonstration of environmentally safe carbon capture and storage (CCS) and innovative renewable energy (RES) technologies but at the time when this became operational (2012), the management that earlier strongly had promoted CCS was replaced and Vattenfall also faced other challenges for its CCS programme. The NORDICCS project kept the network and research running, and now, when the second period in Sweden and the Nordic countries has renewed interest for CCS technologies on industrial processes (iron, steel, cement, refineries), this competence and community is there. The NORDICCS project thus made it possible for Swedish researchers and stakeholders to maintain knowledge and contacts during a period when these were not a national priority.

The Swedish research team at Chalmers University of Technology that participated in the NORDICCS project is the leading research group in CCS in Sweden and has since – thanks to the project – contributed to several public reports and inquiries. The research leader prepared a report for the Swedish Environmental objectives working group, which had an impact on the final proposition. The Swedish Government asked the research group at Chalmers for report on CCS technologies as a background document when preparing the Green conversion and competitiveness bill. The report outlined the possibilities and challenges of CCS technology (carbon capture and storage) in terms for them to be understood by laymen and thus contribute to a discussion of the need for a Swedish strategy for CCS. This document, however, had little impact on final policy, according to its main author. Finally, the research team are now working on a recent assignment for the Swedish Energy Agency, compiling the research front in the CCS area. A specific Swedish interest has been BECCS (Bio-energy with carbon capture and storage) where e.g. Linköping University has studied issues relating to acceptance. However, there has been no attempt to operationalise the concept so far.

This Nordic community and network also includes researchers and industrial partners from Iceland, previously not part of Nordic CCS cooperation. The NORDICCS project has very much contributed to all this happening. Iceland has vast envisaged capacity to store CO_2 in young basalts, a storage capacity which could be on the same order of magnitude as the North Sea basin. This was the surprising result of the storage atlas exercise in the project. The real capacity is now tested in the CARBFIX project at Iceland, and valuable information has been gathered from this pilot plant operation.

For the industrial partners, the NORDICCS project contributed to implementing new knowledge, methods or technology in the internal processes of the organisation. The project has been valuable also in making it possible for the organisation to participate in subsequent R&D projects co-funded by a public funding body.

The project pursued industrial cases, and to think as a region with common goals and opportunities. CCS cannot necessarily be confined by territorial borders, which made it an ideal project for Nordic rather than national collaboration.

The results of the storage atlas are used in Mission Innovation (MI, a global initiative of 22 countries and the European Union to dramatically accelerate global clean energy innovation). In particular, the collaborative constellation and how it was carried out have attracted interest. It is also used in EU projects, and in the Norwegian full-scale project (Gassnova).

Goal fulfilment and relevance

The project depended on Nordic cooperation and data input and delivered above expectations in all aspects. The objectives set up at the start of the project were all met. Each of the project partners had very clear roles in the project, and they all delivered what was expected of them.

According to the project participants, the main contributions of the TRI programme can be summed up as:

- Increased visibility of Nordic research in a European context
- Increased international competitiveness of Nordic research institutions
- Research results that serve the needs of the society

Sustainability

The NORDICCS project has had no direct continuation in further projects. An application to Nordic Energy Research for a Flagship Projects grant reached the final stages but was ultimately not successful. But the network of Nordic researchers and industrial players that the project helped creating lives on, as evidenced in several project proposals including some of the NORDICCS participants. The project built a Nordic research team in the CCS area, and this would otherwise not have happened. NORDICCS project partners are now working together in different constellations in different EU projects.

The two summer schools are seen as a very good experience and an asset that can be picked up and made use of again, if funding can be secured. The two occasions, the argument goes, provided in-depth knowledge on how to best carry them out and how to reach out to relevant participants (either as students or as lecturers). Those who participated in them as students are now in many cases employed in highly relevant positions nationally in the CCS landscape.

The earlier mentioned Norwegian CCS Research Centre (NCCS) is funded 50 per cent by the Research Council of Norway, and 25 per cent each from industry and other partners. The NORDICCS project cannot lay sole claim to this centre coming into existence, but some of the work carried out and results achieved in the NORDICCS project was decisive in the centre becoming a reality. Several of the NORDICCS partners are present also in the new centre; University of Oslo, Statoil, Norcem, NTNU, Tel – Tec. No partners from other Nordic countries participate in NCCS.

A recent development is the invitation from the Research Council of Norway to apply for funding for a continuation of the project. This happened in late 2017, when RCN asked the NORDICCS researchers at SINTEF to prepare a proposal to the national research programme CLIMIT. RCN showed certain enthusiasm for the idea of a Nordic cooperation project and gave an open mandate as to what a continuation should include. The idea from SINTEF was to focus on skills and knowledge out to industry, rather than doing pure research. These collaborative projects between researchers and industry would involve 2–3 PhDs in each project.

SINTEF contacted the NORDICCS partners, who were all interested in a “NORDICCS 2”. In January 2018, however, SINTEF learnt that the funds for the CLIMIT programme will be significantly lowered this year. New applications to CLIMIT should also have a high level of research content: the NORDICCS project was more a network project than research. This probably means that SINTEF will not submit a proposal to the CLIMIT programme, even though all the doors are not terminally closed and other possibilities are being considered.

In any case, SINTEF had already invited research partners in NORDICCS to discuss a possible future project. They are interested in moving on and find a way to continue the collaboration. Discussions will continue, and partners will explore what possibilities might exist to pool together a larger project based on individual project partners bringing their own national funding money into a common project pot.

A critical aspect of this (and similar) ambitious programmes that address societal challenges is that they require a long-term approach. It may not be optimal to fund four-year projects that end abruptly. A funding agency, such as in this case Nordic organisations, could benefit from having a plan for how to take the project and its different results further.

Communication

One of the work packages in the project was specifically dedicated to communicating the project and its results. The final report from the project suggests that in order to achieve a lively societal debate about CCS, within which thorough and broadly supported decisions about CCS in the Nordic region can be made, CCS needs to be discussed by more actors and in a more concrete way. This is particularly important in those countries where a CCS debate is not that visible today. Results also show that vague policy signals are seen as problematic. Similarly, results suggest a closer dialogue between policymakers and the industry.

Improved communication is particularly important with regard to overcoming knowledge asymmetries in areas that are identified by the industry as important to increase CCS activities. In addition to this, there is a need for increased dialogue between the different countries' policymakers if the potential transnational CCS solutions investigated in NORDICCS are to become a reality.

Whereas a considerable barrier for deployment of CCS in the Nordic region presently lies within the socio-political level, communication at the local level is also important. Opposition towards implementation of CCS projects at the local level, particularly in Europe, has been thoroughly documented. Reflecting this, findings show that the awareness and perceptions about CCS in municipalities in the Skagerrak-region varies greatly.

NORDICCS arranged the parliamentarian side event at the 65th Nordic Council meeting in the Norwegian Storting in 2013 as well as a number of public events in all the Nordic countries. The publications list from the NORDICCS project contains 113 contributions. The project website (https://www.sintef.no/Projectweb/NORDICCS/) is no longer being updated but contains a wealth of information for decision makers and other stakeholders to use.

Summary and lessons learnt

The CCS technologies are unusually suitable for cross-country collaborations, as they involve several distinct aspects (capture, transport, storage) that require multidisciplinary collaborations and also physical space of different characters. CCS technologies are high on the agenda in Norway, and this is where scientific and industrial knowledge is most developed. The country invests in large research and demonstration programmes (such as CLIMIT research and CLIMIT demo) and demonstration facilities such as NCCS and the Mongstad facility. Norway is, and has always been, the leading country in the area in the Nordic region. For this reason, collaborating in a project in this area may have been most beneficial for partners from other Nordic countries.

The NORDICCS project contributed notably to put CCS on the public agenda also in Sweden and Iceland. For several years, there was very little movement in Sweden in the CCS field. The NORDICCS project was based on a network for CCS that had been created in the Nordic region: it kept the network and research running, and thus maintained the competence and community.

CCS technologies are not as much in focus for the national policies in Finland and Denmark. The project partners from these two countries consider the experience as good, and it may lead to future projects in the area (as indeed it already has for one Danish and one Finnish project partner). There is, however, no great expectation that CCS technologies will achieve higher priority in these countries.

National projects do not enable as efficient collaboration between Nordic R&D organisations and companies, which was essential in the NORDICCS project. The collaboration between Nordic R&D organisations was strengthened significantly, and also brought in researchers that formerly were not part of the network. Collaboration between different project partners has continued also after the project. New project proposals have been prepared together with partners of the project. Several project partners point to new perspectives and ways of thinking, a valuable scientific network and increased possibilities for future R&D cooperation in the Nordic countries as Nordic added values created by the project. These are results that would not have come about in a strictly national project – and, in any case, a national project with similar objectives and scope would not have been able to receive funding in any of the individual Nordic countries.

All project partners asked about it agree that the NORDICCS project, in one form or another, should continue. The successful outcome of the project as evidenced by feedback from industry, politicians, NGOs, as well the partners, is a strong case for continued Nordic collaboration. The project has generated a Nordic "CCS team" with a common vision, and an enthusiastic spirit. A continued joint collaboration would facilitate a holistic approach to the Nordic challenges and efficient use of resources. Building a Nordic team of excellence in CCS is in itself a notable result, and it could be argued that the Nordic organisations at least in part would have an obligation to nurture the investment made. The argument could be made that Nordic institutions should strive to help the participants maintain this momentum for the benefit of the region's energy and climate strategy and policy.

This raises the issue of how a funding agency could best ensure that the results and experience of a project collaboration are exploited. It may not be optimal to fund four-year projects that end abruptly: a longer-term approach is advisable. This would be especially relevant for ambitious programmes and projects that address societal challenges and require (or at the very least benefit from) collaborations across borders. A funding agency, such as in this case Nordic organisations, could benefit from having a plan for how to take the project and its different results further. This would not necessarily need large amounts of extra funding, but a clear plan and some dedicated smaller funding for the following year or two of a project.

