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Energy Technology Innovation Systems in a Transnational Perspective: Small States, Public Ownership and Diverging Policy Rationales

PIRET TÕNURIST

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TALLINN UNIVERSITY OF TECHNOLOGY
Faculty of Social Sciences
Ragnar Nurkse School of Innovation and Governance

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Supervisor: Professor Dr. Rainer Kattel
Tallinn University of Technology, Estonia

Opponents: Professor Dr. Per Högselius
KTH Royal Institute of Technology, Sweden

Professor Dr. Lars Coenen
Lund University, Sweden

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Declaration:

Hereby I declare that this doctoral thesis, my original investigation and achievement, submitted for the doctoral degree at Tallinn University of Technology has not been submitted for any academic degree.

/Piret Tõnurist/

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V Tõnurist, P. and K. Valdmaa. 2013. “Impact of Climate Change Policy Discourse on Energy Technology Research: the Case of Estonian Science and Industry Linkages.” Revised version of the paper presented at the 6^{th} Annual Conference of the Academy of Innovation and Entrepreneurship “Innovation and Entrepreneurship for Inclusive and Sustainable Development.” Oxford, UK, 29-30 August 2013. (5.2)

INTRODUCTION

Focus and aim of the thesis

Climate change has become a formidable challenge for energy systems. To answer this challenge governments are increasingly engaged in the formation and direction of energy innovation systems towards sustainable energy transitions. This, however, is marked with high levels of uncertainty, complexity, interdependence and inertia. First, because of the technological challenges, scarce resources and high sunk costs of investments; second, because of the high level of lobbying by advocacy coalitions; and lastly, because the international regulatory systems governing climate change are continuously changing. Governments are called to foresee changes on all these multiple levels and signal within energy innovation systems the direction of investment, while using various policy instruments. This puts high demands on the capacities, organization and integrity of public policy bodies, which are not always met. Thus, there are significant limits to the capacity to project and govern transitions-in-the-making. Furthermore, policy rationales connected to the energy sector are not always clear-cut and one-dimensional. First, from the global climate crisis discourse an agenda has emerged calling for expedient change and decarbonization ("*technological fix*") of the energy sector; second there are economic interests connected to the development of energy technologies (the so called "*green growth*" agenda); third, there has been a long-term debate surrounding energy security ("*electric vulnerability*") in Europe and in the world, with calls for more investment in and internationalization of energy systems in order not to be dependent on single energy supply routes nor energy sources. Consequently, policy makers have to maneuver very complex minefields of interests when dealing with the energy sector.

As such, this thesis looks into the interaction of public policy and underlying politics with technological change in the energy sector. What we suppose is that policy change occurs in co-evolution with both technology and institutions (Borrás and Edler 2015). Because the challenges outlined above are intrinsically connected to technological development, it would be easy to fall into the trap of linear policy-making, concentrating on the supply of new energy technologies. This, however, is shown not to work in the energy sector (e.g., Suurs and Hekkert 2009). Hence, more complex, systemic solutions are called for. This thesis tackles these problems from different angles developing an analytical approach that is technology specific, accounts for institutional differences, transnational linkages and the geography of change (namely the role of state size in technological change processes) in energy technology innovation systems. For this the author puts together recent developments in innovation systems (IS) literature – specifically technological innovation systems (TIS) –, arguments from economic geography (the relative size and proximity of states) and research done under global value chain (GVC) stream. TIS, among other innovation system perspectives, was chosen due to its focus on technology-specific effects, but also because the unit of analysis in most empirical accounts is on the network level, which will help to integrate the GVC perspective into the analytical framework.

The main arguments of the thesis are developed in four original articles. In all articles the author of the thesis has been the sole or lead author (**I, II, III, IV**). In the first article, the author of the thesis pursues the issue of state size in times of globalization and argues that objective measures of space have become obsolete during times of increasing interconnectedness and economic liberalization (**I**). The article reaches the conclusion that "*size*" is dependent on three factors: economic structure, development level and core-periphery relationships. In terms of technological development this can be connected to the concept of "*proximity*" (Boschma 2005) that has recently been applied to innovation systems research (Lundquist and Trippl 2013). The thesis outlines the problems and possibilities for small states in the context of increased internationalization of technology (**I**, 14-15). Furthermore, the article introduces the importance of global production networks (GPN) as important parts of dispersed knowledge production and the influence of multinational companies (MNC) on the economic power of small states. Thus, the article builds the backbone for the reasoning to look at states' innovative capabilities in a transnational perspective.

In the second single-authored article (**II**), the author looks at the role of state-owned enterprises in energy innovations systems in a small state context. The complex nature of governing energy innovation systems and the conflicting rationales influencing these systems are outlined through the example of Eesti Energia, a state-owned energy company in Estonia primarily engaged in non-renewables. The article shows how the innovation policy agenda can compound with the environmental and energy security agenda and even fiscal policy interests in the context of state-owned enterprises. Innovation systems in the energy system are, thus, confronted with immense policy legacies; even more so as most energy sectors have been and are still characterized by public ownership. Nonetheless, in the liberalized market economy even state-owned enterprises (SOEs) move in GVCs and this, as was shown in the case of Eesti Energia, can be a way for companies to deliberately decrease the control of national governments (**II**, 10). The case study, in the context of the current thesis, shows the importance of both accounting for national institutional contexts and also transnational value chains in describing energy technology development.

Two articles in the main body of the thesis were co-authored: one with Dr. Erkki Karo on the role of SOEs in the oil and gas sector (**III**) and the other with colleagues from Belgium and the Netherlands, who helped collect the data to analyze the effect of market liberalization reforms on incumbent electricity producers in Belgium and the Netherlands (**IV**). The former outlines the role of state-owned enterprises globally in the energy sector and describes their potential as innovation policy instruments in varied policy contexts (**III**). Furthermore, different policy rationales influencing SOEs in the energy sector (and beyond) and the importance of different institutional environments for energy technology innovation systems are outlined. Moreover, the article makes a case for the influence of diverging political interests on SOEs' innovation activities in the energy sector through case studies of different government controlled oil companies in the world. The latter co-authored article (**IV**) outlines the possible impact of applying traditional, market-based policies in the energy sector and not discriminating between technologies. Thus, the article shows through the cases of the Belgian and the Dutch energy sectors the need for technology-specific approaches and, thus, the potential role of technology innovation systems analysis.

The Appendix of the thesis contains a paper co-authored with Kaija Valdmaa on the effect of global climate change discourse – the so-called sustainability agenda – on domestic energy-R&D networks (**V**). This article strengthens the claims made in article **IV** showing that supporting innovation indiscriminately is not enough to induce change in energy technology innovation systems. The paper outlines the dangers of linear, technology-fix-based innovation policy discourse through the example of science and industry linkages within the energy sectors. The article shows that if more precise, technology-specific approaches to innovation policy are not taken, it can stall sustainability transitions in the energy sector.

Put together, the five original works that the thesis is composed of outline the need for a technology-specific energy innovation systems analysis that accounts for both space – national and transnational effects – and various policy agendas in the complex policy legacies within the energy sectors. Consequently, in the following introduction of this thesis the author tries to go beyond the elements of energy innovation systems (networks, hierarchies, markets described in the articles) and outline a more comprehensive picture of energy technology innovation systems that accounts not only for technological momentum, but also for space-specific tendencies and power relations (exemplified by small states' challenges in internationalized technology development processes). There is a lot of room in innovation systems literature to conceptually identify the role of transnational linkages, learning processes, global value chains and relationships with the wider international context. Innovation systems literature, while seemingly all-encompassing, seems to neglect many of the former dimensions. As such, one of the main critiques of the innovation systems approach is the static, mechanical and descriptive focus of analysis and the disproportionate focus on science and technology (S&T) rather than the loci of innovation (Dodgson et al. 2011, 1146). Thus, for example, innovation systems analyses tend to marginalize the market (inter- and intra-firm relations) and focus more on the non-market institutional dimension of innovation (Bleda and Del Rio 2013). As policies and funding of research and development (R&D) are increasingly moving to supra-national levels (see Tõnurist and Kattel 2015; **I**), also innovation systems should be analyzed on supranational levels. The TIS approach adds to the debate by stressing the need to combine factors that are intrinsic to technologies with contextual elements to create the conditions for technological development and its adoption (Bento and Fontes 2015). Integrating the global value chain approach with the technology innovation systems helps to more specifically analyze backward and forward linkages between actors (also on the firm level) in GVCs and understand how these affect learning and innovation.

The following research questions are addressed in the thesis:

(1) What are the main policy rationales governing the energy sector and how do these affect innovation and technological development in energy innovation systems?
(2) Which components of technology innovation systems should be analyzed to respond to the challenges that the energy sector is currently facing? What are the conceptual weaknesses in theory that should be addressed to reach a more realistic depiction of innovation processes in multiscalar energy innovation systems?
(3) What roles do geography and state size play in transnational energy innovation systems? How can transnational linkages in energy innovation systems be studied? What could be the potential role of small states in transnational energy innovation systems?
(4) What is the potential role of state-owned enterprises in transnational energy innovation systems?

The introductory section of the thesis is developed as follows. First a short methodological overview of the thesis is provided. This is followed by the delineation of challenges in technology innovation systems in the context of the energy sector. We approach the subject through the lens of sustainability transitions in the energy sector and discuss the conflicting policy rationales governing energy innovation systems (covered also in articles **II**; **III**; **IV** and **V**). Specifically the technology innovation systems approach is used (which is also the one applied most frequently in the context of energy technologies) to introduce a technology-based dynamic into a multiscalar, transnational energy innovation systems approach. The benefits and weaknesses of the TIS approach for such a purpose are outlined. Specifically, the effect of geography is separately brought out, and a new focus on global value chains in evaluating innovation systems is proposed. This discussion ends with outlining the role and difficulties of small states in transnational energy innovation systems. This is especially important due to the sheer size of the global sustainability challenge the world is facing: with the global nature of the problem, large-scale, international technological development projects and the influence of emerging economies on energy demand, the role of small states in energy innovation systems seems to be almost insignificant. However, Mowery et al. (2010) argue that what is needed for a sustainability transition in the energy sector is not a new "*Manhattan project*", but rather more learning and experimentation with different technologies. Small states with less complex structures may be apt spaces for entrepreneurial action that spurs on learning, technological diffusion and leap-frogging (Mazzucato and Perez 2015). In a separate section, where the author discusses the contributions of the thesis to the aforementioned debate, the missing role of state-owned enterprises in the energy sector is also discussed in the context of transnational TISs. The last section proposes new avenues for research.

METHODOLOGY

Methodologically this thesis is cross-disciplinary including approaches from political science, management studies, governance studies, evolutionary and institutional economics, and innovation studies. As it is a combination of independently written articles, the methods applied are divided between different sections of the thesis.

The *theoretical analysis* of the thesis in its underlying assumptions draws heavily upon evolutionary economic theory (Nelson and Winter 1982), institutional economics (Powell and DiMaggio 2012) and recent developments in economic geography applied to innovation systems analysis (e.g., Lundquist and Trippl 2013). At the same time, traditional management theories were systematically reviewed in several of the articles (e.g., **II**; **III**) to illustrate some of the gaps in conventional theoretical perspectives. All articles in the thesis also follow a public policy narrative and, specifically, search for the role of the state in technological development.

In more theory-heavy contributions – for example when defining the concept of the "*size*" of states (**I**) –, the thesis relies on cumulative theoretical review (using both theoretical and empirical studies as input). When identifying the main policy rationales of state-owned enterprises (**III**) and the characteristics of the global climate change discourse (**V**), systematic theoretical reviews were carried out with combined citation searches and the snowball method.

In the *empirical analysis* we combined different methodologies for analyzing the case studies (**II**; **III**; **IV**; **V**). In most cases data was triangulated from different sources to increase the validity of the studies. In general, several data sources were found to minimize the risk from single data sources. In the case study of Eesti Energia (**II**) a combination of in-depth, semi-structured interviews and document analysis was applied. Looking at the developments of the oil sector (**III**), three different cases (Statoil, Norway; Petrobras, Brazil; and PDVSA, Venezuela) were selected based on a pre-analysis of different state-owned enterprises in the oil sector and the connected national policy context. Cases were selected due to their illustrative properties (as "*crucial cases*" for the phenomenon under study (Eckstein 1992) and a comparative case-study methodology was applied (Yin 2003). Similarly the analysis of the effects of energy market liberalization on innovation and the role of market structures in the cases of Belgium and the Netherlands (**IV**) adopts a comparative research design. The aforementioned case studies do not aspire to be representative for a larger population – they are used for "*theory building*" purposes only (Amaratunga and Baldry 2001). As such, through the cases, contextual factors surrounding the unit of analysis are identified. In the paper analyzing the effects of the climate discourse on scientific networks (**V**), first, a basic discourse analysis was carried out to identify the broad narrative changes in the Estonian policy context, and second, an integrated approach applying both quantitative (network analysis) and qualitative methods (documentation analysis, semi-structured interviews etc.) was applied to research the change in practice.

Together, the mixed methodological approach can be seen as a way to overcome the tragedy of "*wicked*" or even "*super wicked*" problems in innovation policy-making in the energy sector. Levin et al. (2012) define the aforementioned in the context of climate change by four key features: (1) time is running out; (2) central authority, which is needed to address the problems, is weak or non-existent; (3) those who cause the problem seek to provide the solutions; and as a result, (4) policy responses discount the future irrationally, even if faced with catastrophic future impacts. When these features are combined – as is the case in the field of sustainability transitions in the energy sector and especially the climate crisis – traditional methodological approaches are not equipped to identify potential solutions (ibid.). We will show below that this is especially the case in innovation policy design. When investigating energy innovation systems, the goal is to concentrate on not only simple, static effects, but (positive and negative) feedback loops in the system dependent on complex policy legacies within the energy sector (Jordan and Matt 2014). This requires system thinking and reflexive learning – iterative and recursive approaches – not only from the policies involved, but also in methods applied to the study of energy innovation systems. Rather than "*single shot analysis*", social sciences in this context should identify a "*connection of chains of contingencies that could shape the future*" (Bernstein et al. 2000, 53). This is also the baseline for the following discussion on energy innovation systems and sustainability transitions and the development of the new analytical approach to study multiscalar, transnational energy technology innovation systems.

Traditional policy context in energy innovation systems

"*Policy debates often come to resemble a babel of tongues, in which participants talk past rather than to one another*." (Bobrow and Dryzek 1987, 4)

Usually policy instruments – e.g., tradable emissions permits, CO_2 taxes, green certificates – regulating the energy sector operate under market failure principles and do not distinguish between different technologies. For example, the main policy vehicle in the EU – the Emissions Trading Scheme – focuses on "*getting the prices right*", which has proven to be unsuccessful in the face of the sustainability challenge (Fagerberg et al. 2015).[1] Energy markets in general usually fail to internalize the environmental costs of energy supply (Jacobsson and Bergek 2011, 41). Furthermore, most of these instruments do not take into account the varying concentration and the structure of energy markets (see **IV**) in planning policy instruments.

For example, in most EU countries electricity industry ownership is still public or mostly public (Bacchiocchi et al. 2015, 75).[2] Thus, public investment in the energy sector has an important pull effect on R&D and innovation (**II**; **III**) as most technological development happens in the associated industries in the value chain that supply the technology to the energy sector (Gallagher et al. 2012). Thus, ownership structures in the energy sector can also affect technological development (see discussion in **IV**). For example, state-owned enterprises tend to have more long-term, large-scale funding for technologies with high fixed costs,

[1] Uniformity of regulation in the energy sector has shown to produce asymmetric effects also outside the realm of technological development. For example, Bacchiocchi et al. (2015) examined the impact of standard regulatory reforms on household prices of electricity across the EU countries and found opposite effects for the EU15 and the new member states. Furthermore, they show that electricity prices were significantly higher in new member states with privatized energy sectors.

[2] While the EU's energy market reform has been regularly described by three pillars – unbundling, liberalization of markets and privatization (**IV**) –, the European Commission has been fairly neutral about calls for energy sector privatization (Bacchiocchi et al. 2015, 72). Nevertheless, many EU member states have privatized their energy sectors, while government ownership with sound public sector management *per se* is not an enemy of market liberalization nor innovation (Del Bo 2013; Sterlacchini 2012). Nevertheless, in the liberalized market conditions market incumbents tend to support incremental technologies (**IV**). Thus, liberalization coupled with privatization usually coincides with a decrease in R&D investments (ibid.), although, some small recovery in investment levels has been recently noted (Jamasb and Pollitt 2015).

such as nuclear technology, hydroelectricity and deep-water drilling projects (**II**; **III**). Private companies tend to invest in smaller-scale technologies, and the expectation that private capital would support large-scale investments into renewable or low-emission technologies on their own has not been confirmed (see e.g., Florio 2013; **IV**).

In general, Jacobsson and Bergek (2011) argue that under market conditions the main consideration of developing specific technologies is their marginal cost (most cost-efficient technologies), and this is not enough to spur on sustainable transitions in the energy sector (see also Azar and Sandén 2011; **IV**). Different technologies do not have the same life-cycle patterns (e.g., photovoltaic (PV) technology is characterized by learning-by-doing and wind-power systems by more complex sub-systems and component designs, see Huenteler et al. 2014) – as renewable energy technologies are in various stages of development, their cost dynamics differ. Going from the formative to the growth phase in the technological life-cycle (TLC) usually means "*the valley of death*" for many technologies (Murphy and Edwards 2003; see also example in **II**). This happens when initial public sector investments in R&D diminish and private investment horizons are relatively short compared to the overall need for energy transitions (Bergek et al. 2013). During upscaling, technologies usually move from experimentation with small unit-scale technologies to scaling up at the industry level and to global diffusion (Wilson 2009). Going from one phase to another can take considerable time (e.g., Wilson 2012). This means that also policies supporting energy technologies have to be distinctive to different TLCs (e.g., Foxon and Pearson 2008). Hence, technology-specific policy instruments rather than one-size-fits-all solutions may yield a better return in the energy sector.

Linear, technology-neutral policies tend not to take the diverging cost dynamics, risks, value chains and bottlenecks and endogenous learning processes into account and fail to stimulate investments (e.g., see Suurs and Hekkert 2009 in the context of second-generation biofuels in the Netherlands; also discussion in **V**). Most innovation policies put the emphasis on economic growth – general ability to create value added through new innovations sometimes in specific industrial sectors – rather than fundamental transformative changes (Alkemade et al. 2011; **V**). Thus, the innovation policy rationale and the sustainability transformation rationale are only aligned when they contribute to both economic growth and sustainable development at the same time (Alkemade et al. 2009). In transition policies the orientation is towards more specific problem areas and challenges[3] – climate change, secure energy supply etc. – rather than general R&D supply-oriented problem designs usually employed by standard innovation policies or

[3] In the context of transition policies, Weber and Rohracher (2012, 1040-1041) describe these as "*issue-centred policies*" or "*issue centred policy areas*," but in the context of climate change they are often referred to as "*grand challenges*" (see e.g., the recent debate leading to the Paris climate conference; EPRS 2015).

even innovation systems analysis. Hence, the legitimacy of policy intervention in transition policies is generally different from the traditional neoclassical policy debates. Consequently, transition policies and the employed policy instruments (experiments, visioning and scenario studies) are usually set apart from traditional (regulatory, tax-based, financial support) policy measures and planning (Meadowcroft 2009). Therefore, actual policy formation in energy innovation systems, as described above, still tends to be driven by the traditional market failure rationale (e.g., Dodgson et al. 2011; **II**; **IV**).

Most sustainability transition analyses do not, however, take the political circumstances – which make the adoption of policies probable – into account (Meadowcroft 2011, 73). Hence, economic growth oriented innovation policies can strengthen the existing lock-in in energy innovation systems (Geels and Schot 2007; **V**). While transition policies may search for ways to phase out old industries with new production systems, innovation policies may focus on sustaining the old systems (Alkemade et al. 2011; **II**; **III**; **V**). Furthermore, sustainability goals may not always bring economic profit – despite the prevalent green-growth rhetoric and the much-cited Porter hypothesis (Porter 1991; Porter and van der Linde 1995) – and thus, their source of legitimacy and policy rationale conflicts with the one of innovation policy.

Recently many authors have argued that innovation policies should be aligned with energy technology development objectives and the overall energy policy (Chiavari and Tam 2011; Grubler et al. 2012). This also entails the integration of demand-side policies to get out of the "*stop-start*" development process of many energy technologies (Grubler et al. 2012). However, the sustainability rationale specific understanding of super wicked problems is not applied in theory or in practice in the context of innovation policies. Nevertheless, EU innovation policies have recently started to cite "*societal challenges*" (see, e.g., European Commission 2014), but simply layering policies with different goals can cause serious misalignment (see Kern and Howlett 2009).

In the next sections we look into different approaches to studying innovation and sustainability transitions in more detail, before specifically concentrating on the possible extension of the technology innovation systems approach to studying space-specific energy technology innovation systems.

SUSTAINABILITY CHALLENGES AND INNOVATION IN THE ENERGY SECTOR: DIVERGING AGENDAS

> "*Evolutionary innovation policy is not about keeping markets close to a perfectly competitive state so that resources are optimally allocated but about keeping them open to experimental conditions and to the structural changes entailed by novelty creation.*" (Bleda and Del Rio 2013, 1050)

The European Union (EU) has set a target to reduce carbon emissions by 80-95% below 1990 levels by 2050 (European Commission 2011). This is a very ambitious goal, especially as in 2010 fossil fuels accounted for 80% of global primary energy supplies, while renewables (including hydropower) made up only 13% (IEA 2012). Not only is this a question of energy supply, but also global demand for energy is expected to increase at a faster pace than the switch to renewable energy sources, making the global carbon output rise (IEA 2014). At the same time, global electricity demand growth is not uniform, and low growth rates of electricity demand in developed countries have been associated with utilities giving up their long-term investment projects (Jamasb and Pollitt 2008; Salies 2010). Thus, sustainability transition within the energy sector is truly a global challenge, and changes in singular localities may not produce the effects the climate crisis challenge requires (**V**). Furthermore, transitions-in-the-making can be rather uneventful and, thus, difficult to grasp for both policy makers and private companies concentrating on immediate returns (Hughes et al. 2013).

Nevertheless, decarbonization is not the only agenda pressuring energy sector innovation systems – there are also enduring challenges of energy security (Skea et al. 2011) and the potential for green growth, as mentioned before, following the Porter hypothesis (Porter 1991; Porter and van der Linde 1995). This, however, has also been associated with free market environmentalism (Cotugno and Seltzer 2011) and business-oriented goals (**V**). Furthermore, the energy security/vulnerability agenda may conflict with the economic agenda: for example, while much celebrated smart grids may create possibilities for saving on the demand side and facilitate better real-time control over transnational energy flows and fluctuations from new, unstable renewable energy sources, they simultaneously increase the dependence on electric power supply and ICT infrastructure, which can fail and be hacked (Lagendijk and van der Vleuten 2013). Thus different goals tend to compound in developing energy technologies (see also the argumentation in **II**; **III**; **IV**; **V**). As such, energy systems present us with a truly super wicked problem as there is a need to re-orientate highly path-dependent energy systems with high levels of incumbent power which is heavily reliant on fossil fuels (Levin et al. 2012; Carlson and Fri 2013). Consequently, policy feedback loops causing path-dependency can undermine sustainability goals (Weaver 2010, 137; see also in the context of specific cases in **II**; **IV**; **V**). Thus, there is a need for a new approach to understanding transitions in energy systems that in unison accounts for the technological development and politics within the energy system and the social-economic impact of the former (on the economy, sustainability and security). The narrative of sustainability – sustainability transition – of energy production and demand seems to be key, because it highlights the underlying processes of regulatory change, policy-making and technology legitimatization currently happening in the energy sector (Markard et al. 2015). Nevertheless, sustainability transitions present many challenges to policy makers (Turnheim et al. 2015):

(1) they cross multiple scales, geographies and temporalities;
(2) there is a high level of uncertainty connected to radical innovations, which makes predictions imprecise;
(3) there can be a high level of inertia connected to existing socio-technical systems;
(4) there are many competing public goods and social objectives that innovation needs to fit with (e.g., decarbonization, energy security, economic growth); and lastly,
(5) the governance processes of socio-technical change are complex and frequently contested (ibid., 240-242).

Consequently, transformative processes in the energy sector are characterized by high levels of uncertainty across different dimensions. Energy technologies are historically very slow to diffuse (Grubler et al. 2012), and it is by no means clear which energy technologies will prevail in the future low-carbon mix (Skea et al. 2011; Hoggett 2013; 2014); hence, policy makers want to keep energy systems open for options (e.g., Ekins et al. 2011). It is difficult to identify which technology pathway will be the most effective, even if there are a variety of low-carbon technologies already available (e.g., Hoggett 2014). Efforts to directly control technological development can produce unintended effects from hype, slow development, cut-throat competition with incumbents and alternative solutions to also rapid, unforeseen diffusion (e.g., Deetman et al. 2015; see also **IV**; **V**). Furthermore, energy sectors are largely infrastructure-dependent (see discussion in **IV**), which means that for sustainability transitions to be successful, the nature of the governance challenge in transforming large-scale and complex infrastructure systems needs to be understood (Bolton and Foxon 2015). This means that there are very different actors from the side of both production and consumption of energy and beyond – utility companies, energy sector regulators, policy makers and end users – involved with the process (Smith et al. 2010). Consequently, policy complexity in the energy sector is very high: the global energy system is characterized by interconnectedness (various feedback loops, complex networks), unpredictability, nonlinearity, path dependency and openness (boundaries of the system are not always clearly defined) (see Cherp et al. 2011). Energy systems can spectacularly adapt to external pressures – e.g., climate goals – while preserving their inner structures. As mentioned above, as part of the super wicked problems, incumbents causing the problem are eager to be involved in solving the former, but this in many cases means "*sailing effects*" of fossil fuel technologies (**V**). Therefore, it is not surprising that fossil fuel subsidies totalled $550 billion globally in 2013 – more than four times those of renewable energy (IEA 2014). This is holding back investment in energy efficiency and renewable energy technologies and the diffusion of the latter (**IV**; **V**).

Policy makers need to, therefore, intentionally design policies that "*stick ... but are not stuck*" (Jordan and Matt 2014, 233). System resilience, adaptability and flexibility are brought out as key to create a space to adjust policies and deal with unforeseen effects (Grubler et al. 2012). In this line "*adaptive policy making*" has emphasized reflexivity in complex and uncertain environments – thus, especially putting the focus on policy learning, experimentation (Marchau et al. 2010) and also "*applied forward reasoning*" (Levin et al. 2012). Thus, learning processes should be a central feature in policy-making processes in energy technology innovation systems (Rogge and Reichardt 2015). However, the reality of policy contexts and existing policy capacities does not usually meet these demands. Often policies in the field of energy transitions are not well coordinated, due to the adoption of multiple sets of niche strategies encompassing different technologies and economic sectors (Costantini and Crespi 2013; **II**). Furthermore, the same policies even in the same sector can be used to pursue different ends – e.g., reduction of greenhouse gas emissions and energy security (Costantini et al. 2007; **II**). Taking these various policy legacies and complexities on board, the next sections will outline an analytical framework to approach energy technology innovation systems from a transnational perspective.

