Piret Tõnurist, Kaija Valdmaa, Ringa Raudla, 2019. "Impact of Climate Discourse on National Scientific Networks in Energy Technologies: The Case of Estonian Science and Industry Linkages."
Halduskultuur: The Estonian Journal of Administrative Culture and Digital Governance 20(1), 20-45

Impact of Climate Discourse on National Scientific Networks in Energy Technologies: The Case of Estonian Science and Industry Linkages

PIRET TÕNURIST, KAIJA VALDMAA, RINGA RAUDLA

Abstract

This article examines how the global climate change discourse influences the implementation of national science policy in the area of energy technology, with a focus on industry and science collaborations and networks. We develop a set of theoretical propositions about how the issues in the global discourse are likely to influence research agendas and networks, the nature of industry-science linkages and the direction of innovation. The plausibility of these propositions is examined, using Estonia as a case study. We find that the global climate discourse has indeed led to the diversification of research agendas and networks, but the shifts in research strategies often tend to be rhetorical and opportunistic. The ambiguity of the global climate change discourse has also facilitated incremental innovation towards energy efficiency and the potentially sub-optimal lock-in of technologies. In sum, the Estonian case illustrates how the introduction of policy narratives from the global climate change discourse to the national level can shape the actual policy practices and also networks of actors in a complex and non-linear fashion, with unintended effects.

Keywords: climate change, environmental technologies, clean technologies, energy technologies, science policy, innovation, policy feedback

1. Introduction

In the scholarly literature on climate change, the discursive construction of problems and the ensuing policy changes have received increasing attention (Dayton 2000; Lorenzoni and Benson 2014; Reusswig 2010). In particular, using the insights from discursive institutionalism (e.g. Schmidt 2008; 2010), it is argued that in order to understand and explain policy change, we have to examine the effects of discourse and the role it plays in bringing about changes (e.g. Lorenzoni and Benson 2014; Hope and Raudla 2012). According to discursive institutionalism (DI), the term "discourse" covers the substantive content of ideas and also the interactive processes in which the ideas are construed and communicated (Schmidt 2008; 2010). While a variety of approaches in social sciences have explored the role of discourse in politics and policy (see, e.g., Leipold and Winkel 2017 for an overview), DI also pays attention to how policy discourses become *institutionalized*. Although the role of discourse in explaining policy change has been examined in many studies by now, there are fewer studies that look at how discourse affects policy *implementation* at different levels of governance (for exceptions, see, e.g., den Besten et al. 2014). This paper hence seeks to contribute to the DI discussions about how a discourse that has evolved at the global level can influence the implementation of a policy in a specific policy domain at the national level.[1]

In particular, the goal of the article is to analyze the effects of the global climate change discourse on the implementation of national policies. As the solutions to climate change are high-technology-centered (Wesselink et al. 2013), we selected the science policy domain for our analysis (Shackley and Wynne 1995; Demeritt 2006). Within the broader *domain* of science policy, we zoom in on the specific policy *field* of energy technologies, since it is regarded to be the most important sub-field of climate-related technologies (e.g. Kuehr 2007; Ekins 2010). Given that the global climate change discourse entails competing sub-discourses – with one narrative focusing on environmental problem-solving and another being more business-oriented – it would be insightful to examine how these competing approaches influence the actual policy implementation in a specific country. Our paper argues that the introduction of policy narratives from the global climate change discourse to the national level can influence the actual policy practices and also networks of actors in a complex and non-linear fashion, with various unintended effects.

When looking at the effects of the discourse on policy implementation it is important to explore how different aspects of the discourse influence the *networks* of actors involved in the policy domain, since it is the interactions within those networks that can play an important role in influencing the eventual policy outcomes. This is particularly pertinent in the domain of science policy due to the high inter-dependence between industry and R&D facilities. The existing studies that have looked at the effects of the climate change discourse on science policy have primarily focused on climate technology transfer as part of low-carbon, renewable technology diffusion (Karakosta et al. 2010) but have ignored the effects on the dynamics of networks, which encompass a broad range of actors engaged in these climate-related technologies (policy makers, enterprises, research institutes, universities etc.) and are responsible for the actual innovative activities (Taylor 2008). Studies in evolutionary economics (Schmidt et al. 2012) have tried to address parts of this research gap, but the interdependence of R&D goals and the direction of innovation have not received enough attention. Also, these studies have not focused on the role of discourse in shaping the developments. Furthermore, when it comes to energy technologies they are usually studied from a technology-centric approach by innovation scholars (e.g. technology innovation systems, e.g. Gallagher et al. 2012), which does not fit the multi-disciplinary logic of climate-related technologies. Especially regarding clean technologies, multi-disciplinary scientific networks are rarely studied, and more emphasis has been put on company collaborations (Caprotti 2012).

Thus, in this paper we will focus on the dynamics of collaborative scientific networks (in particular industry and science collaboration (ISC) or industry-science linkages (ISL)). In the theoretical part of the paper we will develop a set of propositions about the effects of the global climate change discourse on the implementation of science policy in the field of energy technologies. The plausibility of these propositions will then be examined by looking at the case of Estonia. The case study of Estonia presents an opportunity to explore the effects of the changes in the global policy discourse in a small-country context that, first, had no significant environmental policy prior to the 1990s; and, second, had, until the beginning of the 2000s, a mono-technological energy sector with a very high GHG impact. Thus, it would allow us to

1 "A policy domain" is "a component of the political system that is organized around substantive issues" (Burstein 1991, 328).

trace the effects of the global climate change discourse on local policy implementation in a particularly pure form.

The paper proceeds as follows. In section 2, we identify the main trends in the global climate policy discourse that are relevant for the scientific networks in the field of energy technology and develop a set of propositions about how the discursive elements are likely to affect the implementation of science policy in energy technologies. In section 3, we present the methodology used for the Estonian case study (descriptive network analysis, structured interviews, analysis of documents and projects), followed by the empirical analysis in section 4. Section 5 provides a concluding discussion.

2. Global climate change discourse and shifts in the implementation of national science policy

2.1 Global climate change discourse: relevant aspects for science policy in energy technologies

According to the global climate change discourse, human activities (including the burning of fossil fuels and clearing of forests) have led to the concentration of green-house gases (GHGs) in the atmosphere, which, in turn, is affecting the global climate (for overviews, see, e.g., Dayton 2000; Reusswig 2010). Thus, according to the global discourse, which has become institutionalized in the Kyoto Protocol, governments should take steps to reduce the emission of GHGs. There are, by now, numerous studies which discuss the emergence, institutionalization and impacts of the global climate change discourse (Caprotti 2012; Wittneben et al. 2012). In this paper, we zoom in on those aspects of the global climate change discourse that are likely to affect the implementation of science policy in the field of energy technologies.

A core element of the global climate change discourse is advocating for the development and adoption of more energy- and other resource-efficient technologies that have a reduced or zero effect on the environment. There are, however, several issues with the dominant global climate change discourse that are likely to influence the implementation of science policy in the field of energy technologies.

First, the problem of climate change has been framed as a "global issue", in need of "global solutions" (Miller 2004) and rethinking the whole system (Johnson and Suskewicz 2009). Such discursive constructions, however, have increased ambiguity on the national policy level in terms of the course of actions that should be taken (see Figure 1 for the core elements of the global climate change discourse).

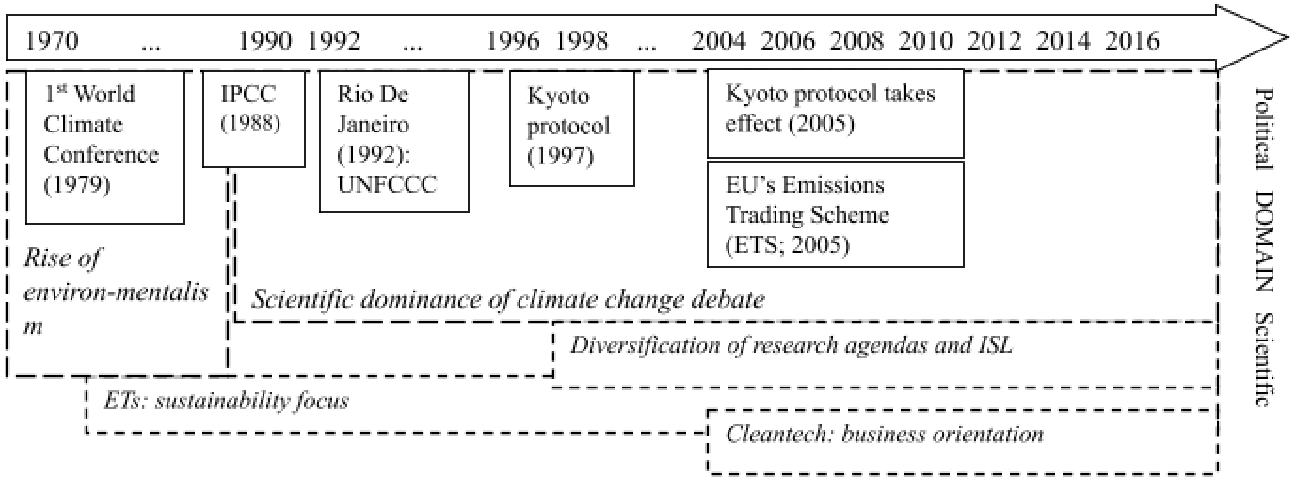


Figure 1: **Climate change: main political agreements and evolution of trends/elements in the global climate change discourse**

Second, one of the main deficiencies in the dominant discourse is the fact that through the Intergovernmental Panel on Climate Change (IPCC) and the Kyoto Protocol it has become a very linear discourse concentrated around science policy (e.g. Pielke 2010; Beck 2011), as opposed to also encompassing technology policy (and interactions between science and technology). The dominant narrative is that since it is scientifically proven that some technologies produce more greenhouse gases that have a clear effect on the climate, if we change the technologies it is possible to reduce the emission of GHGs. In other words, it has been argued that a simple "technical fix" is possible from an objective, value-neutral scientific approach (Wesselink et al. 2013), and too little attention has been paid to various policy goals, political commitment, and allocated means. The various policy goals can encompass more socially oriented objectives, like cleaner environment or equal resources for all (including future generations), or more business-focused goals, like fostering new innovative and clean energy technology sectors for boosting the implementation of basic science, or supporting fossil fuel power plants for the stability of the energy system. All of these policy directions can have either a short- or a long-term focus (depending on the level of political commitment) and can receive direct or indirect financial support, short- or long-term investment security – which all influence science, technology and innovation policy around energy technologies.