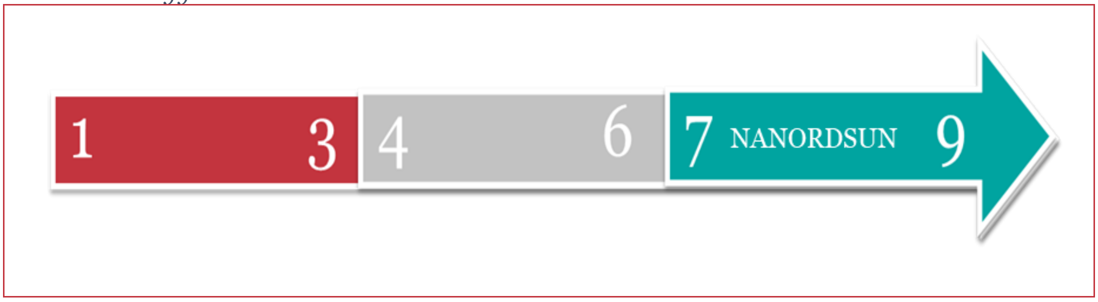
Case study: NANORDSUN

Executive summary

The NANORDSUN programme was very ambitious in aiming to develop nanowired solar panels, but did not succeed in delivering a fully equipped installation of this new type of solar panel. Nevertheless, the programme did gain new insights (technology readiness level 1–6) on the subject. In addition, a company was founded, using the new discoveries in the area of nanowires, and the research has been disseminated through important academic and popular journals. The research continues at the different faculties, and the researchers have been granted additional funding by the European Union.

The NANORDSUN programme had the ambition to develop a nanowired solar cell that would become eventually a consumer-based product. This product has not yet reached the market but is in the final stages of development. There is a large number of spin-off projects in the field of nanowired lighting. Currently the NANORDSUN programme has reached a technology readiness level of 7, having managed to demonstrate the product into an operational environment, and having undergone testing to identify bottlenecks in the technique.

Figure 1 Technology readiness level NANORDSUN



Technopolis (2018)

In terms of social readiness, the NANORDSUN programme has shared insights into the technique with the relevant stakeholders. The dissemination of knowledge came about through the close connections between programme and the market, with two private parties collaborating in the programme. The newly discovered insights were directly adapted and used. The NANORDSUN programme has reached level 5 on the societal readiness scale, having proposed nanowire-based solutions and having disseminated this knowledge to the relevant stakeholders in the area.

Figure 2 Societal readiness level NANORDSUN

Technopolis (2018)

Project Background

Brief description of the project

The NANORDSUN programme was part of the Top-level Research Initiative 'Energy Efficiency with Nanotechnology'. The programme aimed to contribute to the promotion of the Nordic region as a pioneer within the climate, energy and the environment sector, promote Nordic business, be an example of excellent quality, and create a connection to similar funds within EU Programmes. The idea was that the NANORDSUN programme would work together with both industry and outreach, and communicate their ideas. NANORDSUN had the objective to use nanotechnology

> *'... to develop cost and energy-efficient solar cells to harness the energy from the sun as effectively as possible. In view that silicon nanowire cells have been shown to exhibit efficient light trapping that consequently enables silicon nanowire solar cells to use only about 1 percent of the material used in equivalent thin-film silicon solar cells, NANORDSUN's immediate aim is to focus on the research and development of low cost and highly-efficient III-V semiconductor core-shell radial p-n junction nanowire solar cells.'*[27]

The programme aimed to bridge the academic theory with the commercial reality. The collaboration between the Swedish entrepreneurs and the researchers was initiated to bring more efficient solar cells based on nanotech to the market. The programme managed to develop nanowired cells, as well as master other important aspects of the technology. The programme also developed the technology to produce and process nanowired solar cells.

The programme structure has not been documented, the only note that can be made on this matter is that the programme was a public-private initiative. The programme ran between the autumn of 2010 and the autumn of 2013. The budget consisted of two components: one part consisted of 10 million NOK from TRI to NANORDSUN, and the other part consisted of 15 million NOK of own funding.[28]

The consortium consisted of six partners, four Swedish, one Norwegian, and one Finnish. Of the four Swedish partners, three were from the Skåne region; two were private (Sol Voltaics AB & Obducat AB) and two were Universities (Lund University & The Royal Institute of Technology in Stockholm (KTH)). Both the Norwegian and the Finnish partners were academic, the Norwegian University of Technology and Science Trondheim, and the Aalto University from Finland respectively.

Background and rationale of the project

The programme has a background that starts from a project granted by the European Commission in 2008, the AMON-RA project, which:

> *'is intended to result in a new type of solar cell, combining advanced hetero- and nano-structures with silicon photovoltaic technology. By applying state-of-the-art photovoltaics design to semiconductor nanowires and nanotrees and assisted by tailor-made theoretical modelling and advanced processing, we aim to demonstrate high-efficiency multi-junction photovoltaic cells made from previously impossible materials combinations. The high degree of self-assembly and insensitivity to lattice parameters inherent in the nanowire growth process will also make it possible to produce such cell relatively cheaply and on inexpensive silicon substrates. In AMON-RA, we will also evaluate the solar cell designs on a systems level, with special attention to future industrialization and upscaling.'*

The AMON-RA project consisted of a consortium which included two of the NANORDSUN partners: Sol Voltaics and Lund University. The research done within the AMON-RA project led to the discovery

[27] http://www.toppforskningsinitiativet.org/en/programmer-1/program-3/nano-materials/Always%20the%20Sun%20-%20A%20New%20Ray%20of%20Sunshine.pdf

[28] Semiconductor nanowire based solar cells NANORDSUN (PowerPoint presentation)

of nanowired based solar cells. The NANORDSUN programme was built on this discovery, and tried to commercialise the technique with the support of Obducat AB. The consortium that applied for the programme was led by professor Helge, then connected to the NTNU in Trondheim. He managed to connect two corporate and four academic partners. At NTNU there had been active research into nanowired solar cells in the years preceding the NANORDSUN programme. The consortium partners set the goal to demonstrate and produce a nanowired solar cell, with the aim to launch more efficient solar cells. The consortium was built on the idea that they had complementary skills, and the involved participants felt they could use this to bring about a breakthrough in the field.

Results and effects

Outputs and results

The programme produced different kinds of outputs and results, including:

- three PhD theses
- 29 peer-reviewed articles
- one spin-off in the Trondheim area, called Crayonano
- 9 FTEs linked to this spin-off

On top of these outputs, the programme engaged in activities to disseminate and communicate the knowledge they had obtained. The programme organised meetings for which they invited researchers and representatives from other universities, programmes, institutions and companies. The yearly meetings consisted of a presentation of the new findings and a workshop. Participants came from the EU network of excellence Nanophotonics for energy efficiency.

The programme participants have applied for three patents, two of which were granted, and one was denied. The patent applications were done by researchers from different nationalities: one was Austrian, one Norwegian, and the rest came from Sweden (Table 5).

Table 5 Patent applications

Title	Radial p-n junction nanowire solar cells
Inventor(s)	Cheng Guan Lim and Helge Weman
Assignee	Norwegian University of Science and Technology
Jurisdiction (Sweden /Europe /USA etc.)	International
Year of application	2013
Patent granted (Yes / No / Application pending)	No
Year of patent granted	
Title	**Recessed contact to semiconductor nanowires**
Inventor(s)	Åberg Ingvar [Se]; Magnusson Martin [Se]; Asoli Damir [Se]; Samuelson Lars Ivar [Se]; Ohlsson Jonas
Assignee	Sol Voltaics
Jurisdiction (Sweden /Europe /USA etc.)	International
Year of application	2012
Patent granted (Yes / No / Application pending)	Yes
Year of patent granted	2015 in some countries
Title	**Concentric flower reactor**
Inventor(s)	Alcott Greg [Se]; Magnusson Martin [Se]; Postel Olivier [At]; Deppert Knut [Se]; Samuelson Lars [Se]; Ohlsson Jonas [Se]
Assignee	Sol Voltaics
Jurisdiction (Sweden /Europe /USA etc.)	International
Year of application	2012
Patent granted (Yes / No / Application pending)	Yes
Year of patent granted	2017 in some countries

Self-Assessment

Impact

At the technological readiness level of 1–3, the programme resulted in a number of publications in important journals (Nature and Nature Photonics). The researchers involved with the programme indicate that many of the results would not have been achieved were it not for the network brought in by the consortium. Those who were involved indicated that the process of developing the solar panels based on nanowired technology took longer than expected. The technology showed some limitations at the technological readiness level 4–6, nevertheless, at the end, the researchers and affiliated companies were able to produce a couple of prototypes.

The research in the programme contributed to high-impact research articles in such as Nature and Science, was presented at invited talks at international solar cell conferences, and had media coverage in technical magazines and newspapers (interviews and leaflets spread to the general public). The programme results still contribute to the present research and business activities. According to the self-assessment, the Nordic added value was the opportunity to do better networking and the continued collaboration on new programmes. It has supported the Nordic Industries: Sol Voltaics, Obducat and CrayoNano. A change in research practice has led to Sol Voltaics pioneering “aeorotaxy” growth of nanowires, and CrayoNano has pioneered nanowire growth on graphene substrates. The economic impact has been an increased competitiveness for Sol Voltaics, Obducat and CrayoNano. The societal impact has been an increased public awareness in the area of solar energy, through the publication various media articles.

The three PhD candidates connected to the research programme came from a Nordic country, and they remained in Nordic countries after they completed their PhD.

Goal fulfilment and relevance

The goal of the programme was to produce a product based on nanowired solar cells. This product had to be more efficient than standard solar cells, and had to be produced at a lower price than normal solar cells. The consortium managed to produce prototypes, however these prototypes were not yet market competitive when the programme ended. The programme was too ambitious, and it has taken more time than expected to commercialise the research.

Although the researchers had pointed out the limitations of the technology, it appeared hard to overcome these early stage problems. A specific bottleneck was the fact that nanowires need a larger surface area than regular solar cells. This may sound like an advantage, considering the ability to collect more sunlight, however as most defects occur on the surface this led to more defects than predicted.

The programme has led to a specific expertise in single junction nanowired solar cells. As such, the goal that they should contribute to establishing expertise in the energy sector has been reached. In addition, the programme has led to a product that could potentially contribute to the mitigation of climate change (on a limited scale). The collaboration between the involved research institutes contributed to a temporary heightened activity of the Nordic innovation system, especially within the Skåne region and the region around Trondheim. These regions have benefited from the programme on the long-run, as the spin-offs were established in these regions. The research has delivered theoretical insights that have potential in a variety of nano-related technology applications.