INNOVATION IN THE ENERGY SECTOR – A SYSTEMIC APPROACH

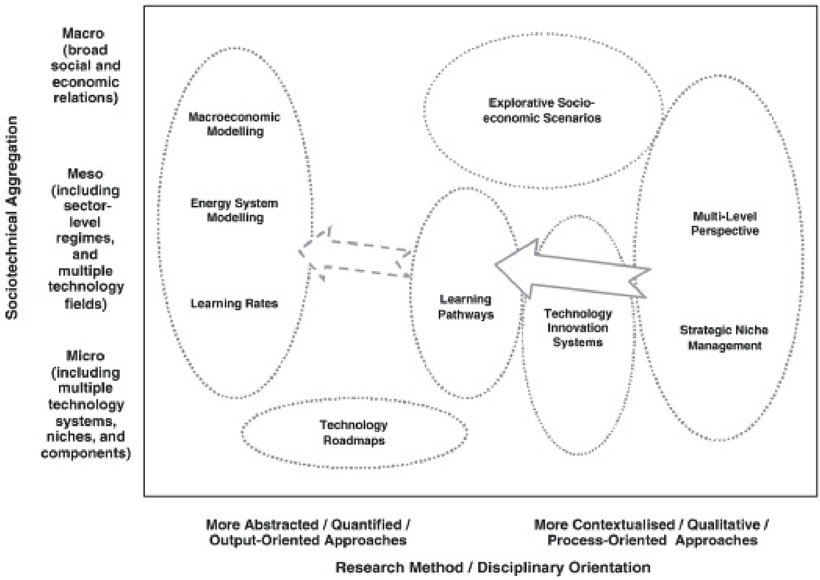
There are many different research approaches applied to the study of innovation within the energy sector. For example, transition pathways are analyzed in socio-technical transition studies (Foxon et al. 2010; 2013) and broader governance studies that put experimentation into the process of transformative change (Wise et al. 2014). Winskel et al. (2014) describe these approaches in a matrix of orientation and the level of aggregation of the research approach – see Figure 1 below. The more frequently applied theoretical perspectives are the Multi-Level Perspective (MLP) and technological innovation systems[4], next to more practical technology roadmaps and energy system modelling.[5] As transitions pathways are

[4] MLP as part of socio-technical transition analysis specifically differentiates three levels – niche, regime, landscape – in the analysis of technological transitions. The niche creates the networks and learning environment, the regime the rule-set defined by institutions and infrastructure, and the landscape includes the factors connected to the diffusion of a technology (see, e.g., Markard and Truffer 2008). While TIS concentrates mostly on drivers and barriers of innovation diffusion, MPL addresses technological change as assimilation of new technologies within a social process on multiple levels (Safarzyńska et al. 2012, 1014). Some studies explicitly integrate TIS and MPL approaches (e.g., Markard and Truffer 2008; Hellsmark 2010; Meelen and Farla 2013).

[5] Methods used in these approaches – e.g., retrospective analyses (sociotechnical transitions), detailed assessments of the future (e.g., initiative-based learning) and future scenarios (quantitative systems modelling) – are all rife with challenges when it comes to their relevance to policy-making (Turnheim et al. 2015). For example, both sociotechnical transition analysis and also TIS analyses are retrospective in nature, meaning that policy insights are derived from past experiences with governance and institutional patterns (Nilsson et al. 2012).

the result of interactions between multiple levels of structuration in socio-technical systems (Jacobsson and Bergek 2011), it is difficult to control actors' behavior and processes or account for the level of uncertainty with so many different elements. With so many interdependencies, innovation systems analysis seems to be the most appropriate; some have even started to actively incooperate the sustainable transition agenda into the approach (ibid.; Smith et al. 2010). The main premise of innovation systems literature is that it is impossible to evaluate a component of the innovation system without seeing its fit with other structural elements and the innovation process. In effect, the approach looks at (also institution-driven) capabilities and their fit and effect on innovative performance within these systems (Lundvall et al. 2011).

Figure 1. Research approaches for energy system analysis



Source: Winskel et al. 2014, 101.

At the same time, innovation systems analysis is conceptually very heterogeneous (see Gault 2007; Soete et al. 2010). There are different approaches to innovation systems: national innovation systems (NIS) (Lundvall 1992; Nelson 1993; Edquist 1997) – both broad and narrow –, regional innovation systems (RIS) (Cooke et al. 2004), sectoral innovation systems (SIS) (Malerba 2005; Dolata 2009) and the aforementioned technological innovation systems (TIS) (Carlsson and Stankiewicz 1991; Johnson and Jacobsson 2001; Hekkert et al. 2007). Many researchers do not consider these different perspectives to be either-or approaches to innovation systems, but see them as interlinked and embedded systems of innovation (Markard and Truffer 2008). For one, both innovation systems approaches – especially TIS – and also MLP (built on socio-technical transitions) are often used together in the study of transition management and strategic niche management (Geels and Schot 2007; Markard and Truffer 2008; Smith et al. 2010; Geels 2010). Thus, TIS as part of the sustainability transitions analysis can be seen as a multi-level approach with multidisciplinary tendencies with substantial cross-overs from other theories (e.g., Markard and Truffer 2008). This has been called the "*Dutch School*" of transition research, usually mixing historical macro-perspectives with actor-based, micro-economic and institutional foundations (Grubler 2012, 10).

Consequently, among different innovation systems approaches, TIS scholars have been the most frequent to adopt their framework for the study of socio-technical transitions (e.g., Markard and Truffer 2008; Markard and Hekkert 2013). This is not entirely surprising as TIS is the most frequently applied innovation systems analysis framework in the field of energy and clean technologies (Truffer et al. 2012; Markard et al. 2012). Using the TIS framework, Gallagher et al. (2012) have specifically coined the concept of energy technology innovation system (ETIS), which should cover all different elements of energy systems (both supply and demand): including technological development cycles, innovation processes, feedbacks, actors, institutions and networks.[6] Nevertheless, originally the TIS framework was not meant for transition studies (Carlsson et al. 2010). This creates new challenges for the innovation systems approach. These will be outlined after the short delineation of the conceptual background of the approach.

TECHNOLOGY INNOVATION SYSTEMS APPROACH

At its theoretical core, TIS applies the traditional technology life-cycle perspective. Carlsson and Stankiewicz (1991, 111) provide the first definition of a technology innovation system as a "*network of agents interacting in a specific economic/industrial area under a particular institutional infrastructure or set of infrastructures and involved in the generation, diffusion, and utilization of technology*." Similar to the Dutch school of governance, the approach concentrates on distributed agency and learning/feedback effects in a network-based model: the main structural components in TIS are actors, networks – source of agency – and other passive elements (Wirth and Markard 2011). Actors can be both individuals and organizations (research institutes, public bodies, etc.) or

[6] ETIS is supposed to identify patterns across different technologies and contexts, and in its first adoptions it tries to avoid the functional approach, discussed in detail below, which prescribes many hypotheses to TIS analysis (Grubler et al. 2012; Winskel et al. 2014).

networks of actors such as value chains (Bergek et al. 2008a).[7] In essence, the TIS perspective is primarily a meso-level approach with structures and functions on the technology system level (Markard et al. 2015, 82; Kukk et al. 2015, 47; see further argumentation in Hekkert et al. 2007). This is seen as more empirically "*manageable*" compared to national, regional or sectoral systems of innovation that primarily operate on the macro-level. Saying that, at its theoretical core, TISs can be delineated over several different dimensions (Bergek et al. 2008a):

(1) breadth of technological field;
(2) vertical scope (value chains);
(3) spatial focus (local, regional, national, global) and
(4) knowledge fields or product-based approaches.

The main relationships that TIS scholars concentrate on in IS analysis are: first, essential differences between systems (due to different structures); second, the creation of variety and non-linearities (due to systemic interaction and cumulative causation); and third, rigidity and path-dependency (due to structuration) (Markard et al. 2015, 80-81). The latter two relationships hint that TIS specifically has been concerned with the growth of new systems – technological niches –, thus, also in the field of energy studies TIS scholars have been predominantly engaged with the emergence of new renewable energy technologies (Bergek et al. 2008b).

Due to prior critique over methodological confusion (along with other IS approaches), technological innovation systems have recently taken a more a "*problem-oriented heuristic*" approach (Wieczorek et al. 2015, 130). This has manifested itself in the much applied functional approach to innovation systems (Hekkert et al. 2007; Bergek et al. 2008a; Hekkert and Negro 2009; Markard and Truffer 2008; Markard et al. 2009), and many have proceeded to measure the strength of those functions in practice (e.g., Negro et al. 2007; Bergek et al. 2008a; 2010; Bleda and Del Rio 2013). TIS also includes market formation explicitly as one of the key functions within the approach (usually not discussed in detail in other IS perspectives) as it deals with the growth of emergent technologies – a list of functions based on Hekkert et al. (2007) is presented in Table 1 below.[8] However, most of these functions are specific to the formative phase of technological innovation systems, because most TIS studies concentrate on the former (Bergek et al. 2008b). Although some works also examine the more mature phases of TLCs (e.g., Karltorp 2014), this has not been incorporated in the functional approach yet, so, the problems/functions cannot be applied to, for

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[7] The TIS perspective was primarily developed to extend and complement micro-level studies in business and management literature (Jacobsson and Bergek 2004). Although there are researchers who engage with the micro-level determinants of TISs – network formation and coalitions, creation of collective resources, market creation etc. (e.g., Musiolik et al. 2012; Kukk et al. 2015) –, this has not been the main focus of analysis.

[8] A slightly different list of functions or key processes has been suggested by Chaminade and Edquist (2010).

example, technologies in decline (Kivimaa and Kern 2015). For instance, also in the growth phase of a TIS other functions may become more prevalent, e.g. resource mobilization – human, financial capital, natural resources and infrastructure – can become critical (Karltorp 2014).

Table 1. Functions of TIS

FUNCTION	DESCRIPTION
ENTREPRENEURIAL ACTIVITIES: EXPERIMENTATION AND PRODUCTION	Creation of new knowledge, networks and markets to take advantage of business opportunities
KNOWLEDGE DEVELOPMENT	Creation of new knowledge bases, R&D variety and mechanisms of learning
KNOWLEDGE DIFFUSION/EXCHANGE	Exchange of new knowledge among different actors to foster new learning processes
GUIDANCE OF THE SEARCH	Processes that lead to the convergence in development (also as government target-setter) for new technologies based in expectations, consumer demand, societal discourse
MARKET FORMATION	Creation of (niche) markets for new technologies, with the help of tax regimes, demand-based policies, new standards etc. to create a competitive advantage
RESOURCE MOBILIZATION	System inputs: allocation of financial, human and physical resources to make knowledge production possible for a specific technology
CREATION OF LEGITIMACY	Due to the uncertainty of innovation, technologies require some level of legitimacy for actors (political lobby) to commit to their development and stand against system inertia

Source: Based on Hekkert et al. 2007, partially adapted from Wieczorek et al. 2013.

In addition to the functions of the formative phases of energy technology innovation systems, the TIS perspective also engages with the traditional economic “failure” debate, along with other IS approaches; however, it does not deal with “*market failures*”, but “*system failures*”. These can be characterized as interactional problems of actors within the system and institutions that drive them (Bleda and Del Rio 2013, 1039). Some argue that in the context of sustainability transitions the main contribution of IS literature is the possibility to analytically identify system weaknesses, problems or blocking mechanisms (Jacobsson and Bergek 2011). Klein-Woolthuis et al. (2005) identify the following system failures connected to structural elements of TIS: institutional failures (related to institutions), interaction failures (related to networks), infrastructural failures (related to technology and physical infrastructure) and capabilities' failures (related to actors and their ability to absorb new knowledge). See also a broader list of system failures provided by Weber and Rohracher (2012) below in Table 2. They also identify systems failures explicitly connected to transformative change, demand articulation, policy coordination and reflexivity (ibid.).

Table 2. Overview of failures in the context of transformative change

	TYPE OF FAILURE	**FAILURE MECHANISM**
MARKET FAILURES	Information asymmetries	Uncertainty and short time horizon of private investors lead to undersupply of funding for R&D
	Knowledge spill-over	Public good character of knowledge and knowledge spillovers lead to socially sub-optimal investment in (basic) R&D
	Externalization of costs	Leads to innovations that can damage the environment or other social agents
	Over-exploitation of commons	Exploitation of public resources in the absence of institutional rules (tragedy of the commons)
STRUCTU-RAL SYSTEM FAILURES	Infrastructural failure	Lack of physical and knowledge infrastructures due to large scale, long time horizon of operation, low returns on investment
	Institutional failures	*Hard institutional failure:* shortcomings of formal institutions such as laws, regulations, and standards (esp. IPR and investment)
		Soft institutional failure: informal institutions (e.g., social norms and values, culture, entrepreneurial spirit, trust, risk-taking) hinder innovation
	Interaction or network failure	*Strong network failure*: intensive cooperation in closely tied networks leads to lock-in into established trajectories and a lack of infusion of new ideas, due to too inward-looking behavior, lack of weak ties to third actors and dependence on dominant partners
		Weak network failure: too limited interaction and knowledge exchange with other actors inhibits exploitation of complementary sources of knowledge and processes of interactive learning

TRANSFOR-MATIONAL SYSTEM FAILURES	Capabilities failure	Lack of appropriate competencies and resources at actor and firm level prevent the access to new knowledge and lead to an inability to adapt to changing circumstances, to open up novel opportunities, and to switch from an old to a new technological trajectory
	Directionality failure	Lack of shared vision (goals, direction of the transformation process); inability of collective coordination of distributed agents; targeted funding for R&D, demonstration projects and infrastructures to establish corridors of development paths; and insufficient regulation/standards to guide and consolidate the direction of change.
	Demand-articulation failure	Lack of demand-articulating competencies: insufficient spaces for anticipating and learning, absence of orienting and stimulating signals from public demand
	Policy-coordination failure[9]	Lack of multi-level policy coordination (e.g., regional/national/European or between technological and sectoral systems); horizontal coordination between research, technology and innovation policies on the one hand and sectoral policies (e.g., transport, energy, agriculture) on the other; vertical coordination between ministries and implementing agencies (deviation between strategic intentions and implementation); and no coherence between public policies and private sector institutions; no temporal coordination (mismatches related to the timing of interventions by different actors)
	Reflexivity failure	Insufficient ability of the system to monitor, anticipate and involve actors in processes of self-governance; lack of distributed reflexive arrangements to connect different discursive spheres, provide spaces for experimentation and learning; no adaptive policy portfolios to keep options open and deal with uncertainty

Source: Adapted version of Weber and Rohracher 2012, 1045.

Functions and system failures alone, however, cannot be the basis of policy (Wieczorek and Hekkert 2012). Furthermore, from an evolutionary perspective,

[9] One can also differentiate between vertical (between different levels of government) and horizontal (e.g., in RTI, sectoral policies and cross-cutting policies, e.g. tax, economic policies) policy coordination failures (OECD 2005). There can also be temporal misalignment of policy interventions when a variety of policy actors are involved (Sartorius and Zundel 2005).

many of these “system failures” are just normal parts of the change process. Unfortunately, most TIS-based analyses do not go into detail about the evolutionary dynamics of IS; they seem to concentrate more on system formation rather than its dynamics (Bleda and Del Rio 2013). Applying a very strict failure- or function-based policy logic can also enforce linear policy thinking, which has been widely critiqued by IS scholars (also in the TIS stream). Moreover, as outlined above, TLC differences may also render TIS functions to a degree obsolete. Consequently, Jacobsson and Bergek (2011, 45) outline broader structural processes connected to the development of energy innovation systems:

(1) Supply chains: often new supply chains cross various economic sectors;
(2) Formation of social, political and learning networks (system policy maker, user-supplier and industry-academia);
(3) Institutional alignment;
(4) Knowledge accumulation (technology as both an output of TIS and its structural entity).

Consequently, transformation challenges are not only dependent on technological development, but also the time it takes to build up relevant social support, supply chains and capital goods industries. This can be illustrated by the time it took the steam engine to find its commercial market or how long it took wind turbines to supply a significant part of the energy supply (Jacobsson and Bergek 2011) or the fact that carbon capture and storage (CCS) units are still not on a large scale integrated into newly built power plants (van Alphen et al. 2010). Many diffusion problems connected to energy technologies can, therefore, be connected to gaps in value chains (e.g., the lack of adoption of CCS units is associated with the gap in the value chain between electricity companies and mines/gas companies, which should inject CO_2 stored in CCS units into the subsurface; ibid.). This means that new technologies and associated industries should be developed in parallel for immediate uptake. This, however, rarely happens, because sometimes whole new value chains are required for a technology to diffuse (e.g., Hellsmark 2010). This is a good impetus to conceptually integrate value chain analysis to the innovation systems approach, but before doing so, some additional weaknesses of the TIS approach have to be outlined and accounted for.

WEAKNESS OF TECHNOLOGY INNOVATION SYSTEMS APPROACH

Taking into account both the different levels of socio-economic transitions and temporality effects, researchers and policy makers have to “*zip back and forth in time*” and “*zoom in and out of levels*” (Garud and Gehman 2012, 992) to make sense of complex energy innovation systems. Most innovation systems research – concentrating on national policies, regions or sectors – is in general found not to be able to respond to the growing globalization and fragmentation of production

(Carlsson 2006; Lundvall 2013). In a multiscalar perspective it becomes increasingly difficult to delineate where important actors, networks and institutions are located; for example in the case of multinational companies (MNCs) (Bergek et al. 2015). Conceptually the TIS approach seems to have an advantage in that regard: it can follow the vertical and spatial breath of the whole technology field.

However, also the technology innovation systems approach has some core weaknesses in that regard, especially in the way it has been empirically applied. As argued before, TIS being a meso-level approach, there can be a danger that the approach overlooks crucial micro- or macro-level activities that influence the development of the system (e.g., Truffer et al. 2012). Due to an academic explosion of the use of the functional framework, there is also a rather myopic concentration onto formal problem definitions, inward orientation and lack of attention to geography, politics and interaction with other technological innovation systems (Bergek et al. 2015; Markard et al. 2015). As such, TIS studies often limit their analysis to a single country level (e.g., Negro and Hekkert 2008; Hekkert et al. 2007; Bergek et al. 2008b; Hillman et al. 2008). Below we will highlight three main critiques – methodological nationalism, lack of attention to interactions between different TISs and politics of transition – that in our opinion influence the conceptual use of the TIS approach most in creating a spatially aware energy innovation system.

Methodical nationalism

While one would assume that technological innovation systems cross geographical borders (Markard and Truffer 2008), most TIS analyses assume that technological, sectoral and political contexts overlap. This means that most analyses assume that TISs are primarily locally embedded; which in some cases, in developed countries with large industrial bases and internal markets, may be indeed true. Thus, most TIS analyses have focused on the national scale (Coenen et al. 2012). This has been associated with the trap of "*methodological nationalism*" (Coenen 2015, 71), which is justified by the importance of national institutions for technology development and diffusion and the aim to primarily inform domestic technology and innovation policy (Wieczorek et al. 2015, 129). However, it seems to severely underestimate the role of other countries and their institutional contexts in developing technologies, the importance of global markets and the interlinkages between various technologies developed in global value chains. Up until recently, international aspects of TISs have been discussed under the broad term of "*exogenous forces*" without a clear delineation of their impact (Coenen and Truffer 2012; Markard et al. 2012). For example, countries can react to exogenous pressures strategically, and this is not only a one-way interaction (for example think about different actors and their influence on pipeline politics (see references in Van der Vleuten and Högselius 2012). While climate policy literature acknowledges constituency pressures and political constraints (e.g., Hovi et al. 2009), these are not studied in the context of technological innovation systems.

Especially in varying geographical contexts, where TISs are not that well developed with small markets and a small number of actors (contrary to most prior studies of national TISs that have entered the growth phases with already well-developed supply chains, defined products and emerging consumer bases), these "exogenous forces" might wreak the most havoc (also Bergek et al. 2008b; Coenen and Truffer 2012). With this, the perspective has neglected to account for the possible interconnectedness with other innovation systems – national, regional and sectoral (Jacobsson and Bergek 2011).

Interactions between technology innovation systems

Although it is usually assumed that TISs are located within broader structures and dynamics of specific sectors in the economy (also due to its connection to the concept of socio-technical regimes; Smith and Raven 2012), TIS has been previously criticized for the lack of interaction with other socio-technical systems and technologies both emerging and mature (ibid.; Wirth and Markard 2011). This is important both on the energy company level and also on the industry level[10], because technological diffusion does not depend on stand-alone technologies (Adner 2006). Interaction of multiple technological innovation systems needs to be taken into account with varying technology lifecycles, system maturation and possible decline. New technologies are often fundamentally different from existing technological structures (Musiolik et al. 2012). This requires a more cyclical, evolutionary understanding of innovation systems development.

Technological mix within the energy sector affects R&D and innovation (e.g., Salies 2010, Sterlacchini 2012), and especially in the transition perspective (for the whole energy sector to change) multiple TISs need to interact (Sandén and Hillman 2011). Recent contributions try to account for the former by describing the interaction of different TISs in different modes (Wirth and Markard 2011; Sandén and Hillman 2011). Especially when talking about TISs as part of the transition process, other relevant technologies in the broader innovation system need to be considered. As such, different TISs can have an integrative,

[10] For example, on the company energy technology portfolios, if nuclear and fossil energy technologies are dominant technologies, then it seems to impede radical innovation in renewable technologies, while with hydro-electric energy the effect seems to be opposite (Markard and Truffer 2006; Salies 2010). Thus, incumbent companies within the energy sector may not be the best firms to implement radical innovations (Watson 2008), especially when their dominant technologies are nuclear or fossil fuel related.

symbiotic/co-dependent (interrelated), competitive or even parasitic relationships (ibid.; Truffer et al. 2012). Consequently, different TISs and value chains can also conflict – for example, there can be fierce competition for natural resources (e.g., biomass is a raw material for both established industries and also emerging technologies, bio-methane technology; Wirth and Markard 2011). This is especially so, because established industries are often not willing to pursue radical innovations (Dosi 1982; **IV**) and usually, established market incumbents try to hold onto the current system and technological standards (Smink et al. 2015). Thus, Costa-Campi et al. (2014) show that financial barriers are not the determinant of R&D investments in the energy sector, while market domination by established incumbents has a significant negative influence on innovation. Consequently, networks and interactions between TISs can be both too weak (inhibiting knowledge-sharing) or too strong, causing lock-in (Weber and Rohracher 2012; Wieczorek and Hekkert 2012).

For the TIS perspective to gain depth as a framework more cross-disciplinary research should be done. One must be very careful in drawing the technological – and territorial – borders of TISs, and Bergek et al. (2015) argue that it would be beneficial first to identify the global set of TIS elements and then to move onto the spatial delimitation of the subsystem of the global TIS that describes the most important interlinkages. Hence, the identification of TIS boundaries also within the energy sector cannot be uniform and follow case-by-base analysis (Coenen 2015; Markard et al. 2015). Recently works on interlinkages and parallel development of several TISs have started to emerge (e.g., Suurs and Hekkert 2009; Sandén and Hillman 2011; Wirth and Markard 2011), and some works have analyzed the ties of TIS with the broader policy setting (e.g., Kivimaa and Virkamäki 2014; Markard et al. 2015).

Politics of transition and energy

Politics and policy processes are in general weakly conceptualized in technology innovation systems analysis and also transition management analyses (Smith et al. 2010; Coenen and Díaz López 2010; Weber and Rohracher 2012; Turnheim et al. 2015; Kern 2015). Concepts of power, politics and agency have been recently integrated into transition management (Avelino and Rotmans 2009; Meadowcroft 2009; Geels 2014; Weber and Rohracher 2012; Truffer et al. 2015); however, they are rarely studied or highlighted in empirical cases. As such, political circumstances that are supportive to TISs and sustainability transitions are often left unexamined by TIS scholars (Markard et al. 2015). Usually the assumption is that faced with "*obvious*" global challenges some consensus will be reached, but assuming this, many questions are left unanswered. How are societal or transition goals determined? How are resources allocated? How are decisions enforced? The political process in which these questions are answered is characterized by a plurality of opinions and discursive struggles (see **V**). While the TIS framework argues for non-neutral innovation policies, it does not explain how, under conditions of scarce resources, choices between different options are made (specialization versus diversity) (see Watson 2008). At the same time, scarce resources can be important drivers of structural innovation policies (Smith et al. 2010; Weber and Rohracher 2012).

It is clear that different actors – including companies, civic society etc. – can influence or even manipulate political institutions in the regulative process by building up expectations and creating their own legitimacy in political debates (Smith and Raven 2012; see also Högselius 2009a in the context of nuclear power). Stakeholders act across different policy arenas and influence the process; especially large companies are very skilful in the art (see, e.g., Högselius and Kaijser 2010 in regard to electricity deregulation in Sweden). Thus, power and agency matter for the formation of transition visions and also the capacities to fulfil the former: e.g., Weber and Rohracher (2012, 1043) juxtapose decentralized power supply with the prevailing centralized large-scale energy supply model to exemplify the fact that any reconfiguration within the current energy supply system needs to account for the interests and power of dominant utility companies. Hence, the market and political power of different actors within the IS matters for transition efforts and for the level of resistance to the deployment of new technologies (Geels 2014). Thus, dominant policy networks and coalitions can both support or stand in the way of TISs in the energy system (Kern and Smith 2008; Markard et al. 2015). Henceforth, there is a need to understand how actors shape innovation systems and their institutions, including policies. Also the recent innovation policy mix literature has emphasized the need to understand policy processes in how they affect technological change and potential policy-mix effectiveness (see Flanagan et al. 2011; also Reichardt and Rogge 2015; Costantini et al. 2015 in the context of environmental technologies). Simply put, there can be various political strategies and policy rationales (as outlined above) at play in the transition of energy sectors (Wesseling et al. 2014).

One can even question how normative TIS-based analyses (generating evidence in support of specific technologies; Bening et al. 2015) are and whether this is actually useful in analyzing transition processes.[11] TIS studies analyze the impact of policies on the performance of, most often, specific renewable energy technology systems (Foxon et al. 2005; McDowall et al. 2013). As TIS analysis is usually applied to emergent technologies it is found to take the existing inertia from incumbent socio-technical systems as given, and it does not explain the

[11] There is some disagreement about what policy makers actually expect from academia as input for innovation policies concerning systemic problems. Usually academia does not provide detailed policy solutions, but analyzes interdependencies and systemic problems which can also make TIS-based policy recommendations broad and rather generic (Bening et al. 2015). However, it has been argued in many cases that academia should not be called on to make political decisions (Shove and Walker 2007; Stirling 2010).

reasons – politics – behind it. Thus, the TIS approach has also been critiqued for its suitability for transition analyses (Geels 2011; Kern 2015).

Overall, innovation system analysis needs to also address the "*politics of policy*" (Jacobsson and Bergek 2011, 55) or the "*politics of transitions*" (Lawhon and Murphy 2012): this means that not only should the effects of policy be attributed to technology outcomes (as is usually the case in empirical TIS analyses), but also that the process of legislative/policy change and external influence should be examined together with the competences of policy makers. Furthermore, the significance of political beliefs, power structures, processes of politics and even differences in democracy[12] to TIS becomes clear when global TISs are analyzed in different national contexts (Bergek et al. 2015, 60). There is very little information about how variation in context structures (influence of history, economic structures and cultural preferences) affects TIS development, policy design and transition pathways. As such, considerably different issues may rise in industrialized, emerging and developing economies in terms of TIS development, which would probably also influence the dominant functional approach of the framework (Blum et al. 2015).

