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Understanding indicator choice for the assessment of research, development, and demonstration financing of low-carbon energy technologies

Lessons from the Nordic countries

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Abstract: Rapid decarbonization of whole countries requires additional research, development, and demonstration of low-carbon energy technologies. Governments support research, development, and demonstration in this area with various financing instruments. These instruments are frequently assessed by carrying out indicator-based evaluations. So far there is no standard set of indicators for this purpose. This study looks at research, development, and demonstration financing in the Nordic countries, which are frequently mentioned as leading countries with respect to eco-innovation. Different indicators are identified, selected, and analysed. The analysis of the indicator-based evaluation method includes the acceptance of an indicator, its ease of monitoring, and its robustness as assessment criteria. No indicator or set of indicators emerges as clearly superior from the analysis. Indicator choice is subject to trade-offs. This means in turn that there is room for directing evaluation results by choosing certain indicators over others. The study concludes by discussing potential policy implications of biases in indicator-based evaluation of low-carbon energy technologies research, development, and demonstration funding.

Keywords: decarbonization, indicators, low-carbon energy technology, Nordic countries, policy evaluation, research development and demonstration
JEL classification: O38, O48, Q42, Q55

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1 Introduction

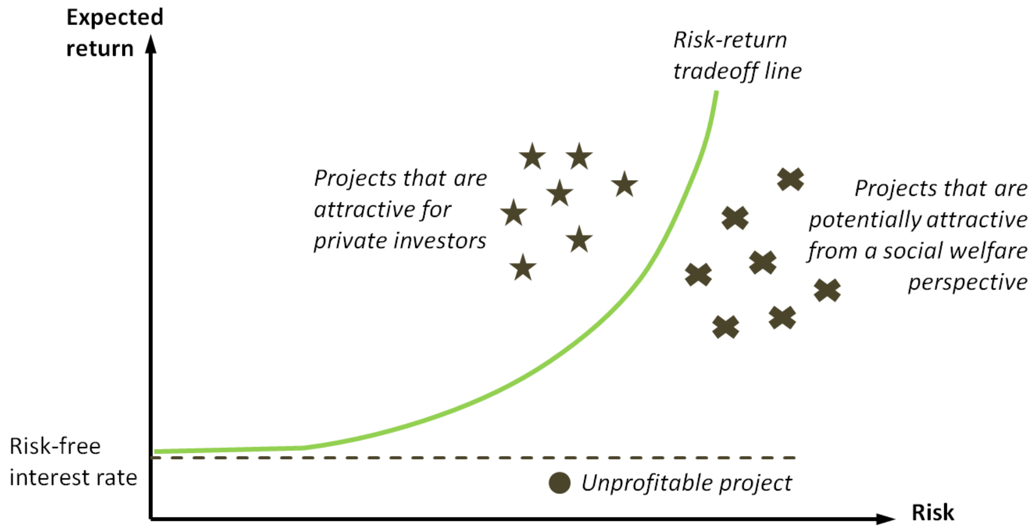
Limiting global warming to two degrees, as compared to pre-industrial temperatures, preferably less, is a target that is not only backed by climate science, but also a target that has international political support (as expressed in the Paris Agreement of 2015). Many scenarios show potential pathways to reach this target, both at the global level and at the national level. However, the majority of these scenarios rely heavily on the large-scale deployment of negative-emission technologies (Edenhofer et al. 2014). What these scenarios have in common is that in order to decarbonize industrialized economies on time, further research, development, and demonstration (RD&D) of low-carbon energy technologies (LCET) and of technologies inducing 'negative emissions' are urgently needed (Clarke et al. 2014; Anderson 2015). The large technological challenges ahead include: integrating intermittent electricity from renewable energy sources into the grid, storing excess generation of electricity from renewable sources, electrifying transportation and (where beneficial) also heating, decarbonizing processes in heavy industry, making carbon capture and storage (CCS) cost competitive, and last but not least making final energy consumption more efficient. In addition to new technological solutions, the speed of deployment and the integration of solutions into the energy system are also critical factors in climate change mitigation.

When decarbonization scenarios go beyond technological feasibility, and economic factors are accounted for, the focus is often on costs and additional investment needs (Gupta et al. 2014). The importance of (low) abatement costs in climate change mitigation policy is well-reflected in some of the main policy instruments, such as carbon-energy taxation, carbon trading, and green and white certificate schemes (Somanathan et al. 2014). All of these instruments have in common that they trigger the deployment of low-cost abatement options as they induce marginal changes in price structures. From a national perspective, this choice of abatement policy is justified as the domestic climate change-related benefits do not outweigh the costs of the unilateral adoption of more expensive abatement options (Stavins 2014). From an economic policy point of view, governments also need to identify the sources of market failures in the generation of technology change, particularly the ones related to RD&D and (under-) investment in innovation (Jaffe et al. 2005).

The 2008/09 global financial crisis gave some momentum to efforts to scale up public RD&D financing of LCET. From South Korea's Green New Deal to the US Recovery Act and the Chinese Economic Stimulus Programme various national fiscal expansion policies included large shares dedicated to 'green' areas in general and LCET in particular (Sonnenschein and Mundaca 2015; Mundaca and Luth Richter 2015). The focus of different green stimulus programmes varied from infrastructure investments, to loan and guarantee programmes for green companies, and further RD&D into LCET. However, the significant public support to LCET innovation was not sustained after the crisis (Rhodes et al. 2014).

In addition to the social benefits from reduced CO_2 emissions, there are further arguments for an involvement of the public sector in financing RD&D in LCET. Firstly, due to positive spill-overs the social rate of return of RD&D investments and public venture capital (VC) is often higher than the commercial return rate (Griliches 1992). Secondly, LCET is in many cases particularly difficult to finance as it has high capital requirements and a long time to market (Criscuolo and Menon 2014). Thirdly, there are potentially profitable projects that are simply too risky for private investors, but still attractive from a social welfare perspective (see Figure 1).

Figure 1: Selection of potentially profitable projects from a private and public VC investor's perspective



Source: Author's illustration based on Grünfeld et al. (2011).

In order to scale up RD&D activity in this area and make it more efficient, it is critical to know if governmental intervention can correctly identify LCET RD&D initiatives with high social returns that are under-supplied with financing from the market. Thus, it is relevant to understand both the motivation for setting up new public RD&D support instruments and how their success is assessed and measured. As success is a normative concept, different stakeholders may have their own specific criteria and/or indicators for success of public RD&D in this context.

While there are various methods for evaluating the performance of RD&D support policies, many of them rest on few aggregated indicators, such as public and private RD&D expenditure as well as patent counts (Bozeman and Melkers 1993). These indicators alone do not reflect the complexity and dynamics of public RD&D, let alone innovation processes (Gallagher et al. 2006; Bergek et al. 2008), which involve various stakeholders with varying perspectives. The quantitative estimation of innovation policy indicators has been frequently criticized for rarely coming to conclusions with high policy relevance (Bergek et al. 2008).

The approach of *evaluating* indicators addresses this criticism without completely abolishing the indictor-based method. Indicator evaluation in the field of low-carbon energy RD&D policy is neither very far developed nor tested. Notable attempts are: Gallagher et al. (2006) who discuss the merits of various input, output, and outcome metrics but do not apply a uniform indicator evaluation framework; Wilson et al. (2012: 781) who roughly estimate the suitability of various indicators to research 'directed innovation efforts in response to climate change mitigation'; and Carley et al. (2012) who propose an evaluation framework for 'energy-based economic development' which includes the categorization of relevant indicators but not an actual indicator evaluation.

The purpose of this study is to assess the performance of indicator-based evaluation in the context of LCET support policies and to contribute to the structured assessment of potential indicators. The Nordic countries have been chosen as a geographic area of study. Norway, Sweden, Finland, and Denmark have innovation ecosystems in place which provide dedicated support to various low-carbon technologies. All countries perform well on indexes related to eco-innovation. In the Global Green Economy Index 2014, Sweden ranks first, Norway second, Denmark fifth and Finland eighth (Dual Citizen LLC 2014). Finland, Sweden, and Denmark are also among the top five countries in both the 2014 Global Cleantech Innovation Index (WWF and Cleantech Group 2014) and the EU Eco-Innovation index (European Commission 2015).