As a result of the experimental work and modelling, the researchers found that it is possible to get higher solar cell efficiency than was expected. Theoretically, this can become even higher than the prototypes that are produced so far. However, limitations the researchers have had to deal with include problems with the materials, and the increased need for material maintenance. The model has shown a conversion rate of 35 per cent for a single junction.

Sustainability

When the programme finished, the researchers did not continue to work together in the same composition as during the programme. Yet, the collaboration has not ceased, and the connections of the programme remain vibrant between the different entities of the programme. NANORDSUN researchers from Lund University have received new funding by the EU to continue their work. The NANORDSUN participants from the NTNU have received funding at a national level from the Research Council of Norway (Table 6).

The main reason that the consortium did not continue to work as a whole after the programme finished was that a some of the partners developed new interests during the research period. The corporate partners have continued to work with Nano solar tech and the academic partners are continuing their work on nanotech-based light. The spin-off that was established in Trondheim is directly related to this new nanotech light.

Table 6 Most important additional funding

Project title	Total amount granted (€)	Year granted	Funding source	Comment
Nanowire-based tandem solar cells	3,561,841	2015	EU	Coordinated by Lund University
GRANASOL	1,000,000	2015	Research Council of Norway	NTNU, Norway

Self-assessment

Communication

There was no direct communication strategy within the NANORDSUN programme. The dissemination of knowledge by NANORDSUN occurred during the general TRI meetings, through participation of programme researchers in panel discussions. The most public attention came from the launch of the spin-off by one of the project partners: this was covered by a four-page article in the international magazine International Innovation (Table 7).

Table 7 Most important scientific and media attention

Title	Reference of source	Year
Always the Sun	www.ResearchMedia.eu	2012
Better solar cells and LEDs	Aftenposten (Norwegian Newspaper)	2014-04-11
Nano-knowledge give super solar cells	Gemini.no	2014
Small and good	Dagens Næringsliv (Norwegian Newspaper)	2014-04-10
NANORDSUN; Semiconductor nanowire-based solar cells. Solving the Climate Crisis- A Nordic Contribution	NordForsk	2015-09-01

Self-assessment

Summary, lessons learnt

The principal of the programme indicated that especially the TRI programme provided a stable framework in which there was a solid effort to maintain a strong consortium. The funding enabled the researchers to expand their network and to be more aware of their Nordic colleagues. The consortium partners managed to develop their own niche after the funding stopped, with help of national and European funding. The principal indicated that NordForsk was the main driver of the increased collaboration between partners.

The programme also incubated innovation in the field of Nanotechnology in a wider sense. The aim of the energy and climate framework was to stimulate research and innovation related to this topic. This was only partly achieved. The Skånish companies continued with developing nanowired solar cells, the academic interest faded and changed focus to lighting. As the solar cells are not yet available on the market, their real impact on the energy sector cannot yet be measured. The most valuable outcome of the programme is the stimulation and incubation of innovations on nanowired solar technology in Sweden and nanowired lighting technology in Norway.

Researchers related to the programme recommend continuing having this kind of call. They recommend that the calls should be annual, rather than at irregular intervals. This way people are in a better position to prepare a proposal. They additionally recommend in increase in the overall funding budget, so that more consortia can be funded. The outcomes may improve if all the good programmes that apply get funded. Continuous and annual calls will motivate Nordic scientists to check the calls of NordForsk as often as they check their national calls.

Case study: HG Biofuels

Executive summary

In the HG Biofuels project ("High gravity hydrolysis and fermentation of lignocellulosic material for production of bio-fuels"), two universities (Chalmers University of Technology and University of Copenhagen) and three companies (Statoil, SEKAB and Inbicon) collaborated on developing high-gravity processes for production of ethanol and butanol. This is in itself not a new product on the market, but the project influenced a new way of carrying out the fermentation process. The project brought together different competences including process design, chemical engineering, enzyme technology, fermentation technology, microbial physiology, plant cell wall chemistry, wood processing and life cycle assessments. By working together on three different processes addressing different angles, making academia and industry meet, the project made significant progress on the utilisation of Nordic raw materials and accelerated the development of high gravity processing of lignocellulose material. Based on the technical development, the life cycle assessment, the project led to significantly improved technology and clear conclusions on future targets for further improvements and developments. The cross-disciplinary organisation of the project was an important aspect and led to insights that would not have been achieved otherwise.

The HG Biofuels project resulted in 17 peer-reviewed articles and 19 oral presentations at international conferences. Three PhD students graduated in the course of the project; two of these now work for private companies in the sector in Sweden, one is an assistant professor at the University of Copenhagen. The project led to four related research grants from national funding agencies, to a total value of €4,047,000.

Project background

Rationale and objectives of the project

The realisation of sustainable bioeconomy solutions depends on the efficient processing of biomass. High gravity technology is one important aspect to realise such processes. The major objectives and deliverables in the project were to:

- Advance the technology for production of 2nd generation liquid biofuels (ethanol and butanol) at very high gravity by improving process integration, hydrolysis procedures, developing novel robust fermentation organisms and optimising fermentation conditions
- Expand the knowledge-base on yeast and bacterial growth and physiology under industrially relevant (and challenging) conditions using various Nordic lignocellulosic feedstocks. Both Nordic wood and agriculture residues pre-treated with hydrothermal pre-treatment and steam pre-treatment will be used
- Use LCA as a tool to evaluate, from an environmental point of view (i) yeast-based ethanol production under high gravity conditions and (ii) to assess research steps necessary to make butanol conceivable as a biofuel in addition to ethanol

Structure, duration, budget and funding

The project was granted funding in 2010, and the Top-level Research Initiative contributed with 6 million NOK (out of a total budget of 8 million NOK). The (future) project leader at Chalmers University of Technology saw an opportunity and contacted a professor in LCA at the same university. The researchers at University of Copenhagen were already part of their professional network. The project team was completed with two companies the researchers at Chalmers had collaborated with, and a Danish company that the researchers in Copenhagen had contacts with.

Chalmers University of Technology was the project owner, and the following partners from three Nordic countries participated in the project:

- R&D-partners:
  - Chalmers University of Technology, Department of Chemical and Biological Engineering

  - Chalmers University of Technology, Department of Energy and Environment
  - University of Copenhagen (Denmark)
- Industry partners:
  - Statoil (Norway)
  - SEKAB (Sweden)
  - Inbicon A/S (Denmark)

The project combined the competences from the partners to enable the development of a high gravity process concept for ethanol and butanol production. The industrial partners Inbicon and SEKAB supplied the pre-treated biomass, pre-treated wheat straw and spruce, respectively. Enzymatic hydrolysis was studied by the Biomass group at the University of Copenhagen. The study of the ethanol fermentation process step was carried out by Chalmers and University of Copenhagen, while butanol fermentation was performed by Statoil. Selected experimental results were used to perform life cycle assessment (LCA) for the production of ethanol at high gravity conditions, from feedstock cultivation to final product, in order to evaluate its performance from an environmental perspective.

Background and rationale of the project

From the project participants' perspective, the Top Research Initiative was launched at a favourable moment. This was an urgent development area, where the whole economy of a technology is based on high gravity skills. Sweden had plunged into biofuels, with a great focus on cellulose ethanol: this was one of the most important projects in this development and a prerequisite for developing Swedish cellulose ethanol technology. There was also considerable movement in the matter in Denmark; the company Indicon built a large demonstration facility, in conjunction with an EU environmental meeting in Copenhagen. The interest in Norway was less clear, although Statoil at the time was committed to the butanol fermentation process.

The configuration of the project and project partners was relatively quick and easy. The partners brought complementary competences, and with knowledge of different policies and market perspectives. There was a Nordic consensus that it was an important area and getting funding from TRI was seen by the project partners as a quality stamp.

Results and effects

Outputs and results

The project has resulted in three PhD graduates. Two of these now work for private companies in the sector in Sweden, one is an assistant professor. Four related research grants have been identified, three from Swedish research funders (two from the Swedish Energy Agency and one from Formas) and one from the Danish research council, to a total value of € 4,047,000:

Project title	Total amount granted (€)	Year granted	Funding source	Comment
Bioetanol från gran och havreskal via processen "High Gravity Multifeed" – samtidig försockring och jäsning	500,000	2016	Swedish Energy Agency	Project working on the multifeed concept developed in HG Biofuels
Xylose fermentation and cell propagation for efficient lignocellulosic ethanol prodcution	700,000	2016	Swedish Energy Agency	The project relates to the importance of cell propagation that was an outcome of the HG

				Biofuels project
Upgrading of renewable domestic raw materials to value added bulk and fine chemicals for a bio-based economy – technology development, systems integration and environmental impact assessment (BIOBUF)	2,540,000	2013	FORMAS – Swedish Research Council for Environment, Agricultural Sciences and Spatial Planning	The basis for the project, to integrate technical and systems research to develop biorefineries stems from the HG Biofuels outcome
The lignin-cellulose electron shuttling mechanism	307,000	2014	Danish Council for Independent Research	The basis for the project was the results from the HG Biofuels project showing that LPMOs played an important role in the hydrolysis at HG conditions.

The project has not triggered any spin-off companies or patents, nor was this expected to happen.

The project leader held a plenary talk at the ESBES conference in Dublin in 2016, on the subject "Bioethanol and other processes for the bio-based economy – development of robust cell factories and robust processes". She was also part of the expert panel for possible new funding scheme, Bioeconomy in the North, in 2017. In 2014, the project leader and members of the project team published the article "Lignocellulosic ethanol production at high-gravity: Challenges and perspectives" in Trends in Biotechnology, 32, 46–53.

Impact

Scientific impact

In approaching high gravity ethanol fermentations, several strategies were developed to overcome the challenges that come with high gravity fermentations. Addressing the challenges spans from improved process technology, improving enzymes and microorganisms to increased understanding of the challenges from a life cycle analysis perspective (Xiros, C., M. Janssen, R. Byström, B.T. Børresen, D. Cannella, H. Jørgensen, R. Koppram, C. Larsson, L. Olsson, A.-M. Tillman, S. Wännström (2017) Toward a sustainable biorefinery using high-gravity technology. Biofuels, Bioproducts and Biorefining, 11:15–27).