Some attempts have been made to integrate the issues connected to policy learning and governance into the TIS approach. Nevertheless, these approaches have been rather broad, emphasizing "systemic reflexivity" (Fogelberg and Sandén 2008, 68; see also van Mierlo et al. 2010) – as the ability to acknowledge diversity of patterns of societal policy-handling, experiment, monitor and learn and alter policies based on feedback from outcomes – or by broadening the TIS approach by including "*regimes*" and "*landscapes*" from the MPL-framework (as a conceptual justification to look at higher level problems – incl. governance arrangements – within the approach; Hillman et al. 2011). For reflexivity, higher-order learning spaces have to exist where policy makers reflect on different condition and outcomes (ibid., 336). Thus, policy makers need to balance between both long-term signals and commitments but also work on the modulation of interventions and their timing, taking into account the dynamics of different technologies (e.g., experimentation, sunset clauses, degressive support) (Turnheim et al. 2015, 241).

GEOGRAPHIC TURN OF TECHNOLOGICAL INNOVATION SYSTEMS

Initial contributions to the TIS framework emphasized that technological development crosses spatial boundaries (see, e.g., the dimensions outlined by Bergek et al. 2008a presented above), thus, distinguishing the approach from other

[12] See Lijphart (2012) on patterns of democracy; also literature on the effects of varieties of capitalism in Hall and Soskice (2001).

innovation systems approaches (Carlsson and Stankiewicz 1991; Carlsson 1997). However, due to the aforementioned bias from "*methodological nationalism*" (Coenen 2015, 71) this perspective on technological development was not studied in great detail. Recently there has been a "*geographic turn*" in transition studies (e.g., Truffer and Coenen 2012; Hansen and Coenen 2015; also in the urban context, Hodson and Marvin 2012) – the emergence of "*geography of transitions*" (Smith et al. 2010) or "*geography of innovation*" (Asheim and Gertler 2005). This does not mean that national analyses should be abandoned for the global or European scale, but the mix of local, national and transnational dynamics connected to energy transitions should be studied (Van der Vleuten and Högselius 2012).

Slowly it has been acknowledged that outside of the selected country or region, there can be other foreign or global parts of the TIS that contribute to the performance of the system. Especially in sustainability transition analyses the variation and spatial distribution of structural configurations of IS has been noted (Berkhout et al. 2011; Dewald and Truffer 2011; Späth and Rohracher 2012; Truffer and Coenen 2012; Raven et al. 2012; Truffer et al. 2015). In some works also the transnational dimension of the TIS framework has been outlined (e.g., van Alphen et al. 2008; Coenen et al. 2012; Gosens and Lu 2013; Hansen and Nygaard 2013; Binz et al. 2014; Schmidt and Dabur 2014; Bento and Fontes 2015; Gosens and Coenen 2015).

This theoretical development has been led by the input from evolutionary economic geography (see overview in Hansen and Coenen 2015). There are two types of studies: one that adopts the "proximity" school of economic geography influencing network formation (e.g., Coenen et al. 2010), while others concentrate on the social nature of space – relational geography (Raven et al. 2012). In the first approach, "proximity" is not only defined in terms of geographical closeness, but also as cognitive, organizational, social and institutional proximity (Boschma 2005; Ponds et al. 2007; Frenken et al. 2009). In this line, broader socio-institutional and cultural setting is very important in developing working innovation systems across (national) boundaries (Trippl 2010). Thus, cross-border synergies result from the co-existence of high levels of functional proximity (innovation abilities and knowledge-generating capacities) and optimal levels of cognitive distance (related variety) in both economy and wider knowledge production system (Lundquist and Trippl 2013). This can also facilitate or hold off transnational innovation policy formation (see further argumentation in Tõnurist and Kattel 2015).

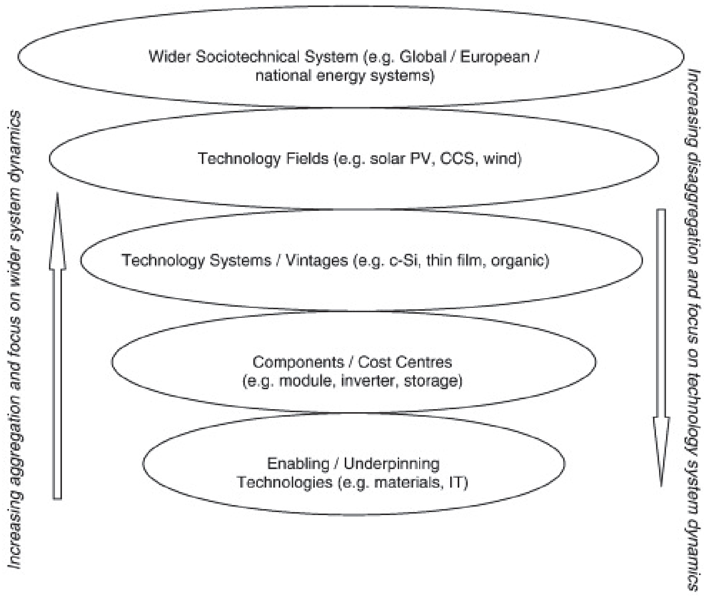
Being sensitive to local collaborations, local embeddedness – which has been the focus of TIS and other IS analyses before – does not mean that international and global relationships do not have an important part in technological development (in the case of developing sustainable technologies, see Carvalho et al. 2012). Hence, there is a dual focus in evolutionary economic geography on both the local buzz and global value chains (Bathelt et al. 2004). Consequently, based on the input of economic geographers, Coenen et al. (2012) bring out two different elements of territorial embeddedness: institutional embeddedness and transnational linkages. While institutions also tend to internationalize, in many cases they remain territory-specific; while in global production networks (GPN), value chains become increasingly international and modular. From a socio-cognitive perspective, Fontes et al. (2015) specifically argue that actors in these networks and value chains – both local and global – spatially ground TISs.

Consequently, innovation does not only depend on the local embeddedness of companies in specific localities, but also on the ability of actors to access assets from global networks and different territorial contexts (see Bergek et al. 2015). This also introduces questions of interaction of different national TISs which may technologically be complementary, but in industrial policy perspective may be competing (e.g., PV TISs in both Germany and China; Quitzow 2013). Here, important questions are how multiscalar TIS dynamics can be analyzed within a specific country and how to note when and how manufacturing and market parts of the value chain start to follow spatially different routes (Bergek et al. 2015, 59). These issues can cause serious legitimacy problems within national policies financing national TIS (see, e.g., Dewald and Truffer 2012). For example, the development of renewable energy technologies can impose high financial burdens onto taxpayers that may create public resistance (O'Keeffe and Haggett 2012), especially if the returns from the investment do not manifest in the country in question. Consequently, it is important to understand hierarchical power relationships and value creation within these multiscalar processes. It may also be possible that some elements will remain outside of the control of regional authorities and national governments, and also these limitations need to be acknowledged in order not to waste resources on ineffective measures. Especially from a relational perspective mostly sustainability transition scholars have studied the influence of various decision makers on different scales and global relations on the transition processes (Coutard and Rutherford 2010; Hodson and Marvin 2009; 2010; Binz and Truffer 2011; Späth and Rohracher 2012).

This introduces new topics to the TIS analysis, including value chains, knowledge flows, collaborations, location of "innovative hot spots", regional variation in innovation contexts and also the role of cities in emerging technologies (Markard et al. 2015, 84). The geographic turn in transition studies also highlights the importance of the geographic and cultural context for technological development and the resulting institutional embeddedness. Hence, technological pathways to energy sector transitions can be different in different localities and also dependent on networks established on varying scales. This brings forth the interconnectedness of different socio-spatial scales: global, national, regional and local. Furthermore, socio-technical transitions span not only different scales – territorial, cultural, organizational and jurisdictional – but also temporal dimensions (Wiseman et al. 2013). In a recent article, when comparing TIS's and

MPL's approaches to energy systems, Winskel et al. (2014) arrive at broader nested hierarchies in energy systems (see Figure 2 below). The higher in the hierarchy, the more difficult it is to change the structural architecture of the system (Safarzyńska et al. 2012, 1013).

Figure 2. Nested hierarchies in energy systems



Source: Winskel et al. 2014, 100.

This is not just important for the development of the TIS framework, but also for policy interventions: based on the scale and place of the core elements of the TIS, policy interventions can be tweaked (Markard et al. 2015). Different technology innovation systems can also differ in their spatial boundaries, for example, some can be local, others global, and they can also be intertwined with each other (Binz et al. 2012; 2014). Consequently, there is a need to analyze how geographical contexts matter and why, and also the transnational linkages that bind different technological contexts. Engaging different scales has become increasingly important in the context of energy technologies, as was outlined also in the sustainability transitions debate. In the following section we will try to expand the innovation systems perspective outlined above by including the perspective of global value chains into the approach to account for the afore-described transnational linkages and power relations.

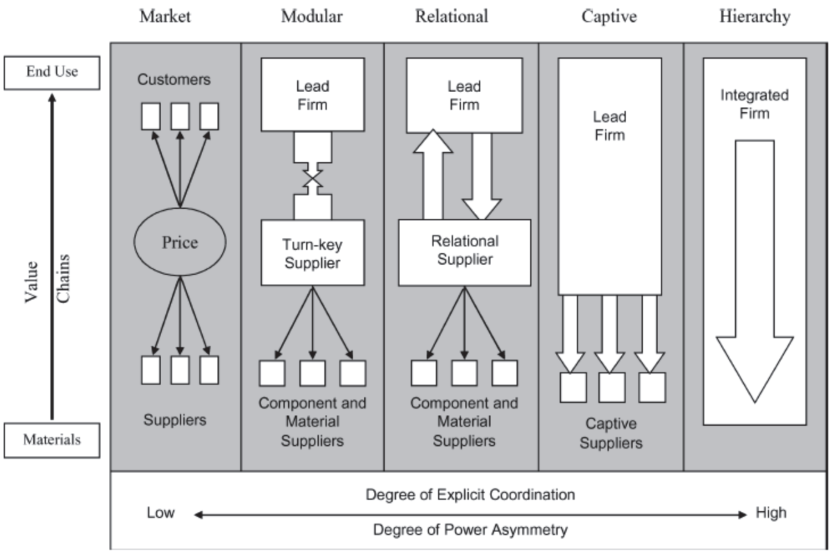
GLOBAL VALUE CHAINS AND INNOVATION SYSTEMS

Local technology initiatives are increasingly connected and interdependent across different localities in both national and global networks (Bulkeley et al. 2015; see also discussion in Tõnurist and Kattel 2015). Thus, the proportion of international technological collaborations is increasingly growing. For example, De Prato and Nepelski (2014) report (although using the example of ICT) that the international technological collaboration network is more and more dense (125 countries in 2007 compared to 79 countries in 1996). Although most of the R&D is still performed in home countries, there are growing internationalization tendencies when it comes to the acquisition of knowledge and resources for technological development (Dunning and Lundan 2009). Investigating "green" patents Noailly and Ryfisch (2015) find that around 17% of such patents are the result of multinational companies investing in R&D outside of their home countries. Therefore, for example, industries behind clean-tech technologies are becoming increasingly globalized (Nahm and Steinfeld 2014; Huenteler et al. 2014), with the core loci of production in China and India and also a part of the R&D moving there (Coenen 2015). Consequently, technological development does not stop at national borders: local networks (examined in TIS) are – and are further becoming – sub-networks of larger international ones – part of the GVCs/GPNs (Coe et al. 2008; Agostino et al. 2011).

These processes could be better described by looking at innovation systems and global value chains or global production networks together in one approach. Since the beginning of the 2000s the GPN and GVC concepts have gathered popularity in describing geographical fragmentation and international expansion of supply chains (e.g., Gereffi et al. 2001; 2005; Dicken et al. 2001). For a recent review of the GVC approach, see Gereffi and Lee (2012) and Gereffi (2014). The GVC literature puts the emphasis on international linkages, networks and knowledge exchange both in inter-firm and intra-firm relations. Analytical categories that are analyzed in the framework are production and trade networks linking large and small suppliers and domestic economies, trajectories of social and economic upgrading and downgrading (product, process, functional and chain upgrading), access and exclusion to GVCs (both firms and countries), roles of lead firms conditioning entry and mobility of GVCs, multiple governance structures of GVCs (international and domestic, public and private, chain-based and civic) that link different components to the international system and shift from trade in goods to trade in value added (see Gereffi 2014).

Among the aforementioned, GVC literature has specifically examined how global networks are governed (e.g., Gereffi et al. 2005; Ponte and Sturgeon 2014). Usually the governance structures are analyzed along the lines of Gereffi et al. (2005) and their five basic types of GVC governance: market, modular, relational, captive and hierarchy – see Figure 3 below. The types are identified based on three key variables: complexity of transactions, ability to codify transactions, and capabilities in the supply base (ibid.). In these lines, governance structures of GVCs and the effects they have on up- and downstream actors have been previously widely studied (e.g., Palpacuer et al. 2005; Sturgeon et al. 2008; Pietrobelli and Rabellotti 2011; Ponte and Sturgeon 2014).

Figure 3. Five types of global value chain governance.



Source: Gereffi et al. 2005, 89.

Table 3. Cross-cutting supply chain issues

ISSUE	IMPORTANCE
POLICY CONFIDENCE[13]	Reduction of risk and perceptions of risk, as companies and investors are wary of entering a supply chain or scaling up their activity, unless they are confident that a supporting policy regime is in place
SUFFICIENT SKILLS	Enough people with the right skill-sets to manufacture, install and operate technologies or deliver different approaches
ACCESS TO MATERIALS	Access to affordable and stable supply of material, as a shortage can alter the economics of a technology and impact its commercialization

Source: adapted version of Hoggett 2014, 298.

Most often GVCs are analyzed in the context of specific sectors/industries, but also some cross-cutting supply chain issues have been identified (see Table 3 above). Mostly, however, GVC analysis tends to covers several dimensions – input-output structures of activities in the supply chain, geographical configurations and institutional context (Bair 2009) – at the same time; and usually, with the help of these determinants, the reasoning behind the placement and the ability to carry out high- and low-value activities (distribution of financial value) in specific industries is advanced (e.g., Dedrick et al. 2010). The value thesis can also be characterized more bluntly by "*rents*" (Kaplinsky and Morris 2001) – resource rents on the downstream of GVC and Schumpeterian rents in the upstream of GVCs. Here the focus point is usually the developmental level and exploitative effects of GVCs. Thus, GVC analysis is predominantly applied from the perspective of comparing developed and developing, bottom of the pyramid countries (Angel and Rock 2009; Berkhout et al. 2009; 2011; Hansen and Nygaard 2013; Schmidt and Dabur 2014; Huenteler et al. 2014).[14] Thus, usually weak GVC

[13] The largest challenge to policy makers seems to be the uncertainty inherent to the process of innovation. In the energy sector, private companies do not respond to short-term, volatile policies as the technology development is very expensive and risky (Astrand and Neij 2006; Nemet 2010), and investments are associated with very high sunk costs (see argumentation in **II**; **III**). Thus, policies need to be credible, reasonably stable and long-lasting (ibid.; Bosetti and Victor 2011; Jamasb and Pollitt 2015). Specifically in the context of TIS, Andersson et al. (2014) argue that policies should counter and minimize both unexpected accelerations and tipping points in technological life-cycles with specific risks and losses and power struggles.

[14] In this line GVC and innovation systems research have converged in the same direction. Also IS scholars have found that innovation systems in developing countries are fundamentally different from those in developed countries (e.g., Altemburg 2009). As governments in developing contexts are specifically called to build up various capabilities,

positions – due to weak linkages and low functional proximity – are highlighted, and even if countries have strong resource bases, this can lead to vicious circles of development due to the dominance of Western firms (Arias et al. 2014). This because local companies usually have access only to resource rents and are therefore in the domain of diminishing returns. In the context of environmental studies, also the distribution of environmental costs is closely scrutinized, and the process of "*greening of the value chain*" is examined (Irland 2007; Faße et al. 2009).

As the above shows, traditionally value chain analysis looks at the power relationships between various actors. The limitation of GVC analysis is that little attention is given to the institutional context beyond the level of development. While Coe et al. (2008) argue that also GVC/GPNs are embedded in "*multiscalar regulatory systems*", systematic analysis of this is still lacking. At the same time, the effect of singular policies or regulations on the GVC has been previously studied. In a recent paper, Curran (2015), for example, concentrated on the effect of EU trade policy on the PV global value chain. Furthermore the effect of both public and private standards on GVCs' strategic choices has been highlighted (Coe et al. 2008; Lee et al. 2012; Manning et al. 2012; see also Gosens and Coenen 2015 – they discuss the effect of transactional actors and networks on the formation of clean-tech TIS). While governments and international organizations influence strategic choices of GVCs (see, e.g., Sturgeon et al. 2008), how states can affect these governance structures is not that well conceptualized (Coe et al. 2008; Ponte and Sturgeon 2014). While some have recently argued that states' capacity to influence GVCs has decreased (Yeung 2014), there is little empirical evidence of the latter beyond sector-based case studies. Hence, GVC research on its own is not sufficient to understand how different linkages between localities and industries evolve (Sturgeon 2009). However, this does not mean that there are no efforts made to expand the approach.

As with the conceptual adoption of the IS approach (Sharif 2006), OECD has been moving into GVC research in the past decade (e.g., OECD 2012; 2015) and has recently started to apply country competitiveness factors (broadly under the concept of national innovation systems) to GVC research (see, e.g., OECD 2013). Going historically further back in the academic debate, also Ernst and Kim (2002) looked at GPNs, starting from the innovations systems perspective (although not concentrating heavily on the latter dynamics). Pietrobelli and Rabellotti (2011) are among the first to go beyond this and look at learning in innovation systems together with the GVC approach, albeit also in the context of developing countries. While there are not many studies that deal with this issue conceptually – as previous TIS studies which have examined the transnational dimension have

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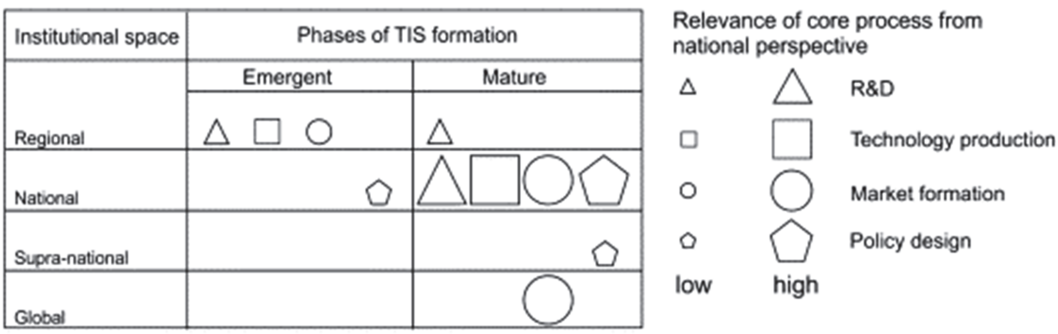
networks and knowledge – create learning processes within the systems – and appease conflicting interests, governance dynamics are at the core of these systems (Lundvall et al. 2011; for the case of energy technologies in Marocco, see also Vidican 2015).

put the attention outside the value chain – during the last Globelics conference (in 2015, Havana, Cuba) in a joint session with other participants, Bengt-Åke Lundvall and Gary Gereffi discussed the possibility to combine the innovation systems perspective with the global value chain perspective. In this line, Jurowetzki et al. (2014) called for the end of "*intellectual tribalism*", showing through bibliometric analysis how innovation systems analysis and GVC approaches have overlapped in the past decade.

Furthermore, it seems that as TIS scholars have matured with the technologies they have studied (predominantly in the field of renewable energies technologies)[15], they have also had to expand the approach (see Markard et al. 2015). As outlined above in the "*geographic turn*" of TIS research, this has called the attention of TIS researchers also to international knowledge flows (Binz et al. 2014), global value chains (Dewald and Fromhold-Eisebith 2015) and also recently interactions between up- and downstream parts of TIS value chains in different localities (Bento and Fontes 2015). See, for example, the simple model proposed by Dewald and Fromhold-Eisebith (2015) in Figure 4 below, accounting for TIS formation and the scale of its development processes (we are, however, slightly skeptical of this model, as the core idea behind the TIS approach is that TLCs differ and thus, so do the tasks and operations in different phases of systems formation).

Figure 4. Model of multiscalar and dynamic TIS formation



Source: Dewald and Fromhold-Eisebith 2015, in press.

Nevertheless, adopting technological complexity on the component level and the value chain level is difficult (e.g., Blohmke 2014 discusses this in the context of renewable energy pathways). Value chains differ across technologies and their

[15] Typically the importance of private actors increases with the maturity of technological innovation systems (see Suurs and Hekkert 2009). This also includes MNCs with GVCs.

maturity levels, consequently, also the roles different actors can play in them vary (see, e.g., Hoggett 2014 for a comparison of nuclear and PV value chains). Hence, positions in value chains – downstream or upstream (in specific TIS) – can influence the innovation activities (R&D, nature of technology transfer) companies carry out (Mazzanti and Zoboli 2006). Value chains in energy systems are especially complex, involving many different actors, technologies, fuel sources, operating at different locations and scales, and they are shaped by both global and local policies, rules and regulations (e.g., Hoggett 2014). There can be both locally embedded and global parts of GVCs (Huenteler et al. 2014). Photovoltaics are a good example of a global value chain with different national TISs being part of the downstream (markets, e.g. in Australia), midstream (producers, e.g. in China) and upstream (producers, e.g. Germany) parts of the industry (Markard et al. 2015, 79). See Table 4 for a brief overview of different energy technology GVC characteristics in selected industries. This succinct analysis clearly illustrates that even in the same sector and similar industries – PV, wind turbines etc. – there are competing technologies with different technological trajectories and also GVCs.

Table 4. GVC characteristics of energy technologies in different industries

	CARBON CAPTURE & STORAGE	HYDROCARBON	NUCLEAR	WIND TURBINE	PHOTOVOLTAIC	BIOMASS
TLC PHASE	Three different technology routes: post-combustion, oxyfuel and pre-combustion; TLC phases differ – most emergent or early growth (technology demonstration) phases	Mature; however continued development of enhanced oil recovery esp. in terms of reaching ultra-deep oil fields (e.g., 4D seismic technology, floating production systems etc.); LNG technologies influence on GVCs; GVC elements: exploration, extraction/production, refining, distribution, consumption and carbon capture	Mature; high level of standardization; Generation II nuclear power plants most common; GVC very complex (vast number of components); GVC elements: construction, operation and maintenance, and decommissioning	Growth and deployment phase in Europe (customization of technology) Mature in China – Chinese companies develop a smaller range of wind turbine models; licensed from EU companies (few years behind TLC – affects strongly GVC)	Two main technological options for materials: crystalline silicon (PV-SI) – growth phase – and thin-film – emergent to growth phase (niche technology; USA dominates) + ongoing research on 3rd-generation technologies; GVCs differ accordingly	Mature; different deployment technologies in, e.g., biofuels, biomass digestion, gasified biomass, CHP etc.
GVC GOV. TYPE	Very complex value chain (incl. risk-averse regulated utilities, e.g., in the US)	Variation in the extent to which upstream (e.g., 40% world's oil output by 10 companies; large role of SOEs), midstream and downstream activities are integrated; networks sparsely populated; states are key actors in both the upstream and downstream phases	Pyramid structure of GVCs with technology vendors the top tier; captive	Hierarchy in EU companies (Denmark, Germany) vertical integration of GVCs; components sector characterized by relational value chain; China entered the GVC through an independent innovator's case (mainly SOEs) – modular GVC model	For PV-SI between market and modular (relatively large number of producers, in the consolidation phase; some firms operating across GVC tiers)	Local nature; optimal configurations of plant locations to raw material

MARKETS	Nascent markets; significant gaps in the value chain (obstacles in upscaling include high capital intensity[16], uncertain revenue stream and regulations and too complex value chain); investment deadlock; possible huge markets in the coal industry (similar to SO_2 scrubber technologies in recent decades); incr. number of post-combustion pilot plants	Global; current re-orientation of product flows to oil-poor regions, esp. in East Asia	Nuclear power reactors in operation in approximately 30 countries; most new builds in Asia, CEE, and the Middle East	Europe has been the traditional lead market in wind power industry with Denmark and Germany the pioneers (however, with saturated growth rates by now), however, they have been successful in creating supply-side hubs	PV-SI: moving towards oligopolistic markets; much of the supply chain has shifted to Asia; midstream industry receives the lowest profits; downstream industry (BOS components and deployment) the second highest profits; demand highest in Italy, Germany, USA, China, Japan	China and India are the two largest consumers of biomass in the world
RESOURCES	Total investment in CCS R&D has increased (esp. in the US) for demonstration projects; largest operated CO_2-storage reservoir is located in an aquifer below the North Sea; demonstration projects planned and realized also in Algeria, Norway, Australia, Japan, Netherlands, China, Canada, Germany.	Technological development coincides with the discovery and ploy to develop new deep-water frontiers, e.g. in the Gulf, Russian Far East or Central Africa.	High costs and specialist skills needed; significant bottle-necks; concentration of power in the hands of few companies; e.g., only four companies in Japan, China, Russia are able to provide ultra-large forging for reactor components	European enterprises still dominating the global market; Chinese and Indian companies heavily entering the market	Top ten patent assignees in Japan, the United States and South Korea; in the polysilicon segment China dominates the manufacturing segment (cell production and module production); Top suppliers China, Taiwan, USA, Japan and Germany	Heterogeneous raw material; unpredictable quality; uncertainty in terms of raw material/final product unit price fluctuations, seasonal demand variations

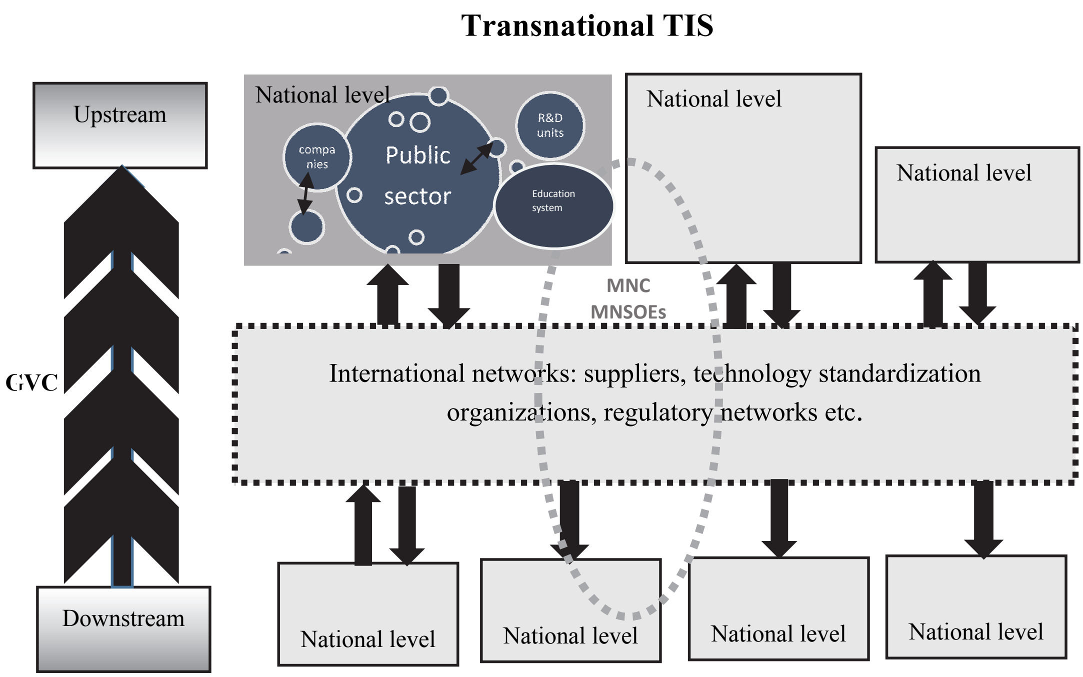
Source: Author based on Nolan and Rui 2004; Gallagher et al. 2006; Bridge 2008; Hellsmark and Jacobsson 2009; Rai et al. 2010; Lema et al. 2011; van Alphen et al. 2010; Markewitz et al. 2012; Su 2013; Shabani and Sowlati 2013; Shabani et al. 2013; Gülen 2014; Hoggett 2014; Huenteler et al. 2014; Dewald and Fromhold-Eisebith 2015.