Although the time period of this analysis covers 1998 to 2012, a more recent development, the Paris Agreement (UNFCCC 2015) adopted in 2015 under the UNFCCC for tackling climate change beyond 2020, deserves special attention as it is one clear result in the long line of the Conferences of the Parties (COPs) of UNFCCC comparable to the Kyoto protocol and, for example in the context of EU strongly related with the Energy Union priority, making energy more secure, affordable and sustainable for all (European Commission 2017). Even more remarkable is the new EU energy legislative framework – the Clean Energy for All Europeans package – which has been concluded on all aspects, and the updated 8 legislative acts will be formally adopted in the first part of 2019 (European Commission 2019). The main aim of the package is to facilitate the clean energy transition of the 21st century, make a significant step towards the creation of the Energy Union and deliver on the EU's Paris Agreement commitments.

Third, although the global climate change discourse includes clear social goals – at least when it comes to GHG-reduction – it also entails considerable ambiguity with regard to what technologies would fall under climate-related technologies and climate-crisis led innovation (see Figure 2). Specifically, we can encounter terms like "clean", "green" or even "eco" and "sustainable" technologies (e.g. UNCED 1992; OECD 1995; Kuehr 2007). Within the "climate crisis"led innovation debate these terms are sometimes used interchangeably (Kuehr 2007; Carrillo-Hermosilla et al. 2010; Schiederig et al. 2012), while they may actually signify very different technologies, in terms of their nature (high vs low tech), maturity level and investments required. This ambiguity of the global discourse, in turn, is likely to influence the implementation of energy technology policy at the national level.

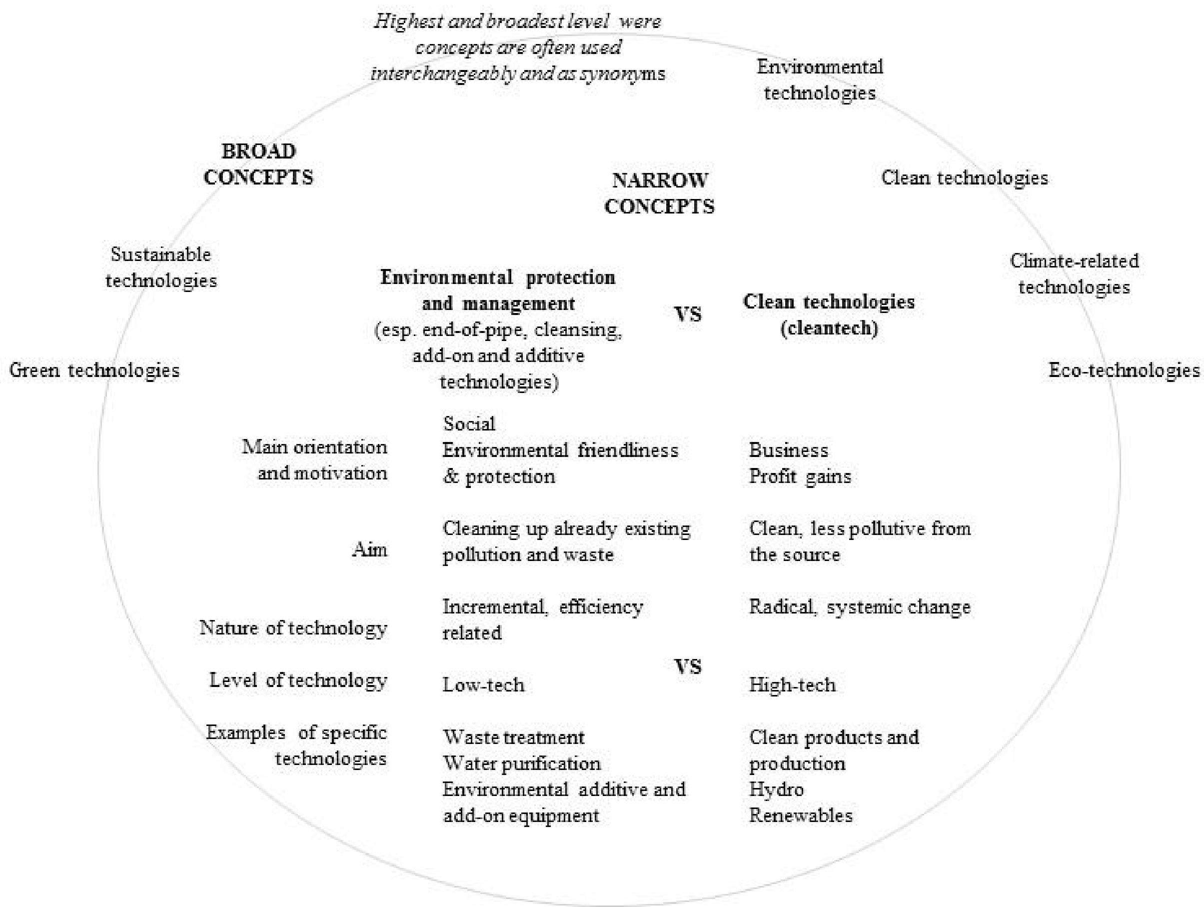


Figure 2: **Links between different concepts of environmental technologies, their level of technological intensiveness, radical and incremental innovation, etc**.

Fourth, the global climate change discourse entails competing sub-discourses: one narrative focuses on environmental problem-solving and another is more business-oriented (Caprotti 2012; Okereke et al. 2012; Kuehr 2007; O'Rourke 2009). These narratives, in turn, have different implications for what kind of innovations should be fostered. Following the environmental problem-solving narrative would mean that the focus should be on social goals and the development of *environmental protection and management technologies* ("environmental protection technologies" from now on) and more precisly *end-of-pipe* type (aimed at cleaning already existing pollution and waste), while the business profit-centered narrative would favor the focus on technologies that are already clean from their source – *clean technologies* or *cleantech* in short. Due to the ambiguity of terminology pertaining to the different technologies (as explained in the previous paragraph), these different narratives, with their different underlying logics, may not necessarily be explicitly acknowledged in national level policy-making, which may lead to ambiguity in what kind of innovations and research should, in fact, be fostered to combat climate change. However, these different approaches can lead to very different results of innovation, both in terms of cost efficiency and ethical concerns (e.g. equity across generations in terms of available energy resources).

In the existing studies, only limited attention has been paid to how the global climate change discourse would influence the implementation of science policy. Some find that the global climate change-led discourse has not changed the academic world formally to a large degree, maintaining that environmental innovation research is still in its infancy (Andersen 2008, 3), while others argue that the climate-crisis debate has increased the role of so-called sustainability science (Komiyama and Takeuchi 2006), which is more the case in the fields of *environmental protection technologies* rather than *cleantech.* In the following, we will discuss in more detail what the implications of the above-mentioned issues in the global climate change discourse are likely to be for scientific networks/ISL in the field of energy technologies.

2.2 Diversification effects and shifts in research strategies

The ambiguity of the broad terms like "climate-related", "sustainable", "green" or "environmental" technologies (which are used interchangeably as broad synonyms in this article) and not defining specific technologies under these loose areas in the global climate change discourse can lead to the same ambiguity in designing and implementing technology programs at the national level. Specifically, the ambiguity problem of "clean" vs "environmental protection and management" technologies in the global climate discourse (described above) can carry over to the policy field - as technology programs are also usually concentrating on broad areas like "climate-related" technologies. Such a broad approach, however, can become a challenge for the traditionally mission-oriented government policies like science policy (and science funding). The mission-oriented nature of policy means that it sets specific goals and outlines concrete activities to achieve these goals.

More specifically, we can make the following predictions about the effects of the global climate change discourse on the implementation of science policy in energy technologies. Due to the ambiguity in the global climate change discourse about what technologies should be fostered to combat climate change (UNCED 1992; OECD 1995; Kuehr 2007; Ekins 2010), most technological innovations are assumed to lead to higher efficiency and some environmental benefits. In practice this means that researchers usually define their own industry and technology categories to describe the "green" or "clean" sector. We can also observe that fields like ICT, chemistry, and material sciences have moved closer to environmental sustainability with the rise of green chemistry, green ICT, and green material technologies. Our first set of predictions is, hence, that the discursive ambiguity at the global level would lead to the *diversification of research agendas and ISL* at the national level. Due to the multi-disciplinary nature of the technologies under the "umbrella" of climate change, there is likely to be a diversification effect in the research areas of energy technology (Proposition 1.1). This means that a very wide range of research in terms of fields, but also levels (from basic to applied), can be undertaken under the broad area of climate change and environmental sustainability. The research topics can range from low-tech environmental protection technologies like end-of-pipe and additive technologies to totally pure high-tech clean technologies like hydro technologies. In addition to the diversification of research topics, we would also expect a diversification effect in the collaboration networks and ISL (Proposition 1.2). The diversification effect means that collaboration networks and ISL can have very diverse structures and working logics: basic vs applied, low vs high tech, short- vs long-term, close to the market vs far from the market. What structures and logics are used in specific ISLs (also what business model and direction of innovation is taken) depends on the research areas of ISL (social orientation vs business focus and incremental vs radical innovation direction taken) (see further explanations in sections 2.3 and 2.4).

Second, the global climate change discourse is likely to influence the priorities expressed in the national level science policy – i.e. the funding programs would specifically emphasize that funding is provided for research that helps to mitigate or combat climate change (Bailey et al. 2011; Bailey and Wilson 2009). In the implementation of science policy, in turn, this can lead to the adoption of different strategies by the research groups. On the one hand, we can expect that research groups genuinely change their research agenda and also form new research networks, according to the research funding priorities expressed in national policies, which emphasize the development of technologies that help to combat climate change (Proposition 2.1). On the other hand, we can expect that the existing research groups respond strategically to the funding incentives and try to show, rhetorically, that the research they are doing is connected to climate change (thus, for example, traditional energy research groups would adjust their activities, at least nominally, to show that they are doing research on environmental or clean technologies) (Proposition 2.2).

2.3 New business models and corporate influence: social vs business focus

It is important to differentiate the newest concept that has been used above – "*cleantech*" - from other environmental technologies (focused mainly on environmental protection and ethics) due to its business-model orientation (see Caprotti 2012). Its main idea is that the end result should be qualitatively "cleaner" and more resource efficient, which may not be the case of traditional ETs first popularized in the 1970s and 1980s (Schot 1992). Examples of traditional ETs include environmental protection technologies like end-of-pipe technologies (pollution treatment) (Yarime 2003) or environmental additive equipment[2], which may actually speed up resource depletion (Frondel et al. 2007).