One important outcome from the project was a new principle for high gravity fermentation technology. Traditional technology using simultaneous saccharification and fermentation, resulted in very poor fermentation of the high gravity spruce material that was applied in the project. Key challenges to overcome was the poor mixing and mass transfer and low viability of the cells resulting in stuck fermentation. Different feeding strategies of enzymes and solid substrates has been reported in the literature, showing a partial solution to the problem. As all the fermentation performed under high gravity fermentation resulted in stuck fermentations, the project focused on how the cell viability could be increased. As a result of the research, feeding of cells was introduced in a multi-feed simultaneous saccharification and fermentation and could demonstrate an efficient fermentation of high gravity steam-pre-treated spruce.

This was the first time the researchers at Chalmers and University of Copenhagen collaborated in a project. This significantly increased the contacts, and the project leader claims that "we influenced each other's scientific views and work". For the professor at Chalmers responsible for the LCA analysis, this was the first time she applied her work on biofuels The LCA analysis was an integral part of the project, and the experience has opened up a new field of interest for her research group.

Societal impact

The project further developed the concept in new projects, leading to a significantly increased ethanol yield and productivity. HG Biofuels involved industrial partners teaching the researchers aspects of the fermentation important in larger scale. Due to the established contacts with SEKAB during HG Biofuels, the project later on also tested the multi-feed concept in demo scale, showing for the time the highest ethanol concentration achieved in the demo plant. An important aspect of this case is that it demonstrated very clearly that new ways of approaching the process technology can make a non-fermentable stream well fermentable. In the proceeding projects modelling has been applied and brought about several important insights. This multi-feed concept is now being used at the plant owned by RISE and run together with SEKAB.

Beneficiaries were academic peers and the business sector (scale-up of lignocellulose-based processes). Since follow up research is nationally funded, the main geographic scale of impact has been nationally in Sweden and Denmark. Results have been disseminated globally to the scientific community.

Goal fulfilment and relevance

The project reached its main goals. It made significant progress towards technical solutions for efficient high gravity ethanol production. Analysis of environmental impact and identification of necessary technical improvements laid the foundation for further developing such processes to allow sustainable bioeconomy solutions.

The results from the project showed that process design and choice of hydrolysis/fermentation strategy are critical factors that significantly affect the yield and thereby the environmental impact. Operating processes at high solids concentrations is technically challenging, especially at lab scale. The project offered several approaches to technically improve high-gravity fermentations, some of which have been proven in demo scale trials. The studies of continuous processes for enzymatic hydrolysis and fermentation are of special interest. Increasing the solid loading may potentially reduce energy consumption for the separation, but the efficiency of the hydrolysis needs to be improved (or environmental footprint for enzyme production reduced) to allow a sustainable production.

Life cycle assessment is usually done based on mature industrial processes. In this case, however, experimental lab data were used to assess the environmental impact of a technology in its very early stages of development. This resulted in methodological challenges that have not been sufficiently addressed so far. Based on the technical development, the life cycle assessment, the project led to significant improved technology and clear conclusions on future targets for further improvements and developments.

The development of a butanol production process at high gravity did not come to fruition. Statoil, the project partner responsible for butanol fermentation, decided to close this line of business during the course of the project.

Sustainability

Although the project did not continue in its original form, there are several sustainable results:

- The project developed what is an established technology today. By 2012, the development of the technology had come quite far. The Swedish business partner in the project, SEKAB, had built a plant but could no longer bear the its cost (some 15–20 million SEK/year). SP Technical Research Institute of Sweden (now RISE) entered and took responsibility for operating the business together with SEKAB. The plant is run at higher dry levels, and it is now possible to process dry peaks in a way that could not be done when the project started. The multifeed technology is another lasting element of the project. “If the technology had not existed then, the plant would not have existed today”, a person in charge at SEKAB says
- The project served to further strengthen good cooperation between Chalmers and SEKAB, and the project led to some important spin-off projects
- The EU project Valchem (VALue added CHEMical building blocks and lignin from wood) runs from 2015 to 2019 with a budget of €18,502,703. SEKAB is one of four project partners as supplier

of materials and technology. The knowledge and contribution from SEKAB was crucial for building the project

- The research continued in a Swedish collaborative project named Biobuf, financed by Formas, in which several of the Swedish partners from the TRI project take part
- A Danish research partner says a new laboratory system for testing hydrolysis and fermentation was developed and have been important in following projects. In addition, new insights into new enzymes were discovered that have formed the basis for a new research topic in the group

The researchers at Chalmers and University of Copenhagen have applied for several projects to continue their collaboration, although none have yet been granted. The researchers keep in continued contact, and lecture at PhD courses at each other's universities.

Indicon did not run it for so long –realising they could not run it profitably. Indicon is not talked about much today.

At that time: gave contact with Indicon (did not lead to a real deal but valuable ongoing contact; we learnt with each other). Contact with Statoil was also valuable, we learnt. So the contact area with the other companies was the most important

Communication

Academic peers, business sector (scale-up of lignocellulose-based processes) have been the target groups for the project results. This has mainly been achieved nationally (as follow up research is nationally funded) and internationally (disseminated to the scientific community). Also, project participants specifically mention that the final programme conference was very good.

Summary, lessons learnt

All project partners who have contributed to this case study consider the project a success, and a very positive experience. The collaboration with the other Nordic partners gave unique opportunities and access to resources that would not have been available in a national project. The Nordic format allowed for a project with a low level of bureaucracy, where questions that are high on the agenda in the individual countries could be put in focus. The project team put significant effort into mobility, which created a good foundation to build the relationships. The trustful relations between academia and industry allowed discussions of important aspects of the processes with benefits to all participants. There was no need for complicated rules, and the responsibility for running project meetings was shifted between the partners. The project partners also point out that the good project management worked very well. The project produced a relatively large number of publications.

All participants used the same raw material streams and shared data on the same process allowing a truly integrated study. There was a clear Nordic added value as such in the choice of raw material streams to work with. The industrial participation was important, and natural; the funder insisted on this, but it would probably have happened in any case.

One recommendation would be to look at the area more generically (biomass as raw material, forest and agro) – this could result in a powerful synergistic interaction on a sugar platform, alternatively on the lignin. There is some funding nationally on this, but joint efforts are equally needed.

Another opportunity would consist in infrastructure cooperation. This happened in the forest area (in the EU ERIFORE project, now finished). There should be a political interest in the Nordic countries in this.

HG Biofuels focused on the process chain, not the innovation chain. Research such as this, in which different aspects are linked together, would be valuable. There is a need for research on bio-based products – there is a need to better understand what is happening in nature, and to be able to measure it.

The project leader summarises the project in the following way: “We managed to get a lot of results for relatively little money. Further funding opportunities from Nordic organisations, long-term visions in the programmes and possibilities to plan ahead would be welcome”.

Case study: SVALI

Executive summary

SVALI is a Nordic Centre of excellence equipped to research changes in the land-ice volume in the Arctic and North-Atlantic area. SVALI is one of the centres dedicated to delivering insights on the interaction between climate change and the cryosphere. The programme started in 2010 and continued until 2016. The programme organised a PhD School and had a horizontal work package dedicated to communicating the findings of the programme.

SVALI was a climatologic research programme that did not carry the intention to provide any sort of prototypes, products or commercial services. The programme contributed to fundamental research at an international and high level. The researchers managed to combine the results from many different universities to come to new estimates and views on the development of the distribution between land and land ice. The fundamental research can be considered to have reached the technology readiness level 2 (formulation of theory) (Figure 12).

Figure 12 Technology readiness level

Technopolis (2018)

From its start the programme had the ambition to reach out to both academics and non-academics. The programme successfully supported 17 PhD students, published 72 peer-reviewed articles, and shared their ideas on more than 50 conferences. The ideas were communicated to a wider audience through a website called Isskolen. This website was developed to teach children about glaciology (Figure 13). They shared their ideas and solutions with researchers and policymakers, spoke with key stakeholders in Paris and gained feedback on the potential impact of their research. Therefore, the SVALI project recached level six on the societal readiness level scale.

Figure 13 Societal readiness level

Technopolis (2018)

Project background

Brief description of the project

The SVALI programme was based on multidisciplinary and cross-national scientific collaboration. The programme was multidisciplinary on account of integrating observations from different areas of expertise. They developed a thematic structure, which contains three themes, with the objective to better *'understand the stability and dynamics of the cryosphere, and the implementation of new and* *improved process formulations that have not been adequately addressed in current Earth System Models (ESM) before.'*[29]

The programme's three themes are each divided into three work packages, resulting in a total of nine work packages. Each theme had a thematic leader: two were from Iceland and one from Denmark. All the themes and work packages shared the aim to contribute to educational, scientific and societal purposes.

The first theme was called *'Observing the present – baseline and changes'*. In this work package, a benchmark for the ice-volume/mass of each glacier region is constructed for future measurements. This theme investigates the ice-dynamics through observations of ice velocities and velocity variations within in-situ measurements. Besides the benchmarking and the observations of ice velocities, the first theme established a dataset of Nordic mass-balance observations.[30]

The second theme was aimed at *understanding the physical processes* of the Arctic region. It aims to quantify the effect of climate variations on subglacial hydrology through modelling the mass loss from melting glaciers and the *'interactions of atmospheric, cryospheric and hydrological processes at glacier surfaces'*.[31]

In the third theme, the results of theme one and two were put together and expanded upon, to understand the *present changes and predicting the future*. Researchers formulated glacier-atmosphere interactions in order to acquire new models of glaciers. In this last thematic area, *the response of glaciers to climate change will be explored as well as the natural and anthropogenically induced variability and stability of glaciers within the Earth system in the past and under different anthropogenic carbon emission scenarios.*[32]

Besides the thematic structure, the SVALI programme also had a horizontal dimension. This horizontal dimension is split into three work packages called horizontal activities. One of the activities consisted of running the graduate school for PhD students and postdocs mentioned earlier. This graduate school also organised workshops, summer schools and cross-border integration projects. The second work package aimed to create a dataset and models that could support advanced Earth system modelling. The third work package of this horizontal theme was called outreach and dissemination, which included: *'…including an NCoE leaflet, website, educational material and activities, scientific assessments, summaries for policy and decision makers, press releases and exhibitions.'*[33]

The programme received a budget of NOK 12,390,000. This budget was primarily used to finance the hiring of scientific staff. Seventy-six per cent of the budget was spent on hiring postdocs and PhDs. The consortium that received this funding consisted of institutes from Denmark, Finland, Iceland, Norway and Sweden. It consisted of the 17 following partners: University of Oslo, Norwegian Polar Institute, IT Centre for Science Ltd., NBI University of Copenhagen, Danish Meteorological Institute, DTU Space, GEUS, Uppsala University, Norwegian University of Life Sciences, University Centre in Svalbard, Finnish Meteorological Institute, Icelandic Meteorological Office, University of Iceland, University of Lapland, Arctic Technology Centre/DTU Civil Engineering, Norwegian Water Resources and Energy Administration, Stockholm University, and University of Helsinki. There were no business orientated partners involved.