[16] Capital intense technologies can be subject to negative learning effects (i.e. negative learning by doing) especially in the context of very complex technologies from the scale-up processes resulting in diseconomies of scale (costs increase rather than decrease with accumulated experience), as in the case of nuclear energy (Grubler 2010).

The conundrum is that while global parts of the value chains influence domestic investments and production, most national policies and institutions (apart from large economic powers) usually do not affect the global parts of the value chain as much (Markard et al. 2015), especially when dealing with countries with very small economic power. National policy makers are left to look for windows of opportunity to influence GVCs in these parts and work towards international standardization and knowledge sharing activities (see, e.g., De Coninck et al. 2009; in the context of Asian innovation systems, see Chaminade and Vang 2006). Consequently, national boarders should not be taken as the starting point for analysis. In practical terms, it may be much more enlightening to look at the international technological dynamics and GVC dynamics first and then build the TIS up from the bottom up. Look at how the actors within the TIS define their innovation system and place in the value chain – where the knowledge is generated, where the markets are, which location-specific institutions matter to various actors, how institutions influence specific actors and their investment decisions (see also Wieczorek et al. 2015). At least in theory this should fit with the latest innovation policy fad in the EU – "*smart specialization*" – which is built on the "entrepreneurial discovery" approach (Foray et al. 2009); however, the technological focus, interactions and possible areas of interest are more complex than in the aforementioned policy process. Furthermore, we suspect that the policy outcomes of applying multiscalar TIS analysis compared to the smart specialization logic will be markedly different, as the first would look at the role of local knowledge in GVCs, while the latter starts from local networks and advantages.

Putting things together, the main insight from innovation systems analysis, and especially TIS, is that integration and governance patterns of a GVC will be influenced not only by firm-level efforts, but also regional and national context and underlying technological characteristics (see also Jurowetzki et al. 2014). This means that technologies are not only developed in firm-based GVCs, but also global research networks. In both cases the hierarchy and power of GVC relations should be accounted for – as shown above, this has received very little attention in TIS-based or other innovation systems analyses. On the whole, the formation of TIS is embedded in the broader context, also higher, nested system levels (SIS, NIS). In Figure 5 below we propose a first illustrative model of transnational technology innovation systems that could be applied for the analysis of space-aware, multiscalar energy innovations systems.

Figure 5. Transnational technology innovation systems



Source: Author.

The model describes the hierarchies and relative power in GVCs (e.g., also the role of MNCs and multinational state-owned enterprises (MNSOEs)) and the influence of the latter on TIS learning. In this perspective, the TIS approach gives an understanding of technological dynamics to the conceptual model, while GVC/GPN outline the power relations and the capacity formation for international transfer of technology (see also Lema and Lema 2012 on the latter point) and value flows in transnational linkages. As shown in Figure 5 above, the relationships may not be multi-directional and in some downstream states the GVC may impose its own operating logic onto technology development, with the states themselves having little impact on the nature of the relationship. Furthermore, also Schumpeterian rents and value can thus flow outside of the country. As argued before, the actors, institutions and networks of innovation systems can be structurally coupled with different places and networks and here also MNCs in global value chains can play a large role (Jacobsson and Bergek 2011; Bergek et al. 2015). MNCs can become conduits through which knowledge and resources circulate across national borders (Wieczorek et al. 2015, 132). This is also highlighted in Figure 5.

To conceptualize energy innovation systems realistically we have to go beyond the current state of the analysis, as was shown in the section of TIS weaknesses; and indeed the GVC approach forces the innovation systems approach to also look at geography, politics and power behind changes in systems. However, the understanding of the broader institutional context is weak in both the TIS and GVC approaches, thus this specifically has to be kept in mind in future studies – we will exemplify the importance of the former with the example of small states in the following section.

MULTISCALAR ENERGY INNOVATION SYSTEMS AND SMALL STATES

Defining small states the author has argued that the size of the state depends on countries' economic structure, developmental level and geography (core-periphery relationships) (**I**). Taking the debate regarding transnational value chains and technology innovation systems into account, we can go a step further and argue that when it comes to reaping the returns of technological development in the field of the energy sector, "*size*" depends on the "*proximity*" of countries – be it functional, cognitive, geographical etc. – through their positioning in GVCs. Taking the TIS perspective on board, distance becomes relative to not only geographical scale, but also social, cultural and institutional proximity, which, at least to some degree, is dependent on technology – its level of maturity, knowledge base, supply chains etc. – and the actors' place in global value chains, their possibilities for different rents.

Of course "objectively" small states (traditionally by the size of population or GDP (**I**)) will have some difficulty when technologies reach the growth phase and require large-scale demonstration projects and production levels. Hence, objective size (developmental level, human capital) along with relative size (core-periphery relationships) will influence the possibility to create lead markets for technology experimentation. Small states may not be able to develop appropriate energy technologies domestically (see, e.g., van Alphen et al. 2008), due to a lack of critical mass in R&D and markets to test upscaling processes in more advanced technology growth phases. Thus, in small states TIS are usually only partial (see, e.g., Palm 2015 for the case of the PV TIS in Sweden), and the higher the specialization, the more important are regional and global linkages for companies (Chaminade and Plechero 2015). At the same time, this does not have to be a final blow for the role of small states in transnational energy innovation systems or even global-sustainability transitions – national energy technology portfolios can be successful if they only produce a few relatively big successes (Scherer and

Harhoff 2000; Anadon et al. 2011).[17] However, it is questionable where technological rents in GVCs will end up if ties with the local industry are very thin.

Nevertheless, as hinted above, market size and R&D intensity of destination countries play a role in R&D internationalization (Noailly and Ryfisch 2015). Technology diffusion has been connected to relative advantage, size of potential market, disruptiveness and existence of antecedent markets, technological complexity and infrastructure needs (see Wilson and Grubler 2011; Bento and Fontes 2015). Locations matter both in terms of institutional context (Binz et al. 2012) and also because of the possibility to engage with end-users, experiment and create lead markets for sustainability transitions (on the latter see Dewald and Truffer 2012; Walz and Köhler 2014; Quitzow et al. 2014). With technology maturation core processes extend outside of the local setting (see, in the context of Germany and globalization of photovoltaics value chains, Dewald and Fromhold-Eisebith 2015). Usually innovation has been found to occur first in the central countries – the core – where it passes through experimentation and reaches maturity for market commercialization (Grubler 2012). When the initial barriers are removed and technologies reach new regions from pioneer countries, then international patterns of diffusion can grow significantly (ibid.; Bento and Fontes 2015). In the full growth phase and the deployment of energy technologies, small states will arguably have more difficulties in breaking through to higher levels of global value chains, because their demand positions and, thus, market value to GVCs are much smaller. This does not, of course, decrease the value of, for example, the deployment of decarbonization technologies for the goal of sustainability transitions, but in terms of traditional innovation policy rationale, it may not be viewed as a positive activity.

Another opportunity for small states is to create lead markets for the testing of up-and-coming technologies. Nevertheless, while advanced energy technologies exist, it is by no means easy to leapfrog energy technologies (Gallagher 2006) if some key knowledge is missing from the value chain. Consequently, the potential for lead markets is not uniform and depends on the technological profile and existing place-specific capabilities (e.g., Edler et al. 2012). Thus, in very complex systems, deploying new technological solutions may be a very super wicked problem – there are simply bigger and more vested interests involved within the energy system. Small states with less complex structures, closer and more flexible networks may be more apt spaces for the creation of experimental spaces[18]: for entrepreneurial action that spurs on learning, technological diffusion and

[17] At the same time, public sector energy technology portfolios are not as diverse as one might expect, and more than half of the public R&D spending in OECD countries has gone to nuclear energy technologies (Grubler and Riahi 2010).

[18] On the flip side, this may also mean that small states can be more prone to energy-production lock-in due to closer and stronger networks within TISs and, therefore, larger control of incumbents.

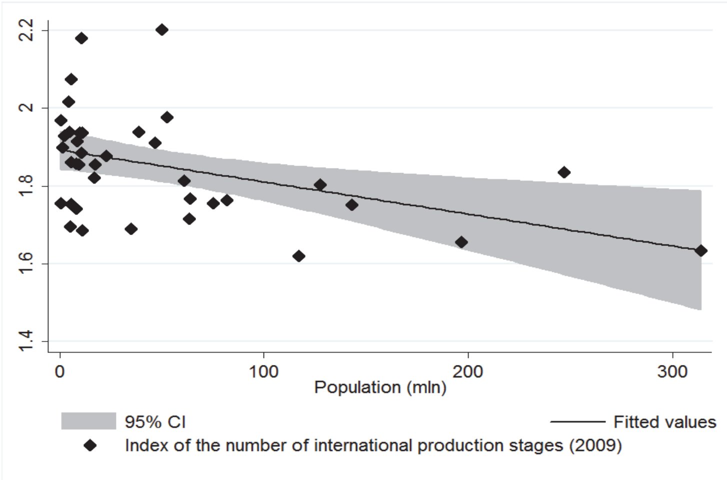
technological leapfrogging (Mazzucato and Perez 2015). This, for example, could give an edge to smaller states in the case of faster adoption of smart grid solutions, local, renewable distributed power generation etc.[19] Nonetheless, this is heavily reliant on existing capabilities and resources and the local legitimacy of such actions. Hence, it does not mean that all small states will be capable of leapfrogging energy technologies. Sometimes also windows of opportunity can be missed in much bigger states – see, for example, a case of missed opportunities in Germany in energy efficiency of windows that could have led to development in passive houses in Nill and Kemp (2009, 676). Consequently, small countries may – under the right conditions – be apt to experiment with new technologies if a political consensus can be reached (see also the discussion in **I**, 14-15). Lead markets, for one, can be created through different measures, although also the associated risks and uncertainty have to be taken into account.[20]

From another perspective, GVCs can create new opportunities for small state TISs, especially if their initial activities are connected to higher-value activities – R&D or core capabilities of energy technologies, Schumpeterian rents –, as it creates new opportunities and expands market horizons. At the same time, it exposes small state economies and companies to additional risks and increases the information asymmetry (see Gereffi and Luo 2014). Henceforward, what is probably the most interesting is that TIS systems in small states will "*go global*" faster (e.g., in larger states such as Germany or the Netherlands, emergent energy technology value chains can rely on local industries longer), which means that states need to think early on how to hold their positions in global production networks not to be swallowed up by larger partners. Figure 6 below illustrates the dynamic between international production stages and state size.

[19] With the spread of sector- and technology-specific policies, the gaps in technology value chains have become more apparent, thus also spurring on discussion over demand-side innovation policies to encourage experimentation and further development (Edler and Georghiou 2007; see also Lember et al. 2015) especially in the scaling-up phase and learning-by-doing. On the whole, to reduce emissions from fossil fuels means that renewable energy technologies need to scaled up (Grubler 2012), but with it, also social practices need to change (Jamasb and Pollitt 2015). More attention is, thus, also put on user-led innovation, which may be more manageable in smaller, quickly adapting localities.

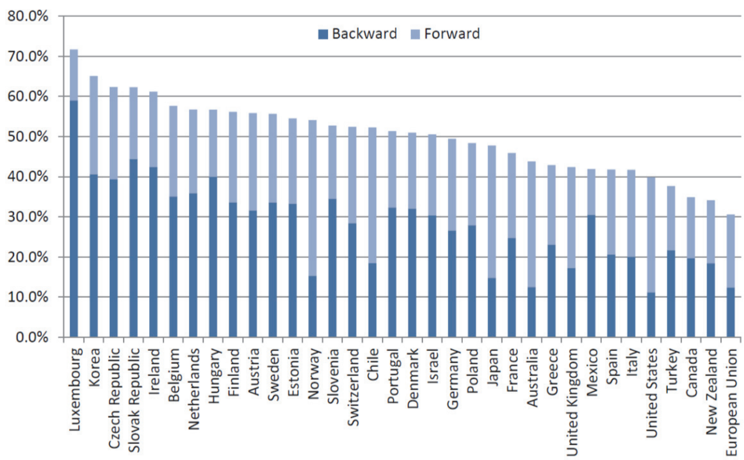
[20] For example, even if green technologies are becoming more international, local demand and environmental restrictions still play a role in spurring on R&D in the related technologies in addition to increasing absorptive capacities of incumbent companies (Noailly and Ryfisch 2015). For example, Dechezleprêtre et al. (2011) reach the conclusion that countries with a stronger climate policy exhibit more patenting for climate-mitigation technologies.

Figure 6. International production stages index[21] and size of states (p= 0.0051)*



Source: Author, based on OECD Global Value Chains indicators (stats.oecd.org; accessed 1 November 2015); *China and India omitted.

Figure 7. GVC participation index in OECD countries (2009)[22]



Source: Backer and Miroudot 2013, 12.

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[21] The index of the number of production stages measures the length of production processes when the intermediate inputs for the realization of a final product or service are sourced from foreign countries. In this case, the minimum value of the index can be zero if all the intermediate inputs required are sourced from within the country (OECD 2015).
[22] Foreign inputs (backward participation) and domestically-produced inputs used in third countries' exports (forward participation), as a share of gross exports (%)

GVCs can therefore be a compensatory mechanism for companies coming from peripheral areas, i.e. relatively "small" states (Grillitsch and Nilsson 2015). Transnational linkages can be used to complement missing resources and capabilities on the national level (Wieczorek et al. 2015, 138). Figure 7 above shows that small open economies – such as the Czech Republic, the Slovak Republic and Luxembourg – source more inputs from abroad from GVCs compared to larger countries. At the same time, the GVC participation index is less correlated with the size of countries, because while bigger economies may not have as high foreign content in their exports, their role in GVC is quite significant if intermediates in other countries' exports are taken into account (in the US the respective numbers are 15% to 40%; Backer and Miroudot 2013, 12). The positive finding from this debate for small states is that TISs on the local level do not need to perform at a high level in the domestic context if their positions in GVC are strong; however, in this case also a lot of the control over TIS may lie outside of the national border with other countries and also international actors (e.g., Gosens et al. 2015). This makes the networks in linking actors across spatial levels an important factor for small states.

As such, national system limitations can be counteracted by TISs and GVCs in related countries (Wieczorek et al. 2015, 143), but it does not mean that small states can *a priori* capture value and rents from these value chains. National policy makers dealing with energy innovation systems in small states have to decide which components of the value chain they want to support locally and what regulations to adopt regarding other parts of the value chains outside of the country (Blohmke 2014). The main opportunity for states, according to Gereffi et al. (2005, 92), is to spur on and allow "*local firms to learn how to make internationally competitive consumer goods and generates substantial backward linkages to the domestic economy*." Consequently, it is questionable if small states (both economically and in terms of local sustainability transitions) will benefit in their energy sectors from such expansions if the intra-state networks remain rather thin. Knowledge spillovers are an important part of the development of new energy technologies (see, e.g., in the case of photovoltaic solar energy – Watanabe et al. 2002; and wind energy – Lako 2004), and if local capabilities in TIS are missing, then the core of activities and thus also Schumpeterian rents, can move quickly into transnational networks and end up in bigger innovation hubs. For example, recent research on clean technologies shows that developing niche clusters is not enough: related variety and branching and combinatory innovations are needed for industry development (Frenken et al. 2007; Asheim et al. 2011; Strambach and Klement 2013). To conclude, within the multiscalar energy innovation systems, the importance of functional distance and related variety is essential for small states' energy innovation systems.

All in all, it is difficult to provide small states with concrete policy recommendations on how to deal with transnational energy technology innovation systems: from the innovation policy perspective governments can search for competitive advantage and possibilities for Schumpeterian rents in GVCs for locally developed energy technologies or develop test beds for up-and-coming niche technologies. In terms of the security agenda this might help to also diversify energy supply and demand and deal with vulnerabilities within the system, but it can also create new weaknesses within the energy system (e.g., overreliance on ICT infrastructures in the case of smart grids). The transition discourse is by far the most complex, and it colors much of the aforementioned debate and future technological development in the field; however, weaknesses in the aforementioned should also be taken into account. Hence, policy-wise small states need to balance both self-serving economic and security needs with the need for energy transitions. The illustrative model, proposed in the previous sections, will hopefully help to highlight the power and role of different actors, also small states, in transnational energy innovation systems.

CONTRIBUTION OF THE THESIS TO THE DEBATE

Previous discussion has advanced the academic debate concerning energy innovation in a number of ways. First, we have highlighted the conflicting policy rationales – sustainability, economic and security-related rationales – governing the energy sector. All of the above introduce their own logic to technological development in energy innovation systems. Second, we used the technology innovation systems perspective coupled with the global value chains discussion to build a new model of multiscalar, spatially-aware transnational technology innovation systems. By highlighting the main weaknesses of both approaches (lack of scale, geography, interaction between technological systems and energy politics in the case of TIS; and concentrating solely on firm-level effects and discounting the importance of the institutional setting in the case of GVCs) we hope to move to a more comprehensive and realistic depiction of innovation processes in energy innovation systems. As one of the important scale effects is also the size of states that influences the possibility to reap value/rents from energy innovation systems, also the case of small states was discussed in the afore-described model. In this way the argumentation takes a step further from the material presented in independently written articles. Nevertheless, the articles comprising this body of work also add specific value to the discussion above and beyond.

Paradoxically, the journey towards more technologically and spatially-aware innovation systems in the field of energy innovation systems started with a paper concerned with defining state size in a globalized economic setting (**I**). Through the discussion of the effects of globalization, open economies and GPN and MNCs, the relative size of states was outlined. While innovation systems were not mentioned explicitly in the paper, many of the underlying assumptions and the cited papers come from this perspective. The article led to the realization that there is a large gap in innovation systems analysis when it comes to juxtaposing one innovation system with another – seeing them in a synergic, competing etc. relationships. The article coincided with the time when innovation scholars started to give more attention to the role of developing countries in innovation systems analysis (e.g., Altemburg 2009). In the former, governance as a tool for system upgrading and building capacities was especially highlighted. Nevertheless, the interaction and interdependencies of various innovation systems – and also the transnational vehicle of such communications and learning – was still missing from the theoretical debate. In TIS this "*vehicle*" is technology and networks and the learning effects that converge around it. Consequently, the definition of relational "size" in global economies paved the way to the acknowledgement of the technological momentum behind GPN/GVCs and the need to combine the aforementioned approaches with the innovation systems perspective.

The following two contributions on state-owned enterprises in the energy sector (**II**; **III**) were innovative in their own right as both helped to introduce a completely new topic to the analysis of public enterprises – namely their role in innovation policy management. As argued above, and in the contribution with Dr. Erkki Karo (**III**), governments still control large shares of the global energy sector, and many of the largest multinationals in the field are government-controlled businesses. Consequently, state-owned enterprises and subnational government investments are a large part of the energy sector. What makes these companies special is the fact that – as in the cases presented in the articles (**II**; **III**) – state-owned enterprises are basically given free reign over primary resource in the energy sector and, thus, also resource rents at the downstream of value chains. In many ways in non-renewable, resource-dependent sectors they seem to act counter-intuitively to societal sustainability goals, adding to super wicked problems (**II**); some do, however, follow the innovation policy rationales (e.g., Statoil, Petrobras since 1980s) and start to act as systemic innovation actors (**III**, 14). While most innovation activities in the energy sector are carried out – and thus, also Schumpeterian rents are created – outside of the energy production section in associated industries, SOEs can have a strong technology-pull mechanisms (employing innovation demand measures) to the development of energy technologies and whole value chains connected to them.[23] Both articles (**II**; **III**) also show how and why public ownership may provide a better basis for long-term investment horizons.

Furthermore, SOEs are becoming MNCs in their own right, making investments abroad to take control of value chains, reduce transaction costs (Cuervo-Cazurra

[23] Government-supported technology transfer is argued to be not enough for significant global energy transitions (Anadon et al. 2011). Nevertheless, energy technologies usually diffuse by private means – through licensing agreements, FDI, international trade (Gallagher et al. 2012, 151) – also the playing field of SOEs.

et al. 2014; in the case of the Swedish Vattenfall, see Högselius 2009b) or, in the case of thin and narrow domestic research networks, buy in input from abroad, bypassing the domestic system (in the case of Eesti Energia, see **II**). Internationalization can, of course, also be caused by political or economic security objectives (Kaplinsky and Morris 2009; Cuervo-Cazurra et al. 2014). This is especially true for SOEs in resource-based industries (ibid.). Consequently, similarly to MNCs, SOEs can become government conduits in global value chains in the multiscalar energy innovation systems described above – in search of Schumpeterian rents – in private networks and transnational relationships, where (small) states have little legitimacy or capabilities to maneuver. Thus, SOEs can facilitate learning and technology transfer in domestic value chains and GVCs (see **III**). As unified units they may also have less coordination problems and transaction costs in participation in and with different GVCs. However, what sometimes is important is that there is a political mandate for such activities. Although SOEs can become independent innovators in their own right (as, to a degree, was the case with Eesti Energia; **II**), it does not mean that they will also pursue social sustainability goals in their innovative activities without stimuli. The largest state-owned enterprises in the world are largely among the fossil fuel producers – oil and gas companies (**III**) – which means that their interests may run counter to sustainability rationales. Thus, the importance of power, politics and agency in energy innovation systems can be outlined by looking at state-owned enterprises in energy innovation systems. Consequently, studying state-owned enterprises in the multiscalar model of energy innovation systems may shed light on many of the issues we have outlined in the prior discussion.

The peculiarities of small state energy innovation systems in the case of Estonia were also outlined in two contributions (**II** and **V**). In both cases some of the peculiarities of small state innovation systems were highlighted: for example, in the case of Eesti Energia the fear of too strong and thin networks (**II**) and, in the context of the climate discourse, the copy-paste adoption of international standards and policy momentum was outlined (**V**). Furthermore, these papers show that contextual variables matter and institutional context and interaction between different technological innovation systems can really influence value changes in the energy sector. The final two papers (**IV**; **V**) also serve as a cautionary tale in the context of the aforementioned debate of what happens if linear policy-making is allowed to run free even if sometimes the final goal – countering the climate crisis (**V**) – is undeniably positive. Global discourses tend to generalize, as is the case with the climate crisis narrative, and the technological nuances and the underlying assumptions of change seem to get lost. Thus, very broad-based narratives of sustainability solutions (**V**) or market failures (**IV**) seem to create almost coincidental and unintended impacts. This makes governing super wicked problems in energy innovation systems very difficult and furthermore, engaging and directing energy technology value chains almost impossible.

AVENUES OF FUTURE RESEARCH

In the previous discussion the author has proposed a new analytical perspective to multiscalar energy innovation systems based on both contributions from innovation systems analysis and research done under global value chains. Future research could expand the debate by operationalizing the model in practice. At first, focusing on a limited number of interlinked national TISs and their position within GVCs may be more manageable before describing complete global TISs with the associated linkages. Also the aspect of competition between TISs (both globally and locally) would benefit from more thorough academic debate.

Understanding the dynamics of TISs on a transnational level (acknowledging both the opportunities and dangers) requires also a much higher level of capacity and capabilities from the government. Thus, analysis of state capacities in the context of super wicked problems should be advanced. If we also adopt a global, multiscalar understanding of technological development, then new insight is needed on how to influence the connected GVCs also from the outside (at the moment research is mostly concentrated on governance factors in intra- and inter-firm networks). In many ways studying SOEs in these value chains and their move from resource rents to Schumpeterian rents (or creating the basis for these rents in connected domestic industries) may be a very illuminating illustration of processes and possibilities of engaging GVCs.

Furthermore, the relationships between and the influence of country-level factors of TISs on the international level should be analyzed. As argued above, the variation in geography and functional proximity, relative state size, institutional differences and economic power can become explaining factors of learning effects in transnational innovation systems and thus, also influence technological trajectories in the energy sector. Here one cannot discount the overwhelming influence of great powers – e.g., China and India – on GVCs. This should be analyzed further from the perspective of transnational energy innovation systems, especially in the special context of state capitalism in the case of China. This highlights the topic which was stressed manifold in the prior discussion: multiscalar innovation system analysis needs to account for differences between countries and the role of different institutional contexts. Especially on the international level, looking at transnational networks and value flows, there is a lot of theoretical room to take the argumentation further.

Specifically for the energy sector, we cannot discount the role of power and politics in energy innovation systems. While this is sometimes discussed in the context of regulatory reforms towards global climate mitigation, there has not been a lot of attention regarding the effects of the latter on both technological search and energy technology diffusion in different contexts. Power relations are also shaped by the dominant discourse and conflicting narratives; the impact of conflicting policy rationales in energy innovation systems, and the (technology-specific) governance of super wicked problems needs to be advanced in both theoretical and empirical contributions.

Although this thesis has not discussed in detail new trends of user- and demand-centred innovations connected to the energy sector – partially influenced by the new smart city environments (sharing economy, influence of ICT, smart grids, but also distributed energy production networks etc.) –, these present interesting avenues for both research and policy in the context of energy innovation systems also in small states. As was hinted above, urban environments in small states can become test beds for lead markets for experimentation for new energy technology solutions in larger, international TISs.

On the whole, the thesis highlights the need for more research on the co-evolution of energy sectors, institutions, global value chains and technology.

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SUMMARY IN ESTONIAN

Energiatehnoloogia innovatsioonisüsteemid rahvusvahelises perspektiivis: väikeriigid, riigiettevõtted ja erinevad poliitikaloogikad

Kliimamuutused on esile tõstnud vajaduse muuta energiasektor jätkusuutlikkumaks ja vähendada süsinikemissioonide hulka. Samas on tehnoloogilised muutused energiasektoris väga riskantsed, ressursimahukad ning kõrge määramatuse määraga. Kuid mitte ainult seda: energiasektorit mõjutavad ka rahvusvahelised regulatsioonid, mis pidevalt muutuvad ja vähendavad investeerimiskeskkonna stabiilsust, ning turul osalejate väga erinevad poliitilised ja majanduslikud huvid. Seetõttu võib energiasektori jätkusuutlikkust näha kui super riukalikku probleemi (ingl *super wicked problem*), mille lahendamiseks hakkab aeg otsa saama, kuid keskne valitsus, kes peaks probleemi lahendusega tegelema, on nõrk (Levin *et al*. 2012). Lisaks iseloomustab super riuklikke probleeme erinevate huvide põrkumine: need, kes on probleemi põhjustanud (nt fossiilseid kütuseid kasutavad energiaettevõtted), püüavad selle lahendamises osaleda. Seetõttu kirjeldab käesolev väitekiri kõigepealt erinevate poliitiliste kaalutluste – kliimamuutused, energiaturvalisus ja innovatsioonipoliitika (roheline majanduskasv) – mõju energia innovatsioonisüsteemidele. Tuginedes evolutsioonilisele majandusteadusele, eeldab antud väitekiri, et poliitikate muutused energiasektoris kerkivad esile koos tehnoloogia ning institutsioonide koosevolutsioonile.