However, in Finland and Sweden in particular, the gaps between the evidence of emerging cleantech innovation and the evidence of commercialized cleantech innovation are large (WWF and Cleantech Group 2014). In financing terms, this gap is often referred to as the 'valley of death'. Within cleantech the sub-sector of LCET is particularly challenging due to long times to market and high capital requirements (Bürer and Wüstenhagen 2009; Ghosh and Nanda 2010). Both the success of their cleantech industry and the remaining challenges in financing LCET innovations all the way to the market make the Nordic countries a suitable case study to identify and analyse indicators for the assessment of RD&D support policies.

The next section in this paper includes the overall research design, a brief overview of the applied methodology, and the indicators that were used. In Section 3 the analysis of the indicator-based evaluation framework is presented. Section 4 discusses policy implications of indicator choice and Section 5 concludes.

2 Research design and methods

The research was framed as an exploratory case study of public RD&D financing of LCET in the Nordic countries (see subsection 2.1). The study is constructed around indicator-based evaluation, confronting a literature review of indicators in RD&D policy evaluation with the actual usage of indicators in the Nordic countries (see subsection 2.3). In order to enhance the understanding of indicator choice, an assessment of the indicator-based evaluation method, as such, was performed (see subsection 2.4). Both primary and secondary data were collected to understand the respective funding instruments, their performance, and indicators used for their evaluation (see subsection 2.2). Limitations and caveats associated with this study are also explicitly addressed (see subsection 2.5).

2.1 Case study research

The case study of public RD&D funding of LCET in the Nordic countries was carried out at two levels: at the aggregated national level and at programme level. Public RD&D funding of LCET comes in different forms, including grants, tax credits, loans, loan guarantees, VC, and other forms of equity financing, which also includes the funding of funds. The classification of instruments is not fully accurate as mixed forms exist, such as subordinated loans that often count as equity or high risk convertible loans that may become equity investments (see also Table 1).

There are only a few support schemes that are exclusively for LCET and it is important to note that there is not an agreed definition of LCET. For this study we considered various renewable energy technologies, energy efficiency technologies, and CCS, while excluding nuclear power and efficiency improvements of conventional thermal power plants.

The case study included only national support mechanisms. Further support schemes exist both at the supranational and subnational level, but were not included in the research.

Table 1: Overview of RD&D financing instruments and key organizations in the Nordic countries

Financing instrument	Organizations offering this type of financing
Grant	Danish Energy Authority, Innovationsfonden (DK), TEKES (FI), Innovation Norway, Research Council of Norway, Enova (NO), Swedish Energy Agency, Vinnova (SE)
Tax credit	Research Council of Norway (SkatteFUNN)
Loan (and guarantee)	Finnvera, TEKES, Innovation Norway, Swedish Energy Agency, Almi (SE)
Venture capital and equity	The Danish Growth Fund, Sitra (FI), Finnish Industry Investment, Investinor (NO), Industrifonden (SE), Almi (SE)

Source: Author's compilation.

2.2 Data collection

Data has been collected from multiple sources. National-level quantitative data stems from databases of the IEA, IMF, and OECD, as well as national statistics offices. Primary data about specific RD&D instruments was collected through interviews. For this purpose, data from earlier studies that were based on interviews has been revisited (Lidgren and Dalhammar 2012; Sonnenschein and Saraf 2013). In addition to academic literature, grey literature was a significant secondary data source for this study. Programme reports and evaluations were important for the understanding of the way RD&D instruments are enacted and assessed. Sectoral studies and policy reports provided further information about private sector investments into LCET. Legal texts provided clarity about the legislative framework in which support instruments are placed.

The interview data that was used for this study is based on semi-structured one-on-one interviews with fund managers and public officers dealing with specific public cleantech support instruments. The case study research is partly built on the interview data, partly on academic literature, grey literature, and legal texts. Case study research was not used to comprehensively research the performance of RD&D support but to identify indicators of success. In order to better illustrate how various indicators were used to assess success, exemplary performance data was collected. Evaluations based on case studies have the advantage that hypotheses from literature can be reviewed in the complex context of a specific case (Yin 2014), e.g. whether the indicators prevailing in academic studies such as RD&D budgets and patent counts have a similarly prominent role in the case of LCET support in the Nordic countries.

2.3 Indicator-based evaluation framework

Conceptualization of indicator-based RD&D policy evaluation

A multitude of indicators are used in both the monitoring and evaluation of RD&D policy. In order to structure the assessment process, indicators can be organized in different ways. A common differentiation is made between input, outcome, and impact indicators (Fischer 1995; Guedes Vaz et al. 2001; Neij and Åstrand 2006). Input indicators describe the resources that are put into a policy measure, outcome indicators are used to depict the response to the measure (e.g. in terms of patent applications, prototypes, new products and services, or cost digression), and impact indicators show resulting changes in society and the environment. Sometimes outcome indicators are further differentiated between direct project outputs and the results of policy intervention with respect to policy objectives (Miedzinski et al. 2013).

Another (complementary) approach to conceptualize the use of indicators is to view them as a way to operationalize criteria for policy evaluation (Mickwitz 2003). Relevant criteria that were used to structure this study are administrative capacity, effectiveness, and additionality. It is debatable whether *administrative capacity* should be seen as an evaluation criterion as such or as a 'determinant of implementation' (Vedung 2000: 226). Following the IPCC (Kolstad et al. 2014), it was used as a criterion in this study as it made it possible to include the frequently used input indicator, public RD&D expenditure, in the analysis.

Effectiveness refers to the degree to which 'achieved outcomes correspond to the intended goals of the policy instrument' (Mickwitz 2003: 426). For this study the scope of this definition was expanded and further indicators were included, which were *de facto* used to assess the effects of a financing instrument but for which no explicit goals were formulated. Due to the large number of potential indicators that relate to effectiveness this criterion can be further partitioned into environmental effectiveness, technological progress, and commercial effectiveness, which follows similar subdivisions in the literature on the evaluation of energy-innovation policy (Carlsson et al. 2002: 243; Carley et al. 2012: Figure 2).

The *additionality* criterion complements effectiveness as it is the degree to which achieved outcomes differ from a baseline development that assumes the absence of the respective policy instrument. The challenge of attributing specific developments to individual policy instruments is large. Hence, the assessment of additionality is and can only be indicative (Scriven 1991). Still, it is a core criterion to establish accountability for the success or failure of RD&D support policies. While administrative capacity is closely linked to input indicators, and effectiveness is mainly assessed with outcome and impact indicators, the additionality criterion is cross-cutting and a differentiation can be made between input additionality, outcome additionality, and impact additionality (Georghiou 2002).

Democracy-related criteria like *legitimacy* and *transparency* were not included in the evaluation, but they are potentially relevant in this case, since in RD&D support programmes considerable subsidies might be granted to few selected companies. As the transparency of a support measure is closely linked to the way the measure is administered, this criterion is at least partially covered in the analysis of administrative capacity. Another prominent criterion in the assessment of RD&D policy is *economic efficiency*. It was not included in this study to limit the scope and avoid the computation of complex cost-benefit analyses.

Indicators used in the evaluation of LCET support policy

The list of potential indicators for the success of RD&D support to LCET is long and includes various input, outcome, and impact indicators. The review of indicators used in the context of LCET support policies is presented in Table 2. The table excludes social indicators and environmental indicators other than the ones related to greenhouse gas emissions. It differentiates between national level indicators and programme-level indicators and is structured according to the chosen evaluation criteria discussed above.