Background and rationale of the project

The project has its background in the research area of glaciology. Within this research area, a strong Nordic network developed over the last decade, which included annual meetings and a constant exchange of ideas and views among the involved specialists. Researchers in this area who attended these yearly conferences developed the ambition to form a consortium and were waiting for a call as big as the TRI call. The participants of the programme knew each other from conferences and through

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[29] http://ncoe-SVALI.org/project/index.html

[30] http://ncoe-SVALI.org/project/theme1/index.html

[31] http://ncoe-SVALI.org/project/theme2/index.html

[32] http://ncoe-SVALI.org/project/theme3/index.html

[33] http://ncoe-SVALI.org/project/horizontal/index.html

cross-border research that was funded by national funds. The ambition to start a programme on the scale that NordForsk provided was thus already present. The call for tenders was the direct trigger to submit a proposal that was already agreed on by the involved researchers, being well aware of the capabilities of the team. When the call came the consortium was formed quickly and a proposal was submitted.

Results and effects

Outputs and results

The programme led to a range of tangible and intangible results. It generated an influx of new insights and knowledge on the subject, as well as new or stronger connections between Nordic researchers within the area of glaciology.

The first output of the programme was the opportunity for eighteen senior researchers to work together to reach a level of excellence within their research area. These researchers were attached to the earlier mentioned research institutes, Meteorological centres and other research facilities.

The prestige and reputation of the programme helped the SVALI researchers to find additional funding besides the TRI grant. The researchers related to the consortium managed to acquire six additional scientific grants, both during SVALI, and after the programme finished. Two of the six additional grants were acquired during when the programme was active, the other four grants were given a year after the programme ended. The main financial contributor to the SVALI team besides NordForsk was the Icelandic Ministry of Environment. On top of the initial funding by NordForsk, NordForsk granted the programme with another NOK25m under the flag of the Nordic eScience Globalisation Initiative. The programme received European funding from the CryoVEx programme which was set up by ESA.

The most important output of the SVALI programme was the successful publication of 72 peer-reviewed articles and 27 reports. These publications were not the only dissemination output of the programme, the researchers related to the programme also gave presentations at more than 50 conferences.

As a result of the ambition to spread the findings and ideas to a wider public, a website was launched which was completely dedicated to report and communicate the research findings in layman's language. This website provides access for a broad audience to read and learn about the programme. The programme management did not only focus on the dissemination of their results to adults: another website, designed to provide high school students insights on glaciology, was launched under the name *isskolen.dk*. This website provides information, videos and an interactive game. The Isskolen website can be accessed in nine languages: Icelandic, Danish, Finnish, Swedish, Norwegian (Bokmål), English, German, French and Kalaallisut (West Greenlandic). Beside the websites and academic publications, there were also eleven general reports published containing findings from SVALI.

Impact

The impact of the project on scientific research has been positive. Three involved researchers indicate that they strongly agree that their involvement with the programme has enabled them to recruit new PhD candidates, in addition to senior researchers.

It was not only easier to find skilled researchers, but the existence of the TRI programme also helped the participants to strengthen the cooperation with other Nordic research institutions (i.e. universities, university colleges or research institutes). The three researchers who reflected on our questions indicated that they strongly agree with the fact that the collaboration with NordForsk had a positive impact on this.

There were three researchers who indicated that the programme did not have an impact on the Nordic business sector; they stated that there was limited value creation through the development of products processes or services. The mobility of the former PhD candidates was relatively high, only two out of ten remained at the University that they were working on during the programme. From the eight other

PhD candidates six remained in Scandinavia, one went to work in Germany, and one continued in the United States. The PhD candidates all remained within the academic research sector.

> *"The main impact of the NCoE is that the TRI programme has given us the opportunity to develop the Nordic cooperation in cryosphere science to a new level. This has led to new integrated research of the cryosphere in our region and has given a strong fundament for future collaboration and joint research proposals both on a Nordic level and on a European level.*
>
> *Wide and extensive collaboration between the Nordic Institutes working in glaciology has thrived during the lifetime of SVALI and has resulted in many new initiatives. There has been made progress in the research on glacier volume changes in the 20th Century, glacier hydrology, calving mechanism and implementation and coupling of glaciers in Earth System Models (ESM). Many runs with ESM have been made specifically for SVALI, where the focus has been on developing and validating the presentation of refreezing, retention and albedo in the surface mass balance part of the ESM. The research has gained increased international visibility and the project researchers organised a final conference in Greenland in June 2015 in collaboration with ESA-CCI project." (http://www.esa-icesheets-cci.org).*

The second important achievement is the development of the graduate school with shared education resources for PhD candidates in the involved universities. All the glaciology-related courses that are held in each university are now acceptable at the other member universities. This is a cooperation that will have long-term impact and continue beyond the lifetime of SVALI.

As part of the outreach activity should also be mentioned the web-based ice school that is implemented in all Nordic languages in addition to English (http://isskolen.dk/wp/).[34] The ice school published exercises, videos and information for young students. Technopolis Group did not get access to the website statistics, therefore the primary source could not be put to use. Instead, we used the activity of the forum and the number of views on YouTube of the available videos has been reviewed to analyse the impact of Isskolen and to estimate the number of visitors to the website.

Table 8 Statistics videos Isskolen.dk

Video	Producer	Views (subscribers)
Helicopter taking off from a crevassed area on the Greenland ice sheet	Isskolen SVALI	324 (0)
Helicopter taking off from a flat area on the Greenland ice sheet.	Isskolen SVALI	212 (0)
Large Calving Event at Helheim Glacier in Timelapse, Greenland, 12 July 2010.	Swansea University	81,000 (90)
350 Days in the life of a retreating glacier	Exteme Ice Survey	80,000 (9.500)
Time-lapse of a calving glacier in Greenland	PROMICE Greenland	2,063 (47)
Calving glacier	Isskolen SVALI	751 (0)
Animation of meltwater affecting glacier flow and calving	PROMICE Greenland	2,158 (47)
A Greenlandic calving glacier from a	PROMICE Greenland	327 (47)

[34] From the self-assessment

Video	Producer	Views (subscribers)
helicopter		
Surface melt on the ice sheet	PROMICE Greenland	2.434 (47)

YouTube.com and Isskolen.dk (2018)

The videos that were produced and launched by Isskolen had between 212 and 751 unique views. The forum is at the moment inactive and there are no indications that it was active in the past. The website did not reach a broad audience if only 751 children watched the video, indicating that the website is not used on a large scale.

Goal fulfilment and relevance

The programme has reached its goal of providing knowledge related to the ice volume of the Arctic and North-Arctic area. The answers of each work packages have been published as a report in pdf form on the SVALI website and are free to access. Besides the reports there is also a broad database available that is composed of measurements done for the SVALI programme.[35] The database is free to access and can be used for further research.[36]

The programme had a strong focus on the development of new scientific knowledge and the dissemination of these results to a wide public. The results were noticed and regarded by the international glaciology community as excellent, the researchers were asked to speak at the climate conference in Paris (2015) and the Nordic climate conference in Copenhagen (2011). The programme results can be described as leading within the research area, achieved through the combining the strongest Nordic researchers and research institutions on this specific topic.

The result had an unexpectedly wide reach, with a high level of awareness at an international level. The main driver of this new attention was the high number of presentations and meetings that were organised by the involved researchers.

Sustainability

There was no direct continuation of the programme. Nevertheless, new programmes developed from the network that SVALI has built the preceding years. The most predominant follow-up was the IStech programme, using the data that was collected by the SVALI research group. Besides the IStech programme, the researchers found their way to European funding provided by the ESA.

There was the intention to collect new funding, and applications were done by collaboration on a Nordic scale, however these proposals have not yet been rewarded with new funding. The researchers from the former SVALI consortium are now working on a project proposal on snow science. Without the funding the researchers would not have been able to develop the current high level of collaboration.

Communication

As mentioned earlier the SVALI programme was represented at the international climate conference in Paris (2015). The researchers connected to the SVALI programme have been active in hosting and joining seminars within the academic society, with more than 50 presentations. Their attendance at these seminars and their presentations contributed to their exposure. The SVALI programme organised annual meetings to discuss the findings from the programme. There was also an active transfer of knowledge through the SVALI summer schools. Besides the spoken dissemination of knowledge, the research team is hosting an informative website for children.

[35] http://ncoe-SVALI.org/data/index.html

[36] http://www.cryoclim.net/cryoclim/subsites/data_portal/

Summary, lessons learnt

The added value created has been at a scientific level, with an increase in collaboration between researchers from Iceland, Denmark, Sweden, Norway and Finland. The strengthening of the research network is of high added value. The high-quality research opened doors for the programme; for example, the consortium was invited by the EU to speak about future calls on this area, and researchers from SVALI were asked to share their opinions on the future of glaciology in Europe. The extent to which SVALI had an influence on the research agenda of the EU can be seen as a direct result, with indirect political implications. The funding was of high added-value for the research area, because without the funding from TRI the programme would not have been able to be executed. The size of the funding was essential to the success of the programme. In fact, the collaboration with the funder was extremely good in general. The researchers from SVALI all agree that if they had to decide to do it all again they would. The prestige of NordForsk as funder opened doors and made it possible to collaborate with large international organisations as ESA. The reputation of the research groups of the involved Universities is now internationally seen as excellent.