The rapid emergence of the concept of *cleantech* in the US at the beginning of the 2000s can be linked to purposeful activities of a small range of institutional entrepreneurs within the global climate change discourse, promoting a "business model" that pulls together a range of technologies that have both economic and environmental value (Cleantech Group 2007; O'Rourke 2009; Cleantech.org 2015). Since this new sector is multi-disciplinary and relies strongly on networks and different interdependent institutions, it has significant implications for the implementation of science policy.

2 Under environmental additive equipment or environmental additive technology we mean add-on measures and solutions that do not reduce resource use and/or pollution at the source by using cleaner products and production methods (like cleantech does) but instead curbs pollution emissions by implementing add-on measures – this is what end-of-pipe technologies do (Frondel et al. 2007).

Consequently, if we look at the members of ISL and recall the difference in the global discourse about business-oriented cleantech vs socially motivated environmental protection, there may be very different firms taking up "greening" activities (e.g. cleantech vs environmental protection) responding to the climate change discourse, signaling their own interests to policy makers and bringing in specific goals, motivation and technical capabilities to ISL (Kemp and Foxon 2007). This leads us to our third set of propositions, which argue that the nature of ISL can vary considerably, depending on the motivation and nature of the collaborating company (i.e. whether it comes from environmentally motivated "traditional" environmental protection technology or the more recent, business-model-based *cleantech*).

Especially during the last decade, a firm-centric and market-driven approach to value capture has emerged in the global discourse, which is a highly profit-oriented approach ("do well by doing good", Richtel 2007). From the social perspective, it is not important which reasons are behind the adoption of clean technologies in response to climate change (whether they are purely environmental or more profit-oriented); thus, regularly the motivations of firms are not discussed in analyses of eco-innovations (Berkhout 2005). However, from the perspective of potential policy feedback and influence on science policy/direction of R&D (e.g. from the perspective of ISL, the incentives to invest, technologies and time-frames), the different motives (environmental protection vs business orientation) can play a considerable role. On the one hand, ISL with the *cleantech* sector can be expected to be *longer* and more durable due to the more complex, transformative investment into high-tech (Proposition 3.1). On the other hand, an opposite effect could be expected due to the strong *business nature* of *cleantech* ventures – meaning a push for ready-to-market collaboration with research units and, thus, short-term contracts between research units and industry (Proposition 3.2). When the ETs in question within an ISL are additive and efficiency-related (especially in the case of end-of-pipe technologies), collaborations close to the market can be expected because additive (also add-on) technologies are more incremental and do not need as much R&D and innovation as radical *cleantech* (Proposition 3.3) (links between incremental and radical innovation and ET-s are explained in the next section).

2.4 Direction of innovation: incremental vs radical change

The energy sector depends on complex and often very expensive technologies for which it is hard to make adoption decisions before acquiring the technology (Cowan and Daim 2011). It is not characterized by rapid technological change, but is among one of the lowest innovation-intensity sectors in the world (Jamasb and Pollitt 2011), where similar technologies have dominated the sector over a century. This makes the long-term direction of R&D (its transformative nature) more essential than the rate of innovativeness (market adoption, etc.) that is generally analyzed in connection to ETs. The problem with translating radical changes from basic science into workable solutions in a sector with many network barriers is substantial.[3] Yet, due to the "linear" and "value-neutral" technical approach of the global climate change discourse (Wesselink et al. 2013) and the multi-disciplinary nature of ETs, far more attention has been paid to the *rate* of innovation rather than the overall *direction* or the transformative[4] nature of innovation (Johnstone 2005, 21) in the global climate discourse.

3 The multitude of systemic problems of technology diffusion in the energy sector is well described in Negro et al. (2012).

4 Incremental innovation entails step-by-step additive improvements that do not distrupt the underlying system. Radical innovation disrupts the system and thus, in most cases gives it a new technological, organisational or other direction (Garcia and Calantone 2002). The rate of innovation does not refer to incremental or radical change but the level of activity taking place (Popp et al. 2010, 878); it often includes measures such as new products reaching the market, yearly patent volumes or market penetration rates. It would be, however, important to also look at how transformative the underlying technologies are: do they really switch the overall value chain to carbon neutrality or not, do they have the potential to distrupt the status quo (i.e. provide a new direction for the functioning of the energy system)?

However, a distinction between *incremental* and *radical* innovations should be made in assessing the change in the direction of overall innovation produced by the policy momentum related to the global climate discourse. It plays a significant role in discussing ETs in the energy sector, especially when technological solutions for the reduction of carbon emissions are considered. As such, environmental technologies can encompass both product innovations (Ekins 2010) and simply additive (end-of-pipe) and process-integrated technologies (Hemmelskamp 1997). In other words, the innovation can range from more radical cleantech, where new and cleaner or totally clean (from their source) technologies are introduced, to more incremental environmental protection and end-of-pipe technologies, which are add-on or additive technologies that clean up already existing waste and pollution (also called cleansing technologies), but they do not have to be "cleaner" in their essence. Whether science policy is focusing on cleantech or end-of-pipe technologies may have very different effects on the long-term direction of innovation. Thus, for example, end-of-pipe technologies in energy technologies such as the carbon capture and storage (CCS) may be reinforcing lock-into fossil fuels (Unruh and Carrillo-Hermosilla 2006; Markusson 2011). Also, if policy implementation focuses only on incremental innovation and low-ambition end-of-pipe and additive technologies there might be no chance for radically new energy technologies to emerge.

Coming to our last set of propositions, as innovation activities differ depending on the specific conditions of existing competition, market strategy and on the maturity of the technology involved, and most importantly, depending on the nature of technology researched – end-of-pipe technology focused on incremental and cleantech on more radical innovation (Kuehr 2007; Markusson 2011; Hellström 2007) – also different directions of innovation can be expected of ISLs in the *energy sector*. On the one hand, in the implementation of science policy in the field of energy technologies, in cleantech, totally new ISLs might emerge that have a radical direction of innovation (Proposition 4.1). On the other hand, ISLs in traditional cleansing, efficiency-related and additive end-of-pipe energy technologies are likely to have an incremental innovation direction (Proposition 4.2). Radical changes in innovation directions have a higher probability to produce new products and processes that are cleaner in their essence, while incremental changes in direction are likely to contribute to "sailing effects" of traditional energy technologies. The "sailing effect" creates a situation where the threat to the traditional technology of being displaced by new technology triggers investments in the old established technology, increasing its performance (De Liso and Filatrella 2008). This, in turn, can also lead to lock-in of technologies and non-optimal solutions for the energy sector.

The distinction between incremental innovation (end-of-pipe technology focus) and radical innovation (cleantech focus) under the broad range of ETs is important to understand because radical innovation – clean technologies – may require large up-front investments. As such, it should present more lucrative business opportunities, but it would also be much more capital intensive and there would be longer time frames connected to such investments, which can be far from commercialization. Hence, since it is radical in nature, many *cleantech* start-ups are university spin-offs (e.g. van Geenhuizen and Soetanto 2012). This, moreover, means that non-emitting technologies (being also a synonym of clean technologies) have far steeper learning curves (Junginger 2010), and support measures are needed to catch up with the profitability of current technologies (Azar and Sandén 2011).

3. Research methods

In order to examine the effects of the global climate change discourse on the implementation of science policy in the field of technology policy in Estonia - specifically on research topics, collaboration and networks, and ISL - we adopted the research strategy of a case study. Using a case-study approach to explore our research question is appropriate given that it allows us to explore a range of different factors at play in a holistic way and also to take into account the country context (del Río González 2009; Yin 2013). A variety of data sources also helps to describe economic and social relationships between firms and R&D units and the change in the direction of technologies that is central to our research interest. In line with the case-study approach, we used a variety of data sources in our analysis, including existing studies, secondary data, structured interviews, media articles, policy and project documents, and network analysis. Our analysis covers the time period from 1998 to 2012.[5] As more rigorous environmental goals strongly entered the Estonian energy sector with joining the EU in 2004 (Tõnurist 2015), the change in policy paradigm is best captured by the aforementioned timeframes. In addition, as Estonia achieved its renewable energy goal of 2020 (25% in gross final energy consumption) already in 2011 (Eurostat 2019) it created additional academic interest in how the dynamics in the ISL reflect the statistics. For the structured in-depth interviews, the 11 most salient research groups in energy technologies and their collaboration networks with companies in the ETs/clean technology sector in Estonia were chosen. 11 interviews with representatives from energy-technology research groups were conducted from April to May 2013; 4 interviews were carried out with the representatives of the R&D departments in the three main technology universities[6] in Estonia in October 2013; 20 interviews with Estonian cleantech companies were conducted in June and July 2011. The length of the interviews was 1-3 hours. The research groups were selected on the basis of one criterion: they all had received public funding at some point between 1998 and 2012. The interviews included questions about research areas and ISL (including other contacts with companies, such as internship programs, lectures, board membership etc.), the strength of ties, and changes in the strategic behavior and the content of research activities. The network analysis was carried out based on personal and project records of the largest technology-oriented universities in Estonia from 1998 to 2012. A network was created on the basis of all research collaboration: the nodes illustrate individual scientists and firms and the edges R&D projects and contracts between them (see the descriptive Figures A.1-A.5 in the Appendices). This makes the networks bipartite or two-mode as it is important to keep the data about researchers at the individual level, because changes in the composition of research groups are not uncommon. Networks were later weighted for the monetary value and length of contracts to control for the strength of ties. This consolidated the networks and diminished the significance of very small contracts, while the main structure and trends of the network remained. Since the strength of ties and informal communication are difficult to analyze through project data alone, we used the interview data to triangulate the information gathered

5 The empirical data for this analysis was collected under different research projects in 2011 and 2013: 1) the project of “Public funding of research activities in Estonia” under the national Research and Innovation Policy Monitoring Programme initiated by the Estonian Ministry of Education and Research between 2011 and 2015; 2) the Central Baltic INTERREG IV A project “Enabling a Global Vision for the Baltic Clean-tech industry” (Global Vision) from 2011 to 2013.

6 Our study covered the largest technology oriented universities in Estonia – TalTech, Tartu University (TU), the Estonian University of Life Sciences (EULS) – and a separate research institute (National Institute of Chemical Physics and Biophysics). TalTech is the main contributor of energy technologies in Estonia, while in other universities singular RE-centered research units have emerged during the 1990s.

from documents. In the interviews, we found that monetary value was not the best measure to describe collaboration strength as the former was more linked to the size of the private partner. Thus, we relied more on the self-reported information of scientists to determine the strength of relationships. In addition, document analysis was carried out to compose a profile for each research group. The documents included government funded research proposals, project reports, co-publication analysis and career data from the electronic database, the Estonian Science Information System (ESIS). These profiles were created to have a more in-depth view on the strategic activities of research groups and also to account for shifts over time, which is difficult to outline solely through network analysis.