Väitekiri uurib, kuidas energia innovatsioonisüsteemid arenevad, läbi kahe laiema teoreetilise prisma: tehnoloogilised innovatsioonisüsteemid (Carlsson ja Stankiewicz, 1991; Carlsson, 1997) ja globaalsed väärtusahelad (Gereffi *et al*. 2005). Kuigi innovatsioonisüsteeme käsitlevad teoreetilised perspektiivid on väga heterogeensed, kattes nii riiklikke, sektoriaalseid kui ka regionaalseid innovatsioonisüsteeme, siis tehnoloogiliste innovatsioonisüsteemide lähemist on kõige sagedamini kasutatud just energiatehnoloogiate elutsükli põhiseks analüüsiks (Truffer *et al*. 2012; Markard *et al*. 2012). Tegemist on meso-tasandil oleva teoreetilise lähenemisega, mis keskendub peamiselt tehnoloogiate arengutega seotud organisatsioonide õppimisprotsesside ja võrgustike uurimisele. Kuna innovatsioonisüsteemid ja tehnoloogiavõrgustikud on muutunud järjest rahvusvahelisemaks, siis tuleb uurida ka rahvusvahelisi võrgustikke, mis mõjutavad energiatehnoloogiate arengut. Selleks püüab antud väitekiri ühendada innovatsioonisüsteemide lähenemise globaalsete väärtusahelate analüüsiga, luues uue analüütilise raamistiku mitme-tasandiliste, rahvusvaheliste energiatehnoloogiate innovatsioonisüsteemide uurimiseks. Analüütilise raamistiku näidetena käsitleb antud väitekiri väikeriikide ja riigiettevõtete rolli mitme-tasandilistes energia innovatsioonisüsteemides. Seega otsib väitekiri vastust neljale omavahel seotud olevatele küsimuste blokile:

(1) Mis on peamised poliitikaloogikad, mis mõjutavad innovatsiooni ja tehnoloogilist arengut energia innovatsioonisüsteemides?
(2) Missuguseid tehnoloogiliste innovatsioonisüsteemide komponente tuleks analüüsida, et leida lahendusi energiasektori tänastele väljakutsetele? Missuguste teoreetiliste nõrkustega tuleks tegeleda, et jõuda realistlikuma energia innovatsioonisüsteemide toimimise kirjelduseni?
(3) Missugust rolli mängib geograafia ja riigi suurus rahvusvahelistes energia innovatsioonisüsteemides? Kuidas uurida rahvusvahelisi sõltuvusi ja võrgustikke viimastes? Missugune võiks olla väikeriikide roll rahvusvahelistes energia innovatsioonisüsteemides?
(4) Missugune on riigiettevõtete potentsiaalne roll rahvusvahelistes energia innovatsioonisüsteemides?

Väitekiri koosneb neljast teadusartiklist (**I**; **II**; **III**; **IV**), ühest lisas olevast konverentsipaberist (**V**) ning sissejuhatusest. Väitekirja autor on kahe artikli ainuautor (**I**; **II**) ja ülejäänud artiklite esimene autor (**III**; **IV**; **V**). Tulenevalt analüüsivate probleemide komplekssusest ja töö püüust lisada väärtust just energia innovatsioonisüsteemidega seonduvate teooriate käsitlusse on väitekirja metoodiline lähenemine multidistsiplinaarne. Töö teoreetilised alused on läbivalt mõjutatud evolutsioonilisest majandusteadusest (Nelson ja Winter 1982), institutsionaalsest majandusteadusest (Powell ja DiMaggio 2012) ja viimase aja arengutest majandusgeograafias, mis on rakendust leidnud innovatsioonisüsteemide rahvusvahelistumise uurimisel (nt Lundquist ja Trippl 2013). Töö empiirilises analüüsis kasutab väitekirja autor nii kvalitatiivseid võrdleva juhtumianalüüsi meetodeid (**II**; **III**; **IV**; **V**) kui ka kvantitatiivseid meetodeid (võrgustike analüüs (**V**)).

Väitekirja sissejuhatus annab esmalt ülevaate energiasektorite jätkusuutlikkuse probleemist ja viimase seostest erinevate tehnoloogia arendamise loogikatega. Autor leiab, et jätkusuutlikkuse paradigma lähtub teistsugustest eeldustest, võrreldes innovatsioonipoliitikate ja energiaturvalisuse eesmärkidega. Seetõttu võivad olla ootused energia innovatsioonisüsteemidele väga erinevad ning nii riiklikud kui ka rahvusvahelised poliitikad, mis mõjutavad sektorit ja arendatavaid tehnoloogiaid, võivad olla vastukäivad. Praktikas kasutatakse peamiselt turuloogikal põhinevaid poliitikaid energiasektorite mõjutamiseks ja kuigi tänapäeval arvestavad ka innovatsioonipoliitikad järjest enam sotsiaalsete väljakutsetega (nagu kliimamuutused), võivad olla majanduskasvul ja jätkusuutlikkusel põhinevate poliitikate instrumendid koordineerimata ning vastuoluliste eesmärkidega.

Järgnevalt annab väitekirja sissejuhatus ülevaate energiasektori muutusi analüüsivatest teooriatest jätkusuutliku arengu perspektiivist, keskendudes tehnoloogia innovatsioonisüsteemide lähenemisele. Viimast on kõige sagedamini kasutatud taastuvate energiatehnoloogiate arengu analüüsimiseks ning see oma eelduste poolest (keskendudes tehnoloogiliste teadusvaldkondade ja erinevate tasandite (kohalik, regionaalne, rahvuslik, globaalne) uurimisele (Bergek *et al.* 2008a)) sobilik rahvusvaheliste energiatehnoloogiate innovatsioonisüsteemide uurimiseks. Nimelt on erinevate energiatehnoloogiate tehnoloogilised elutsüklid väga erinevad ning nende innovatsioonisüsteemidega on ka seotud erinevad osapooled (mõned energiatehnoloogiad on nt teadusbaasilt ja -võrgustikelt tunduvalt rahvusvahelisemad kui teised).

Siiski on praktikas antud teoreetilisel raamistikul ka mitmeid puudusi: fokusseerimine tehnoloogia elutsüklite algfaasile, üksikute riikide põhine lähenemisviis (metoodiline natsionalism), erinevate tehnoloogiate ja tehnoloogia innovatsioonisüsteemide omavaliste sidemete ning poliitika ja võimusuhete tähelepanuta jätmine jt (vt lähemalt Bergek *et al.* 2015). Samas on viimase kahe aasta jooksul tehnoloogia innovatsioonisüsteeme uurivad teadlased (nt Binz *et al.* 2014; Coenen 2015) püüdnud läbi evolutsioonilise majandusgeograafia antud probleemidele vastata ning viia uurimisobjekt rahvusvahelisele tasandile, arvestades riiklikke, regionaalseid ning globaalseid erinevusi. Viimast seostatakse tehnoloogiliste innovatsioonisüsteemide ja ka ülemineku uuringute (inglise keeles *transition studies*) „*geograafilise pöördega*“ (nt Truffer ja Coenen 2012; Hansen ja Coenen 2014). Et vastselt tärganud akadeemilist debatti täiendada, lisab antud väitekiri lähenemisele globaalsete väärtusahelate perspektiivi, mis vaatab täpsemalt rahvusvaheliste võrgustike jõusuhted ning lisandväärtuse loomist erinevates väärtusahelate osades. Kuigi antud teoreetiline perspektiiv keskendub peaasjalikult ettevõtte tasandile ning uurib arenevate ja arenenud riikide omavahelisi jõupositsioone, siis globaalsete väärtusahelate perspektiivi tugevused aitavad täiendada tehnoloogiliste innovatsioonisüsteemide lähenemist. Kahe teoreetilise raamistiku ühendamisel pakub autor välja uue, mitme-tasandilise ja rahvusvahelise tehnoloogia innovatsioonisüsteemi analüütilise mudeli, mida saaks edaspidi energia innovatsioonisüsteemide uurimiseks kasutada. Analüütilist mudelit näitlikustab arutelu viimase mõningatest võimalikest dünaamikatest väikeriikide energiasüsteemides. Nimelt on väikeriikidel vähem ressursse tehnoloogiate arendamiseks, kuid samas võib väiksemates ning paindlikemates ühiskondades olla ühelt energiatehnoloogialt teisele üle hüppamine (ingl *leap-frogging*) tunduvalt kergem kui suurtes riikides. Samuti sisenevad väikeriigid tunduvalt kiiremini globaalsetesse väärtusahelatesse ehk väikeriigid peavad poliitikakujundamises arvestama rahvusvaheliste tehnoloogia innovatsiooni-süsteemidega peaaegu koheselt. Viimane loob väikeriikidele nii võimalusi kui ka probleeme tehnoloogiate arendamisel kui ka sellest kasu saamisel.

Väitekirja aluseks olevates artiklites arendatakse antud analüütilise mudeli erinevaid aspekte ja alustalasid edasi. Esimeses väitekirja koosseisu kuuluvas artiklis (**I**) arutatakse riikide relatiivse suuruse üle globaalses, vabaturumajanduse kontekstis. Artikkel defineerib väikeriikide suuruse läbi majandusstruktuuri, arengutaseme ja majandustegevuse, tuumik-piiriala suhete. Nii illustreerib väitekiri globaalsete väärtusahelate ja tootmisvõrgustike olulisust erineva suurusega riikidele. Väitekirja teine (**II**) ja kolmas artikkel (**III**; viimane kirjutatud kahesse dr. Erkki Karoga) uurivad riigiettevõtete rolli innovatsioonipoliitikate juhtimises ning seeläbi ka energia innovatsioonisüsteemides. Viimased loovad uut teadmist mitte ainult antud väitekirja teoreetilise raamistiku raames, vaid edendavad kogu riigiettevõtteid käsitlevat akadeemilist debatti. Energiasektoris on riigiettevõtete roll siiani väga oluline ning ühed suuremad fossiilsete kütuste tootjad on riigi omanduses olevad rahvusvahelised ettevõtted (**II**; **III**). Seetõttu ei saa rääkida suurtest muudatustest energiasüsteemides ilma kaasamata analüüsi riigiettevõtete rolli. Enamasti on riigiettevõtetele antud üle nö tasuta kontroll ressursside (tihtipeale maavarade) üle, mistõttu võib ettevõttel puududa motivatsioon innovatsiooniprotsessis osaleda (ning tihtipeale ka avalik sektor ja kodanikud seda ei oota) ning ettevõtted asuvad globaalsete või lokaalsete väärtusahelate madalamatel tasemetel, kogudes ressursipõhiseid renditasusid. Samas näitab väitekiri, et riigiettevõtetel on potentsiaalselt suur roll energia innovatsioonisüsteemides (nt nn „kannatlik kapital“ – vt **III**, 3). Veelgi enam, kuna riigiettevõtted rahvusvahelistuvad aina rohkem erinevatel kaalutlustel, siis on neil ligipääs energiatehnoloogiate globaalsetele väärtusahelatele, mida tavaliselt enamik riike (va võib-olla suurriigid) otseselt vabaturumajanduse tingimustes mõjutada ei suuda.[24] Seega võib riigiettevõtetel ka väikeriikide energia innovatsioonisüsteemides olla oluline roll.

Viimased kaks väitekirja juurde kuuluvat artiklit (**IV**; **V**) näitlikustavad seda, mis juhtub siis, kui erinevatel poliitika eesmärkidel ja loogikatel energia innovatsioonisüsteemides vahet ei tehta. Esimene neist (**IV**) kirjeldab, mis mõju võib olla turuloogikal põhinevatel energiasektori reformidel innovatsioonile, kui reformid ei arvesta sektori struktuuri ja ka erinevate osapoolte innovaatilise käitumisega. Antud temaatikat ilmestavad artiklis Belgia ja Hollandi energiaturgude liberaliseerimise protsessi juhtumianalüüsid. Väitekirja lisas olev artikkel (**V**) loob täpsema ülevaate kliimamuutuste globaalsest diskursusest ja sellel põhinevast tehnoloogipoliitika loogikast (mis on võrdlemisi vastuoluline), mille mõju tehnoloogia arendamise erinevatele aspektidele pole seni täpsemalt analüüsitud. Sedavõrd ilmestab väitekiri lineaarsete innovatsioonipoliitikate ohte ning vajadust süsteemsema tehnoloogiapõhise analüüsi järele. Mõlemad eelnevad artiklid näitavad, et super riukalike probleemide lahendamiseks on vaja süstemaatilisi ja koordineeritud lahendusi.

Koostöös eelkirjeldatud artiklite ja töö sissejuhatuses välja arendatud uue analüütilise raamistikuga pakub käesolev väitekiri välja ka mitmeid erinevaid teemasid edaspidiseks teadustööks. Esiteks, kutsub väitekiri teadlasi analüüsima innovatsioonisüsteeme rahvusvahelises perspektiivis ning kasutama globaalsete väärtusahelate perspektiivist tulenevaid uurimisküsimusi (õppimisest, võimusuhetest, lisandväärtuse paigutumisest väärtusahelates) rahvusvahelise

[24] Siiski on ka kaudseid viise väärtusahelate kujunemise mõjutamiseks – nt läbi rahvusvaheliste standardite (De Coninck *et al*. 2009; Aasia innovatsioonisüsteemide kontekstis vt Chaminade ja Vang 2006).

tehnoloogiaarengu dünaamikate kirjeldamiseks. Teiseks, toob väitekiri välja, et kohalike tehnoloogia innovatsioonisüsteemide suhestumist rahvusvahelistesse võrgustikesse tuleb detailsemalt analüüsida, välja selgitades ka erinevate institutsionaalsete keskkondade mõju energiatehnoloogiate innovatsioonisüsteemidele nii lokaalselt kui ka globaalselt. Kolmandaks leiab väitekiri, et ei tohiks unustada poliitika suurt rolli energia innovatsioonisüsteemide kujundamisel ja toimimisel. Viimasel on potentsiaalselt suur mõju energiasektori jätkusuutlikule arengule ning seda peaks tunduvalt enam innovatsioonisüsteemide akadeemilises debatis arvesse võtma.

Super riukalike probleemide lahendamine esitab riikidele väga suuri väljakutseid – antud väitekiri on loodetavasti samm viimaste teoreetilise kontseptualiseerimise suunas ja seda ka rahvusvahelises perspektiivis.

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PUBLICATIONS (articles I-IV)

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What Is a "Small State" in a Globalizing Economy?

Piret Tõnurist
Tallinn University of Technology, Estonia

Abstract

Globalization delineates the definition of a "small state" from objective markers of size. After a brief review of previous definitions of small states, this article focuses on the growing influence of "smartness" or "innovation" determining the "size" of states in times of globalization. The influence of globalization through the most prevalent trends – the increasing openness of economies, the internationalization of technology, the emergence of global production networks and the growing influence of multinational corporations – is explored as this article tries to shed some light on the concept of "size" in the 21st century. In the course of an extensive literature review, this article reaches the conclusion that the economy structure, developmental level and geography (core-periphery relationships) play a decisive role in the real "size" and development of states.

Key Words: small states, innovation, globalization, size of states, development.

1. Introduction

Economist Paul Streeten (1993) has written that "we know a small country when we see it." Indeed, no one debates the existence of small states, but scholars have very different ideas of what the definition entails. During times of increasing economic globalization one might ask: what is small in the 21st century? This article will try to answer the question by an extensive literature review. A synthesis of relevant theoretical and empirical studies is provided for this theoretical précis.

Today, globalization is a manifestation of the influence of information technology by which cultural, economic and social changes occur. Thus, it can be seen as the most important contemporary economic process: it arguably enforces countries and companies to adapt to the new ICT paradigm (Schienstock 2007). This process pressures countries towards liberalization, internationalizes science and technology and increases competition (Freeman 2003, 48). Hence, on the one hand, globalization is seen as synonymous to economic integration and the decline of the importance of geography (e.g. Benner 2003; Bunnell and Coe 2001), but on the other hand, all actors are not affected equally (e.g. Reuveny and Thompson 2007).

Globalization and the ease of transportation and communication have led to a surge of outsourcing to low-cost locations. However, knowledge-intensive activities mostly remain in advanced economies. For a competitive advantage, the existence of a competitive local cluster in terms of productivity and innovation is perceived to be increasingly important (regarding cluster economics, see Porter 2000). Thus, the spatial impact of globalization manifests as a greater variety of possible knowledge linkages and global production networks (GPNs). These networks agglomerate knowledge capital and innovative activity to a small number of highly specialized high-technology spaces in the higher tiers of GPNs and de-agglomerate production in the lower tiers. Therefore, the most prevalent trends of globalization seem to manifest themselves with the expanding openness of economies, the internationalization of technologies and "geographic dispersion" (Ernst 2002) of production. These processes influence the innovation-based growth that is for now the economic measure by which the sustainable growth and success of countries is defined. In the global economy, innovation and innovation-based productivity growth are seen as pre-requisites to economic success (for a review of relevant literature, see Benneworth and Hospers 2007; Temple 1998). Through a greater emphasis on the endogenous nature of innovation (through the great influence of the works of Schumpeter, see, e.g., 1975 [1942]) and a systemic approach to the latter (Lundvall 1992; Edquist 1997; Freeman 1995), economic growth is assumed to be achieved.

The emerging de-agglomeration of industries and the structure of new GPNs create challenges for developed and developing countries alike. Adding to this dichotomy the "size" of states, it becomes undeniably hard to separate "smallness" from other factors and effects of the social world rooted in politics, economics or geography. Therefore, this article will try to define the concept of "smallness" as a (dynamic) marker for states which it directly influences regarding their economic activities (e.g. making economies of scale more difficult to exploit or becoming over-dependent on one or two export products and export markets). Through the threefold influence of globalization – the increasing openness of economies, the internationalization of technology, the emergence of GPNs and the growing influence of multinational corporations (MNCs) –, this article will try to shed some light on the concept of "size" in the 21st century.

2. Context-specific definitions of "smallness"

Until now, "smallness" has been looked at from an international-relations perspective (the small power and the impact a state has on the international system (e.g. Keohane 1969; Rothstein 1968)), or it is defined by primary indicators such as population size (e.g. Hein 1985; Kuznets 1960), geographic area/territory (e.g. Jalan 1982), gross domestic product (GDP) or in terms of trade (portrayed in Read 2001). Combinations of two or more measurements have also been used (Downes 1988; Taylor 1969). Still, power-relations tell us more about the international arena and not much about the everyday challenges smaller states face internally. Furthermore, some relatively small states (e.g. Israel) can have a considerable influence on international politics. On the other hand, GDP does not say much about the state's economic power, development level or the "quality" of economic activity in general. There are highly successful small(er) states (such as the Scandinavian economies, esp. Finland) apparently coping very well with globalization. However, other measurements are lacking in that regard as well (for a compact critique of measurement problems, see Thorhallsson 2006).

Using population as a marker (and it is the most popular characteristic) does not really render a definite result: small states have been defined from 1 million (Hein 1985) to 20 million (UNIDO 1979) and over, with different cut-points in between. The Commonwealth Secretariat (1997) for one has now defined that a country of 1.5 million people or below is small. Others have found characteristics and common problems of "smallness" in much larger states (e.g. Kuznets 1960; Collier and Dollar 1999; Armstrong 2003).[1] In fact, all definitions based on some empirical measure or combination of the latter have a strong arbitrary element to them. For instance, the World Bank defines small states very narrowly with populations under 1.5 million.[2] This is a clearly arbitrary delineation: in the case of the Baltic countries, this would mean that Latvia and Lithuania are not small states, while Estonia is. Yet, looking at the socio-economic and administrative challenges these three countries face, the similarities are impossible to overlook.[3]

Indeed, one can speculate that the special interest of the respective academic field itself – international relations, economics or public administration – has defined the "size" of smallness. This ongoing debate does little to clarify small-states theory and Thorhallsson and Wivel (2006) argue that even if an absolute or any relative criterion is used to define "smallness", it will always be subjective and arbitrary. Hence, in the context of globalization, it would be misleading to use objective measures (population, territory, etc.) as cut-points between small and large – if anything, they should be interpreted more as a "continuum" (e.g. Rampersad 2000). Nonetheless, the question remains: what does the continuum consist of?

As stated before, to survive in the global economy, innovation-based productivity is key. Therefore, the viability of states hinges on the ability to counteract or even benefit from the globalizing forces. Looking at the common characteristics and problems of "small" states (thus far identified in the small-states literature (cf. Randma-Liiv 2002; Benedict 1966; Handel 1981; Katzenstein 1985; Kuznets 1960; Walsh 1988)) from the perspective of globalizing trends, we can find the defining features that make countries "small" in this new socio-economic paradigm. In this line, the ability to cope with globalization (through the relative power in the arena of international relations, economics or even the capabilities from public administration) would deem it questionable to mark a state "small" as the size itself is defined by comparison and the most influential force in the 21st century is indeed globalization.

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1 Furthermore, Handel (1981) correctly points out that the criteria of territory or population alone can be misleading as geographically small states can have large populations (e.g. Singapore), and large geographical states can have small populations. Thus, the line between "micro state", "small state" and "middle power" is blurred (cf. Neumann and Gstöhl 2004, 6).

2 See, e.g., World Bank. 2000 and Briguglio et. al.2006. While the former focuses on the problems of the Caribbean, the latter is much wider in scope.

3 For a detailed discussion, see, e.g., Raadschelders, 1992 and Crowards, 2002.

3. "Size" and the challenges of globalization

Globalization redefines national borders and their roles in specific factors, followed by negative and positive impact (see e.g. Freeman 2003). Henrikson (2001) finds that decolonization, the end of bipolarity, democratization, trade liberalization and the digital revolution have given all states more freedom. However, increasing openness tends to make countries more vulnerable, exposing them to intensifying competition and fluctuations of global markets. Indeed, there is a tendency towards "internationalization of problems" (Axtmann 2004, 269), because key factors and processes that control policy outcomes are located either regionally or internationally. Based on Katzenstein's (1985, 2003) research, which argued for the "flexibility" of smaller states, one might conclude that they are actually particularly well-prepared for a world of deregulated financial and increased trade flows. On the other hand, one could argue that states with limited populations (and thus human resources) are but pawns in a game they cannot control or even manipulate (see, e.g., Briguglio 1995; Menz 1999). Where trade and finance are concerned, the size of states has a strong tendency to determine the yield to global politics and vulnerabilities rather than opportunities (Payne 2004). But the lack of control of financial flows between countries is not specifically a "small states" problem.

Previously, many economists (cf. Vogel 1979 through Neumann and Gstöhl 2004; Handel 1981; Lucas 1988) maintained that the size of a state determined its wealth due to the small domestic markets (higher costs of production and lower economies of scale and lack of competition) with the dependency on external trade and recurring trade deficits. Limited resources and smaller home markets have been found to increase export-dependence and lead to more pronounced dependence on foreign capital or no power over fluctuations of the international market (see, e.g., Andersen and Lundvall 1988; Baker 1992). These limitations might as well carry on to a low diversification of economies (and low R&D expenditure).

Certainly, sociologically the most prevalent characteristic of limited human resources/population is the overlapping roles of individuals (a prevalent theme from early works on small states and societies, see, e.g., Benedict 1966[4]). It might enhance learning but it personalizes jobs and limits career opportunities for others, which can lead to the best "brains" fleeing the country (Farrugia 1993). However, Browning (2006) argues that more than ever, "size" is now, in the era of globalization, a perceptual marker (see also Lamoreaux and Galbreath 2008) of being smart and innovative, because in the current post-Cold-War world, the framework of big-small is increasingly less relevant. However, it cannot be assumed that the mechanisms (e.g. R&D effort and spillovers (see Kiander et al 2002)) are the same in all states, differing in population, available resources and even industrial structures.

Thus, through the most prevalent economic trends that are emerging because of globalization – expanding openness of economies, internationalization of technology

[4] Benedict is often credited with differentiating between small states and small societies: the main criteria of size for "territories" ("states") are area and population, whereas the criteria of size for "societies" are the number and quality of role-relationships.

and the geographic dispersion of economic activity –, the determinants of the "size" of states are changing. The new socio-economic paradigm, the ICT paradigm (see Perez 2002), is shifting the bearings of the entire social and economical world, and this includes the concept of size. Global competition has increased, and the world has opened, the economy itself is going through a transformation to which the coping mechanisms are different, varying the characteristics determining the economic size of states. This process can marginalize some "objective" characteristics of "size" and introduce others to the table. Using the three prevailing trends of globalization mentioned before, this article will continue to explore the "size" and especially the "smallness" of states in this new paradigm.

3.1 Expanding openness of economies

Globalization has promoted the "structural openness" of economies (Ebner 2004), and although all states are open to a degree, the extent of openness varies. The "hollowing out" thesis (Ettlinger 1999, 339) holds that supranational institutions have eclipsed the nation-state as the locus of power. Indeed, an emphasis on "Washington Consensus" (Williamson 2002) style policies (low inflation, balanced public budgets, etc.) have led governments to pull back from playing an active role in the economy. On the one hand, the importance of an industrial policy has diminished, and on the other, an over-emphasis on innovation policies targeting mainly high-tech sectors has emerged (Lundvall et al. 2002). These policies tend to de-agglomerate economies even further and make countries more dependent on outside forces. The last three decades made developing countries, and particularly those more integrated into world financial markets, swing at the rhythm of highly pro-cyclical external financing (Griffith-Jones and Ocampo 2007). As a result, poorer nations seem to be characterized by the effect of being locked into a "vicious circle" (Reinert 2006, 8) with reverse flows of capital following periods of financial crises from developing to developed countries. The current crisis and its strong ripples around the world show how fragile this openness is.[5]

Deregulated markets and a more laissez-faire role of the state (Casey 2004) are believed to generate a climate of heightened risk, uncertainty, contingency and considerably reduced bargaining power of states (Coe et al. 2008). High-level structural openness (a high share of trade in GDP) requires the pursuit of export-led growth policies (see Armstrong and Read 2006; Moses 2000), which is a double-edged sword, because export preference requires integration into the liberal policy realm. Extreme openness combined with limited home markets (and their stage of complex-

[5] Financial instability is a long-term growth path of laissez-faire capitalism: finance flows are always subject to what economist Hyman Minsky (1919-1996) calls a "Ponzi" investment profile (magnifying the (almost) natural "urge to speculate" (Minsky through Pediaditakis and Thomaidis 2006, 2) in companies that need to increase their borrowing speculatively just to stay in business, but to which, according to good credit assessment, bankers should not lend under any circumstances) that exhibits extreme financial fragility irrespective of whether the funds are used for productive or wasteful purposes and irrespective of the robustness of the financial system and the attractiveness of the domestic environment (see further Burlamaqui and Kregel 2006).

ity) means that states are in danger of becoming “price-takers” in export markets and having very little influence over their terms of trade. Modest political and economic resources of states leave them generally unable to exercise significant control over the condition or regulation of these markets (see, e.g., McCann 2001). The high level of concentration in domestic economic activity and trade, coupled with the high exposure to exogenous global shocks, means that their growth can be expected to be of greater volatility.