Table 2: Indicators used in the literature on LCET support policies

	National level	Programme level
Administrative capacity		
	RD&D spending	RD&D spending
	RD&D staff (and their formal qualification)	RD&D staff (and their formal qualification)
Effectiveness		
Environmental effectiveness	CO_2 emissions	CO_2 emissions
	CO_2 intensity of energy supply	
	CO_2 intensity of the economy	
Technological progress	Patents (filed, granted, cited)	Patents (filed, granted, cited)
	Scientific papers (incl. PhD theses)	Scientific papers (incl. PhD theses)
	Learning rates	
	Technology/abatement costs	Technology/abatement costs
	Technology performance/efficiency	Technology performance/efficiency
	Energy efficiency/intensity of the economy	
Commercial effectiveness	Jobs	Jobs
	Exports	Exports
	Turnover	Turnover
		Turnover/employee (productivity)
	Profits	Profits
	Return on investment	Return on investment
	Number of enterprises	
	Energy cost savings	Energy cost savings
Other	Energy self-sufficiency	
	Share of renewable energy in energy supply	
Additionality		
	Ratio of public and private RD&D spending	Ratio of public and private RD&D spending
	Jobs per energy output	
	Net employment effect	
	Macroeconomic multipliers	
		Scale and timing of private sector RD&D activity

Source: Author's compilation based on Stosic et al. (2016), Wilson et al. (2012), Carley et al. (2011), Carley et al. (2012), Gallagher et al. (2006), Neij and Åstrand (2006), Jacobsson and Rickne (2004), Spangenberg (2004), Kleinknecht et al. (2002), Schoenecker and Swanson (2002), and Grupp (2000).

Key indicators in the context of public RD&D financing of LCET in the Nordic countries

The above indicators have been brought forward in literature, while in the practice of policy assessment not all of them are applied equally and only a few of them at the same time. In order to reduce the scope of this study and increase its relevance, only the most salient indicators in the case study of RD&D support to LCET in the Nordic countries were analysed. Moreover, only numeric indicators were chosen and indicators included in the analysis had to be relevant at both national and programme level. Selected indicators included RD&D spending, CO_2 emissions, patents, commercial indicators (turnover, exports and jobs), return on investment (ROI), and the ratio of public and private RD&D. Further clarification about the chosen indicators follows, while the actual analysis of these indicators is presented in Section 3.

The indicator 'CO_2 emissions' has to be seen as a group of indicators rather than a well-defined single indicator. Differentiations can be made according to the gases that are included (all GHGs or only CO_2), the sectors that are covered (whole economy, fossil fuel combustion, power generation), and the treatment of trade effects (production- and consumption-based approach).

In this case, CO_2 emissions from fossil fuel combustion and a production-based approach was the most appropriate selection.

The commercial indicators were grouped together as they are typically part of the same accounting system at the national level; also at the programme level they are often measured and presented together. In this study, the indicator ROI means the returns on public investments into LCET RD&D. Further potential indicators in the context of public RD&D financing of LCET in the Nordic countries are briefly discussed later in this paper.

As well as RD&D budgets, administrative capacity, in terms of knowledge and skills, was also highlighted in the interviews as a key input factor for the success of public interventions. Despite the fact that the importance of good management of RD&D financing schemes was clearly recognized in the case study, this did not seem to be reflected in evaluations. Input indicators related to administrative capacity, such as the number and qualification of fund managers and public officers in RD&D schemes (Gallagher et al. 2006), were not frequently used in this specific case. The importance of knowledge and skill inputs into a public financing scheme differs between instruments. While grant schemes are often straightforward to implement and administer, public VC requires more involvement of the staff that are administering the fund, e.g. active participation in the management board of a supported enterprise. In the case of VC activity of the Danish Growth Fund a recent evaluation criticizes for instance the 'overhead burdens associated with direct investments' (Murray and Cowling 2014: 78).

When the focus is put onto the technological progress that RD&D funding stimulates, output indicators, other than patent counts, are the number of supported PhDs and bibliometric indicators, neither of which were explicitly used in this specific case and are potentially subject to large biases (Jacobsson and Rickne 2004).

Only one additionality indicator was chosen to be part of this study, since the outputs and outcomes from publically financed RD&D programmes are rarely tested for additionality, if they are monitored at all. Some evaluations in the Nordic countries do consider aspects of behavioural additionality by asking supported companies about the scale and timing of their RD&D activities and how they were affected by public financing instruments (Braein et al. 2002). There are, however, no results specific to LCET support.

In addition to numeric indicators, qualitative assessments can provide further indications about how programmes are managed with respect to additionality (Gallagher et al. 2006). In this context the institutions which safeguard additionality of public RD&D in the Nordic countries indicate whether additionality is taken seriously, and hence more likely to occur, or not. Furthermore, the choice of support instruments, as such, affects additionality. Low risk loans were found to be the least additional instrument in an evaluation of Innovation Norway, while high-risk loans and grants showed high degrees of additionality (Pöyry 2013).

2.4 Assessment of the indicator-based method

Once indicators used to assess RD&D support to LCET in the Nordic countries were identified, categorized, and selected, they were analysed in order to assess the indicator-based evaluation method. The analysis focuses on the *acceptance* of relevant stakeholders, on the *ease of monitoring* an indicator, including measurability and data availability, and on an indicator's *robustness* against manipulation.

This evaluation approach is inspired by the 'RACER framework' for indicator choice in impact assessments (European Commission 2005). RACER stands for relevant, accepted, credible, easy to monitor, and robust. Both relevance and measurability have also been suggested as criteria for the assessment and selection of green growth indicators (OECD et al. 2013). Interestingly, another suggested criterion for the selection of green growth indicators is *analytical soundness* (OECD et al. 2013: 8). This further stresses the need for a structured framework for indicator choice.

The relevance of an indicator was not included as a criterion in the study since it varies strongly depending on the main policy objectives of a support mechanism, such as economic development, technological progress, and reduced environmental impacts. In contrast, the acceptance of an indicator was included in the analysis, since the results of an assessment that is based on poorly accepted indicators is not likely to resonate with key stakeholders and, hence, will have less of a policy impact. Moreover, indicators that are difficult to monitor or can only be monitored at very high costs are less likely to be applied in evaluations. The more expensive it gets to monitor the development of indicators, the harder it gets to justify resource use for evaluation. In contrast, the robustness of an indicator does not have immediate influence on programme evaluation, as less robust indicators can still be influential if they are widely accepted and monitored. Still, robustness is crucial from the academic perspective as indicators that are not robust may not provide conclusive indications for the (re-)design of LCET support schemes. Moreover, manipulation of indicators may eventually erode acceptance.

2.5 Limitations

This study covers the Nordic countries, which is limiting in two ways. First, results cannot be easily transferred to other countries as the Nordics are characterized by a high level of development, strong national governments, and large renewable energy potential, which is a combination that cannot be found in many other places. Second, the Nordic countries are still a heterogeneous group with different policies, strengths in different industrial sectors, and different energy systems.

Another limitation arises from the main field of study, which was the role and design of policy intervention. This focus on the government perspective on the financing of LCET innovation potentially caused a bias in favour of existing public financing instruments. Adding the perspective of some private investors in LCET did not automatically remove this potential bias, as private investors benefit from existing public financing instruments and hardly argue against them.

Moreover, the category of LCET is not very homogenous. Industrial scale CCS technology requires, for instance, a different support and a different financing volume than small-scale technologies to improve residential sector energy efficiency. Hence, the findings of this study might differ if the analysis were carried out for one specific technology only.

Finally, public financing of RD&D in LCET is not covered in depth in academic literature. Hence, much of the collected data originated from grey literature, working papers, academic theses, and expert interviews, which have not undergone a thorough peer-review process.

3 Analysis: indicators for public RD&D financing of LCET in the Nordic countries

As outlined above, the development of the LCET sector in the Nordic countries is generally perceived as a success story. In contrast, the role of public RD&D financing in this story is more difficult to grasp as it has not been comprehensively researched. This study contributes to the evaluation of RD&D financing of LCET in the Nordic countries by scrutinizing the use of indicators rather than by presenting a comprehensive indicator-based evaluation as such. Hence, specific performance data from the case study is merely used to illustrate the use of indicators and their assessment.