4. The case of climate-change discourse and energy technologies in Estonia

4.1 The Estonian energy policy context

Estonia is the only country in the world where the principal source of electricity (up to 80%) is the burning of oil shale (kukersite) (see Table 1). The country has been the largest oil shale producer and consumer in the world since the 1960s, but it has come with a considerable environmental impact, which was the largest in the 1980s and has declined since (Raukas and Punning 2009; Mõtlep et al. 2010; Blinova et al. 2012). The energy sector is the main source of GHG emissions in Estonia (see Figure 3).

Table 1: **Energy balance sheet in Estonia** (TJ) (Statistics of Estonia, 15 May 2013)

	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Production of primary energy	132389	131999	140265	162400	154123	160563	155265	180852	175374	172995	205080	208863
... oil shale	108330	106183	111103	132096	124121	129423	125022	146747	142956	134455	161401	166731
... oil peat	3345	3427	6416	3531	2678	3550	4726	4405	2174	3492	3680	3308
... fire wood	20617	22279	22608	26592	27132	27170	25044	29119	29593	34060	38668	36154
... other fuels	76	82	112	113	84	150	150	176	82	169	237	178
... hydro and wind	21	28	26	68	108	270	323	405	569	819	1094	1433

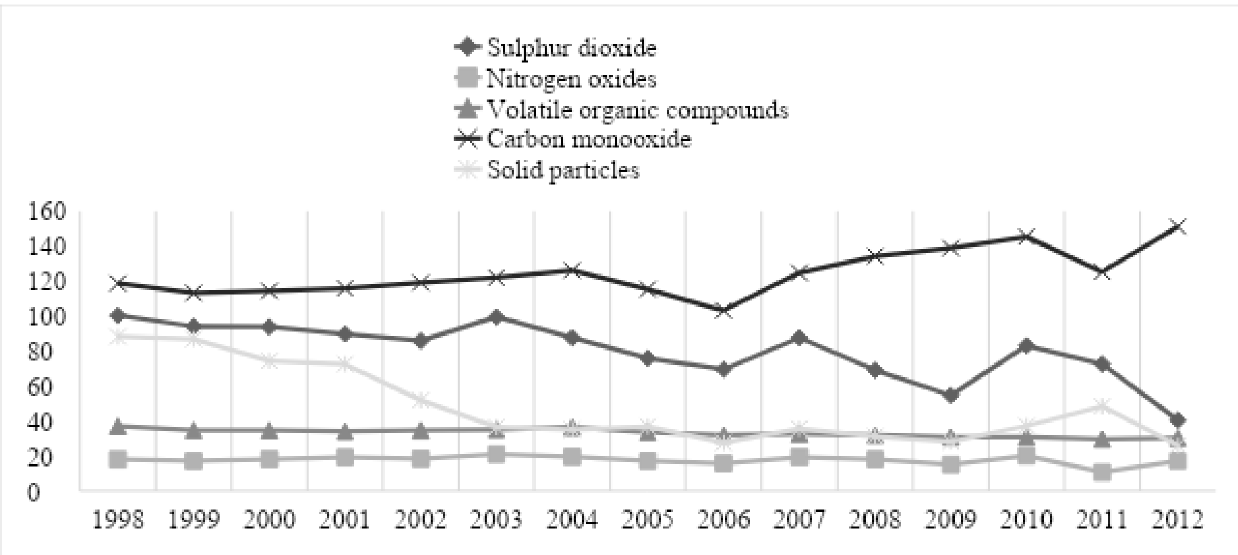


Figure 3: **Air pollution by pollutant from stationary sources** (tons) (Statistics Estonia, 9 March 2019)

On the whole, Estonia has been implementing environmental policies since the late 1980s. Environmental issues entered the policy debate first with the fight against the opening of new mineral mines for heavy industry (e.g. the so-called Phosphorite War, 1987-1988) through which calls for environmental sovereignty developed hand in hand with the general independence struggle of Estonia. This inspired the early adoption of the first environmental protection law in 1990, and environmental pollution levies were established; however, they were not substantial enough to change the energy sector, which was under the control of the government (Valdmaa 2014). In 1995, the country ratified the United Nations Framework Convention on Climate Change (UNFCCC), but legally the year 1998 marked the change in climate policy. As part of the accession process to the EU, the Integrated Pollution and Prevention Control Directive (IPPC) and the EU's clean air policy (Directive 96/62/EEC) were adopted in Estonia in 1998, but the former only took effect later. Also the Kyoto protocol was signed by the country in 1998 and ratified in 2002. However, as indicated in the energy-related policy documents in 1992-2002, the government was mainly concerned with energy security and pricing – rendering environmental concerns secondary. Only with joining the EU in 2004 did the climate change based policy discussion become more prevalent: in April 2004, the National Program of GHG Emission Reduction for 2003-2012 was adopted, and it was the first document that also included the Kyoto target as its main objective. Estonia imposed a CO_2 tax in 2005 and in 2006, and the new Environmental Charges Act was enforced. Feed-in tariffs for RE were introduced based on electricity prices, although at first with low coefficients in the closed market situation (Streimikiene et al. 2007). Several other fiscal measures (including excise duties on fossil fuels) and subsidies were also created by the government after 2004 (an overview of which is available in the Estonia's Fifth National Communication to the UN (Estonian Environmental Research Centre 2009)). While measures aiming at the renewable energy sources diversified, the largest investments in the energy sector remained in oil shale as concerns over energy security prevailed. The government has subsidized heavily the oil shale based electricity production to reduce GHGs: second-generation units with higher efficiency rates have been built, and fluidized bed combustion (CFB) technology (which this expected to minimize environmental pollution) has been implemented (e.g. Dementjeva and Siirde 2010).

The possible future decline in the proportion of oil shale in electricity production could be facilitated by the rise in the use of wind energy, natural gas and biomass (Roos et al. 2012). This would have to be supported by scientific research and public research funding. During the time under review basic research funding measures have been available for the sector; however, there has been a gap in support measures for proof of concept and prototyping in the Estonian R&D system. Thus, the measures have been fragmented in their mission orientation towards climate change, giving more support to high technologies rather than applied innovations needed in the local context.

4.2 Change in ISL in energy technologies

There are approximately 15 considerable research groups in energy technology in Estonia. Our network analysis showed a heavy concentration of influential research groups in energy technologies in TalTech (see Figure A.1 in the Appendix describing the whole network by Eigenvector centrality). The network analysis also showed that the competence regarding the *traditional* energy technologies (oil shale combustion and chemistry) lie with TalTech.

The traditional energy research groups are located in three departments (Faculty of Power Engineering, Chemical and Materials Technology and Mechanical Engineering). In other universities, including Tartu University and EULS, energy technology research groups were not found to be closely linked to the field of traditional energy studies – these research groups were based on strong basic research in *other* fields (material sciences and life sciences) that were found to have *applications* in the field of energy (in Tartu, photovoltaic elements and in EULS, biomass).

Coming to energy technology ISL, there is one general remark that should be made before we examine the propositions. When we look at how the cooperation with the industry and enterprises has generally changed, then based on the network analysis and the content analysis of project reports, we can see that for most traditional energy technology groups their ties with the industry weakened from the 1990s onward, and especially during the period of interest (1998-2012). On the one hand, this is because before the 1990s, the ISL were linked with Soviet Union public enterprises. On the other hand, the research groups needed time to adapt to the new collaboration logics of ETs (described in sections 2.2-2.4), which will be explained below. In the following, we will examine whether the propositions developed in section 2 hold true in the case of Estonia.

First, we can observe a clear diversification effect in terms of research areas (confirming Proposition 1.1) as the central research groups in energy technologies (also in oil shale technologies) have started to include climate change, RE and ETs-related projects in their agenda after the beginning of 2000s, when the multi-disciplinary ETs (discussed in section 2.2) emerged in the climate change discourse (see Figures A.1 and A.2 in the Appendices, which visualize how research groups start to concentrate and traditional fossil fuel based research groups start to integrate RE and ET narratives in their research areas). This is more apparent among research groups that have been more actively involved in industry contracts. This development also reflects the popularization of ETs in the business sector since the beginning of the 2000s, with the increasing initiative of solving environmental problems (but with profit orientation) coming from the companies. Also, the collaboration networks have diversified (confirming Proposition 1.2): for example, the central research groups (also in oil shale technologies) have started to involve more smaller, private companies with short-term contracts, more applied and close-to-the-market projects, in addition to long-term, far-from-the-market projects with a single state-owned energy company, which had previously been the trend.

Though the analysis of research project applications and reports showed clear diversification effects in research topics and networks, the conducted interviews also indicated considerable inertia in research fields and groups (disconfirming Proposition 2.1): even though ETs-related activities received more attention and new funding opportunites compared with the agendas before the 2000s, *no* totally new research groups in areas of "pure" clean technologies as a reaction to funding based on "climate change" emerged. In addition, while many research groups in more traditional energy technology fields perceived a bias in funding towards RE, the interviewed research group leaders emphasized that ISL collaboration projects were led by companies and their restriction-based demand for ETs (see Propositions 3.2 and 3.3), but no significant RE R&D goals or preferences were put in place by funding programs. Instead, the interviews showed that research groups, especially in traditional energy fields (oil shale technology), who incorporated ETs goals to their agenda, did not change their core research areas (confirming Proposition 2.2). This can be expected from research groups dealing with technologies at the end of their life cycles, and it contributes to paradoxes that stand in the way of fundamental changes in the energy sector.

The analysis of the research project applications and reports from 1998 to 2012 and the dynamics of the topics and group members indicates that during the early part of the covered period, some current core research groups grew out of basic research in material technology, with possible applications in the photovoltaic industry. These groups were the main parties that could be seen as working towards clean energy before the 2000s. However, most RE-related research before 2004 was fundamental in nature, and in terms of ISL, the collaboration between industry and universities was clearly one-dimensional – undertaken with one or few familiar partners and including only traditional, efficiency and some environmental projects. After 2004, however, it changed and became multi-dimensional (see the descriptive Figures A.4-A.5 in the Appendices). As the goals of the Estonian environmental policy and also the national level discourse changed between 1998 and 2004, research projects also started to include more environmental concerns about emission reduction and pollution avoidance. According to project reports and interviews there was new interest from the industry (also oil shale based production facilities) to start collaborations with research groups solely based on ETs (in accordance with Proposition 2.2), confirming that traditional energy research groups changed their activities to include ETs (if not fully clean technologies) to respond to funding incentives.