Within the emerging global economy and the GPNs, MNCs’ actions can add up to a collective force that serves as a “mediating middle” (Chen 2008) between the global economy and local economies within apparently “glocal” spaces (Benneworth 2006, 23). However, businesses generally find it easier to outsource perfection-related or cost-reduction-related innovation and perform most of their R&D at home (Kumaramangalam 2003; Jakobsen and Onsager 2005). The result might in fact be a “race to the bottom” (Cox 2008; Nayyarm 2006) with other similar countries, while more advanced countries might fall prey to anxieties about cross-regional disparities in knowledge-based wealth creation within particular nations and about the off-shoring of knowledge-based tasks and jobs (Huggins et al. 2007). For developing countries’ assets in general tend not to complement MNCs’ high-tech assets (Asheim and Vang 2006, 45-46). A swarm of developing countries compete for establishing themselves as cost-attractive areas, without having more to offer than cheap labour, low taxes, poor environmental regulation and “flexible” labour-market laws. Therefore, the outside forces that push for more structural openness might force (especially developing) states even further into cost-based competition in areas of little or no increasing returns when dynamic relationships between actors within their production systems are lax or non-existent.

Consequently, states have become more vulnerable to the consequences of the rapid inflow and outflow of foreign short-term investments, i.e. capital flight. Nevertheless, states need to attract more “sticky”, technologically oriented FDI (Kiander et al 2002; Sutton and Payne 1993; Tiits 2007), but at the same time, they need secure basic domestic research and education, in order to upgrade absorption capabilities and technological adaptability (Baark and Sharif 2005). It has been argued (Archibugi and Pietrobelli 2003) that governments which are keen to host FDI (as most open states with small markets and export orientation are (see Beers 2003)) should not only negotiate the presence of a technological component. They are encouraged to offer tailored incentives to FDI, but at the same time adopt policies to allow other parts of the economy, outside the influence of foreign businesses and investors, to benefit from the expertise developed. Nevertheless, whereas China, for example, is in the driver’s seat to play off one MNC against another, in negotiations with smaller countries, MNCs are able to play off one country against another to achieve the best deal. Furthermore, the limited size of the relevant labour market and skilled labour will influence the range of industries in which states might successfully specialize (Maskell 2000, 62-63).

3.2 Internationalization of technology

Comparative competitive advantages vary between industries and their markets (Lane 2008), and for long-term growth, a stake in the high-technology and increasing returns is essential. As countries differ in the cumulative process of industrial clustering in spatial contexts, the location effect comes into play and makes industrial performance vary across countries (Chen 2008; Hage and Hollingsworth 2000). Knowledge-based sectors clearly innovate in a different way than the more traditional medium-technology sectors (Tödtling et al 2006; Shapira and Youtie 2008). The growing complexity of new core technologies (e.g. micro-electronics, biotechnology or nanotechnology (Koschatzky 2005)) requires a more continuous flow of science-based input (Meeus et al 2001).[6] For states with highly limited resources, there is no point in doubling efforts in basic research when the likelihood of achieving market dominance through it is extremely low (e.g. Kiander et al 2002) and when it is unlikely to keep domestically-generated knowledge spillovers to themselves on the global markets. Therefore, a more active role of governments as well as extensive international ties and investment are needed (Amsden 2001). When states have limited resources even to build this infrastructure, they are more influenced by the increasing complexity of technologies and the dispersive effect that ICT has on the global economy. The improvement in technological sophistication and R&D intensity of the more traditional sectors in the larger countries have increased the competitive pressure on other countries in the same sectors, while the newly industrialized countries increase their production in mature technologies (Lall 2004, 4). This puts even developed states with fewer resources between pressures from opposite sides.[7]

Smaller markets do not enable enterprises to recoup high and rising R&D costs (Herbertsson and Zoega 2003), particularly in a time of shortening product life cycles and increased competition. Limited human resources and market can reduce the opportunities to successfully import technologies (Tisdell 1993) or diminish the motivation of private investors to invest in the country, because it is perceived to be too risky or not very profitable. There are limits to the possibilities of states with limited resources in the early stages of technological development because of thresholds in the high-tech industries and R&D and the importance of “forward linkages” (Andersen and Lundvall 1988, 23). Thus, states may lack the critical mass needed in domestic R&D to distribute their innovations more uniformly across technologies (Korres 2007; Maskell 1996).[8] Consequently, Simai (2003) finds that the way out of this is to make “optimal” use of the internationalization of R&D, which would allow to up-grade the knowledge bases of countries, but only if the “right” policies are implemented.

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[6] The university-industry-government linkages may become even more important in these knowledge-intensive all-purpose-technologies of the future (popularly known as “Triple Helix” models (e.g. Etzkowitz and Leydesdorff 1998).

[7] Described by Walsh (1988, 48-49) as “small-country squeeze”.

[8] Particularly in general-purpose technologies as their contribution generally represents only a small fraction of the global R&D invested in developing the same or similar technology (see Kiander et al 2002).

However, the experience of countries on a lower level of economic development also demonstrates a different pattern concerning the smaller per-capita and total GDP. It influences the amount of funds spent on education or R&D, while the historically accumulated knowledge and capabilities in the society may be even more limited (Simai 2003, 27). These countries must either spread their resources more thinly or select certain areas as priorities for R&D investment. The limited size of the labour market itself increases the penchant towards over-specialization, i.e. “Dutch” disease (locking-in to inferior or aging technological trajectories and resulting low diversification of economy) and employment instability, over-dependence on international technology flows and cooperation (see e.g. Dickson and Hadjimanolis 2001). R&D spillovers in general are difficult to identify and account for, and the nature of the relationship between R&D input and productivity output is one of the least predicable in the scientific and technological economy (Wong and He 2001). Furthermore, according to some (see Sutton 1999), diversity is fundamental, because selective interventions can fail for many reasons, for instance insufficient information, inadequate skills of policy-makers or path-dependency (see, e.g., Breznitz 2006; Parker and Tamaschke 2005; Zhang 2003). Nevertheless, Ketelhöhn (2006, 697) argues that while diversity is indeed more important in determining the “intensity of innovation”, specialization has a stronger role in determining the probability of positive innovation, which might be more important. Furthermore, there are advantages in the economic growth potential from a greater degree of social homogeneity, cohesion and identity, which encourages the formation of social capital and thus lowers many transaction costs (Armstrong and Read 2003; Bräutigam and Woolcock 2001; Hey 2002). Therefore decisions can be reached more quickly; also it is easier to cope with far-reaching structural changes and adjust to new technologies (e.g. Lemola and Ylä-Anttila 2003; Lundvall et al 2002).

High-quality institutions and social innovations thus matter in terms of managing the exposure to global economy, because it can combine openness with dense interaction and internal networking (tendencies that Lemola and Ylä-Anttila (2003) have found in Finland). Indeed, the degree of technological internationalization is more prevalent in countries with low technological intensity (Guellec et al. 2001) (with an incomplete knowledge base and a very weak local base of support industries (Ernst 2002, 500)). This means that states that are involved in higher value-added activities, using human capital more intensively, are more equipped to increase their market size, regardless of the available human resources. This signifies the increasing importance of the developmental level of states and limits the effect of the population variable itself.[9]

[9] However, highly collaborative societies tend to encourage continuing, incremental innovations, accumulations of organization-specific knowledge (they are likely to emphasize closer-to-the-market R&D (Kiander et al 2002; Walsh 1988)), while adversarial, arm’s-length societies, in contrast, generate greater discontinuities between skills and routines, with more radical restructuring of technological competences (Haake 2002).

3.3 Geographic dispersion

GPNs are no longer formed inside the "lines of national borders" (Tiits et al. 2006, 155) but more as interplay of different communications inside particular industries. Yet, this accumulation process will inevitably assume a geographical shape and calls for states to at least develop adequate administrative capacities and abilities to "sell" and support the technological strengths of their innovation and production systems, which influence the location-choices of businesses that are considering their R&D strategies (Archibugi and Pianta 1992). "Core-periphery" relations are generally neglected when technology is researched (see Jauhiainen and Suorsa 2008), although innovation activities and knowledge flows differ strongly between central, peripheral and old industrial areas (Rodrıguez-Pose and Crescenzi 2008). Thus, networking for the sole purpose of innovating is not synonymous with the exchange of "well-structured" knowledge (Maskell 2000, 29), and the success of the former might entail plugging the R&D sites strategically into innovation networks, "cross-cutting different spatial scales" (Phillips and Yeung 2003). While economies are becoming increasingly open, some things find "travelling" more difficult than others. Meske (2002), for one, believes that the international opening-up to high-tech imports and other forms of technology transfer has minimized the need for domestic R&D. Still, the "tacit" components of knowledge (Polanyi 1967) continue to be less mobile and transferable. Furthermore, technology- and industry-specific patterns of innovation are primarily driven by the opportunities associated with each technological paradigm (currently the ICT paradigm).

The economic performance of most states is highly dependent on links with the nearby international "region" (especially when it is close to the "core" of economic activity, e.g. relatively prosperous and high-growth countries (see Beers 2004)). Academic or entrepreneurial collaboration can be notably "thicker" within the same geographic neighbourhood, where similar technological specialization and a "common language" (Guellec et al. 2001) are shared. As the likelihood of academic knowledge spillovers are found to decline substantially with geographical distance (Keller 2002), these technology spillovers are an important asset for foreign high-technology MNCs which make R&D investments in host countries (Beers 2004). However, the absorption capacity and hole composition of the innovation and production system of a state are becoming essential for a balanced, reciprocal relationship and technology transfer with the local industry. Thus, it is not only a problem of economic development and core-periphery relationships, but of the composition of the institutional framework (e.g. the differences of neighbours Denmark and Sweden is well-documented (Benner 2003; Lundmark and Power 2004; Nielsen and Kesting 2003)).

Indeed, research (see, e.g., Yeung 2000) suggests that in the case of relatively "footloose" industrial businesses, strong "institutional thickness" may help to give them a firm footing in specific localities and minimize their willingness to relocate. Export-oriented states with small markets are more "conscious" than large states of the demands of MNCs, as they are typically hosts to only a small number of MNCs (Culpepper 2007). At the same time, the existence of few but large home-MNCs makes it very hard to control the R&D structure. However, states with especially limited human resources are characterized by the centralization of their "corporate network", and a particular "manière de voir" (David and Mach 2003) might be highly constructive to economic cooperation,[10] but it can also amplify the danger of lock-in. With clientelist attitudes, "old boy network" pressures and "elitism" of policy-making, it can jeopardize the legitimacy of policies (Kasza 2004). Furthermore, the danger of over-embeddedness in relationships is ever present, and redundant ties can reduce the flow of new or novel information into the network, while the paucity or total lack of links to outsiders who could potentially contribute innovative ideas, can have negative consequences (Hansen and Birkinshaw 2007).

Nevertheless, nurturing initiatives to grow technological, industrial, etc. potential within the innovation and production system of states appears to be the concern of the administrative capacity of especially smaller states that are keen not to find themselves in the inferior/low-wage/outsourced parts of the value chains within the globalized geographic dispersion. Thus, it could be argued that when resources are sparse, there is no other choice than to specialize in a few technological fields and accept the inherent risk that goes with specialization.[11] If the capacity to facilitate such change is not systematic or non-existent, serious structural problems may arise in states with varied levels of development, as a distinct difference in the technological level and competitiveness might develop between industries which are integrated into the production and supply system of high-technology MNCs and the rest of the economy (see Simai 2003). In sum, it can be argued that increasing openness and integration of the global economy is in fact a dimension for states in which size becomes an important feature for some states: for instance, the inability to create localized technology-intensive production and knowledge clusters can be seen as a feature of size.

[10] Still, the degree of state corporatism that is acceptable in states in Southeast Asia might not be applicable in other forms of relationships between the principles of specialization, division of labour and technical progress which has a spatial expression and relates to different societal conditions (see Ozawa and Phelps 2003; Roberts 2005). Expectations regarding social welfare and equality are historically diverse, fuelling long-term competitiveness, learning and long-term flexibility of the workforce in different contexts (Sicherl and Svetlicic 2006) (e.g. the DISKO study of the Danish national innovation system (referred to by Lundvall et al 2002)). An active labour-market policy should be thoroughly integrated into the policy response of small states (for support in the workplace and the willingness of workers to contribute to change instead of blocking it (Kuznets 1960; Katzenstein 1985)), which is supposed to be one of the key lessons to be learned from the success stories of East Asia (Mehmet 2003). The state encouraged MNCs to establish manufacturing facilities in Taiwan, but unlike Ireland, Taiwan then pushed these companies to procure an increasing number of components locally and to transfer the necessary skills and know-how for their production to local suppliers (Breznitz 2006). However, in the era of globalizing processes, it is a major challenge to try to make culturally and ethnically cohesive states open so that they can allow for the co-existence of cultures and ethnicities without undermining the social capital that keeps them together (Lundvall and Tomlinson 2000).

[11] Embedding strong clusters in an otherwise fairly diverse local economy is preferred, otherwise opening the borders to foreign MNCs generally allows them to dominate the domestic technological scene through inward foreign direct investment (FDI) and takeovers of domestic businesses (see the Flemish dilemma in Capron 2006).

4. What is small in an area of globalization?

Scale is indeed a "fluid and multidimensional concept" (Bunnell and Coe 2001, 570), delineating the complex interactions between physical space, institutional and regulatory jurisdictions and the shifting levels of economic actors. The "size" factor thus far has had important implications for economic performance, and most concerns have been concentrated on the implications of small population size and negligible local markets. Still, the challenges countries face are not exclusive to small size in absolute terms. The discursive structures of "big-small" or "core-periphery" alone do not put innovation and smartness into the dichotomy of size. If we take the latter into account, the driving forces of globalization identified in this article are not insurmountable. In fact, the economic performance of many states, but by no means all, that are thus far characterized as "small", has been strong, whether in terms of their growth rates or income levels (see further Mehmet 2003).

Previous argumentation has led to the conclusion that in the 21st century, "smallness" is not defined by absolute variables, but processes such as increasing openness, internationalization of technology and geographic dispersion have created opportunities and changed the economical and, to a degree, social world in which traditional state variables (see further in paragraph 2 of this article) such as territory, population, total GDP, etc., are not ultimate and defining characters of countries and their size. Today the open capital markets influence all countries both small and large, while indeed the policy responses differ.

Thus, this article shares the optimism of Yeo (2004) who maintains that if (small) countries can learn to deal with the vagaries of large capital flows and a heavy dependence on external trade, they can reap the benefits of globalization. Nevertheless, "learning to deal" successfully with globalization would signify very high levels of policy and administrative capacity, policy leverage and selection (state capacity). Some states with limited populations and/or territories manage to generate a relatively high GDP per capita when compared to other developing countries, in spite of their high exposure to external economic shocks (a phenomenon aptly termed the "Singapore Paradox" (Briguglio et al. 2005)). Furthermore, Bräutigam and Woolcock (2001) found that while relatively small countries are clearly more vulnerable to rapid fluctuations in the fortunes of the global economy, there are no significant differences between small and large countries in terms of the quality of their institutions. However, high-quality institutions in states with fewer resources matter more in terms of managing already high levels of globalization. Stronger state capacity is more likely to produce higher economic growth rates.

States might not be passive victims or neutral arbiters of globalization processes, but the policy tools at their disposal dictate the actions available to them. The policy options at hand for states to host foreign R&D-intensive MNCs are determined by the position that the countries are able to take in a GPN (Ernst and Linsu 2002; McCann 2001). This and the combination of geographic location (most commonly – "remoteness") and economic specialization patterns (Kattel 2008, 16-17), i.e. the position in a GPN, is what determines the pattern of development and growth, becomes the determinant of "size". Development and remoteness (geography) considerably magnify the divergence between states, as developing countries are even more disposed to liberal macro-economic policies and, being unequal partners, they have to bear the most unfavourable consequences with very little administrative capacity to promptly react to them.

For instance, the three Baltic States have a high degree of intraregional trade patterns, although no significant cooperation on R&D, while other countries, for instance Finland and Sweden, have much more universally internationalized trade relations in the ICT area (Falch et al. 2006). The intensity of these different merging points of regional cooperation depends upon the capacity to contribute to the principles of reciprocity and solidarity (Molina-Morales et al. 2002). Having few possibilities of doing so makes countries "small" in the global economy. However, participation of what can now be described as "small" states in regional groupings is arguably a strategy to secure a better trade-off between economic advantage and the protection of sovereign authority and power than is available through participation in global multilateral arrangements (McCann 2001, 293-295). Because especially developing countries have to grapple with unstable exchange rates (and raids of speculation against it), extensive short-term debt by their private sectors, deteriorating terms of trade and rise of protectionism in industrialized countries (see Rampersad 2000), the standard population marker does not hold true. Thus, the development level contributes to the "smallness" of states, and countries with much larger populations could also be considered small.

Population size and available resources can and do influence the inner workings of the economies of different states, but the ability to find niches and context-specific solutions within the changing global economy is not totally out of reach. Therefore, "size" in the traditional sense becomes a constraint only when the effects of these absolute measures lie far outside the control of the state and the institutional infrastructure. This makes it impossible to react to the forces of globalization that influence most countries and in effect make economies "smaller" than the absolute measures lead us to believe. The opposite holds true as well: on account of high developmental levels, administrative capacity or strategically better geographic locations, traditionally "small" countries have more options to react to new paradigms and absorb new technologies, thus growing in economic size (e.g. the Scandinavian countries or the Asian Tigers) (see Figure 1.). If they do so or not is outside of this argument, because even undoubtedly great nations have lost competitive advantages.

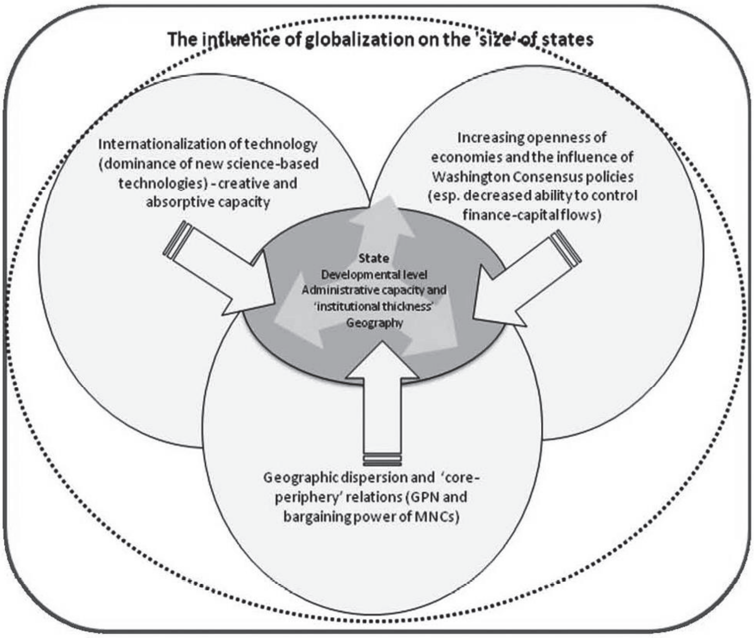

Figure 1: **The influence of globalization on the 'size' of states**

5. Conclusions

This article reaches the conclusion that "smallness" has important implications on the economic performance of states. On the whole, these effects intensify with the influence of geography (core-periphery relationships), the developmental level and the technological and industrial specialization of states. "Size" interplays significantly with the developmental level, economic specialization and closeness to dynamic markets and forefront research. The influence of the latter can help or hinder, enlarge or diminish the positive and negative effects to the nation-state perspective in the new ICT paradigm. Consequently, the capacity to enhance or delimit the effects of globalization and respond to the new forms of economic systematization brought on by new technologies is the key to divide between small and large countries. Therefore, the policy responses to globalization (effects and policy options broadly referred to in paragraph 3) – led today by the ICT paradigm –are available for those states that can capture the "heart" of the paradigm. Thus, through the effects of globalization, the concept of "size" becomes more dependent on the state capacity to administer change and cope with deficiencies (and all countries have them, but the policy-toolkit available for them is different).

The developmental level, administrative capacity (i.e. available policy options and capacity to administer them) and geographic location (closeness to the "core markets") have a more direct influence on the qualitative "size" of the economy then the numeral of the population or territory of the state alone. The ability to focus available capabilities, absorb technologies from abroad and react to change is more essential in the ICT paradigm for innovation-led productivity growth from the perspective of the state. Globalization delineates the definition of a "small state" from objective markers of size to a growing focus on "smartness" or "innovation" and the aspect that influence the latter, thus determining the real "size" of states. The synthesis of works presented above shows that the composition of the economy, developmental level (and thus the capacity to manage change) and specific characteristics, e.g. the geographical situation, play a decisive role at least in the economic size and development of states in the 21st century.

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Piret Tõnurist is a Doctoral Student at Tallinn University of Technology, Department of Public Administration. Her research interests include innovation policy and small states. Correspondence: Piret Tõnurist, Pärnu mnt 342, 11611 Tallinn, Estonia; E-mail: phedre@hot.ee.

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Framework for analysing the role of state owned enterprises in innovation policy management: The case of energy technologies and Eesti Energia

Piret Tõnurist *

Tallinn University of Technology, Ragnar Nurkse School of Innovation and Governance, Akadeemia street 3, 12618 Tallinn, Estonia

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ABSTRACT

This article discusses the role of state-owned enterprises in innovation policy management. This has long been a neglected topic in both management and innovation literature. The paper outlines the most important factors that influence R&D objectives and investments in state-owned enterprises and their interaction with other innovation policy actors and measures. The main contribution of the article is a novel theoretical approach for analyzing the main trends in innovation policy practices in state-owned enterprises. Their possible role in technology advancement, especially in areas requiring large-scale investments, as in energy technologies is discussed. The probable outcomes of innovative investment depending on the constraints present in the system are analyzed. The framework is actualized with a case study of Eesti Energia, a state-owned energy company in Estonia.

1. Introduction

Most of the current research surrounding state-owned enterprises (SOEs) is focused on the issues of efficiency and privatization (e.g., World Bank, 1995; Netter and Megginson, 2001; Omran, 2004; Goldeng et al., 2008). It usually presents a negative picture with regard to the role of SOEs in policy making. As such, traditional governance and management literature tends to ignore innovation as a goal or to minimize its role in SOEs. Policy management practices and the way they affect the inner work of firms towards achieving R&D and innovation objectives are usually disregarded. This stems from a consensus about the role of SOEs as ubiquitous tools in industrial policy-making in prior decades, especially in the context of import substitution schemes in Latin America (Toninelli, 2000), which are at most employed under the 'exceptional' conditions of interventionist politics in East Asia (Amsden, 1989; Stanford, 2008). Nevertheless, with the rise of the latter's economies and different forms of innovation policy governance, these foregone conclusions should not be taken as self-evident. State-run companies still produce a large proportion of the national industrial output in many developed and developing economies (OECD, 2005), even more so after the financial crisis. Thus, one can assume that their role in science and technology (S&T) policies is still significant – in combination with internal R&D expenditures, procurement for innovation, collaboration with research institutes, etc. – even though it has mostly remained unobserved. Above all, SOEs are researched in the context of China as a peculiarity of the state-managed economy (e.g., Yusuf et al., 2006; Guan et al., 2009; Chan and Daim, 2011). However, when it comes down to a broader analysis of innovation policy management (policy specification and policy implementation from a state-centric viewpoint to the traditional national innovation systems framework; Nelson, 1993) in and through SOEs, it is an area of research that has long been neglected in academic debate. This article tries to fill the void.

The paper departs from the assumption that SOEs can be founded (or firms nationalized) in order to reach a wider range of goals, which prevail over simple profit maximization and are aimed at a broader social welfare maximization (Vickers and Yarrow, 1988; Austvik, 2012). In innovation literature, this idea has more often been linked to the concept of the possible 'public good' of R&D in government-controlled companies (Molas-Galart and Tang, 2006). In this line, SOEs could be considered as the prospective drivers of economic development and innovation. Due to the nature of previous research, this may be more obvious in developing/transition countries, but should not be limited to the former. As this is a novel topic in the field, no specific theoretical approach for the latter currently exists in innovation or management literature. For this, a broad framework of the most important factors of innovation policy management in SOEs is developed. Innovative performance pertaining to technological development is analyzed, although the taxonomy could apply to a wider range

* Tel.: +372 620 2651; fax: +372 620 2665.
E-mail address: piret.tonurist@ttu.ee

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of innovative activities. In the following sections, theoretical considerations with regard to governance and the role of SOEs in economic development and innovation policy will be presented. Further, a theoretical framework for studying their role in innovation policy management is developed and a possible variation in broader innovation outcomes is described. The approach with the preliminary propositions is then discussed through the empirical case of Eesti Energia Ltd., a state-owned energy company in Estonia.

2. Theoretical considerations

The change from industrial policy to innovation policy has coincided with the change in governance from 'public enterprises' to SOEs (Galambos, 2000). This has not been merely a nominal change. In the background, agency theory (Berle and Means, 1932; Jensen and Meckling, 1976) has greatly influenced the separation of ownership from the control of SOEs and the identity of both companies and their owners (e.g., Thomsen and Pedersen, 2003; Wu, 2011). In this line, government's asymmetrical managerial know-how has been found to have an unconstructive effect on the performance of state-run companies. This logic of market failure assumes that all policy goals and the continued supply of goods should be addressed only through regulation (Koppell, 2007). If innovation and technology are examined at all, the focus is usually on the effect of ownership concentration (e.g., Shapiro et al., 2013) or on a wide range of ownership structures (Choi et al., 2012) rather than on the specific role of the government who acts upon long-term policy goals. Thus, the traditional argument would presume that due to the lack of control from owners, i.e. general public, there is no 'exit' from investment (Hirschman, 1970) and SOEs would thus have no incentive to increase their performance in order to pursue rewards from innovation (World Bank, 1995). Thus, prior to the privatization process also many R&D units were stripped from SOEs in the 1990s (Acha and Balazs, 1999).

At the same time, SOEs have traditionally had many different goals and also varied reasons for being created (Christiansen, 2013). In the US, they are seen as an extension of the government and its agencies rather than businesses that serve national objectives. And yet, sometimes they act similarly to venture capital funds (Weiss, 2014). In China, the aim of SOEs is to maintain control over strategic industries, build them up and direct capital for investment (Chan and Rosenbloom, 2010; Kroll and Liefner, 2008). Among others, MacAvoy et al. (1989: 12-3) have provided a list of functions ranging from resource preservation (maintenance of vital industry), hording (problems with allocating property rights to national resources), value promotion (interest in non-commercial values) and simply rent collection from resource-based industry. In terms of innovation, this could be broadened to include not just the preservation of resources, but also their creation, e.g., by providing access to technology. This is mostly discussed from the perspective of demand-side innovation policies, where SOEs could be seen as the agencies, procurers of innovation (Rothwell, 1994). However, a much wider approach should be taken and these issues explored, when innovation policy management through SOEs is discussed. In the next sections, these introductory arguments are explored further with special focus on the impact of corporate governance and privatization, which have influenced the concept of SOEs in the policy-making over the past few decades.