Indicators are analysed and ranked according to the criteria acceptance, ease of monitoring, and robustness (see Table 3). The estimation of indicators is presented on an ordinal three point scale (zero, one, or two stars). The results represent the specific case of RD&D financing of LCET in the Nordic countries. Generalizability beyond LCET in the Nordic countries is particularly limited in the case of acceptance, while similar results can be expected for the criteria ease of monitoring and robustness if the study is repeated in a different context.

Table 3: Overview of assessment indicators for public RD&D support to LCET, their acceptance, ease of monitoring and robustness

Indicator	Acceptance	Ease of monitoring	Robustness
Administrative Capacity			
RD&D budgets	**	**	*
Effectiveness			
CO_2 emissions	*	*/**	*
Patents	*	**	**
Turnover, exports, jobs	**	*	o
ROI	o	*	o
Additionality			
Ratio of public & private RD&D	**	*	*
Legend:			
	Indicator is:	*Indicator is:*	*Indicator:*
two stars (**)	*widely accepted by various stakeholders.*	*measurable and data is available.*	*is difficult to manipulate.*
one star (*)	*partially accepted by the stakeholders.*	*measurable but good data is not available.*	*can be manipulated but robustness can be tested.*
no star (o)	*only brought forward by one type of stakeholder.*	*not measurable.*	*is very prone to manipulation.*

Source: Author's analysis.

While most of the results are indicator-specific, there are some cross-cutting results, in particular with respect to robustness. First, the assessed performance may vary significantly depending on the definition of LCET, which is sometimes also referred to as green energy or clean energy technology. The decision to include controversial and capital-intensive technologies such as CCS or nuclear energy in the definition can make a large difference. Time-lags are another aspect that influences the robustness of indicators. While inputs into LCET RD&D are visible right away, outcomes and impacts of RD&D support programmes manifest themselves only after several years. Finally, for all aggregated indicators there is the challenge of attribution. It is virtually impossible to separate the effects induced by individual support schemes from other factors such as larger business cycles and general technological progress. Below, the schematic overview of results (Table 3) is substantiated for each of the six analysed indicators.

3.1 RD&D spending

Acceptance

RD&D spending is a widely accepted indicator in the Nordic countries. Policy makers have stressed the leading role of the Nordics in LCET RD&D by referring to budget allocations (Nordic Energy Research 2015), academics have frequently used RD&D budget data in econometric studies of innovation activity, and public officers in LCET support programmes as well as fund managers stressed the particular role of public RD&D budgets for energy technology innovation in the interviews. At the level of individual programmes, larger public budgets are mostly, but not always, perceived as desirable. The success of commercialization support programmes, for instance, largely depended on the existence of suitable innovative enterprises. By increasing budgets and, hence, the number of supported enterprises, the risk of picking less-promising enterprises increases.

Ease of monitoring

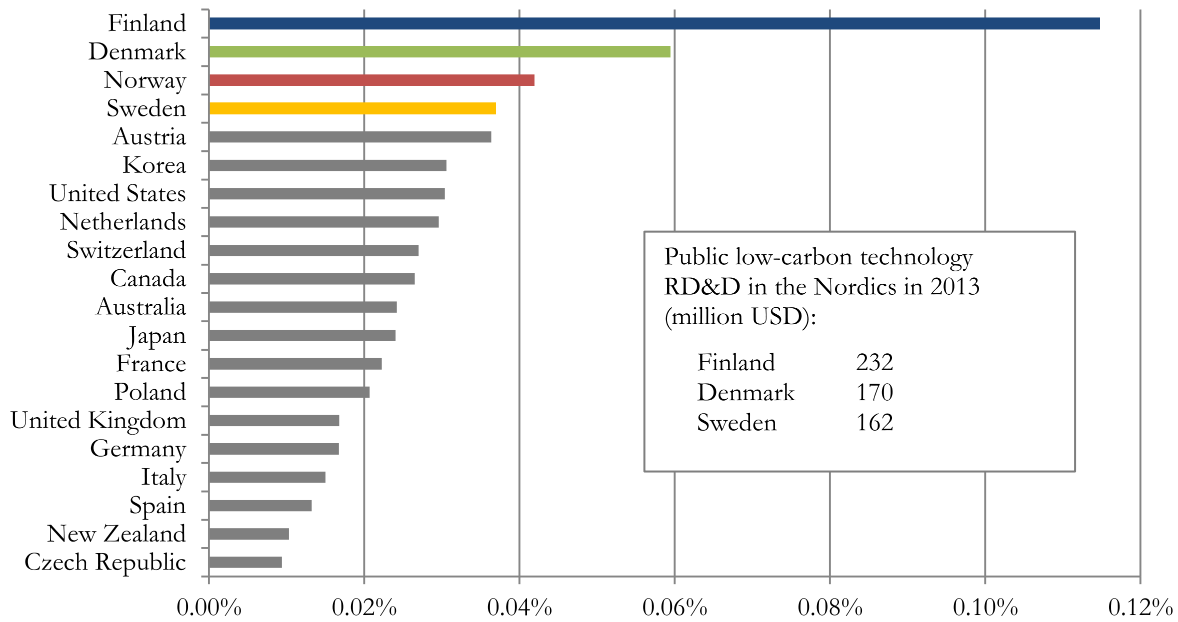
Comprehensive data on national energy RD&D spending of Nordic countries is reported to and published by the International Energy Agency on an annual basis (IEA 2015b). The resolution of the data is fine enough to differentiate between LCET and other energy technologies. RD&D spending data is also available at the programme level, even though it is scattered, so that it requires some data-gathering effort to obtain a systematic overview.

Robustness

The particular presentation of RD&D spending data leaves room for manipulation. Public RD&D spending for LCET can be communicated as absolute values, in relation to GDP, government expenditure, or total RD&D; this data can then be compared to other countries or to a historic trend. Depending on these choices, RD&D budgets can appear larger or smaller.

The share of LCET RD&D in GDP is, for instance, high in the Nordic countries compared to other industrial states (see Figure 2). Presented in a historical context, the same figures tell a different story. The ratio of energy RD&D spending to GDP was three times higher in Sweden in the early 1980s (peaking at 0.14 per cent in 1981), which has to be seen in the context of the oil crises (IEA 2015a).

Figure 2: Average ratio of public low-carbon technology RD&D to GDP between 2009 and 2013



Source: Author's illustration based on 2015 data from the IEA and IMF.[1]

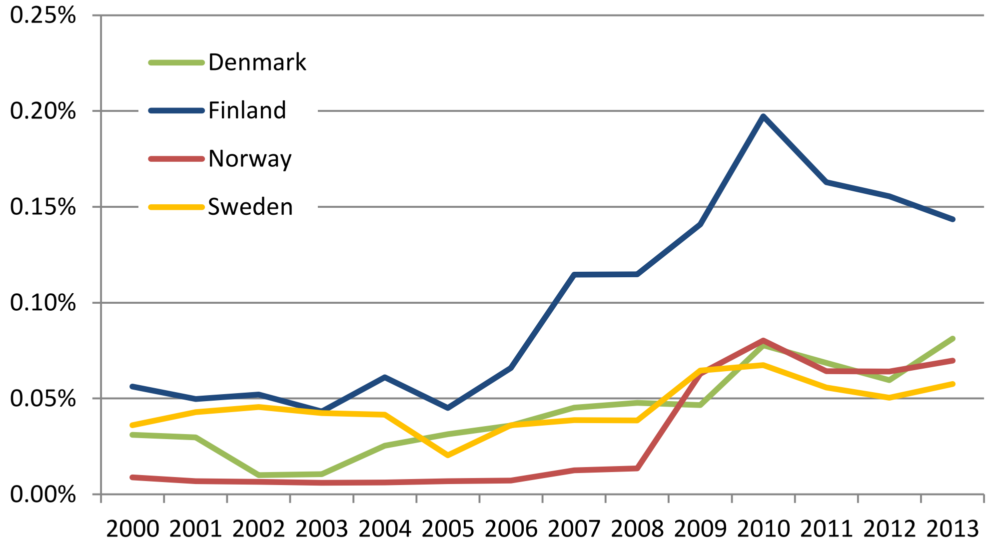
RD&D spending on LCET can also be compared to overall public RD&D spending, which represents about 3–3.5 per cent of GDP in the Nordic countries (as compared to 0.03–0.11 per cent for LCET). At the time of the oil crises, energy R&D made up more than 10 per cent of overall R&D both in Europe and the Americas, a ratio that has dropped to 2 per cent and 3 per cent respectively (IEA 2015a).