Furthermore, there is Nordic added value created through educating 17 full-time PhD students and another 13 associated PhD students involved with the programme. These students are equipped with practical experience gained during the SVALI project.

The most useful result was an expansion of knowledge on the development of the polar areas. The knowledge contributed to the scientific discussion, and to the improvement of Nordic research centres.

A key factor for the success of SVALI was that the research area of glaciology was already established within the Nordic countries. In the future, calls should be made while bearing in mind where the strong parts of Nordic research are located given its potential for strong consortia. The calls should not be aimed at completely new areas but built on the areas of existing strength, as this provides the possibility to make strong contributions at a global level. NordForsk was successful because it did really well in bringing together these groups.

Case study: Enesca

Executive summary

In 2010 the Enesca project was launched to develop a new organic matter for energy storage devices. The project aimed to contribute to finding sustainable solutions in the energy sector and promoting research collaboration among Nordic region countries, in particular Sweden, Finland and Norway. In addition to the positive effects it has had on research and energy industry, the project has drawn attention to environmental challenges in Swedish communities, and stimulated interest of students in the science and energy sector.

The Enesca project has developed one of the fastest charging battery systems. The project team tested the use of celluloid with superfast capacitors. Following some novel research findings, the project has received interest of the business community and as a result has ensured it receives sustained funding to continue its research activities. The technology is currently in development by BillerudKorsnäs, and is in the final testing stage. This operational testing and preparing for launch can be defined as the final level of technology readiness (TRL 9) (Figure 14).

Figure 14 Technology readiness level Enesca

Technopolis (2018)

The outreach of the Enesca project was based on an active campaign to reach children in Sweden and ask them to participate in a brainstorm on how to put new technologies to use. The interaction between the children and the related companies resulted in a number of proposed solutions and a procedure to validate these solutions. They additionally delivered insights in the stakeholders in this area. Therefore the societal readiness level of Enesca is SRL 5 (Figure 15).

Figure 15 Societal readiness level Enesca

Technopolis (2018)

Project background

Given that there are limited mineral resources, there is a great need for the design of sustainable energy solutions, such as environmentally friendly materials in batteries and super capacitors. The Enesca (ENErgy SCAndinavia) initiative represents one of the many attempts to examine and develop a new organic matter for energy storage devices, which are based on the organic materials polypyrrole and cellulose, and are operating in salt containing aqueous electrolytes. Under this initiative, the project "Research towards Nordic industrialisation of The-Salt-and-Paper Battery" was launched in 2010.

The project described here aimed to develop research and development activities which will provide a basis for future commercialisation of a new type of paper-based super capacitors and batteries, which are environmentally sustainable. Thus, the project has been seeking to contribute to battery development through collaborative research with industrial partners.

In order to achieve the above-mentioned aims and objectives, the Enesca project was divided into six work packages (Table 9). The first work package was focused on lab-scale synthesis and analysis of electrode materials. It was expected to provide detailed understanding of structure-function relationships of several electro materials, and examine the running of previous energy storage products. The second work package focused on application scouting and the investigation of current and past commercial energy storage products based on conducting polymers. The study tried to identify potential applications in different market segments and to examine both current and previous attempts in commercialisation of polymer-based storage systems. A lab-scale assembly, the testing of full battery cell prototypes, and the analysis of customer-defined performance constituted the collection of activities under the third work package. To gain knowledge on up-scaling and testing electrode materials, this was followed by a number of pilot line experiments for large scale research and the development of the electrode materials. The fifth work package consisted of issues related to safety, IPR protection, and the ambition to disseminate the project results. The Enesca project aimed to produce a minimum of 10 publications, with at least two of those related to safety of materials. The market overview concluded the list of planned activities with an overview of the end-user needs and an examination of the market potential of the research outcomes.

Table 9 Overview of project work packages

Number of the work package	*Actions of the work package*
WP 1	Lab-scale synthesis and analysis of the electrode materials
WP 2	Application scouting and investigation of current and past commercial energy storage products based on conducting polymers
WP 3	Lab-scale assembly, testing of full battery cell prototypes and customer defined performance
WP 4	Pilot line experiments for large scale research and development of the electrode materials
WP 5	Safety, IPR protection, dissemination
WP 6	Market overview

In order to ensure that the Enesca project had sufficient resources, and represented a collaborative initiative between Scandinavian countries, it involved parties from three countries, namely Sweden, Finland and Norway. Researchers and business developers from Uppsala University (Sweden), VVT (Finland), industrial representatives from FoV Fabrics (Sweden), ETC Batteries and Fuel cells (Sweden) and FMC Biopolymers (Norway) formed the core team of the project. To reach the goals set under safety, IPR protection, dissemination and market overview, as specified in the work packages five and six, the project attracted external partners including the Uppsala University School of

Entrepreneurship, Uppsala University Science and Technology Studies Centre (STS), the industrial marketing agency ConDesign and the film agency Populate.

Due to the fact that the results of the Enesca project were commercially viable, leading to the involvement of various stakeholders in Nordic countries, the project received sufficient and sustainable financing. At the beginning of the project, it was financed by Innovationsbron, whereas currently it is financed by Energimyndigheten, Uppsala Univeristy, KIC InnoEnergy, Nordic Innovation and The Foundation for Strategic Research (Stiftelsen for strategisk forsknig).

Background and rationale of the project

The idea to start a research project originated from Mr. Mateo Santurio, who works at the Uppsala University Holding, which invests in research projects which have a high potential for wide application. He became interested in research of celluloids, as the University was examining I-on membranes. This research seemed to have an application in batteries; therefore, the investor identified a need in conducting an explorative study. Together with a colleague at the Uppsala University an application for funding was filed and they started to search for other stakeholders that could bring knowledge to the project. They proposed collaboration to several research institutes and universities in Finland, and to textile and automotive companies in Sweden with whom the Uppsala University has collaborated in the past. Following financial support in the form of grants, the project started to conduct research activities related to batteries and super capacitors.

Results and effects

Outputs and results

The Enesca project has provided several types of outputs. During the project, five PhD students and several master's students graduated from Uppsala University. These alumni were offered opportunities at the school of entrepreneurship at the University. In addition, the project has strengthened collaboration with industrial partners in Sweden and stimulated the signing of a deal with a material development company.

No spin-offs were established as a result of the project, however, new research questions stimulated discussion within the research community. Moreover, the three inventors/researchers – Mihranyan, Stromme and Nyholm, have applied for a patent ("A composite material in the form of a continuous structure comprises an intrinsically conducting polymer (ICP) layer coated on a substrate") in the US, Russia, Japan, China, South Korea, India, Patent Cooperation Treaty and European Patent Office (EPO). The Enesca project was awarded patents in all countries, except in India and in the EPO.

In total, the project has received two research grants from Sweden, namely €300,000 from VINNOVA in 2013, and SEK 31,040,000 from The Foundation for Strategic Research (Stiftelsen for strategisk forskning) in 2012. The project has not received funding from Nordic countries other than Sweden.

The project team has realised that the research results might benefit the wider research community and has potential to attract the interest of industry. Hence, the project has launched two websites (energyscandinavia.eu and enesca.se), seeking to attract interest of business and research communities. The first website describes the aims of the project in detail, provides access to data, and discusses opportunities and challenges of the project. In contrast, the second website is designed for students at schools and colleges to provide general information about the project, highlight main research results and stimulate interest of students in a project and in sustainable development. In order to encourage the involvement of students in a project, the website invites students to participate in a competition. Applicants can present their ideas for a product or application that needs a particular type of a battery. This is a helpful strategy to generate new research ideas and at the same time disseminate information about the Enesca project. At the moment, around 30 contestants have posted their videos on energy, batteries, and environmental sustainability on the website.

Based on self-assessment of the project team, ENESCA has been very successful in achieving expected outputs. This is due to well-defined project objectives, and a timely implementation of the plan. Effective collaboration by the team, a good and feasible research idea, and support of stakeholders ensured the success of the project.

Impact

The project contributed to development of energy storage and energy efficiency research, and there is potential for applications in the clothing, packaging, e-books, diagnostics, automotive, health and toys sectors. Hence, project results benefit several industries and have potential to further encourage research and investments from the business community.

Several companies from the forestry industry in Sweden have developed an interest in research collaboration and have started to invest in innovations such as the development of cellulose materials from seaweed as developed by Enesca. This has stimulated cooperation between local and global companies in the forestry industry. The market position of the Swedish company BillerudKorsnäs (BK), which is currently leading the project, has significantly strengthened. Since the BK company is looking for ways to equip their products with sensors, in order to enable access for consumers to relevant information about their goods, the Enesca battery is seen as a good technology to provide energy. The company has gained access to new markets and, due to expansion of its activities, has generated a large number of new jobs in Sweden. Hence, the project provided not only research and commercial benefits, but has also had a positive socio-economic impact in Sweden.

As a result of the project, the cross-disciplinary research collaboration between the chemistry and nanotechnology departments at Uppsala University has been strengthened. As a result, more than 40 research papers have been published since the launch of the project. The intensive work done on the project has resulted in the introduction of several courses at Uppsala University. The curriculum of new courses focuses on research scale-up and production. The department of industrial engineering has introduced these courses at Uppsala University, and is experiencing a steady interest from students. The research collaboration between Nordic countries continues, although its intensity has decreased somewhat over time. The PhD students who participated in the project have continued their research activities in Scandinavia. The majority them are employed by universities, and one is working at the BK company.

The school competition, published on the project website, has stimulated introduction of educational material on batteries in Swedish high schools and allowed students to get an insight into energy research and the future of energy sector. Unfortunately, other Nordic partners have not been as successful in disseminating knowledge to schools and other education institutions. As a consequence of the limited participation of non-Swedish partners, the scale of Nordic research cooperation has decreased, resulting in smaller benefits for partner countries.

Undoubtedly, the Enesca project has a positive impact on scientific development, especially battery development, and on Nordic research cooperation. However, it is difficult to assess to what extent the project has raised competitiveness of the Nordic research institutions globally.

Overall, the project has a positive effect on the research and business community, albeit that the benefits are relatively localised around Swedish companies and research institutes, in particular Uppsala University.