2.1. Governance of SOEs

Academic literature on SOEs is mainly found within the framework of corporate governance under the title of corporate financing and profit maximization (e.g., Vagliasindi, 2011). Thus, SOEs have most frequently been studied from the perspective of ownership influence on the performance of the firm (e.g., Aharoni, 2000; Toninelli, 2000); it is usually found that privatized firms show better results (Megginson and Netter, 2001; Shirley and Walsh, 2000). If SOEs' governance structures are compared to private companies, the negative effect of political interference – the exertion of social and political policy goals to company's operations – is accentuated in terms of managerial decisions of SOEs (e.g., Shleifer and Vishny, 1998; Dewenter and Malatesta, 2001). Further, their nature of being 'public', 'state-owned' makes SOEs vulnerable to heightened public scrutiny and accountability, which makes media engagement and image essential in many decisions. With the 'public' as their owner, SOEs can have both non-commercial objectives and profit maximization goals (see the differentiation in the case of SOEs in Canada in Bozec et al., 2002). Thus, business-oriented goals and policy utilization can greatly differ and there can be a discord in the alignment of the aforementioned. As these goals can be highly contradictory, SOEs have to face some uncertainty in connection with making investment decisions; especially because politicians can change their positions depending on the prevailing public opinion. With various political motives, the decisions of the supervisory council may also heavily depend on election cycles. Hence, it cannot be assumed that the supervisory council of a SOE will act in the interests of the organization; firstly because the interests of its shareholders are not as clear as in a private company; and secondly, the composition of the supervisory council might be a mixture of the representatives of different ministries and state agencies (Sprenger, 2010). Therefore, while SOEs are embraced by most governments as private entities, they may be subjected to the same problems in terms of addressing risks, uncertainty, accountability and possible corruption as is the case with most investments in the public sector (Osborne and Brown, 2013).

To cope with the aforesaid, SOEs as private entities in the mixed, public-private environment are assumed to develop organizational routines that are dependent on direct or indirect state support (Nelson and Winter, 1982). Consequently, the majority of SOEs are highly involved with the fiscal planning system of the state (for subsidies, investments or as a financial source for the national budget) and the extent of intervention and the assertion of policy goals can also depend on the latter. Hence, from the perspective of political embeddedness, SOEs may benefit from being more closely connected to the state: namely by influencing regulatory policies (Hillman et al., 2004; Lester et al., 2008) and/or by having access to government-owned resources (Xin and Pearce, 1996). However, interaction with the public budget planning system is a double-edged sword as the privatization of SOEs has been closely linked to the high level of public deficit and the need to pay public debt (for Italy's case, see Felice, 2010: 596–601). Consequently, the degree of the fiscal autonomy of these enterprises is especially important, when their investment decisions are being considered. As mentioned above, from the demand-side perspective, SOEs can act as customers who buy a number of products and services, including technology and R&D from the private sector (Toninelli, 2000). However, all this can also tie into further fears of corruption and manipulation that are central topics in the research of SOEs. As such, the state's willingness to divert business goals in order to achieve its own socio-economical interests can be perceived as a danger (e.g., Shleifer and Vishny, 1998).

The problems outlined above make it clear that the appropriateness of SOEs for innovation and development-related policies can hinge on the interaction between the ownership structures, financing and subsequent monitoring mechanisms (see also Wright et al., 2005; Kankaanpää et al., 2014). Lack of control, multiple, vague and sometimes inconsistent objectives and weak incentives to the management of SOEs can turn into serious problems. Consequently, there are many studies that question the effectiveness of government investor activism under political interest (e.g., Ang and Ding, 2006; Gill-de-Albornoz and Illueca, 2005; Mak and Li, 2001). However, these studies do not go beyond corporate governance and traditional agency problems (see Salleh and Ahmad, 2012). Varied contextual issues can have a much more significant effect on the governance of SOEs. Thus, the performance of different SOEs may vary under the control of the same ministries due to the policy preferences of the ruling coalition, the degree of competition within the industry and the level of cohesion in terms of management (Flores-Macías, 2010). Yet, as shown in the discussion below, it is still possible that government ownership has a positive effect on the functioning and success of enterprises and moreover, on the technological field (see Kole and Mulherin, 1997; Sun et al., 2002). This is of course conditioned by the context in which SOEs manifest themselves and evolve: the specific economic environment, the technology in question and the stage of development (Chang, 2011).

2.2. Role of SOEs in economic development

It is obvious that the ownership status of companies makes a difference in their innovative activities both in terms of investment decisions and their time horizons (see Munari et al., 2010; Choi et al., 2011, 2012). Government's longer time horizons, possibly a wider set of S&T policy goals, access to ample incentives and important infrastructure may play an important positive role in innovation-led economic development (Chang 2008). Gu and Lundvall (2006) have argued that the role of SOEs or state-controlled enterprises in transition economies has been considerable due to the legitimacy of state ownership and the presumed political support. For example in Singapore, state equity has been used extensively in companies for high-risk, high-rewards ventures (Straits Times through Yahya, 2005). In China, Singapore and Malaysia, SOEs and government-linked companies have been actively used in economic policy (Feng et al., 2004; Ang and Ding, 2006; Gabriele, 2010; Ying, 2011; Wong and Govindaraju, 2012). Some studies have also emerged in Europe – for instance about France, Finland and Norway, in which SOEs are described as the reasons behind the states' technological dynamism and export successes (see references in Chang, 2008). However, the findings of these studies are somewhat ambiguous and range from the results that show the efficiency of private firms (e.g., Wang, 2005; Lin et al., 2010) to the better performance of SOEs, when in-house R&D and technical capabilities are discussed (e.g., Gabriele and Khan, 2010; Zhang, 2009; Chen et al., 2009). For the most part, contradictory arguments – 'public good' and spillovers versus profit maximization and maximum productivity – are very broadly juxtaposed. When innovation is discussed, the argument has so far been different from conventional business-specific objectives and maintains that R&D investments in SOEs should follow broader national goals and the dissemination of knowledge as a public good (Molas-Galart and Tang, 2006; Munari et al., 2010). However, as we have discussed above, the goals related to 'public good' are in reality merged with the profit maximization goals in SOEs.

There is an increased pressure on SOEs, even in developing countries, to perform in par with private entities, which forces the managers to put much accent on market share and profitability (Liu and Sun, 2005). And yet, while the direct insertion of public policy goals may have a negative effect on the profit maximization efforts, it does not necessarily imply that this will impair the innovation performance or the development of the innovative capabilities of the company on the whole. Studies show that competitive Chinese SOEs act as important vessels for building up innovative capabilities over a longer period of time (e.g., Hu and Jefferson, 2004; Girma et al., 2009; Tian and Estrin, 2008; Chen et al., 2009; Gabriele, 2010; Hou and Mohnen, 2011; Schwartz, 2009). These SOEs have complex networks within the innovation system, which comprise universities, research institutes and other public enterprises as well as privately owned and foreign-funded industrial firms (Gabriele and Khan, 2008; Niosi, 2008). Nonetheless, it would be hard to imagine that the strategies implemented in Chinese SOEs for the outsourcing of technology could be extended to a wider range of companies outside of SOEs (Motohashi and Yun, 2007) under purely profit maximization goals.

In this line of analysis, SOEs can be regarded as hybrid entities, partially commercial and partially government agencies, which may vary considerably in their policy mandates from national security to the formation of backward and forward linkages for industrial development through the creation of demand or subsidized supply (these goals are already outlined by Hirschman, 1958). Hence, SOEs can have a role especially in demand-side policies, in the so-called 'mission-oriented' R&D policies (Ergas, 1992) both in supporting knowledge creation and the acceleration of the adoption of technologies (Foray et al., 2012). This is very apparent in the case of Gazprom (Goldman, 2008) and other 'mission-oriented' SOEs, particularly in the case of energy companies: e.g., PDVSA in Venezuela, (Mares and Altamirano, 2007); CNOOC, Sinopec Group and CNPC in China (Chen, 2013); Petrobras in Brazil (Dantas and Bell, 2011); StatoilHydro in Norway (Gordon and Stenvoll, 2007); Eskom in South Africa (Krupa and Burch, 2011; Bekker et al., 2008). Access to a larger pool of financial resources for internal R&D is certainly positive considerations for state ownership.

In terms of policy, SOEs can be understood as a way chosen by governments for implementing their economic policies. Their direct connection to companies' activities can help increase innovative capabilities within industrial policy in a more immediate form: through the direct funding of large-scale R&D projects within enterprises or connected public institutions, which are usually target-specific (see Sakakibara and Cho, 2002). In this case SOEs can be seen as a specific way to organize government's policy; as formal organizations they are both the objects and agents of change. The underlying factor is that SOEs can function as capitalist firms and can play a flexible role both in terms of scale and inputs in bringing forth structural changes in very different economies. This means that there should be a balance by which state-owned enterprises follow the guidance given to them by their shareholder; the government should provide direct instructions and some flexibility in terms of targets and actions. However, all this calls for a high level of policy coordination on the part of the government. This raises a much wider problem with regard to SOEs, because they have lost their place in policy-making with the decline of industrial policy and the rise of separate innovation and entrepreneurial policies (see e.g., Noland, 2007). Decentralization and policy autonomy increase problems of coordination, accountability, adaptability and flexibility (Karo and Kattel, 2010). This is important in considering the objectives, investment time horizons and their effect on the innovative activities and R&D subject to ownership.

2.3. SOEs in innovation policy management

If we draw the aforementioned discussion together, diverse interests collide. On the one hand, changing public opinion greatly influences the role of SOEs in innovation policy; and on the other hand, there is a need for reliable, long-term investments in particular for high-risk undertakings so the benefits of state ownership could manifest themselves. There is a risk that the performance of SOEs is evaluated mainly based on how they follow short-term political interests in direct service-related goals, including affordable consumer price levels (social welfare premise), whereas in terms of innovation, these factors may cause lock-in and underfunding. Meanwhile, profit maximization expectations require maximum return on investment and on par performance with the private sector companies. Conversely, R&D projects – at least in the beginning – usually create negative cash flows to enterprises. This can also force companies to focus on short-term goals, if public fiscal planning goals dominate over the SOE's investment strategy. R&D projects involving high-risk and high-reward investments may often fall into what is known as the 'valley of death' through losing funding before their commercialization. This affects in many cases larger SOEs primarily in infrastructure-dependent industries, such as energy utilities (e.g., Balachandra et al., 2010). The higher the dependence on the public budget and the need for SOE's dividend payments are, the lower the level of support for long-term, high level investments is.

And yet, when there is policy coordination between direct SOE-policy goals and innovation/industrial policy, we can anticipate the longevity and stability of investment and possibly better conditions of obtaining financial resources for the investment from the market or elsewhere. Coordination may be strongly led through a 'mission' of high public value, such as climate change, where different interests may collide. However, if the coordination and possible control of SOEs is low and the performance indicators set by the public sector vary a lot, we can also expect SOEs to respond accordingly. In these cases it may happen that SOEs become more independent in responding to differing short-term goals; information asymmetry between the owner (state) and the company will increase, and thus, the company will take *de facto* control over investments decisions.

The above considerations are currently not discussed in academic literature and for the latter, a new theoretical framework and empirical methodology should be outlined. These different considerations can be exemplified the simplest way in the interdependence approach presented in Fig. 1. Depending on the composition of these different factors – actively applied innovation policy goals (policy utilization), policy coordination (alignment of policy management through SOE and other S&T policies, etc.), the public sector's budgetary concerns and therefore low risk tolerance (through the high visibility of returns on investment) and profit maximization – it can be expected that the outcomes to innovation policy management in SOEs will also be different. An example of the aforementioned is presented in Fig. 2.

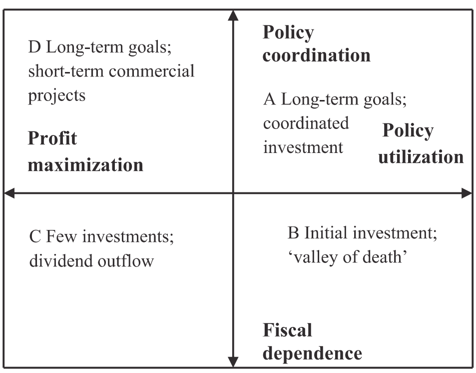

Fig. 1. Factors influencing SOE's innovative performance.
Source: Author.

Further, we will illustrate the framework through an empirical example. Based on the case of an Estonian state-owned energy company, Eesti Energia, the importance of these considerations will be explored further, which will help us move towards a new theoretical framework for the study of SOEs in innovation policy. To begin with, a short overview of the Estonian policy context (both innovation and energy policy and also SOE governance) will be presented and then the case of a state-owned energy company, Eesti Energia, will be discussed. As it is a 100% government-owned and dominant company in a 'vital' industry, it could be classified as a 'key case' in a 'theory testing' approach (see further Thomas, 2011; George and Bennett, 2005). To eliminate potential research bias (Johnston et al., 1999) – distraction from internal and external validity – several outside researchers were asked to review the findings during the writing process. Although the use of several case studies might have increased the external validity of the findings (Yin, 1994; Eisenhardt and Graebner, 2007), the context of the case is the key in relation to the theoretical approach proposed above and thus a single, in-depth case is more advisable (Dyer and Wilkins, 1991). Furthermore, we combined different methodologies for analyzing the case of Eesti Energia and triangulated data from different sources in order to increase the validity of the study: several collaborative sources for analysis were found to minimize the risk of single data sources, which influence interpretations.

Therefore, a combination of in-depth interviews (quantitative and qualitative data) and document and data analysis was applied. Three different overlapping questionnaires, which included both pre-defined answers and open questions, were used during the interviews: questionnaires specific to company representatives, public officials and researchers/experts. In addition to the company contact, interviews were carried out in the SOE's main R&D unit, renewable energy project team, environmental and service quality units. Next, a snowball method was applied in order to identify experts and research contacts who had close contacts with the SOE (all of them turned out to be associated with Tallinn University of Technology, the main research institution that explores energy technologies in Estonia). After that, interviews were carried out with the Estonian Development Fund who is responsible for the preparation of the new Energy Action Plan until 2030+, the Estonian Competition Authority, the Ministry of Finance and the National Audit Office (overview of all interviewees is provided in the Appendix). For additional retrospective analysis, a wide selection of parliamentary records between 1992 and 2013, policy documents, company's financial records and financial statements were used. The case is presented in line with the considerations in Fig. 1. The case study is followed by a short discussion of the proposed theoretical framework.

3. Innovation policy through SOEs: the case of Eesti Energia

3.1. Estonian policy context

There are many studies that look into the transition of companies from the statist, planned economy system to a free market one in Central and Eastern Europe (see e.g., Behrman and Rondinelli, 2002; Tomer, 2002). During the Soviet era, the planning mechanism of S&T policy was integrated into industrial policy and a varied mix of policy actors – all under the control of the state – participated in the complex system of planning and cooperation (Radosevic, 1998, 1999). Research institutes had very good first-hand knowledge of the production processes and strategic actions as within the functional model they bore full responsibility for conducting and coordinating industrial R&D (Beblavy, 2002). This changed in the early 1990s, when Estonia opened its markets and

Proposition 1.	Greater fiscal dependence – more attention to short-term efficiency goals (B; C).
Proposition 2.	Greater fiscal dependence but with some policy utilization – higher public scrutiny of investment and possible discontinuance of investment (B).
Proposition 3.	Greater fiscal dependence and focus on profit maximization – focus on SOE 's dividend and cost policy (C)
Proposition 4.	High policy coordination – long term investment goals (A; D)
Proposition 5.	High policy utilization and coordination, insignificant fiscal dependence on investment – higher probability of long-term coordinated innovation investment (A).
Proposition 6.	Higher profit maximization goals, low policy utilization, higher policy coordination – long - term goals, short-term investment (D)

Fig. 2. Propositions for innovation policy management in SOE.
Source: Author.

liberalized its economy. The reaction against the previous regime – planned economy – resulted in a turn towards another regime, laissez-faire economy, where calculated state intervention in the functioning of the market was discouraged (Feldmann and Sally, 2002; Venesaar, 2007). Hence, Estonia has been identified as a state with a strong preference for market measures and very weak corporate structures; Estonia has also been governed by neoliberal coalitions for the past twenty years (Raudla and Kattel, 2011; Kattel and Thorhallsson, 2013). The attraction of foreign direct investment (FDI) was therefore the prevalent goal in the 1990s in terms of an entrepreneurial policy, as there was no industrial policy to speak of (Török, 2007: 265). Thus, the steps taken to promote entrepreneurship were primarily measures, which had a direct effect on the cost-efficiency (reducing the cost of capital) of companies, and in a liberal frame, this was expected to create opportunities for gaining additional revenues and for seeking further productive investment opportunities.

Against this background, Lember and Kalvet (2014) describe the evolvement of Estonian innovation policy as a road from 'no policy' policy in the beginning of the 1990s to a 'linear'/R&D-based adoption of policies in the beginning of the 2000s with the accession to the EU and this was followed by a more modern mix of policy tools in the middle of the first decade of the 21st century. However, policies that are constructed to be non-selective or market-oriented may tend to support sectors that are already there and may therefore strengthen the existing production structure. Thus, a systematic entrepreneurial policy, which included strategic control over the R&D activities of SOEs was not on the government's agenda, as this would have equated with the state's interaction with the economy – a narrative that had strong negative connotation in public debate. The policy approach to the innovation system mostly emphasized high technology policies and the emulation of the developed economies of the EU (Radosevic, 2009; Suurna and Kattel, 2010). At the same time, sector-specific innovation measures were very low and demand-based policies not used at all (Karo and Kattel, 2010; for a recent overview of the Estonian innovation system, see Christensen et al., 2012). Thus, there are problems of coordination and the lack of inter-linkages within the policy fields within the Estonian innovation system (Karo and Kattel, 2010).

As regards innovation in the Estonian energy sector, the field is heavily dependent on the oil shale-based energy production. While the government has tried to diversify energy production towards renewable energy sources due to the pressure from the EU, the country intends to continue using oil shale in electricity production (see further in Tõnurist and Valdmaa, forthcomimg). Furthermore, there was no considerable pressure from the government to switch to renewable energy: the first environmental protection law was adopted and environmental pollution charges were established in 1990, but, they were not substantial enough to introduce a change in the energy sector that was under the control of the government (Valdmaa, forthcoming). As the sector is still dominated by one government-owned company – Eesti Energia – energy policy issues have also centered on the company. However, in parallel with the aforementioned policy developments, the dismantling of the planned economy and SOEs were high on the agenda in the 1990s (Tiits et al., 2008).

Within Estonia's market-liberal transition model of outsider-oriented strategy, privatization with a preference for foreign capital was implemented under the overall goal of 'efficiency improvement' (see Lust, 2009; Bieling and Deckwirth, 2008), a traditional narrative in the privatization of firms (see review in Sheshinski and López-Calva, 2003). The general logic of the Estonian privatization process, contrary to Russia and some other Central and Eastern European countries (e.g., opting for employee buy-out schemes), was to sell majority control to outside investors, often foreign enterprises. By 1995, the majority of publicly owned companies were privatized and the FDI-oriented strategy opted for. Most industrial and service-oriented SOEs (Eesti Gaas AS (Estonian Gas Ltd.) among them) were privatized by international tenderers and almost no shares were set aside for 'insiders' (employees of the company, domestic buyers, etc.) in the process. By the end of the 1990s, approximately 80% of previous SOEs had been privatized and more than half of the country's generated exports originated from firms with foreign capital infusion (Santalainen et al., 2011). Thus, by the beginning of the 2000s it was clear that the government's support to SOEs was rapidly disappearing and managements of most companies were forced to adopt strategies in order to optimize resources and reduce costs. This also meant that SOEs were ignored in terms of the new innovation-entrepreneurial policy-mix and subjected to the afore-discussed logic of efficiency. As the electricity production is still under the control of the government, 25% of all state assets are owned by SOEs in Estonia (National Audit Office, 2013). However, there is no common, formal document regarding the ownership policy of the state in Estonia apart from a broad-based State Assets Act (National Audit Office, 2007, 2013). SOEs are overseen by sectoral ministries that have regulatory competence in their field of activity. Specific societal obligations, at least in the official governance rules, are imposed only through laws and regulations (the overall structure of SOEs in Estonia is also described in OECD, 2011). Their financial accounting and investment decisions are monitored by the Ministry of Finance. The mandate of ministers to issue direct instructions to the directors of SOEs has been repealed and at present, governmental intervention takes mainly place through a two-tier management structure of companies. The Government may grant subsides to SOEs, but as a form of state aid, they are subject to the control and rules of the European Commission (although, some loans have in prior years been issued to SOEs through the Ministry of Finance).

3.2. *Eesti Energia Ltd.*

Estonia is unique in the sense that it is the only country in the world, where the main source of electricity depends to the extent of 80% on the combustion of oil shale (kukersite) (see Table 1). Russia, Brazil and China have small-scale development projects and Jordan, Mongolia and Turkey have started R&D in the field

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

	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011
Production of primary energy	132,389	131,999	140,265	162,400	154,123	160,563	155,265	180,852	175,374	172,995	205,080	208,863
Oil shale	108,330	106,183	111,103	132,096	124,121	129,423	125,022	146,747	142,956	134,455	161,401	166,731
Oil peat	3345	3427	6416	3531	2678	3550	4726	4405	2174	3492	3680	3308
Firewood	20,617	22,279	22,608	26,592	27,132	27,170	25,044	29,119	29,593	34,060	38,668	36,154
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

(Doyle, 2008: 26). Thus, contrary to the rest of the world, the models implemented for forecasting the development of the energy sector in Estonia still include oil shale as the main source of energy at least until 2030 (e.g., Dementjeva and Siirde, 2010; Vali, 2014; for global trends in oil shale use, see Brendow, 2009). The mining of oil shale started in Estonia already in 1918 and the first shale oil plants were opened six years later (Enefit, 2012). The sole owner of the company is the Republic of Estonia: until the end of 2012, the SOE was under the governance of the Ministry of Economic Affairs and Communication (MEAC) and since 2013, the Ministry of Finance (MoF) exercises the powers of the shareholder. The core of the current SOE was founded in 1939 and it has been produced shale oil for the last 30 years. The SOE itself was established in 1998 by merging more than 20 subsidiaries of energy production in Estonia. The company is also one of the largest employers in the country (with a workforce around 7500 people).

At present, the SOE operates the world's largest oil shale power plants (2.380 MW), which are owned by Eesti Energia Ltd. (Enefit, 2012). The capacities of thermal power plants (PP) Eesti and Balti are the highest and the former is the largest electricity producer in the country, providing 75% of the total production output in Estonia (Kuhi-Thalfeldt and Valtin, 2011). However, these PPs are largely run on an ‘old’ pulverized-fired technology, which is considered to be environmentally dangerous (Blinova et al., 2012). As the SO_2 emissions of the plants did not comply with the requirement of the EU directives, second-generation oil shale units and fluidized-bed combustion technology were subsidized in order to minimize environmental pollution (Väli, 2011; Karu et al., 2008). Until 2011, the government operated under the assumption that after 2015, approximately 70% of the out-dated power generation capacity based on oil shale should be closed down (Kuhi-Thalfeldt and Valtin, 2011). But the European Commission alleviated the conditions set up by the directive concerning integrated pollution prevention and control (2008/1/EC), which made it possible for the older power plants to operate until 2023.

During its relatively long industrial history and considerable experience in updating its out-dated technology, the SOE has acquired significant capabilities in oil shale technologies. This decades-long experience in oil shale extraction and combustion has resulted in the development of a new technology. The retort technology of the 1950s (Galoter) has been replaced to the extent of 70% of the initial technology and was in 2005 patented under a new name – Enefit140. It is the predecessor of the company’s most recent patented technology, Enefit280, which was developed in 2009 to minimize environmental damage and to compliment shale oil production (Enefit, 2012). However, Enefit280 is a complementary technology that helps the company extend the life-span of oil shale-related capabilities owned by the SOE. To pursue the further development of Enefit280, a new partnership with a Finnish-German company Outotec was launched in 2008 for the development of a new solid heat carrier and in 2009, a joint venture under the name Enefit Outotec Technology (EOT) was established.

Thus, Eesti Energia presents an interesting case for innovation policy with two main and somewhat contradictory lines of argument: firstly, the potential to solve environmental issues and to introduce renewable energy technologies through the *de facto* monopoly (which will eventually diminish the market power of the oil shale-based SOE); and secondly, the possibility to attract financially lucrative investments at global scale based on a new innovative technological solution for shale oil production (Enefit280), which would strengthen oil shale-based R&D and development. Both of these solutions could function as the enablers of the diffusion of technological capabilities in Estonia (e.g., through joint ventures with research institutes and the procurement for innovation). Such cases have been discussed above in terms of an ‘active’ industrial policy pursued by the Chinese government. In Estonia, the expansion of the sector and related engineering works could have a considerable effect on economic growth as the value added in the sector per person is four times as high as the average in the manufacturing sector (see Table 2). In 2011, SOEs – first and foremost Eesti Energia – invested more money than all the investments made from the national budget taken together (Interview R; National Audit Office, 2013). The company itself has predicted that in the upcoming years, it will account for an increase of 1 to 3% of the GDP (Vals, 2014).

However, as Eesti Energia is one of the largest companies in Estonia, it is also subjected to other interests, such as profit maximization and increased dependence from the public budgeting cycle. To establish the extent to which these policies are followed in Eesti Energia, factors such as policy utilization and coordination, fiscal dependence and profit maximization (see Figs. 1 and 2 in the theoretical framework) will be discussed below.

3.2.1. *Innovation policy utilization*

The central strategy of the SOE today is oriented towards the extraction of liquid fluids from the mined oil shale and the technology required for the aforesaid (Eesti Energia, 2012a). This is deemed to be a solid strategy, as it has the potential to create a large growth spurt for the company (Interview F; D). The production of shale oil had increased from around 200,000 barrels a year in 1991 to 1.2 million barrels in 2011 (Eesti Energia, 2012a). While the strategy is also supported by the Estonian Government in terms of its goals (Interview P), no serious commitments with regard to substantial investments needed to pursue this strategy worldwide have officially been made so far (Interview R; National Audit Office, 2013). An interesting fact in this regard is that the supervisory council of the company that is controlled by the government (in prior years by the MEAC, now by the MoF) has in the past seven years refused to officially approve the strategy of the SOE (Interview P; R). Nevertheless, the company has got the green light for its initial projects and was also authorized to buy the rights of mining oil shale outside of the country.

In 2012, the SOE launched the commission of a new Enfit280 oil plant and it has plans for two other plants and for the production of diesel fuel from oil shale as of 2016 (Enefit, 2012). By that time,

Table 2
Enterprise value added and productivity measures by economic activity.
Source: Statistics Estonia, 14 May 2013.

		2005	2006	2007	2008	2009	2010	2011
Economic activities total	Number of persons employed	436,536	463,690	484,926	476,885	417,281	400,127	414,456
	Value added, thousand €	6,397,987	8,061,103	9,366,503	8,897,328	7,264,327	7,832,386	9,428,049
	Labor productivity per person employed on the basis of value added, thousand €	14.7	17.4	19.3	18.7	17.4	19.6	22.7
	Total productivity on the basis of value added	0.22	0.23	0.22	0.21	0.22	0.22	0.22
Manufacturing	Number of persons employed	127,001	128,237	127,988	120,923	98,804	95,831	100,127
	Value added, thousand €	1,533,972	1,849,886	2,211,698	2,152,985	1,582,044	1,903,831	2,296,821
	Labor productivity per person employed on the basis of value added, thousand €	12.1	14.4	17.3	17.8	16	19.9	22.9
	Total productivity on the basis of value added	0.26	0.27	0.28	0.27	0.26	0.26	0.24
Electricity, gas, steam and air conditioning supply	Number of persons employed	6930	6655	6488	6290	5874	5681	5671
	Value added, thousand €	291,297	424,441	317,182	299,208	423,117	445,799	475,111
	Labor productivity per person employed on the basis of value added, thousand €	42.1	63.8	48.9	47.6	72	78.5	83.8
	Total productivity on the basis of value added	0.31	0.41	0.25	0.2	0.31	0.27	0.28
Production of electricity	Number of persons employed	2709	2627	2617	2497	2345	2275	2256
	Value added, thousand €	128,326	236,394	109,231	93,245	188,563	171,393	205,937
	Labor productivity per person employed on the basis of value added, thousand €	47.4	90	41.7	37.3	80.4	75.4	91.3
	Total productivity on the basis of value added	0.26	0.49	0.17	0.13	0.31	0.21	0.26

the company intends to produce 22,000 barrels of shale oil a day in Estonia and half of it should be Euro V compliant ultra-low sulfur diesel (ULSD, usable in automotive transportation). The probable amount of shale oil produced in the world is estimated to be around 2.8 trillion barrels, which is several times more than the estimated oil reserves from conventional resources (Ots, 2006). In addition, the company owns oil shale mining rights in Estonia, Jordan and the US and will build up its production capacity in all three countries accordingly (at first in Jordan and by 2020 also in the US, Utah; and will make preparations for search projects for 'resources to reserves' in Serbia, Australia and Brazil).