When looking at the share of LCET RD&D in total government expenditure two major developments can be observed (see Figure 3). First, support seems to have been stagnating since 2010. Second, Finland quadrupled the share of RD&D to LCET in total government expenditure between 2005 and 2010.

Still another way to look at RD&D spending is to compare absolute values, which are low in the Nordic countries as compared to larger countries. The US loan guarantees of US$535m to solar cell producer Solyndra and of US$465m to electric car manufacturer Tesla (Rodrik 2014) exceeded the current capacity of the Nordic countries' RD&D budgets, which seem even smaller in comparison to the support that China grants to some of its renewable energy companies, e.g. US$9.1bn to LDK Solar, US$7.6bn to Suntech Power, and US$7bn to Yingli Solar (Sanderson and Forsythe 2013).

[1] The following exchange rates from national currencies to US$ were used throughout the study: 0.146 for DKK, 1.09 for EUR, 0.114 for NOK, and 0.117 for SEK (December 2015).

Figure 3: Share of low-carbon energy technology R&D in total government expenditure



Source: Author's illustration based on 2015 data from the IEA and IMF.

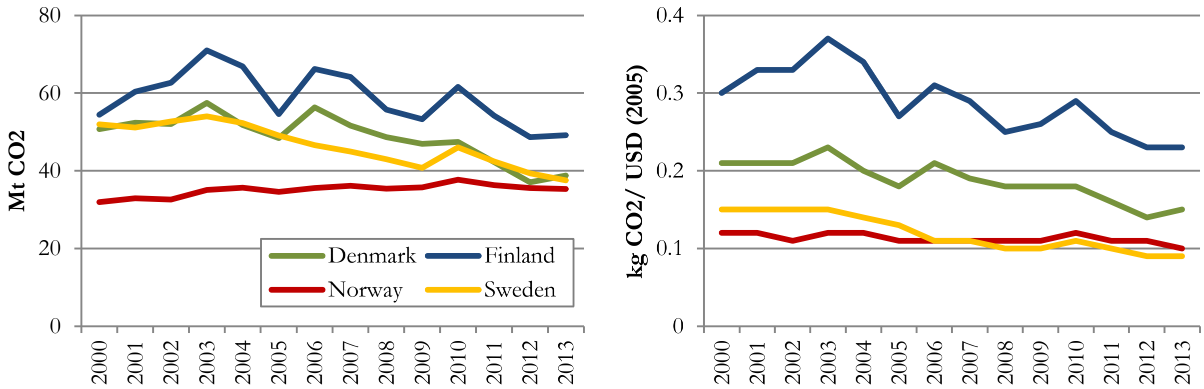
Moreover, a comparably high RD&D intensity at the national level does not mean that all specific programmes and schemes in the Nordic countries have large budgets. RD&D financing for LCET may well be concentrated in a few lighthouse projects, as for example CCS funding is in Norway, which made up more than half of RD&D to LCET in Norway between 2009 and 2012 (IEA 2015b). It was observed that there is too little public funding for LCET for early stage enterprises that have already received seed-funding but often have difficulties securing follow-up financing (Grünfeld et al. 2011; Finnvera 2013).

Finally, RD&D spending is not adjusted for the respective costs of conducting RD&D, e.g. the costs for employing research staff, which are significantly higher in countries like Sweden as compared to many other European countries (Jacobsson and Rickne 2004).

3.2 CO_2 emissions

The most apparent indicator for assessing the environmental effectiveness of public RD&D financing of LCET in the Nordic countries is the development of CO_2 emissions from fossil fuel combustion. It is often presented in relation to GDP growth in order to account for the size of the respective economy. The development of both CO_2 emissions and the emissions intensity of the economy have been very positive in all Nordic countries but Norway over the past 15 years (see Figure 4).

Figure 4: Development of CO_2 emissions from fossil fuel combustion and carbon intensity of GDP in the Nordic countries



Source: Author's illustration based on 2015 data from the IEA.

Acceptance

CO_2 emissions are not widely accepted as a significant impact indicator. On the one hand, investigated policy programmes and the laws in which they are enshrined do refer to the reduction of CO_2 emissions, and also academics comprehensively discuss the role of technology push policies for reducing CO_2 emissions. On the other hand, emission reductions do not play a major role at the programme and project level. The interviews revealed that the reduction of CO_2 emissions is seen as a 'by-product' of the (economic) success of supported enterprises and not as an indicator for success in itself.

Ease of monitoring

CO_2 emissions data is certainly measurable and available at the national level in the Nordic countries but difficult to measure at the programme level, as the lion's share of emission reduction typically does not take place in RD&D projects but indirectly through selling and deploying LCETs on domestic and international markets. Only few programmes included CO_2 emissions in their assessment, e.g. Enova Norway's support for 'new energy technology', which monitored energy savings and CO_2 emission reductions both in absolute terms and in relation to provided funding (Enova 2015).

Robustness

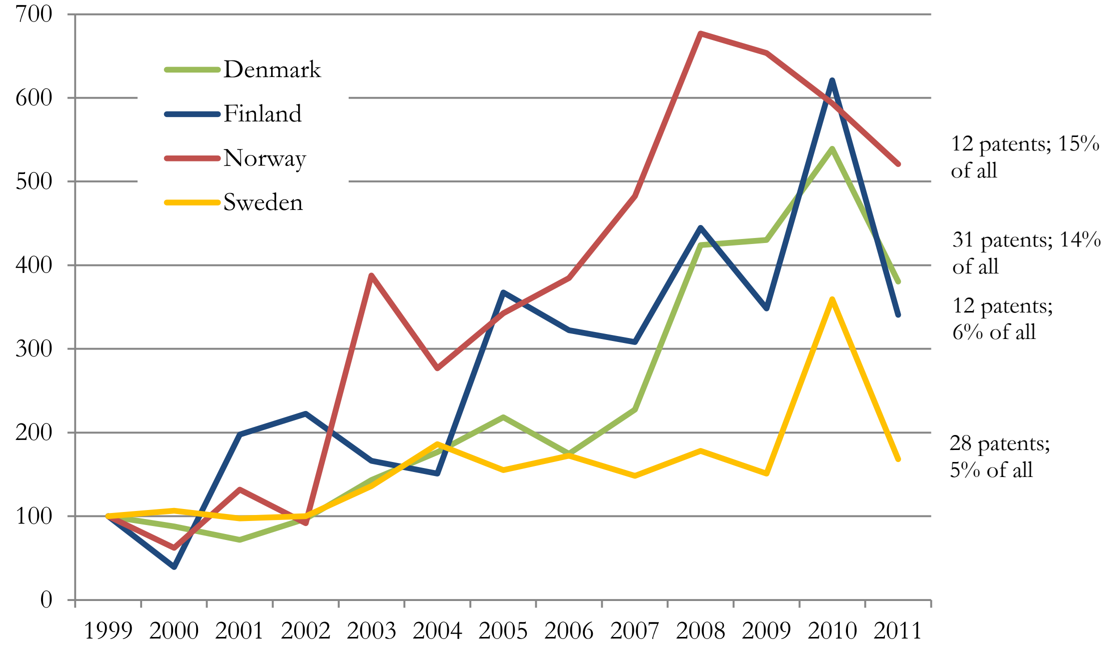
While national-level emissions data is rather robust and an established system for monitoring, reporting, and verification is in place in all Nordic countries, there is a lot of room for manoeuvre at the programme level. Both direct and induced emissions reduction can be monitored, both nationally and internationally. Moreover, the choice of the baseline for evaluating reductions, and not merely monitoring them, leaves room for manipulation. Base years may vary and business as usual scenarios rest on many assumptions.