Goal fulfilment and relevance

At the start of the project specific objectives were defined for each work package. Good project management and effective interaction within the project team ensured the achievement of set goals. The project has been building on strengths of cooperation with various institutions in Sweden, Finland and Norway. In some work packages the project has produced more results than expected, and as such the project has more than fulfilled its objectives. From a R&D perspective, the results are very interesting, and the project has achieved its goals beyond expectations.

The project contributions to finding solutions in environmental and energy sectors correspond to the general aims of the TRI. The relevance of the project is apparent, in the successful transfer of basic research to working prototypes, which have been applied in the business and energy industry.

Sustainability

The research activities are currently funded by companies that are looking for ways to use the developed products for packaging. Some of those companies were involved at the beginning of the project, while others joined later, as the project gained more awareness from the public and the commercial benefits became more apparent to the business community. At the moment, more exploratory research is being undertaken, and commercialisation strategies for new research are receiving a lot of attention from investors. Due to the fact that it has attracted continuous funding, the benefits of the project for the research and business communities and for society are expected to be sustainable in the future.

There are several factors that have contributed to this sustainability. First, the multi-disciplinary research approach and highly diverse and professional team members have ensured complementarity of knowledge and contributed to effective cooperation and high quality of the research. Second, the knowledge on how to commercialise research results was central for involving industrial players. NordForsk has been very effective in identifying communication channels, while the frequent project meetings ensured their attention to communication strategies for research, industrial community and media. The research publications and participation in conferences helped to disseminate information about the project. In addition, the conversations in different schools were effective in drawing people from different sectors and resulted in the idea to starting a battery-related competition at schools, which was mentioned above. The third factor that contributed to sustainability of the project is the effective research strategy of the team. At the beginning the team built general knowledge on the subject, whilst later they have been identifying market trends and adapting to research needs of industrial, business and research communities. As a result, they have a good research reputation, which in turn results in a large number of clients and collaborators.

Communication

As discussed above, the project results have been communicated via several channels. The website was targeting academic and industrial players, seeking to get more research ideas and more funding. The school-competition, which was launched for students, has raised interest of schools, parents and local communities. Due to production of multiple publications, the research results were disseminated widely and encouraged collaboration with industries and research communities across Nordic countries. Such actions were effective at drawing attention to the project from various sides.

It is evident that the project team has designed a comprehensive strategy to ensure visibility of the project. The effective approach to dissemination of information about the project was based on the decision to divide the budget for communication purposes among five major partners. Hence, each partner has been testing various marketing and communication ideas, participating in awareness-raising events and networking. After a year the communication budget has been united, as most successful ideas have been identified and the public in participating countries got awareness about the project. As a consequence of creating an effective communication strategy, the project team ensured sustainable funding and continue stimulating scientific development, building on available findings.

Summary, lessons learnt

The initiative provided an incentive to collaborate, which stimulated knowledge exchange and cooperation between multiple players. Cross-border collaboration has had a positive impact on project results and has created opportunities for future cooperation in the Nordic region. The project has united multiple stakeholders from several countries, thereby ensuring sustainability of the project and its results. Despite that Enesca has been strengthening communication among Nordic partners, the major project participants and beneficiaries are based in Sweden, in particular in the Stockholm area. Hence, the benefits of the project are more localised than expected.

The Enesca project has generated multiple research results and benefits for the energy industry and research community. Among the major achievements of the project is the development of one of the fastest charging battery systems, and the testing of the use of celluloid in combination with superfast capacitors.

Apart from achievements in the research area, the project created benefits for industrial companies, contributed to job creation, raised awareness about environmental sustainability problems within the Swedish community, and prompted interest of students to energy challenges. Due to the continuous nature of research work not all project results are visible yet. Considering the high intensity of research activities, sustainable funding and interest of the business community, the project can potentially bring very prominent benefits for economies and societies of the Nordic region.

The communication strategy has served as an effective tool for drawing attention to the project, getting support from research organisations and investments from business actors. Hence, the importance of communication strategy should not be underestimated.

In order to increase the dispersion of project benefits, to promote sustainability of funding and collaboration among Scandinavian research and industrial players, it is advisable to involve non-Swedish partners on a continuous basis. The BK company, the current leading organisation of the project, involves other Nordic actors in the project. However, these actions are not considered sufficient for sustainable cross-border collaboration and for the development of research and industrial relations between countries. NordForsk can play a role in stimulating such collaboration, for example, it can organise an event or an activity with previously involved actors to discuss challenges and opportunities of future cooperation. The collaboration across several projects would ensure continuous involvement of different actors and promote building stronger partnerships among research and business communities.

Case study: Tundra

Executive summary

The Tundra programme was part of the TRI thematic area '*effect studies and adaptation to climate change*'. The programme ran for five years, between 2011 and 2016. The objective of the programme was to research the climate-animal-plant interaction within the tundra ecosystem. By doing this they had the aim to explore the capability of herbivorous mammals in controlling and inhibiting the expansion of woody vegetation.

The programme had the ambition to reach out to policymakers and politicians, and they had had the opportunity to do this at the climate conference in Paris (2015). Researchers also provided workshops for Sami shepherds to map the drivers and barriers of reindeer husbandry in Fennoscandia. The programme delivered 60 peer-reviewed articles and published one final report. There are no indications so far that the findings of the report have had an impact on local politics.

Research for the Tundra project was throughout the project predominantly fundamental research. As such, they did not have the intention to develop a prototype or a commercialised product, and products were not part of the expected deliverables. This fundamental character can be described as level 2 on the technology readiness level scale (Figure 16).

Figure 16 Technology readiness level Tundra

Technopolis (2018)

The first years of the project had a strong focus on scientific fundamental research and general collaboration within the team to meet the academic deliverables. After reconsideration of the deliverables during the last two years of the project, the scope changed, and the focus shifted more towards outreach through dissemination of knowledge. The project reached a variety of stakeholders from the targeted regions through workshops and connected focus groups. The research identified the problems that might be encountered in the future, and in the final report a solution was proposed to prevent the shrubification of the tundra area. The proposed solution was validated by the involved stakeholders but has not yet been put into practice. Therefore, the societal readiness level of Tundra has reached stage 5: 'proposed solution validated by relevant stakeholders in the area' (Figure 17).

Figure 17 Societal readiness level Tundra

Technopolis (2018)

Project background

Brief description of the project

The programme studied the tundra landscape of Fennoscandia, by analysing the dynamics of climate-vegetation interactions, reindeer husbandry and the Sami culture. These dynamics were studied to understand the potential impact of reindeer grazing on preserving the tundra area. Reindeer grazing might support maintenance of the tundra areas of northern Fennoscandia. The tundra area is under pressure by the expansion of pine tree forests: since the winters are becoming milder, the tree line is slowly moving northwards. The expansion of pine tree forests will harm the ecological system of northern Fennoscandia if the share of tundra vegetation gradually decreases. One of the key characteristics of the tundra vegetation is that snow will remain and forms into a broad surface of white reflection power. 80–95 per cent of the heat from the sun is reflected on the surface snow, this is called the Albedo effect. The Albedo effect contributes to maintaining the current temperature of the earth. If the tundra landscape disappears, this natural heating regulation system will cease to exist. The researchers of the tundra project had the hypothesis that reindeer husbandry and the grazing from these reindeers would hinder forest expansion.

The research was structured in eight work packages, led by 11 different researchers. Six work packages were (co)led by researchers who were connected to a Finnish institution, two were (co)led by professors at Umeå University and there were three Norwegian researchers in charge/co-leading one work package. The budget for the project was 100 million NOK.[37] Funding was provided by the Nordic Centres of Excellence. The consortium consisted of ten partners, all of which had a scientific character. There were six universities involved: Umeå University, University of Lapland, University of Turku, University of Oulu, Finnmark University College and the University of Tromsö. Beside the six universities the Finnish Meteorological Institute, Norden, Norwegian Institute for Nature Research (NINA) and the Northern Research Institute participated in the project. There were no private companies part of the consortium.

The history of the Tundra project goes back to an initiative by professor Lauri Oksanen, a former professor of the University of Turku. The extensive network of professor Oksanen was the basis of the consortium that worked on the Tundra project. Professor Oksanen and his colleagues formulated the ideas on which Tundra was based. The leading researchers were already aware of each other's work and were already publishing together. For example, the Finnish professor Oksanen had already co-authored publications with researchers from for example Norway (University of Tromsö) and Sweden (Umeå University) since 2004.[38] These co-authors were also involved or even leading scientists in the Tundra project.

Table 10 Sample of publications and relations researchers before and after Tundra (search term L. Oksanen)

Article	Year	Tundra Researchers
Vole Cycles and Predation in Temperate and Boreal Zones of Europe	2005	Prof. Erkki Korpimäki Senior Res. Tarja Oksanen Prof. Lauri Oksanen
Herbivores inhibit climate-driven shrub expansion on the tundra.	2009	Assoc. Prof. Johan Olofsson Prof. Lauri Oksanen
Long-Term Experiments Reveal Strong Interactions Between Lemmings and Plants in the Fennoscandian Highland Tundra.	2014	Olofsson, Johan Oksanen, Lauri Oksanen, Tarja Hoset, Katrine
Open tundra persists, but arctic features decline-Vegetation changes in the warming Fennoscandian tundra.	2017	Oksanen, Lauri Oksanen, Tarja Olofsson, Johan

Lund University archive (2018)

37 http://www.toppforskningsinitiativet.org/en/programmer-1/program-1/aapen-utlysning-effektstudier-og-tilpasning-til-klimaendringer

38 Lund University archive: http://eds.a.ebscohost.com.ludwig.lub.lu.se/eds/results?vid=9&sid=f50852ed-2ed4-41ba-b00d-e07e8e480cf7%40pdc-v-sessmgr01&bquery=AU+((Lauri+AND+Oksanen))&bdata=JmNsaTA9RlQxJmNsdjA9WSZjbGkxPURUMSZjbHYxPTIwMDQwMS0yMDEwMTImdHlwZT0wJnNpdGU9ZWRzLWxpdmUmc2NvcGU9c2l0ZQ%3d%3d

The TRI funds provided the researchers with an opportunity to put their ideas together and apply for research funding. The size of the NordForsk grant was crucial in enabling the multidisciplinary and international research required to address this problem.