Another interesting finding is that when we look at the proportions of R&D funding between clean/environmental technologies and traditional fossil fuel focused energy technologies, then the top few research groups now receive proportionally more financing then the rest. This may be largely coming from the bias in the Estonian research funding system, which prefers basic science to applied science and gives preference to high technology. Consequently, research groups that focus on applied research have become weaker and rely on short-term private funding, especially in the energy sector. By concentrating on broad areas and defining no clear specific R&D goals in energy technologies in Estonia, the normative weight was put on the value-neutral scientific endeavor, very much in accordance with the main trends in the global climate change discourse discussed in section 2.

The third set of propositions developed in section 2 argued that the qualitative nature of the emerged networks in scientific collaboration differs depending on the motivations and nature of the collaborating company, which in turn is influenced by the technology at hand (cleantech vs environmental protection and especially end-of-pipe technologies).

According to the interviewed scientists, only the dominant companies in the market (in the Estonian case the state-owned enterprise Eesti Energia and the Viru Chemistry Group) or university spin-off companies were interested in the application of basic science also in the traditional, fossil fuel based fields. However, substantial R&D collaboration in the core areas of the energy companies in general was very rare and occurred mainly in the field of *cleantech* (for example in photovoltaic batteries). To some degree this supports Proposition 3.1 in terms of longer and durable transformative investment in *cleantech* (as explained before, there were only few radical cleantech ISL with some state-owned enterprises and university spin-offs, who had better access to resources and were closer to the universities), but as we had only few cases to describe such long-term relationships, it is not possible to fully confirm Proposition 3.1.

However, as understood by the interviewed scientists, and also found by Valdmaa and Kalvet (2011), most of the companies that have contracts with Estonian research groups want simple environmental impact assessments or solutions that need to be worked out fast and can be easily integrated into the previous technology. The interviewed companies made maximally six months to year-long contracts and wanted immediate results and market applicability or introduction to the production process (supporting Propositions 3.2 and 3.3). Similarly to Proposition 3.1, due to only few cleantech cases, and as the projects were implemented in a very short time (maximum 5-6 years in RE), no clear assessment of Proposition 3.2 can thus be made: the business-oriented *cleantech* approach with strong push for ready-to-market corporations with research units and short-term contracts was not clearly observed. Still, when ISL based on additive projects were concerned, the collaboration took a very short-term, close-to-the-market format, clearly confirming Proposition 3.3.

The interviews additionally showed that while industry giants want to keep themselves informed about the work of Estonian scientists in their related energy area, the companies are not willing to pay for basic research that cannot be implemented in the short term (see additional information about the Estonian energy sector in Tõnurist 2015). Research groups that have been working with and for the industry usually have continued this trend. Only in cases when they have not managed to get public funding have some groups started more active cooperation with the industry. However, this was only the case if they previously also had some contacts with the industry.

Furthermore, in non-traditional energy technology fields, the application of technology remains far from the market due to the dominance of smaller firms in the field and the scale on which the sector requires solutions, not to mention systemic barriers incumbents have put in place. Cleantech firms lack the necessary investment needed to test the R&D on scale. Consequently, local research in areas outside of traditional energy production may remain on a theoretical level, or wider international networks have to be used to popularize or sell the results of this more theoretical research. As such, there were some university spin-offs that contributed to radical cleantech ISL (e.g. photovoltaic technologies and ultracapacitors energy-storing technologies), but they were still an exception to the rule (thus providing only partial support to Proposition 4.1). There was more clear evidence in support of Proposition 4.2: when ISL based on additive projects were concerned, the collaboration took a very short-term, close-to-the-market format, in turn contributing to the "sailing effects" of traditional energy technologies, potentially leading to lock-in of non-optimal solutions for the energy sector, making it more difficult to radically change the energy sector and reduce GHG in a considerable amount. Clearly more cooperation is related to incremental innovation and rudimentary analyses/testing done for the companies. In general, one can expect a direct influence from the structure of the energy sector of the country to the direction of research. Research groups that are mainly dealing with basic research and with more radical innovations are less attractive to the industry because of the long development period, capital intensiveness and high uncertainty (also found by Valdmaa and Kalvet 2011). The summary of whether the theoretical propositions held in the Estonian case are presented in Table 2 below.

Table 2: **Summary of main findings**

Propositions	**Findings**
Prop.1 Diversification effects	
Prop. 1.1 Diversification of research areas	Corroborated
Prop. 1.2 Diversification of ISL	Corroborated
Prop. 2 Shifts in research strategies	
Prop. 2.1 Emergence of new research groups	Not corroborated*
Prop. 2.2 Opportunistic adjustment of research agendas by research groups in traditional energy technology	Corroborated
Prop. 3 Qualitative difference in subsequent collaborative ties between science and industry: social vs business orientation	
Prop. 3.1 *Cleantech* ISL is longer and more durable	Not corroborated*
Prop. 3.2 *Cleantech ISL has a strong business nature and short-term contracts*	Not corroborated*
Prop. 3.3 Incremental ETs projects (efficiency and additive nature) imply projects close to the market	Corroborated
Prop. 4 Direction of innovation: incremental vs radical	
Prop. 4.1 New cleantech ISL has radical innovation direction	Not corroborated*
Prop. 4.2 Efficiency related and additive environmental protection technologies have an incremental innovation direction contributing to “sailing effects” and lock-in of technologies	Corroborated

* More research needed.

5. Discussion and conclusions

The global climate change discourse has influenced policy-making at all levels of governance. However, the impact of the global discourse on national policies, real practices, and the interactions of involved actors has been under-researched. Our paper brings these issues to the forefront and maintains that policy changes based on a broad and high-level global discourse can have unintended and multi-directional effects in the implementation of science policy and, more specifically, in the domain of energy technology. This argument is elaborated through an overview of the main issues within the global climate change discourse and how these issues are likely to influence science and industry collaboration and also the direction of innovation. We argue that while the broad-based policy discourses and policy changes may be easily transferrable from country to country and from sector to sector (meaning the spread of ETs to different countries and to various technology sectors), they can also accommodate diverging, almost contradictory approaches (e.g. *cleatech* vs *environmental protection and especially end-of-pipe technologies*) due to feedback from different interested parties (researchers, companies, investors, etc.).

In the theoretical framework we explained how the global discourse relates to policy practices and how issues with the discource can influence the implementation of science policy in the domain of energy technologies. Based on a review of the global climate change policy discourse we developed four main groups of propositions connected to the change in the research activities in both firms and research institutes, and we examined the applicability of these propositions in the case of Estonia. The propositions and their applicability have been outlined in Table 2. First, we show that the global climate change discourse has led to the *diversification effect of research agendas and ISL* (corroborating Propositions 1.1 and 1.2). Second, in terms of *shifts in research strategies in response to the global climate change discourse,* we found no evidence of the emergence of totally new groups in cleantech (not confirming Proposition 2.1), while the traditional energy technology research groups have adjusted their research, at least formally, and included the ETs agenda in their research (confirming Proposition 2.2). Third, we expected that the form, quality and motivation of collaboration networks depends on the technology researched: i.e. whether it addresses the socially-oriented environmental protection or the business-focused cleantech part of the global climate change discourse. Based on the Estonian case, however, Proposition 3.1, arguing that cleantech ISL is longer and more durable, and Proposition 3.2, stating that cleantech ISL has a strong business nature and short-term contracts, were not corroborated because of the small number of examples under study. But Proposition 3.3, claiming that environmental protection ISL (efficiency-oriented and additive in nature), have collaborations close to the market was clearly corroborated. Forth, with regard to the *possible direction of innovation – incremental vs radical* – our expectation that cleantech has a radical innovation direction (Proposition 4.1) could not be corroborated due to the limited number of cases under study. However, Proposition 4.2, which emphasized that efficiency-related and additive environmental protection technologies have an incremental innovation direction, contributing to sailing effects and lock-in of technologies and non-optimal solutions for the Estonian local energy sector, was corraborated.

Thus, our analysis shows that when examining the effects of the climate change discourse, it is important to zoom in on the policy implementation level, as well. Even though the national level policy makers have adopted the global climate change discourse in terms of the goal of long-term low-carbon energy production, when we look at the actual implementation of science policy, R&D has not moved hand in hand with the discursive goal. Although the broad global climate discourse has influenced funding decisions in science policy, the impact has not been as profound as expected: value-neutral scientific policy has strengthened some more basic science research groups but also left some more applied groups dependent on industry investment. If more applied research teams are solely dependent on industry contracts, they can function with outside-industrial funding only for a short period, and this is not sustainable regarding the development of the research field. Doing more applied, short-term research hollows out the basic research competences of the group, and in the long run this also reduces the research groups' value to the industry. Successful applied research has to be grounded in profound basic research capabilities – a core competence of universities.

As shown in the case of Estonia, with no clear mission-oriented energy technology financing, the applied research groups and ISL are left to compete within the general science funding system that favors basic research. While this funding system has given precedence to new *cleantech* fields (e.g. photovoltaic and storage technologies), this is not the result of active state policy in the field of energy, and it is very uncertain whether the local GHG-emission output will diminish (the technology can of course be applied elsewhere with global net benefit, but also domestic investment to carbon reduction is essential for reducing GHG). In many cases the willingness of companies to implement R&D becomes the central concern of the actual goals of climate change related policy goals. If companies are not motivated to do R&D and tend to focus more on incremental than radical innovation, there are also limited effects to GHG emission reduction. Here the nature, magnitude, quality and direction of ISL become very important. As investment decisions are not managed centrally, incentives to individual electricity utilities in the market for advancing technologies become more important. Some of these projects may not attract investment from the private sector, and the companies and their collaboration networks with research groups – as shown above – may enforce different dynamics altogether (short-termism, incrementalism, etc.). This indicates that differentiation in terms of policy is needed to capture both short-term solutions (as outphasing of traditional energy technology takes time), but also greater use of renewable, "clean" energy, which is needed for long-term energy security. In order to make a change from oil shale based electricity production towards clean energy, more long-term commitments from policy and funding programs are necessary. Here the correct policy mix becomes the key in addressing many of the problems not only in R&D but also within the industry that take into account the actual effects of the influence of discource in implementation. Hence, the highly scientific/high-technology-oriented and linear understanding has not produced the desired effect in Estonia. Due to the lack of clear and specific R&D funding goals, a radical decrease in GHG emissions has not ensued.