3.3 Patents

All Nordic countries increased their share of LCET patents in total patents between 1999 and 2011 (see Figure 5). This suggests that within the Nordic countries LCET became a more significant area of innovation, which may be partly driven by additional public RD&D financing in this sector. This trend is not restricted to the Nordic countries, but it is likely more pronounced than in many other countries, so that the 'relative technological advantage' of

Nordic countries in LCET may well have strengthened in this period (Haščič and Migotto 2015: 30).

Figure 5: The indexed share of low-carbon technology patents[2] of all technology patents in Nordic countries



Source: Author's illustration based on 2015 data from the OECD.

Acceptance

At the national level, patents are frequently used as proxies for technological progress, both by academics and government agencies. The situation is different at the programme level where patents are mainly regarded as a means to an end. Even if not seen as an end in themselves, patents and the process of protecting intellectual property rights do play a role in the RD&D support that is provided to LCET in the Nordic countries. Patents are simply not regarded as a relevant indicator for success at the programme level.

Ease of monitoring

Patent data of LCET is available at the national level and published regularly. In contrast, patent data is not made available in a systematic way at the programme level, so that the attribution of patents to public support instruments becomes difficult. The Finnish national innovation funding agency TEKES monitors the overall number of patents registered by supported organizations but does not provide a specific breakdown for LCET (Tekes 2015). A Danish study of the green economy compares innovation activity and patenting of green enterprises to all enterprises, showing that the trading of patents and intellectual property rights plays a larger role in green enterprises than in the overall economy (Danish Energy Agency 2012: 38).

[2] This category includes patents in the OECD Triadic Patents family in the area of climate change mitigation technologies related to buildings, energy generation, transmission or distribution, transportation, and technologies related to the capture, storage, sequestration, or disposal of greenhouse gases.

Robustness

Patents are a robust indicator. Data is available, it can be rather easily verified so that there is little room for manipulation, and patents can to some extent be attributed to RD&D projects. Still there is a risk that funding agencies account for a full patent in cases in which they provided only a minor share of the overall project budget.

3.4 Turnover, exports, jobs

Turnover in the LCET sector, its jobs and exports are frequently used indicators in the context of RD&D financing instruments. The most developed and standardized way to measure the commercial development of subsectors of the green economy is provided in national statistics about the Environmental Goods and Services Sector (EGSS), which is defined in the statistical guidelines of Eurostat (Eurostat 2015). However, reporting of the EGSS data is not yet mandatory in the EU so that available data is scattered and cross-country comparisons are not possible.

Acceptance

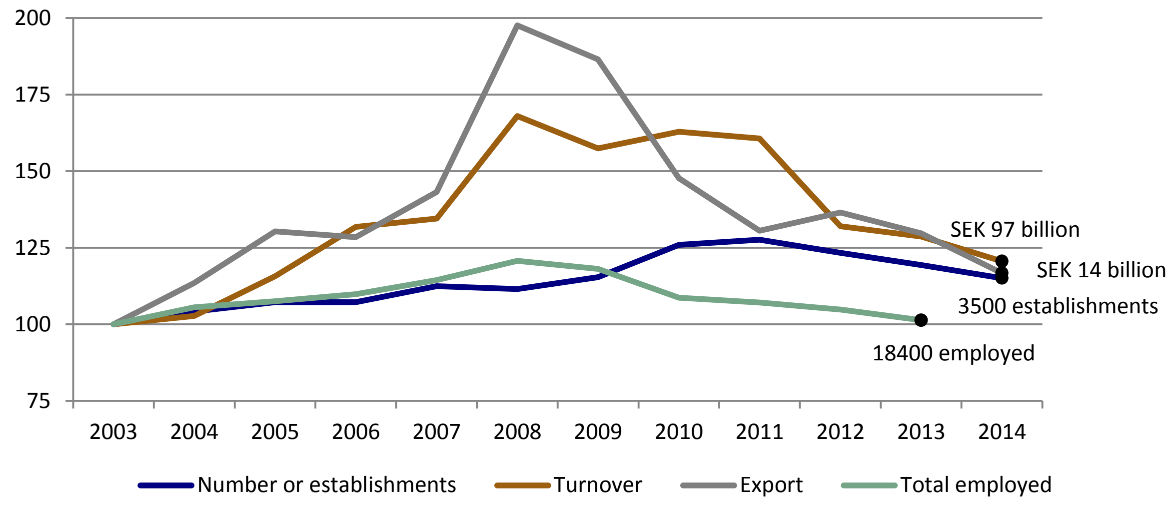
Various stakeholders stress the commercial dimension of RD&D financing of LCET. There is virtually no public support programme in the Nordic countries that does not explicitly refer to economic development. The political emphasis of commercial aspects is a view that was reaffirmed in the interviews where public officers stressed the role of commercialization potential. Even in academia the focus is increasingly put on the commercialization aspect of publically funded RD&D (Jacobsson et al. 2013).

Ease of monitoring

Turnover, jobs, and exports in the LCET sector are measurable and some data is available at both the national level and at programme level, but it is far from comprehensive. Sweden is the only Nordic country that has collected comprehensive data on its EGSS for more than a decade, including specific data on the subsectors, renewable energy, and energy savings (see Figure 6).

The Danish EGSS statistics only cover the years 2012–14, the Finnish statistics do not include the subsectors renewable energy and energy efficiency, yet, and in Norway the statistics office is preparing for the first publication of EGSS data in 2017. The lack of official data from statistics offices is partly compensated for with data from industry associations (Mellbye and Espelien 2013; Cleantech Finland 2014).

Figure 6: Swedish EGSS statistics for the subsectors renewable energy and energy savings 2003–13



Source: Author's illustration based on 2015 data from Statistics Sweden.

In addition to national level data, specific programme evaluations sometimes include the economic outcomes of RD&D support programmes and add to the body of data. The Danish Business Innovation Fund, which financed mainly green economy enterprises in 2010–12, required, for instance, all supported enterprises to communicate five-year turnover and employment targets. These targets were summarized and followed up in a mid-term evaluation (Deloitte 2012), but no further evaluation with actual data is available, yet. This example illustrates a typical challenge of programme evaluations, both in the case study and in general. Once temporary support programmes are finalized, little priority and resources are given to evaluation. No systematic studies have been carried out to summarize and compare commercial results of different support programmes in the Nordic countries.

Robustness

As well as data availability, quality of commercial data also varies. Due to the fact that there is no standardized way to measure commercial indicators for LCET (and the whole EGSS) the data may vary between different sources. In particular, data from grey literature tends to be less robust. One example is Norway's renewable energy sector, for which industry sources frequently report employment of 50,000, a turnover of NOK200 bn and approximately 2000 companies in 2010 (Innovation Norway 2015). This is far higher than the figures published in a more elaborated study, which found 13,700 employees, NOK85bn turnover and 860 companies in 2010 (Mellbye and Espelien 2013). Furthermore, economic data about the LCET sector does not reflect that employment, turnover, and exports could also be generated in other sectors. The actual figures do not reflect the net effect of the respective support policies, i.e. its additionality, but only their gross effects. The claim that the Danish wind power sector employs more people than the Swedish automotive industry is often made in the context of job creation. This is potentially misleading as it does not say anything about the net employment effects of past wind power support policies in Denmark.

3.5 Return on investment

In the case of public equity financing instruments, ROI is an additional commercial indicator under consideration. ROI in this context is understood as the direct profits from public sector investments. There is no exclusive public VC fund for LCET in the Nordic countries, but several public VC funds have LCET companies in their portfolio. These funds typically stress that they operate like private funds and that their main objective is ROI. This supports the findings of Yang and Sollen (2013) who found strong evidence for a *de facto* profit motive in state-owned VC in the Nordics.