The proposal, and the first three years of the programme consisted primarily of academic research. However, a purely scientific approach could only contribute to three of the six goals (C, D & E)[39] set by NordForsk, the other three goals (A, B & F)[40] would require a different approach. Nevertheless, the proposal and deliverables were accepted in this way by NordForsk. The research group did not in the first instance have the ambition to deliver more than academic research outputs. Yet, in the final two years the programme changed focus towards knowledge dissemination, despite the fact that for example in the original proposal there was no space in the budget for a final 'popular' report.

Results and effects

Outputs and results

The outputs and results of the Tundra programme are all of a scientific character. The Tundra programme enabled young ambitious researchers to participate in an international project to obtain their PhD and/or to expand their track as a postdoc researcher. Five PhD students graduated while working on the Tundra programme. Two of the PhD candidates were based at Umeå University (Sweden), one at the University of Tromsö (Norway) and two at the University of Oulu (Finland). Four of the five PhD students continue to do academic research within the Nordic region.

The programme has been supporting 13 postdoctoral researchers, to do their research and provide them with the guidance of 15 senior researchers. The postdoctoral researchers were predominantly Norwegian (9/13), with in addition one Dutch, one Belgian, one Czech and one researcher from Germany.

Between 2011 and 2015, nine grants were awarded related to the Tundra project. Four out of nine grants had a Norwegian source, three were from a Swedish source, and the last two grants came from a Finnish funder. The majority of grants (8/9) were given by public or semi-public institutions, only one small grant came from a private source.

The main scientific output of the Tundra project was the publication of 60 peer-reviewed academic papers. The papers attracted attention within the field of ecological research, and the researchers were invited to present their results during the Paris Climate Conference (COP21).

Besides the scientific output, the project also delivered an additional report to reach a wider public. This public was in first instance not budgeted and would not have been published had NordForsk not given additional funding. For knowledge exchange of the Tundra project this report was of important value. Rather than simply providing information, this report has been written in a way that it provides pathways for adaptation of the knowledge that has been gained through the research.[41] It has been published in four different languages and has been written about by Finnish journalists.

Impact

For a research group it is important to establish international connections to remain competitive. The funding of Tundra enabled Nordic researchers to join forces and bundle their capacities into a strong

[39]

[40] The overall goals are to:

a): Profile the Nordic region as a leader within certain areas of the energy and climate sectors.

b): Strengthen national research and innovation systems.

c): Ensure the highest quality in research and innovation by combining the strongest Nordic communities.

d): Provide a platform for increased international cooperation both within the EU and beyond.

e): Enhance Nordic participation in EU programmes.

f): Strengthen Nordic competitiveness by using research and innovation to counter economic downturns

[41] http://www.utu.fi/en/sites/tundra/media/Pages/home.aspx

shared programme. At the top level, the project did not result in any new professional connections between researchers. However, at postdoctoral level, a wide variety of new and fruitful Nordic research collaborations has been initiated. These new Nordic collaborations appear to be sustainable, since the researchers who worked as postdoctoral researchers in Tundra are now collaborating in the new TRI called ReiGN. The large grants provided by NordForsk had an additional value for the development of science and Nordic research cooperation; researchers involved in Tundra indicate that the amount of funding provided by NordForsk was crucial to the initiation of a project like Tundra.

The outputs of the project have so far not reached the business sector, industry associations, policymakers or the general public. Any effects on ecology and public understanding of challenges to ecology may take a long time to take pace and stretch beyond the first few years after the publication of research findings. Nevertheless, the researchers connected to the project are optimistic about the possible impact on the adaption of their suggestion in Nordic policymaking. In general, it takes ten to fifteen years before ecological/environmental research will influence policymaking. Problems considering ecological tensions will not be on a political agenda of policymakers as long as there are no concrete problems.

The former PhD candidates did not leave academia: four remained at the same university where they worked for on Tundra, one changed within Finland from the University of Turku to the University of Lapland.

in line with the objectives of the programme, the programme did not have any business-sector related outputs, and the research did not result in any product innovations or spin-offs. They did gather the opinion of herders who live in the researched area and used their input to develop insights on how to govern, preserve and stimulate reindeer husbandry.

Goal fulfilment and relevance

The goal of the project was to research: *'How the top down impact of reindeer can be optimally applied to the prevention of shrub encroachment and woodland expansion, and the negative impacts which these processes have on global climate and biodiversity'.*

The programme did reach this scientific goal: the results of the project have shed a light on the application of reindeer to prevent the shrub encroachment and woodland expansion. The programme developed a report presenting thorough and extensive information in layman's language to make this knowledge available to policymakers.

The aims of the Tundra programme were primarily scientific. Although the initial ambitions did not fit completely within the TRI framework, the project did contribute to the profile of the Nordic region as a leader within the ecological and environmental sectors of climate science. Researchers involved in Tundra strongly agree that the programme contributed to strengthening national research and the collaboration between Nordic institutions. On top of the increase in research collaborations on a national scale Tundra has also contributed to the international reputation of the involved institutions, increasing their visibility to EU research programmes.

The emphasis of the project has been on the: *'changes that the Fennoscandian tundra ecosystem experiences currently, as well as on reindeer husbandry'.*[42] Aside from the scientific goals, there were also human resource related goals set by the leading researchers that were involved with the programme, such as: maintaining young promising researchers for Nordic universities, and keeping good people clustered around a challenging programme. The research team did not lose any researchers during the project and was, therefore, able to reach this first goal. As mentioned earlier the trained PhD students remained active working within a Nordic country.

Sustainability

After the donor funding ceased Tundra researchers remained in separate entities working together. One of these collaborations is the in 2016 funded NoCE ReiGN. ReiGN is a Nordic Centre of Excellence in Arctic research, with a cross-cutting character focusing on: genomic, evolutionary theory, life

[42] http://www.utu.fi/en/sites/tundra/publications/Documents/Tundra_final_report_Eng.pdf pp. 13

history theory, ecology, natural resource management, archaeology, anthropology, animal breeding, conservation biology, to bio economy, governance, law and legislation. A large share of the institutions participating in ReiGN have also been involved in Tundra. These institutions are: NINA, Umeå University, University of Lapland and the University of Oulu. Nine new Nordic partners participate in ReiGN in comparison with Tundra.

Communication

The results have been presented in a comprehensive report which is openly accessible and written in layman's language. The report has been published in English, Finnish, Sami and Swedish, so that it could reach all possibly interested policymakers and researchers. The report has an interdisciplinary character that brings together history, sociology, public policy, ecology and environmental science. There is no information available on the presentation of these results.

As well as the report, the research included workshops for herders in Sami, where the results of the programme were discussed with the stakeholders. The discussion in the workshop led to better insights into the issues that reindeer herders are facing such as extreme weather conditions, land use conflict, lack of self-determination and unclear and diffuse legislation. The communication through the workshops helped the researchers to find potential drivers and barriers of reindeer husbandry.

Summary, lessons learnt

The project led to scientific results that should be taken in account in future decisions on tundra preservation-related issues. Because it can take up to ten years before the impact of ecological research can be measured, it is hard to express the Nordic added value beyond its scientific value, which is illustrated by the publication of more than 50 peer-reviewed articles and a strengthened network of young researchers. The most important results that were delivered are the following:

- Projections based on the data from project indicate that without any actions it will be impossible to preserve the tundra landscape.
- The combination of the increasing temperature during spring and the expansion of shrubs will harm the Albedo effect, which in turn contributes to global warming.
- Herbivores have a strong impact on the preservation of the Tundra.
- Reindeer grazing has the potential, if well managed, to prevent the shrubification.
- Grazing has a positive impact on plant biodiversity.
- The tundra should be addressed as a social-ecological system, since it is incorporating humans and their routines, for example, reindeer husbandry.
- Sweden, Finland and Norway should reshape and harmonise their legislation and administration regarding reindeer husbandry.
- *'To improve the quality of decision making, more and better interaction will be needed between stakeholders. Planning and actions regarding future land use and livelihoods should be co-designed by different stakeholders. To overcome the historical apprehension between the parties, a neutral boundary organisation might serve as an appreciated mediator.'*[43]

The lesson that could be learnt from this programme is that the TRI funding enabled multi-disciplinary research projects that would not have been started if the funding had not existed. For this reason, it is important to communicate at the beginning of the project what the overarching programme goals are. The structure and the early expectations of the researchers in this project suggest that their scope initially was too narrow. To enable the researchers to express their ideas and to find connections with policymakers it is recommended to organise seminars and workshops about the overarching programme goals so that Tundra could reach policymakers in more formal occasions.

From the researchers' perspective, the TRI programme was a welcome funding opportunity that enabled them to carry out projects that previously were impossible. If national funding agencies are

[43] http://www.utu.fi/en/sites/tundra/publications/Documents/Tundra_final_report_Eng.pdf, pp60

able to give this grant it must be used within borders. The TRI grant overcame these bottlenecks. It gave the researchers the unique opportunity to do research with a full focus on the future of the tundra. They could research with a large team with partners from different countries, and the grant allowed cross-border research. The researchers were well aware of each other's research and the funding enhanced their scientific collaboration. Especially compared with funding from the European Union, this Nordic funding was a welcome change. The European funding is considered very time-consuming and demanding in terms of coming up with suitable partners. For this reason, Nordic researchers have been reluctant to participate in EU grants. The procedure from TR was very different and rated as an inviting option by the researchers connected to Tundra. They indicated that they enjoyed working with partners from other Nordic countries.

Appendix B Interviewees

Last name	*First name*	*Organisation*
Aarlien	Rune	SINTEF
Björnsson	Halldor	Icelandic meteorological office
Brändström	Jonas	Vinnova
Börre Eriksen	Peter	Energinet.dk
Clausen	Niels Erik	Technical University of Denmark
Edelvang	Karen	Technical University of Denmark
Engström	Rebecka	Vinnova
Friberg	Magnus	The Swedish Research Council
Gjærde	Anne Cathrine	Polyteknisk Forening
Glette	Natalia	Nordic Innovation
Gustafsson	Gunnel	NordForsk
Hagen	Jon Ove	University of Oslo
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