To conclude, our analysis shows the importance of accounting for long-term and multi-directional effects of discursive policy changes and the need for an adequate policy mix depending on the technologies in question and the structure of the economy. The economic structure and the composition, nature and capabilities of the companies in the local industry, as policy feedback mechanisms, may play a significant role in what discourse translates into during implementation.

In future research, more studies are needed to describe the business-model aspect of *cleantech* and its influence on the direction of innovation. Also, it would be useful to undertake comparative studies in order to explore how the global climate change discourse has influenced policy implementation in different countries and to analyze whether the local interpretations of global discourses are different, whether the effects on energy technology ISL and other issues follow similar patterns in different science system, and whether there are also differences in effects in the various sub-fields of energy technologies. Besides, since major restructurings have taken place in all Estonian universities from 2013 onwards, it would also be highly interesting to analyze how these changes have influenced research topics and ISL.

Declaration of interest

The authors report no conflicts of interest. The authors alone are responsible for the content and writing of this article

Acknowledgements

The authors recognize the funding from the Estonian Ministry of Education and Research under the project "Strategy for Science and Innovation Policy" and grants ETF9395, IUT19-13, and PUT1142.

References

Andersen, Maj Munch. 2008. "Eco-Innovation: Towards a Taxonomy and a Theory." In DRUID Conference *Entrepreneurship and Innovation*.

Azar, Christian and Björn A. Sandén. 2011. "The Elusive Quest for Technology-Neutral Policies." *Environmental Innovation and Societal Transitions* 1(1), 135-139.

Bailey, Ian, Andy Gouldson and Peter Newell. 2011. "Ecological Modernisation and the Governance of Carbon: A Critical Analysis." *Antipode* 43(3), 682-703.

Bailey, Ian and Geoff A. Wilson. 2009. "Theorising Transitional Pathways in Response to Climate Change: Technocentrism, Ecocentrism, and the Carbon Economy." *Environment and Planning* 41(10), 2324-2341.

Beck, Silke. 2011. "Moving beyond the Linear Model of Expertise? IPCC and the Test of Adaptation." *Regional Environmental Change* 11(2), 297-306.

Berkhout, Frans. 2005. "Rationales for Adaptation in EU Climate Change Policies." *Climate Policy* 5(3), 377-391.

Blinova, Irina, Liidia Bityukova, Kaja Kasemets, Angela Ivask, Aleksandr Käkinen, Imbi Kurvet, … Anne Kahru. 2012. "Environmental Hazard of Oil Shale Combustion Fly Ash." *Journal of Hazardous Materials* 229, 192-200.

Burstein, Paul. 1991. "Policy Domains: Organization, Culture, and Policy Outcomes." *Annual Review of Sociology* 17(1), 327-350.

Caprotti, Federico. 2012. "The Cultural Economy of Clean-Tech: Environmental Discourse and the Emergence of a New Technology Sector." *Transactions of the Institute of British Geographers* 37(3), 370-385.

Carrillo-Hermosilla, Javier, Pablo del Río and Totti Könnölä. 2010. "Diversity of Eco-Innovations: Reflections from Selected Case Studies." *Journal of Cleaner Production* 18(10), 1073-1083.

Cleantech Group. 2007. "Clean-tech defined." Available at http://www.clean-tech.com/what-is-clean-tech (last accessed 10 June 2011).

Cleantech.org. 2015. "What is Cleantech." Available at http://www.cleantech.org/what-is-cleantech/ (last accessed 23 September 2018).

Cowan, Kelly R. and Tugrul U. Daim. 2011. "Review of Technology Acquisition and Adoption Research in the Energy Sector." *Technology in Society* 33(3), 183-199.

Dayton, B.W. 2000. "Policy Frames, Policy Making and the Global Climate Change Discourse." In Helen Addams and John Proops (eds). *Social Discourse and Environmental Policy: An Application of Q Methodology.* Cheltenham: Edward Elgar Publishing, 1, 71-99.

De Liso, Nicola and Giovanni Filatrella. 2008. "On Technology Competition: A Formal Analysis of the 'Sailing-Ship Effect'." *Economics of Innovation and New Technology* 17(6), 593-610.

del Río González, Pablo. 2009. "The Empirical Analysis of the Determinants for Environmental Technological Change: A Research Agenda." *Ecological Economics* 68(3), 861-878.

Dementjeva, Nadežda and Andres Siirde. 2010. "Analysis of Current Estonian Energy Situation and Adaptability of LEAP Model for Estonian Energy Sector." *Energetika* 56(1), 75-84.

Demeritt, David. 2006. "Science Studies, Climate Change and the Prospects for Constructivist Critique." *Economy and Society* 35(3), 453-479.

den Besten, Jan Willem, Bas Arts and Patrick Verkooijen. 2014. "The Evolution of REDD+: An Analysis of Discursive-Institutional Dynamics." *Environmental Science & Policy* 35, 40-48.

Ekins, Paul. 2010. "Eco-Innovation for Environmental Sustainability: Concepts, Progress and Policies." *International Economics & Economic Policy* 7, 267-290.

Estonian Environmental Research Centre. 2009. Estonia's Fifth National Communication to the UN under the UNFCCC. Available at https://unfccc.int/resource/docs/natc/est_nc5.pdf (last accessed 9 March 2019)

European Commission. 2017. Third Report on the State of the Energy Union. Brussels: European Commission. COM(2017) 688 final.

European Commission. 2019. "Clean Energy for all Europeans." Available at https://ec.europa.eu/energy/en/topics/energy-strategy-and-energy-union/clean-energy-all-europeans (last accessed 9 March 2019).

Eurostat. 2019. "Share of Renewable Energy in Gross Final Energy Consumption." Available at https://ec.europa.eu/eurostat/tgm/table.do?tab=table&init=1&plugin=1&language=en&pcode=t2020_31 (last accessed 8 March 2019).

Frondel, Manuel, Jens Horbach and Klaus Rennings. 2007. "End-of-Pipe or Cleaner Production? An Empirical Comparison of Environmental Innovation Decisions across OECD Countries." *Business Strategy and the Environment* 16(8), 571-584.

Gallagher, Kelly Sims, Arnulf Grübler, Laura Kuhl, Gregory Nemet and Charlie Wilson. 2012. "The Energy Technology Innovation System." *Annual Review of Environment and Resources* 37, 137-162.

Garcia, Rosanna and Roger Calantone. 2002. "A Critical Look at Technological Innovation Typology and Innovativeness Terminology: A Literature Review." *Journal of Product Innovation Management* 19(2), 110-132.

Hellström, Tomas. 2007. "Dimensions of Environmentally Sustainable Innovation: The Structure of Eco-Innovation Concepts." *Sustainable Development* 15, 148-159.

Hemmelskamp, Jens. 1997. "Environmental Policy Instruments and their Effects on Innovation." *European Planning Studies* 5(2), 177-194.

Hope, Mat and Ringa Raudla. 2012. "Discursive Institutionalism and Policy Stasis in Simple and Compound Polities: The Cases of Estonian Fiscal Policy and United States Climate Change Policy." *Policy Studies* 33(5), 399-418.

Jamasb, Toorai and Michael G. Pollitt. 2011. "Electricity Sector Liberalisation and Innovation: An Analysis of the UK's Patenting Activities." *Research Policy* 40(2), 309-324.

Johnson, Mark W. and Josh Suskewicz. 2009. "How to Jump-Start the Clean Tech Economy." *Harvard Business Review* 87(11), 52-60.

Johnstone, Nick. 2005. "The Innovation Effects of Environmental Policy Instruments." In Jens Horbach (eds). *Indicator Systems for Sustainable Innovation*. New York: Physica-Verlag, 21-41.

Junginger, Martin. 2010. *Technological Learning in the Energy Sector*: *Lessons for Policy, Industry and Science*. Cheltenham: Edward Elgar Publishing.

Karakosta, Charikleia, Haris Doukas and John Psarras. 2010. "Technology Transfer through Climate Change: Setting a Sustainable Energy Pattern." *Renewable and Sustainable Energy Reviews* 14(6), 1546-1557.

Kemp, René and Tim Foxon. 2007. "Typology of Eco-Innovation." Project Paper: Measuring Eco-Innovation.

Komiyama, Hiroshi and Kazuhiko Takeuchi. 2006. "Sustainability Science: Building a New Discipline." *Sustainable Science* 1, 1-6.

Kuehr, Ruediger. 2007. "Environmental Technologies: From Misleading Interpretations to an Operational Categorisation & Definition." *Journal of Cleaner Production* 15(13), 1316-1320.

Leipold, Sina and Georg Winkel. 2017. "Discursive Agency: (Re-)Conceptualizing Actors and Practices in the Analysis of Discursive Policymaking." *Policy Studies Journal* 45(3), 510-534.

Lorenzoni, Irene and David Benson. 2014. "Radical Institutional Change in Environmental Governance: Explaining the Origins of the UK Climate Change Act 2008 through Discursive and Streams Perspectives." *Global Environmental Change* 29, 10-21.

Markusson, Nils. 2011. "Unpacking the Black Box of Cleaner Technology." *Journal of Cleaner Production* 19(4), 29-302.

Miller, Clark A. 2004. "Climate Science and the Making of a Global Political Order". In Sheila Jasanoff (eds). *States of Knowledge*: *The Co-Production of Science and the Social Order*. London: Routledge, 46-66.

Mõtlep, Riho, Terje Sild, Erik Puura and Kalle Kirsimäe. 2010. "Composition, Diagenetic Transformation and Alkalinity Potential of Oil Shale Ash Sediments." *Journal of Hazardous Materials*, 184(1), 567-573.

Negro, S.O., Floortje Alkemade and Marko P. Hekkert. 2012. "Why does renewable energy diffuse so slowly? A review of innovation System Problems." *Renewable and Sustainable Energy Reviews* 16(6), 3836-3846.

O'Rourke, Anastasia R. 2009. *The Emergence of Clean-Tech.* PhD dissertation. New Haven: Yale University.

OECD. 1995. *Promoting Cleaner Production in Developing Countries*: *The Role of Development Co-Operation.* Paris: OECD Publishing.

Okereke, Chukwumerije, Bettina Wittneben and Frances Bowen. 2012. "Climate Change: Challenging Business, Transforming Politics." *Business & Society* 51(1), 7-30.

Pielke, Roger. 2010. "Tales from the Climate-Change Crossroads." *Nature* 464(7287), 352-353.

Pielke, Roger. 2012. "Basic Research as a Political Symbol." *Minerva* 50(3), 339-361.