The track record of public VC to LCET enterprises is not well researched but has a rather poor image among analysts in the Nordic countries. The Danish Growth Fund, for instance, has not made any initial VC investments into cleantech since 2011 due to 'poor financial returns on Cleantech investments' (Murray and Cowling 2014). The Norwegian public VC fund Investinor has not made any LCET investments since 2010, either. Some interviewees talked about the complete absence of success stories about public VC investments in LCET enterprises. Even the performance of private VC funds that invest in cleantech is at best mixed in the Nordic countries (Wang 2015). The absence of success may have other reasons than public VC being an inappropriate support instrument, including the poor timing of investments with respect to economic cycles and long lead times in this sector, which means that there have not been many exits, yet (Murray and Cowling 2014).

Acceptance

With the exception of (state-owned) VC fund managers, little support could be gathered for taking ROI into consideration as an indicator for the effectiveness of public RD&D financing of LCET. Several stakeholders argued that the state should support those ventures that are too risky for the private sector but potentially beneficial from a social perspective (see also Figure 1). These are most likely not the ones that promise the highest returns. While it is widely accepted that profit-orientation should be the *modus operandi* for public equity funds, a general profit target is not accepted at all. In the interviews it was suggested that benefits to the state could be assessed in a different way, i.e. by looking at financing costs and at the indirect impact on tax revenue that is triggered by additional commercial activity.

Ease of monitoring

The returns from public VC investments into LCET are measurable, which is straightforward after a portfolio company has been sold (exit). There are, however, large methodological challenges in estimating the current value of existing portfolios. LCETs have a long time to market so that several of the public investments in the Nordic countries could not be exited yet, which impedes the calculation of ROI. Good data for public VC investments in the Nordic countries is not available, and even less so for LCET investments in particular, since LCET investments are typically part of larger VC funds that are not specialized into energy or cleantech.

Robustness

Due to the lack of data, it is not possible to assess the actual robustness of the indicator ROI. Still, it is rather clear how the data could be manipulated and why. Fund managers have strong incentives to overestimate the current value of their portfolio, while entrepreneurs also have to portray their respective ventures as a success story in order to receive continued financing.

3.6 The ratio of public and private RD&D financing

Merely looking at effectiveness is not sufficient to assess the success of a policy intervention. RD&D financing instruments in the Nordic countries showed a clear attempt not only to be effective but also to both ensure the additionality of the intervention and, to a lesser extent, monitor this additionality effect. The most common indicator for the additionality of Nordic

RD&D support schemes was the ratio of public and private RD&D financing, i.e. the consideration of whether public financing has crowded in or crowded out private financing.

Acceptance

The ratio of public and private RD&D was clearly the indicator that was used most to investigate additionality. Its role as input indicator, however, slightly reduced acceptance, as after all additional effects on the environment, technology, and economy were sought after rather than additional financial input, as such. Furthermore, the indicator is not always easy to interpret (see section on robustness), which further reduced acceptance.

Ease of monitoring

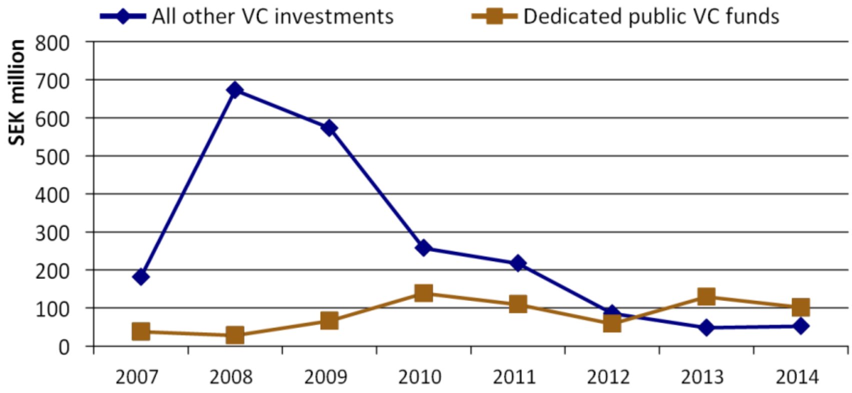
Both public and private RD&D financing are measurable and data is partially available, even though data on private sector RD&D spending is less comprehensive. There is no comprehensive study about private versus public sector RD&D for LCET in the Nordic countries. At the programme level the evidence from evaluations, reports, and interviews clearly suggests very high additionality of public RD&D to LCET in the Nordics. Gaps in the innovation financing cycle of cleantech were identified by various private and public investors (Finnsson 2011). Evaluations of TEKES' (Finland) financing of environmental technology (Valovirta et al. 2014) and of Innovation Norway's Environmental Technology Scheme (Espelien et al. 2014) found high degrees of additionality. In the latter case NOK1 of financing 'triggered' NOK3.6 in private investments. Moreover, in the case of Sweden, public funding seems to crowd in private capital for cleantech investments; and co-investments are particularly common in the sub-sector of energy (Yang and Sollen 2013: 59). While, at the programme level, data on private co-investments in RD&D is collected and, in many cases, even has to be collected, this does not provide any information about private RD&D activity outside publicly co-financed projects.

Robustness

To analyse thoroughly whether the outcome of LCET support was additional in the case of the Nordic countries would require the construction of complex counterfactuals that are typically based on various assumptions, which reduces robustness. The ratio of public and private sector RD&D financing is a simple input indicator and as such it avoids some of these complexities. However, it was pointed out in interviews that the interpretation of the indicator itself is not self-evident. The least problematic case is when public financing of RD&D increases, but its share in total RD&D financing (public and private) remains the same or even decreases. Additionality of public funds is likely as private financing is certainly not crowded out. It is more difficult to interpret when the share of public RD&D increases, since the increased share could be either due to a crisis in private RD&D financing, hence pointing towards a high degree of additionality, or due to crowding out, indicating a low degree of additionality. Depending on the perspective, the same data can potentially be used to argue in favour of or against additionality.

One example for an increased share of public financing is the development of cleantech VC in Sweden. In recent years private VC cleantech investments in Sweden were extremely low compared to the boom in the late 2000s.

Figure 7: Investments of VC funds into Swedish cleantech enterprises 2007–14



Source: Author's illustration based on Tillväxtanalys (2015).

The collapse of private VC investments despite slightly increasing dedicated public VC funds most likely provides indication for a high degree of additionality of public funds, even though they were not successful in crowding in much private funding (see Figure 7).

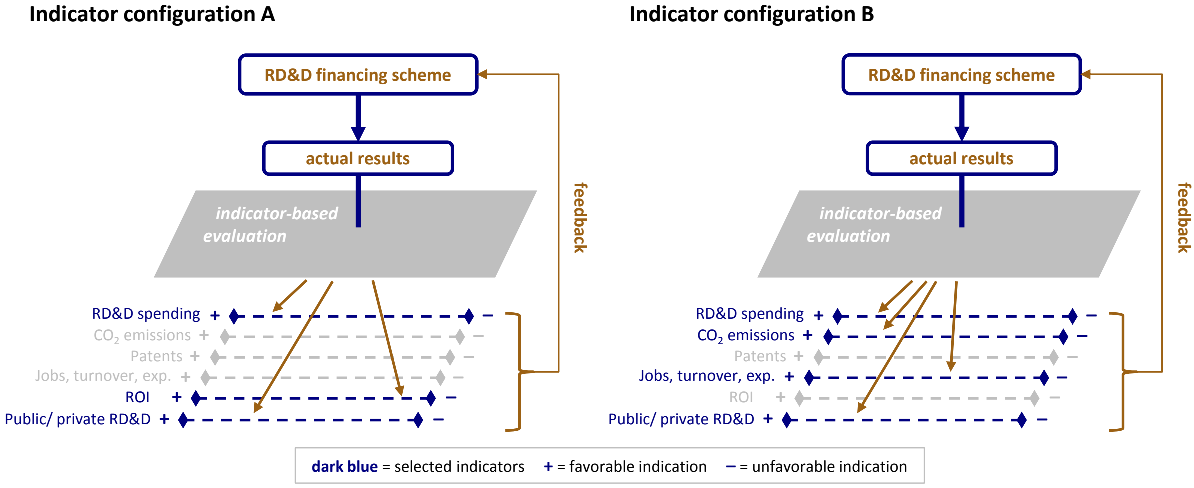
Besides its ambiguity, the robustness of this indicator is further challenged by the fact that private sector RD&D financing data is largely based on self-reporting. Companies have many options for manipulating the data they report, e.g. increasing their budgets by inflating the staff hours they put into an RD&D project.

4 Effects of indicator choice—potential biases and their policy implications

The analysis of six common indicators in the context of RD&D financing of LCET showed that even a basic structured assessment does not result in a clear-cut indicator-based evaluation framework. Trade-offs between comprehensiveness, acceptance, ease of monitoring, and robustness are impossible to avoid. The innovation systems literature responds to the shortcomings of indicator-based evaluation by focussing on the functional dynamics of technical innovation systems, which are certainly important to research, but even harder or impossible to measure (Bergek et al. 2008).

An argument in favour of indicator-based monitoring and evaluation is that it helps to establish accountability of policy makers. If evaluations of RD&D programmes for LCET are carried out at all, they are typically based on indicators. Accepting that these indicators only represent a subset of all available indicators, moreover a subset that is faced with heavy trade-offs, it becomes clear that the mere selection of indicators can have a major impact on evaluation results (see Figure 8). These results then feed back into the policy-making process and may trigger changes in programme design and strategic focus.

Figure 8: The effect of indicator choice in indicator-based evaluation



Source: Author's illustration.

The active selection of indicators may introduce bias into indicator-based evaluation. It is important to note, though, that certain biases might be justified as the specific objectives of a programme (e.g. technological progress or economic growth) make some indicators more relevant than others. The limited, but often existing, freedom to compute and present indicators in different ways (i.e. lack of robustness) introduces further uncertainty about the validity of assessment results. Below, some potential biases and uncertainties in the evaluation of Nordic RD&D financing of LCET are discussed and possible policy implications are described.

A focus on short-term economic performance and ROI

In the case study, the growth of jobs, exports, and turnover, and also profitability appeared to be increasingly important indicators of the public financing of RD&D and its commercialization. At the same time there is some evidence that in the Nordic LCET sector private RD&D spending has recently decreased and public RD&D spending has levelled off (see Figure 7 and 3). The interviews made clear that, in particular, public VC instruments have moved away from cleantech due to low profit expectations and long times to market. Hence, dedicated support for LCET is not likely to perform well in assessments if much attention is paid to the indicators ROI and the (short-term) development of jobs, exports, and turnover.

A bias towards these indicators largely disregards social benefits related to the development and deployment of LCET, such as resource conservation and climate change mitigation, which are not captured by short-term commercial success. This improves the position of other sectors in the competition for public funds. The ICT sector is, for instance, less capital-intensive and has shorter development cycles.

LCET-specific support and commercial success do not exclude each other, and there are examples of that in the Nordic countries. Analyses of the Danish wind energy sector and the Swedish bioenergy sector have shown that 'medium-sized countries can be within the world's leading nations in a specific field of energy technology, if appropriate supply and demand side policies support a certain technology' (Bointner 2014: 738). In order to be successful with respect to commercial performance indicators, public RD&D financing of LCET likely has to be part of a more comprehensive policy mix. Accordingly, fund managers and public officers stressed in the interviews that the business plans of several supported companies could only be worked out if there were demand side policies in place, both domestically and abroad. Demand-side measures include FiTs for renewable energy in Denmark and Finland, the common green certificates market of Norway and Sweden, CO_2 taxes, and deployment subsidies for various LCETs.

The main policy implication of a strong focus on short-term economic performance is, hence, that (further) dedicated support to LCET is difficult to justify if there are no additional demand side policies in place.

Stressing the additionality of financing

Despite the lack of workable indicators, additionality played a central role in the assessment of RD&D financing instruments in the Nordic countries. The strong emphasis of additionality, which could be found in both interviews and reports, was slightly surprising as, in the case of Nordic RD&D financing of LCET, there was virtually no evidence for 'crowding-out' private capital. The apparent importance of additionality can be traced back to regulatory requirements to warrant additionality, which are stipulated in EU state aid regulation. The investigated support instruments included various institutional mechanisms to make sure that the state does not finance 'too much', including co-investment provisions, maximum aid intensities, and limited opportunities for follow-up investments.

It would be an exaggeration, though, to understand these institutions to be safeguarding additionality as a result of a bias towards additionality in evaluation. While the importance of additionality was indeed frequently stressed, actual monitoring happened—if at all—mainly for the input indicator 'ratio of public and private funding'. This supports the thesis that 'additionality can be treated ex ante as a design criterion and ex post as an area where some evidence can be collected but where full measurement may be impossible and in any case is not justified in resource terms' (Georghiou 2002: 64).

It would require further discourse analysis to better understand how the frequent discussion of additionality has influenced the design of RD&D financing measures in the Nordic countries. What has already become clear in this case is that a large emphasis on additionality indicators in the assessment of RD&D support schemes may favour cautious state intervention rather than strong industrial policy push for LCET.

Disregarding decarbonization

Decarbonization was a very prominent objective in the justification and communication of LCET support measures in the Nordic countries, while at the programme level RD&D financing of LCET was rarely perceived as climate policy but rather as innovation policy. Accordingly, most RD&D support to LCET companies was managed by dedicated innovation agencies like Tekes, Innovation Norway and Vinnova, or by ministries of economic affairs.

The challenge to place LCET support within different policy domains is well-illustrated by an evaluation of the Norwegian Environmental Technology Scheme (Innovation Norway). The hierarchy between the programme's objectives 'environmental effect' and 'commercial potential' was not clear and the evaluators recommended 'design[ing] explicit objectives including a clear goal hierarchy as soon as possible' (Espelien et al. 2014: 6), being very outspoken that priority should be given to commercial potential. This reflects a frequently expressed view in this case study, i.e. that commercial success is the best strategy to assure positive environmental impact.

Moreover, previous econometric studies have shown that little direct influence of public RD&D financing on CO_2 emissions from energy can be expected (Garrone and Grilli 2010). Considering further that there are serious methodological challenges to attribute emission reductions to specific RD&D support schemes (Miedzinski et al. 2013), it was not surprising that the indicator 'CO_2 emissions' was largely disregarded in evaluations of the analysed instruments.

The potential policy implication of disregarding CO_2 emissions as an assessment indicator lies in the selection of LCETs that are worth supporting. If emission reductions are not monitored there is a risk that the mitigation potential of a technology is only of secondary concern in the selection of support-worthy RD&D projects and enterprises.

5 Concluding remarks

The main objective of this study was to assess the performance of indicator-based evaluation in the context of public RD&D financing of LCET. The Nordic countries provided an interesting case to study the choice of indicators in policy evaluation, their acceptance, the ease of monitoring them, and their robustness. The analysis clearly showed that a structured assessment of indicators can help to point up the trade-offs and limitations that are inherent in indicator-based evaluation. Selecting indicators can introduce bias. The discussion of LCET RD&D financing in the Nordic countries illustrated how a focus on short-term economic performance may hinder (further) dedicated support to LCET, how stressing the additionality aspect of public financing may lead to rather cautious state intervention, and how the partial neglect of CO_2 emissions in evaluation may shift the focus away from the abatement potential of supported technologies.

If such biases happen to correspond with the policy objectives behind the respective instruments and programmes, they can be justified. If, on the other hand, the ambition is to act according to the targets of the 2015 Paris Agreement, dedicated support to LCET with substantial abatement potential and bold state interventions are needed.

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