Popp, David, Richard G. Newell and Adam B. Jaffe. 2010. "Energy, the Environment, and Technological Change." *Handbook of the Economics of Innovation* 2, 873-937.

Raukas, Anto and Jaan-Mati Punning. 2009. "Environmental Problems in the Estonian Oil Shale Industry." *Energy & Environmental Science* 2(7), 723-728.

Reusswig, Fritz. 2010. "The New Climate Change Discourse: A Challenge for Environmental Sociology." In Matthias Gross and Harald Heinrichs (eds.). *Environmental Sociology*. Dordrecht: Springer, 39-57.

Richtel, Matt. 2007. "Start-up Fervor Shifts to Energy in Silicon Valley." *The New York Times* March 14, 2007.

Roos, Inge, Sulev Soosaar, Anna Volkova and Dalia Streimikene. 2012. "Greenhouse Gas Emission Reduction Perspectives in the Baltic States in Frames of EU Energy and Climate Policy." *Renewable and Sustainable Energy Reviews* 16(4), 2133-2146.

Schiederig, Tim, Frank Tietze and Cornelius Herstatt. 2012. "Green Innovation in Technology and Innovation Management: An Exploratory Literature Review." *R&D Management* 42(2), 180-192.

Schmidt, Tobias S., Malte Schneider, Karoline S. Rogge, Martin J.A. Schuetz and Volker H. Hoffmann. 2012. "The Effects of Climate Policy on the Rate and Direction of Innovation: A Survey of the EU ETS and the Electricity Sector." *Environmental Innovation and Societal Transitions* 2, 23-48.

Schmidt, Vivien A. 2008. "Discursive Institutionalism: The Explanatory Power of Ideas and Discourse." *Annual Review of Political Science* 11, 303-326.

Schmidt, Vivien A. 2010. "Taking Ideas and Discourse Seriously: Explaining Change through Discursive Institutionalism as the Fourth 'new Institutionalism'." *European Political Science Review* 2(1), 1-25.

Schot, Johan W. 1992. "Constructive Technology Assessment and Technology Dynamics: The Case of Clean Technologies." *Science, Technology, & Human Values* 17(1), 36-56.

Shackley, Simon and Brian Wynne. 1995. "Global Climate Change: The Mutual Construction of an Emergent Science-Policy Domain." *Science and Public Policy* 22(4), 218-230.

Streimikiene, D., R. Ciegis and D. Grundey. 2007. "Energy Indicators for Sustainable Development in Baltic States." *Renewable and Sustainable Energy Reviews* 11(5), 877-893.

Taylor, Margaret. 2008. "Beyond Technology-Push and Demand-Pull: Lessons from California's Solar Policy." *Energy Economics* 30, 2829-2854.

Tõnurist, Piret. 2015. "The Role of State Owned Enterprises in Innovation Policy Management: A New Approach to Innovation Policy Analysis." *Technovation* 38, 1-14.

UNCED. 1992. *Agenda 21, Rio Declaration No, Rest Principles*. New York: United Nations.

UNFCCC. 2015. Adoption of the Paris Agreement. FCCC/CP/2015/L.9/Rev.1. Paris: UNFCCC.

Unruh, Gregory C. and Javier Carrillo-Hermosilla. 2006. "Globalizing Carbon Lock-in." *Energy Policy* 34(10), 1185-1197.

Valdmaa, Kaija. 2014. "Development of the Environmental Taxes and Charges System in Estonia: International Convergence Mechanisms and Local Factors." *Policy Studies* 35(4), 339-356.

Valdmaa, Kaija and Tarmo Kalvet. 2011. "Emergence of the Clean Technologies Sector in Estonia." In Kaija Valdmaa and Tarmo Kalvet (eds). *Emergence of the Clean Technologies Sector in the Baltic Sea Region*. Tallinn: Tallinn University of Technology, 158-244.

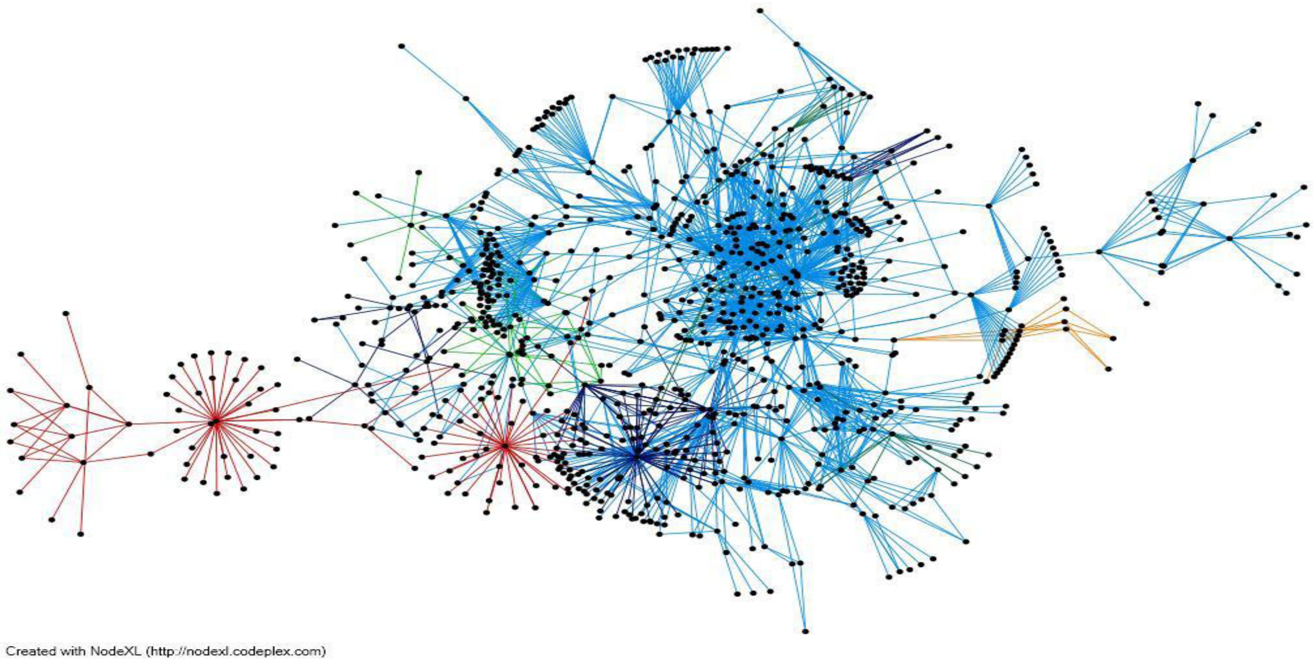
van Geenhuizen, Marina and Danny P. Soetanto. 2012. "Open Innovation among University Spin-off Firms: What is in it for them, and what can Cities do?" *Innovation*: *The European Journal of Social Science Research* 25(2), 191-207.

Wesselink, Anna, Karen S. Buchanan, P. Yola Georgiadou and Esther Turnhout. 2013. "Technical Knowledge, Discursive Spaces and Politics at the Science: Policy Interface." *Environmental Science & Policy* 30, 1-9.

Wittneben, Bettina B.F., Chukwumerije Okereke, Subhabrata Bobby Banerjee and David L. Levy. 2012. "Climate Change and the Emergence of New Organizational Landscapes." *Organization Studies* 33(11), 1431-1450.

Yarime, Masaru. 2003. *From End-of-Pipe to Clean Technology. Effects of Environmental Regulation on Technological Change in the Chlor-Alkali Industry in Japan and Western Europe.* PhD dissertation. Maastricht: Maastricht University.

Yin, Robert K. 2003. *Case Study Research*: *Design and Methods*. 3rd edition. Thousand Oaks: Sage Publications.



Appendix Figure A.1: Energy technology network in Estonia 1998-2012 (based on project information)*

Source: Authors, NodeXL.*Within the descriptive figure the edge color denotes the university (blue and green TalTech (an institute joined the university later); dark purple Tartu University; maroon EULS and brown National Institute of Chemical Physics and Biophysics). The size of the vertices is dependent on Eigenfactor centrality, thus making it dependent on the influence of a vertex within the network (see Yu et al. 1965). The figure has been created with the Harel-Koren Fast Multiscale algorithm.

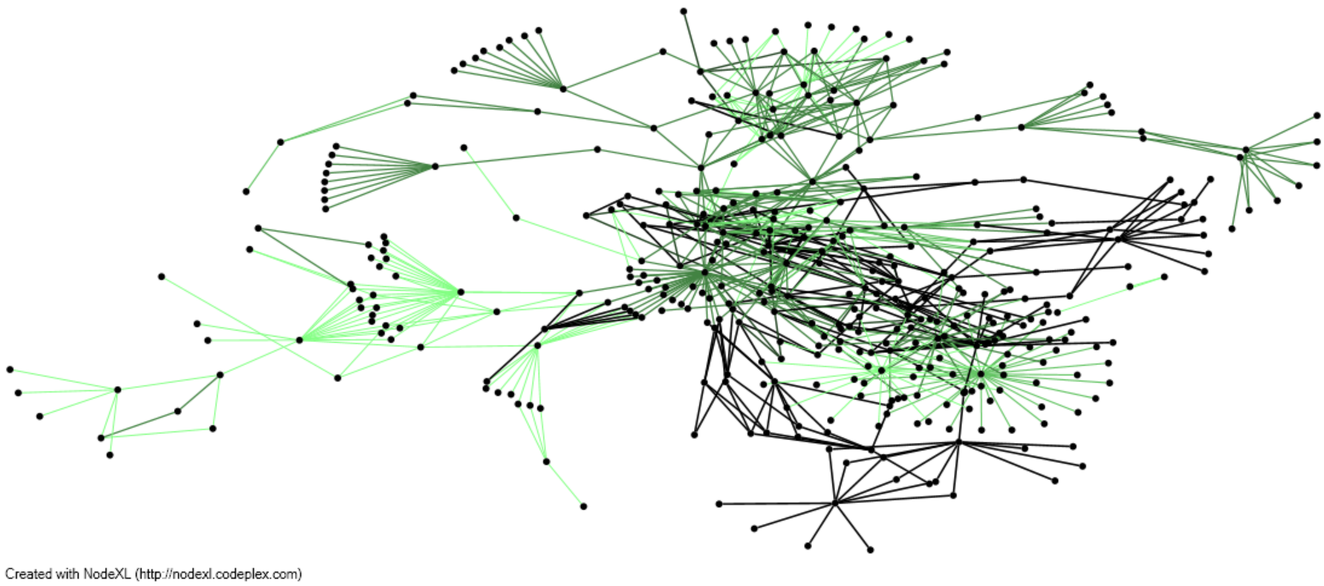


Figure A.2: Energy technology network by type of technology 1997-2004 (public and private funding).

**From here onward the color coding is a spectrum from black to light green that are collated in the following manner: “black” denotes traditional energy technologies (1), sailing technologies (extending traditional projects) (2), efficiency projects (3), environment-centered projects (4) and RE projects “light green” (5). All the figures has been created with the Harel-Koren Fast Multiscale algorithm.

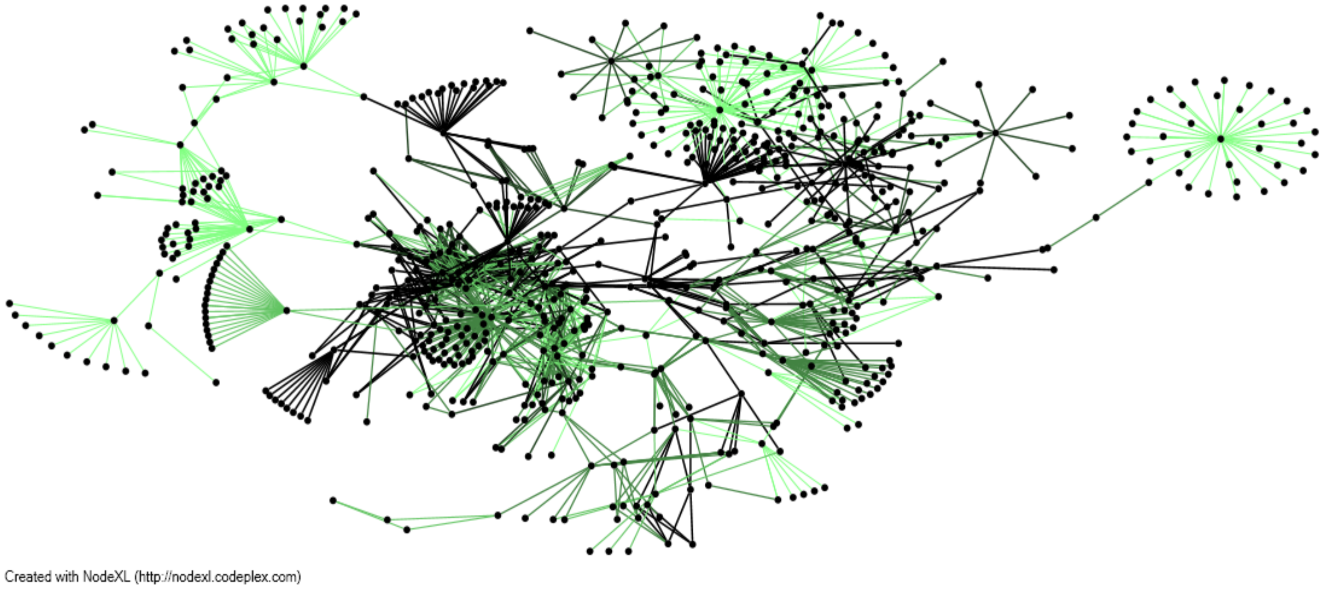


Figure A.3: Energy technology network by type of technology 2005-2012 (public and private funding)

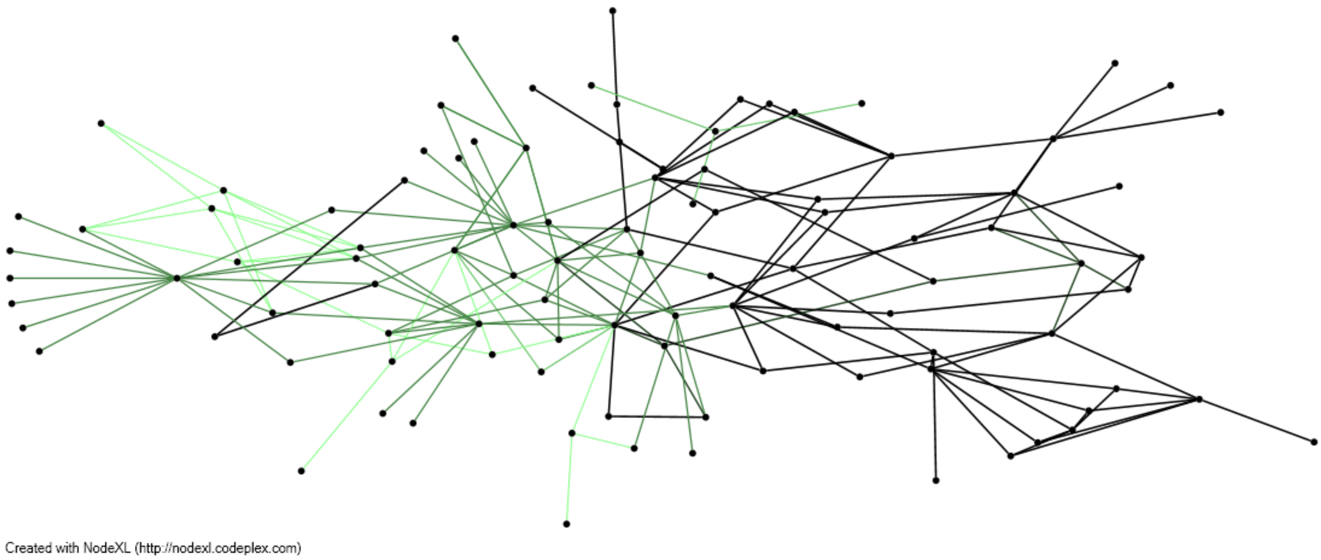


Figure A.4: Energy technology network (contracts with private companies) by type of technology 1998-2004

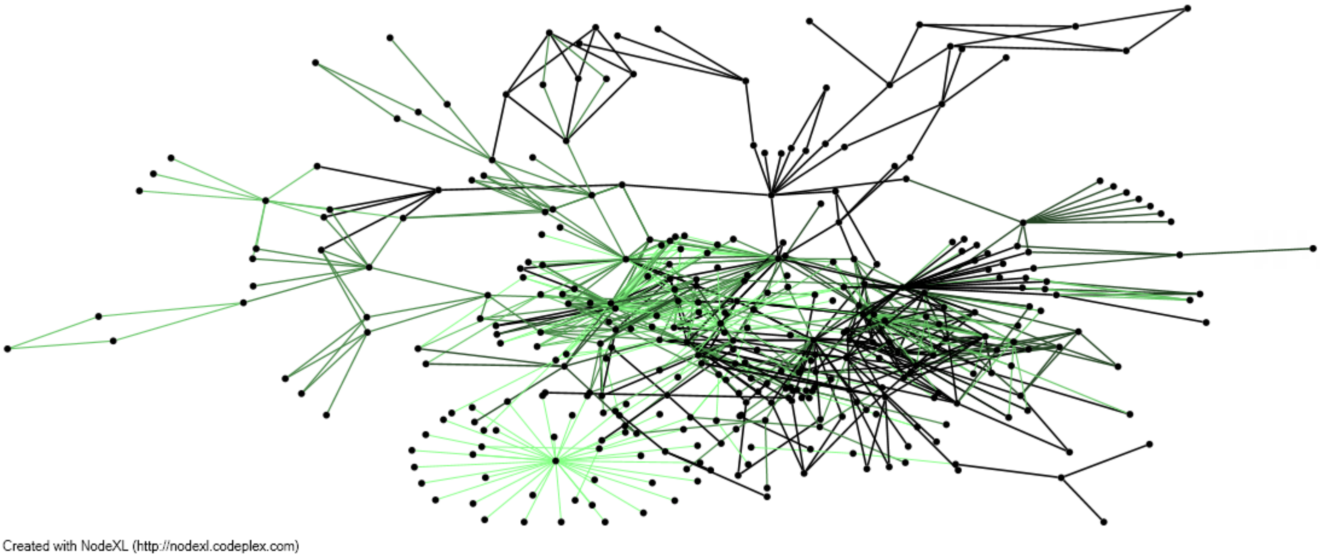


Figure A.5: Energy technology network (contracts with private companies) by type of technology 2005-2012

Piret Tõnurist is the roject manager and leads the work on systems thinking, innovation measurement and anticipatory innovation governance at the Observatory of Public Sector Innovation (OPSI). She coordinates OPSI’s work on transformative innovations, innovation theory development and works directly with OECD member countries on their complex problems. Piret holds a research fellowship at the Ragnar Nurkse Department of Innovation and Governance, TalTech and she conducts research on a variety of topics such as innovation labs, co-production, digitalisation, machine-to-machine coordination and innovation policy management. She has previously advised the Parliament of Estonia and worked as a performance auditor for the State Audit Office in the field of innovation and entrepreneurial policy. She is an active proponent of purpose-driven change in the public sector and has collaborated with different governments, state-owned enterprises and innovation labs across the world. Piret holds a PhD and MA from TalTech in technology governance and MSc from KU Leuven in policy evaluation.

Kaija Valdmaa is the project manager of the Estfeed energy data exchange platform in Elering AS, the Estonian electricity and gas transmission system operator, and a doctoral candidate at Ragnar Nurkse Department of Innovation and Governance, Tallinn University of Technology, Estonia. Her main research interests are in the area of sustainability transitions and system governance with the focus on public policy instruments, science, technology and innovation policy and multi-level governance in small countries looking at clean, green and energy technologies, industry and science collaboration, research funding, taxation and economic steering policies. Previously she has worked with greentech start-ups and growth companies on business and export development issues while managing the greentech sectors in Tallinn Science Park Tehnopol and PAKRi Science and Industrial Park. She is also Co-Founder and Advisor in Cleantech ForEST a cleantech network organisation that accelerates Estonian green innovation and develops a supporting ecosystem. E-mail address: kaija.valdmaa@gmail.com (K. Valdmaa).

Ringa Raudla is Professor of Fiscal Governance, Ragnar Nurkse Department of Innovation and Governance, Tallinn University of Technology, Estonia. Her main research interests are fiscal policy, public budgeting, public administration reform, and institutional economics. Her recent publications include articles in Electoral Studies, Public Choice, Public Administration Review, Governance, Public Administration, Policy Studies Journal, the American Review of Public Administration, Journal of Public Policy, Public Money & Management, International Review of Administrative Sciences, and Journal of Comparative Policy Analysis. She has also worked as a consultant for various governmental organizations, including the Ministry of Finance and the National Audit Office in Estonia, and international organizations, including the World Bank. Ringa Raudla received the Estonian national research award in social sciences in 2018. She is an editorial board member of seven different journals in the fields of public administration, public management, governance and economics.