While this would present a good opportunity for utilizing the knowledge from the local research base (having longstanding experience with oil shale-related R&D), the company has allegedly tried to detach the core R&D in connection with Enefit280 from the local research institutes (Interview F), first and foremost from the Faculty of Power Engineering of Tallinn University of Technology (Interviews G; H; I; M; O). One of the prevalent concerns referred to by the research partners is the SOE's fear that in a very small country, the research units who work together with their direct competitors who produce oil from oil shale (e.g., privately-owned VKG (Viru Chemistry Group)) may present too high risks for the core knowledge of the company. Thus, in the last decade, the cooperation with local researchers has mostly continued in the form of updating the older PPs, in performing local measurements and in providing highly skilled engineers and PhDs in the field to the SOE, but the core R&D is procured from foreign research units in Canada and the US (Interview H). The cost of this is considerable. The procurement procedure implemented in the last 10 years has been described by previously involved researchers as a 'turn-key' investment (Interview K), meaning that the SOE will get a fully functioning plant, combustion unit with the warranty, which means in turn that it is pushed even more to order repair work from outside. This also complicates the collaboration with local R&D units as they were generally the ones who tested the machinery and performed tests for scientific purposes. From 2009 onward, with the establishment of the EOT joint venture, R&D activities have been transferred to the partner's R&D laboratories in Frankfurt, Germany. Thus, while the core technology (Enefit280) originates from the SOE, the R&D capacity now lies with Outotec (including in-house R&D laboratories, engineering teams, pilot testing facilities, advisory and operational assistance, Eesti Energia, 2012a; 2012b). Consequently, the second generation technology for the projects in Jordan and the US will also be provided in full by the EOT. This has already presented some problems in terms of the development of the company, as foreign partners are proven not to be flexible in both financing the technology and ensuring its reliability (Reimer, 2014; Interview P). Thus, the capabilities of evaluating the need for R&D investments have also diminished.

3.2.2. Policy coordination

While the main goals of the SOE in terms of technology are connected to shale oil production, the day-to-day interest of the owner, i.e. the government, is electricity production. In 2013, Estonia entered the open electricity market on the Nord Pool Spot market and while the electricity price has now been taken out of the hands of the politicians and the SOE (previously it was decided by the negotiations between the former two parties and the Competition Authority), the main concerns of the company in the short term are still the price of electricity and the security of supply (Interviews B, F, P). In the long run, the main three factors that influence the strategy of Eesti Energia both in terms of electricity and oil production are climate policy, stricter environmental regulations and resource policies, primarily oil shale mining policy (Interview D). While it is generally acknowledged that the production of electricity from oil shale is "environmentally one of the most harmful ways imaginable" (Interview D), there is no clear plan on when and if oil shale-based electricity production will be phased out (the marginal cost of oil shale will increase especially due to high CO_2 emissions). Clear decision on the latter issue has been postponed as the recent shale gas boom has also sparked a revival of other traditional energy sources, e.g., coal consumption in Europe is expected to grow at least until 2017 (IEA, 2012) and at present, oil shale resources are also researched in China and in the US in light of high oil prices (Jiang et al., 2007; Crawford et al., 2008).

In the long run, however, in view of both heightened climate policy concerns and stricter EU regulations, the decline in the proportion of oil shale is also expected to be influenced by the rise in wind energy and the use of natural gas and biomass (Roos, 2009). Indeed, Eesti Energia has bought into small-scale wind park initiatives, started its own projects and initiated renovations in its plants to include CHP capacities for biomass (Interview E). However, no clear investment plan towards renewable energy sources has been made (Interview R). The inclusion of biomass with the sulfur capture installations in the PPs can be understood as the SOE's strategy to extend the useful lifespan of current infrastructure without further commitment to large-scale oil shale electricity production in light of high political uncertainty (Interview D). Hence, the main reason for postponing investments outlined by all representatives of the SOE is the lack of a clear vision from the owner. Furthermore, the government's strategic vision extends only to 2020 or to 2030 maximally (ENMAK, 2013), which is too short in terms of the long-term investments of Eesti Energia. The SOE makes investments in oil shale-based PPs with the perspective of the next 40 years and in wind parks with the perspective of the next 20 years (Interview D).

This means that the investment decisions made at present have very high sunk costs and may lock the company into a very specific developmental path. This might create a situation, where gradual investments made by the company would designate the entire energy policy and would make it too expensive to move away from oil shale-based power generation due to the infrastructure constructed. So, Eesti Energia has updated the oil shale production capacities in Narva and Eesti PP (by fitting in new units and adding equipment for the capture of sulfur and nitrogen emissions) and will also go ahead with investments to build two new oil shale PP blocks in Auvere that will conform with the environmental standards. This will be the largest one-off investment of the Estonian government in its history. The MEAC steamrolled the investment decision through the Government by referring to energy security concerns although the SOE itself was initially strongly against the investment (Interview D; E; P). At the end of 2010 and again in 2012 it was revealed that the economic evaluation of the economic feasibility of the project was not correct and there was a very high risk of negative return on the investment (National Audit Office, 2010; Vedler, 2012; Interview P). The SOE will not be able to sell the electricity produced from its new installations under open market conditions. Considering the global trends towards renewable energy sources, these large-scale investments may prove to be financially highly unreasonable. Thus, the main fear of the SOE is that in five or 10 years, the government's vision may change again and this would put the finances of the company at risk (Interview D; E).

As mentioned before, the government has defended the investments by referring to energy supply security as the main reason (Vabariigi Valitsus, 2012b). Thus, energy security concerns are ranked very high in Estonia (Parliamentary debates between 1992 and 2013) and at the moment, the oil shale PPs of Eesti Energia provide full energy self-sufficiency to the country. The energy dependence rate is 11.7%, which is among the lowest compared to the EU27 average of 53.8% in 2011 (Eurostat, 2013). As a consequence, the commitment of the government towards renewable energy is on the whole very low and there have been several conflicts between interested ministries: the MEAC, the Ministry of Agriculture and the Ministry of the Environment. In October 2012, the government decided to reduce renewable energy charges as of 2013 by 15–20% on the proposal of the MEAC (Vabariigi Valitsus, 2012a). In terms of renewable energy developments, the Government of Estonia has therefore been seen as an unreliable partner with no clear preferences: the use of oil shale PP and renewable energy sources are both periodically promulgated (Interviews A, D, E, F). At the same time, overextending investments in PPs may hinder the SOE's plans for shale oil production, where biggest growth is expected and which could also lead to a high increase in skilled labor and GDP in Estonia.

These concerns are not readily discussed in Estonian policy-making (Interview P), as it would imply to the state's active role in industrial policy (e.g., the possible increase in employment was almost left out from the models that were developed with the aim of putting together a long-term energy strategy for 2030/2050) (ENMAK, 2013). The case with the international projects of Eesti Energia is totally different: the possibility that the venture in the US, Utah, would create up to 2000 high-paid jobs is widely promoted for local political support (Loomis, 2011). On the other hand, the lack of skilled workforce can be a serious setback for industry changes (Praxis, 2011). If the shale oil industry is developed further, foreign high-skilled labor has to be brought in, which is probably more realistic from non-EU countries and this would create further problems to the conservative government that has been in power for more than 10 years.

3.2.3. *Fiscal dependence*

Eesti Energia has a high degree of freedom to act, but it does not get any direct guidelines from the government with regard to clear investment policy (Economic Affairs Committee, 2013; Interview P, R). While it is usually the problem of stock markets, which are accused of being myopic and of maximizing shareholders' dividend profit at the expense of R&D investments (see Clifton et al., 2010; Salies, 2010), the short-term commitment of the Estonian political elite can be described in the same manner. There have been rumors that in the upcoming years, the equity capital of Eesti Energia should be increased to more than 1000 million euros from the public funds (the CEO has mentioned 700 million euros in the press; Liive, 2012). Although the company has been profitable for the last decade, it does not suffice for the investments planned by the company: on average, the company invests over 500 million euros a year with a very small proportion of international investments (see Fig. 3). So far, the SOE has made most of its investments with borrowed capital and has raised more than 400 loans in the amount of 733 million euros between 2011 and 2012. For the MoF, which has low capabilities for controlling the SOE, the SOE's applications for outside capital and their subsequent evaluations by foreign financial institutions have been a measure by which to evaluate the health of the company (Interview P). However, with the current dept capacity, only the owner's contribution to equity would help keep up investments, especially in the shale oil industry. While SOEs have been notoriously used for government spending and dept collection (Blondy et al., 2013), in the past, due to strict state aid rules, funds have been allocated to Eesti Energia through free CO_2 emission quotas; in the future, between 2013 and2019, the SOE will receive 94% of all emission rights valued around 308 million euros (National Audit Office, 2012). Large capital injections through the state budget are, however, 'painful' to the politicians and hard to explain to the public, especially in view of rising electricity prices (Interview P). The national financial strategy (2014–2017) does not plan these investments in advance. This adds to the high level of uncertainty from the perspective of the SOE.

With the possible oil production under discussion since the end of the 1990s (Riigikogu, 2011, 2010) and considering the fiscal strain, this might present problems to the government famous for the lowest gross dept statistics in Europe (see also Kattel and Raudla, 2013). There have been waves of debates around the possible privatization of the company and/or inclusion of foreign capital. At the end of the 1990s, the government already tried to unsuccessfully privatize the oil shale power plants and started closed negotiations with a US-based company, NRG Energy Inc. (Riigikogu, 2000a,2000b; Lust, 2009). The sale was opposed to by energy experts, opposition politicians and even by the supervisory council of the SOE; it was believed that NRG would generate unreasonably high profits and harm Eesti Energia at the same time

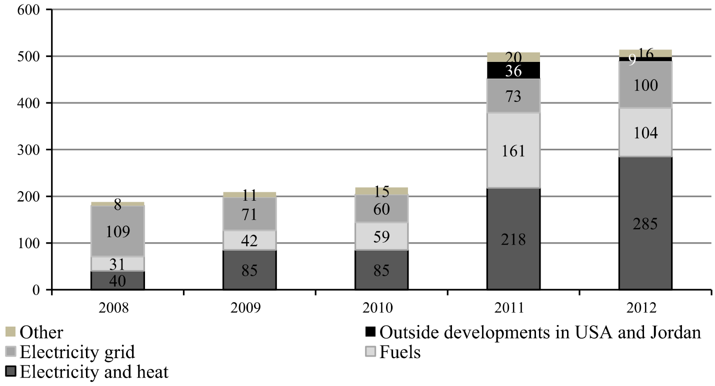

Fig. 3. Investments of Eesti Energia Ltd. (million €).
Source: Author based on Eesti Energia (2013).

by potentially bankrupting the company (Riigikogu, 2003; Kokk and Vedler, 2000). After 2006, the international strategy of oil shale production became a reality under the new management and once again, the company needed high levels of investment and quick capital inflow, which it did not have. This resulted in the second attempt towards the inclusion of private capital, which was made in 2009 and in 2010. The plan was to get 1.300 million euros from stock exchange in order to finance the expansion of shale oil production; to succeed, the SOE had even threatened to move the oil production to a neighboring country Russia, if additional investments were not given to it (through CO_2 quotas). The proposal for an IPO regarding one third of the SOE was made by the MEAC, which was severely criticized by the National Audit Office (2010) and finally called off due to the lack of critical information in the accompanying analysis submitted to the Government. Henceforth, the momentum to push the plans presented by the SOE through has been high and the talks around dismantling the operations and separating the oil production or even selling the latter altogether still linger (Riigikogu, 2013).

Meanwhile, external partners in the initial phases of the projects have already incorporated for the shale oil production: starting with the EOT and followed by international projects, for instance in Jordan (the SOE owns 56% of the project, however, decision-making powers have been given over to the Malaysian partner, who requested that no strategic decisions be made by the SOE as part of its agreement to join the undertaking; Vedler and Vahter, 2013). This has led to speculations that while the public listing of the company was denied by the Government in 2009 through the inclusion of partners to the oil production (first by selling 40% of Outotec and secondly, through the international partners included in the Jordan and the Utah investment), the most valuable part of the company today has been 'self privatized' (Christiansen, 2013). This in effect diminished the control of the state over the company. As the SOE now relies on the decisions made by its outside partners, it has become harder for the Government to 'interfere' with the company's long-term strategic plans, because due to future losses, it is almost impossible to renounce the investments already made.

3.2.4. *Profit maximization*

To complicate matters further, the pursuits of efficiency and profit maximization have not bypassed Eesti Energia either. Dividends from the SOE, along with the dividends from another SOE, Port of Tallinn, have been a source of extraordinary funds

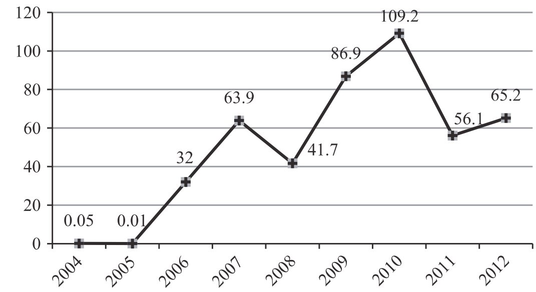

Fig. 4. Dividends paid by Eesti Energia to the national budget (million €).
Source: Author; based on annual financial statements of Eesti Energia Ltd., 2004–2012.

for the national budget in the past years (State Budget Strategy 2014–2017). Dividends from ownership stakes in Eesti Energia are considerable in proportion to the state budget of Estonia. Dividends increased substantially after 2006 and reached the highest point in 2010 during the peak of the economic crisis (see Fig. 4). Over the years, this has taken the form of the government's 'request' to pay out a pre-determined amount during the fiscal planning year that the SOE has to accommodate with (financial statements from 2006 to 2012; Interview F, P, R). While public equity endowments and indirect influence on the rating of the company might have a positive effect, this can also clearly diminish counter-cyclical investments into the SOE during the downturn of the economy. Thus, during the period of the last economic crisis, the dividend outflow (C) – with little regard for future investments and difficulty in broadening the equity stake – has also been characteristic of the SOE's and its owner's rapport. Thus, the company is pressured into maximizing its profits in the short term in order to alleviate the fluctuating needs of the state budget. It is difficult for the neoliberal government to acknowledge that the SOE has been a source of exceptional revenue during the crisis and that combined with the future investments, it could increase and also create high skilled employment (Interview P). Additionally, the SOEs has also paid the state on average of 18 million euros of environmental charges in the last three years (CSR report, 2012).

This is in conflict with the future investment plans and also with the main public concern – electricity price. Before 1996, when discussions over the privatization started, debates in the

Parliament of Estonia (based on the stenographic records of the Riigikogu between 1992 and 1996) primarily concerned the price of electricity or heat or the level of debts that the SOEs in the sector had accumulated. While new topics have emerged, these two issues – utility prices and the salience of the company's finances (conservative risk management) – have remained the main discussion topics in the public media and the parliament (Interviews B; C; P). Presented with highly conflicting goals – utility pricing and profit maximization for the national budget (and the additional investment need) – the owner, i.e. the government has put the blame for price increases solely on the company and thus "undermines the SOE in order to win short-term popularity in the press" (Interview C; Reimer, 2012). At the same time, as mentioned above, the profit maximization goal of the SOE and the goals of the government in energy security where in conflict in 2012 (Vabariigi Valitsus, 2012b), when against the advice of the company, the supervisory council that acts upon a decree of the government approved the building of two additional blocks in the Auvere PP.

Furthermore, while the future profitability of the company has directly been tied to the increasing proportion of shale oil in the company's production, these investments may not be in alignment with public risk tolerance. For example, the risks associated with the SOE's project in the US were downsized or miscalculated in the presentations to the company's supervisory council in 2010 and although the supervisory council voted against the project at first, the top management of the company was able to convince them of the opposite in the following months (Vedler and Vahter, 2013). In 2012, it became clear that the Utah oil shale was not compatible with the current Enefit280 technology and the initial probable loss of the project was estimated to be 100 million US dollars (Vedler and Vahter, 2013) – a considerable sum of money given the total investment capacity of the company (ca. 500 million euros per year). The project in the US seems – at the moment – to have succumbed in the 'valley of death,' a perilous stage right before market introduction, when high investment costs related to the building of production capacities skyrocket. This phenomenon in the innovation investment chain is well documented (see e.g., Murphy and Edwards, 2003). It is quite common in terms of energy technologies as the sunk costs are very high and the results of R&D are confined to the early demonstration stage, not capable of moving into pre-commercial trials (Foxon et al., 2005; Winskel et al., 2006). This problem does not occur only in developing economies, but is also prevalent in other EU countries (e.g., for the case in Netherlands, see Negro et al., 2012; for the case in Sweden, see Jacobsson and Bergek, 2004). Furthermore, smaller, local investments have been under a lot of scrutiny and have received negative attention (Riigikogu, 2013). Due to the public storm of indignation over the investment decisions of Eesti Energia, which may simply be the company's 'business as usual', the partial privatization of the EOT may be called for. This, however, would mean that the Government of Estonia would receive a one-off endowment of cash from its investments, and the company's shale oil production operations would be sold abroad. This would mean that all presently existing synergies with the research institutes and local production units in Estonia would probably lose their importance too.

4. Main findings and discussion

Eesti Energia Ltd. presents a case of a SOE that is a large energy magnate in a small country and has a strong influence on the innovation in the energy sector. One could even say that the latter depends on the investment capabilities and strategic actions of the company. However, due to the small size of the energy market, a lack of considerable competition and energy security concerns, the company and the Estonian energy sector seem to experience a situation of lock-in. While Eesti Energia clearly pursues R&D and innovative investments, there is a serious lack of acknowledgment of these processes and the SOE's role in the innovation policy by the 'owner' and thus, the needs for policy coordination are not recognized either. Returning to the proposed theoretical framework, the current strategic choices for Eesti Energia in terms of innovation policy lie within the lower two quadrants (B, C) of the matrix presented in the theoretical framework (Fig. 1 in Section 2.3). In this line propositions 2, 3, 6 (see Fig. 2 in Section 2.3) describe the innovation policy outcomes and the environment most aptly. Large-scale investments needed for changing the production of energy do not financially match the possible savings that may coincide with the latter, at least in the short term, and threaten to leave risky, but viable projects in the so called 'valley of death' (B). Thus, the first goal of the company would be to maximize the potential of current energy generation from oil shale and thus contribute to sailing effects in technology investments. Due to serious fiscal concerns and high risk levels it is evident that Eesti Energia seeks to limit the influence of the state on its investments. The company makes attempts to attract 'outside' investment leaders through international projects in order to handle the transformation (for the strategy, see also Baliga and Santalainen, 2006; Choudhury and Khanna, 2014). However, this has at the moment clashed with the institutionalized need to avoid uncertainty in the field of the activity of the SOE, for which high normative values have been set – energy supply security. This is generally an area that is strongly kept under political accountability hierarchies. The emerging general lack of trust in the commitment of the government in its long-term policy choices is therefore found to influence not only the current technology deployment, but also future technological trajectories. Furthermore, maximization goals can become amplified for SOEs due to high public scrutiny as in the case of Eesti Energia, which can influence the duration of an innovative project and lower the acceptable level of risk. This is juxtaposed with the general assumption that due to state guarantees, SOEs enjoy a more stable environment of investment – the study shows that this is the case only if other factors related to policy coordination and utilization coincide positively. As shown in the analysis above, this will affect the innovative capabilities and action of SOEs. Hence the framework and the findings have many implications to both theory and SOE/innovation policy.

4.1. Implications to theory and practice

The approach outlines broader trends in innovation policy which do not simply apply to SOEs, but describe also the system in which innovation policy is managed. The case of Eesti Energia within this approach served to explain, how long-term innovation perspective by itself – without supportive fiscal autonomy and management orientation – may lead to significant coordination failures, which in turn could also lead to the eventual loss of the legitimacy of the innovation orientation in the long run. Financial concerns and the subsequent performance of SOEs can fluctuate between short-term prices and the long-term marginal costs of other technological options – this should be put into context of an overall innovation orientation not only internal SOE management practices. Without clear innovation policy goals from governments in mind, we presume that most companies would choose to optimize their cost bases: by lowering variable costs and by increasing them during a substantial innovative change in the core activities of SOEs. Through the empirical case it is shown that these factors become essential to R&D choices and innovative investment strategies of SOEs by considerably influencing the extent and the direction of technology strategies. These lines of motivation can be prevalent in almost all other SOEs; and should be thus analyzed more closely and addressed by policy in line with innovative performance. Thus, SOEs could act as important instruments for fostering a more pro-active and targeted role of the state in innovation. At the same time, given the legacies of SOEs and their governance over the last decades, this rediscovery of SOEs as innovation policy instruments can be challenging.

Due to the fact that political and even academic discussion has excluded SOEs from industrial and innovation policy concerns, their commitment to follow these goals is very low. The governments tend to support the strategic choices only indirectly and the decisions (and responsibility) are left to SOEs, because in terms of possible future revenue, they are difficult to justify to the general public. This can induce counterintuitive strategies in SOEs in many ways and in effect, also resistance to the control of their owners. Former broadens the theoretical assumptions we have about the internal, micro-level management of SOEs. Further, the aforesaid shows how different momentums and normative values in the public sector influence innovative activities in state-owned enterprises. These are important factor that the innovation policy geared towards SOEs should address: first and foremost, addressing the legitimacy of SOEs to take up innovation-oriented tasks in the eyes of the general public to carry higher levels of risk.

To some degree, prior studies have discussed the role of SOEs in development of specific sector (see e.g. Victor et al., 2012); however, the role of the firms as innovative actors has not been thoroughly scrutinized. As such, the framework created can on the one hand in practice explain the direction of the development of SOEs' technology portfolios and their risk-taking behavior; but on the other hand, also the direction that innovation may take in a system-based approach in the sectors, where government ownership still plays an important role. This has become more essential, because state ownership increased during the last crisis and because state investments increase on a daily basis due to 'mission'-oriented innovation policies that are garnered towards the solution of many prevalent societal problems. This raises several avenues of further research.

4.2. *Call for further research in innovation in SOEs*

As discussed above this paper is juxtaposed next to a vast academic discussion regarding the efficiency and privatization of SOEs (see Section 2.1). While innovation in SOEs has been in prior accounts discussed, this has been done in the gauze of short-term productivity or commercialization of R&D from national research laboratories or institutes (Jaffe and Lerner, 2001; Crow and Bozeman, 2013). Nevertheless, this is usually analyzed from the perspective of cumulative research, technology diffusing (e.g. Carayannis et al., 1998; Rogers et al., 2001; Mowery and Simcoe, 2002), rather than the innovation-oriented choices made due to the form or context of ownership. This paper has highlighted the need to expand the aforementioned analysis to include specific characteristics of SOEs and innovative actors into the analysis to better understand the development of new technologies through government entities. Here, both micro-, meso- and macro- – e.g. SOE, policy and system – level factors should be studied in more detail. Thus, also established fields of discussion regarding national R&D laboratories and institutes could benefit from the new perspective on government ownership and its influence. In the current case we see the difference in several dimensions – policy utilization, fiscal concerns, etc. – that may also influence wider technology transfer both positively and negatively. Thus, the approach encompasses more factors tying it to innovation policy management that may help to predict also future investment and innovation outcomes in government entities more precisely.

As such, first of all, in light of the proposed framework, more in-depth accounts of SOEs are called for to highlight further dimensions of influence that enable or enhance SOEs to act as innovation instruments. Especially taken into account the strengthening interest in public procurement for innovation and the growing discussion over mission-oriented technology programs (e.g. in health or environmental technologies). Here the effect of normative values and 'mission'-oriented policies were touched upon only in brief. And yet, depending on the field (sector) and the context of the SOE, they may influence policy utilization, coordination and financial interdependencies. As such, it is paramount that also 'failures' should be observed to get a better grasp on enablers and barriers of SOEs to be innovative actors. Here also across country comparisons of SOEs as innovation actors are called for to distinguish the effect of the policy context and also the effects of weak and strong dimensions of the framework presented in the current study.

Additionally, more research is needed to account for various forms of government ownership. States across sectors – depending on the form and goals of ownership –have more concentrated control over SOEs or have delegated the control over to included private partners. Dispersed ownership patterns can have an additional effect on innovation policy goals, but also innovation outcomes. Furthermore, specific R&D focused entities (research laboratories/ institutes, even development banks) may have a privileged situation within state owned entities having fewer competing goals to deal with, thus, not needing to legitimize their role as innovation brokers or innovators. These issues need to be elaborated in future research to distinguish if there are significant differences that also influence innovative outcomes.

5. Conclusions

The aim of this paper was to discuss how SOEs can also be used as instruments of innovation policy management. The above analysis addressed the innovative decisions in SOEs from the perspective of four essential interwoven stimuli/deterrence factors connected to policy utilization, policy coordination, fiscal dependence and profit maximization that are specific to the these private entities in government ownership. While in theory the 'public good' is central to the existence of SOEs, the reality is that without broader goals (including innovation policy), short-term profit maximization seems to prevail at present both in empirical case studies and in academic discussions on governance and management. As long as profit maximization and fiscal dependence prevail in these systems of policy practice, 'short-term yield' goals will triumph not only in relation to SOEs, but also in R&D subsidy systems, tax policy, regulation, etc. In order to discuss these contradictory processes in innovation policy management, this article proposes a new framework to approach the subject. The theoretical approach will hopefully make it possible to analyze the different outcomes of innovation policy and the practices across policy management systems and will first and foremost make visible the non-conventional forms of innovation management – namely these, where innovation through SOEs is currently degraded. The case of Eesti Energia was used as a 'key case' in the article for testing the theory. In order to understand these challenges, more comparative and extensive accounts of SOEs as innovation entrepreneurs will be needed that will add detail to the approach and will re-introduce state-owned enterprises as innovation policy instruments into academic literature and policy practice.

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Appendix

List of interviews

Interview A, The Estonian Development Fund, conducted on 4 March 2013.

Interview B, The Ministry of Economics and Communication and the Competition Authority, conducted on 8 March 2013.

Interviews conducted in Eesti Energia Ltd.:

Interview C, conducted on 19 October 2012.

Interview D, conducted on 12 February 2013.

Interview E, conducted on 11 March 2013.

Interview F, conducted on 16 April 2013.

Interviews conducted in energy research groups and with energy technology experts at Tallinn University of Technology (the main research institute that explores energy issues in Estonia)

Interview G, conducted on 3 April 2013.

Interview H, conducted on 5 April 2013.

Interview I, conducted on 8 April 2013.

Interview J, conducted on 16 April 2013.

Interview K, conducted on 17 April 2013.

Interview L, conducted on 18 April 2013.

Interview M, conducted on 18 April 2013.

Interview N, conducted on 23 April 2013.

Interview O, conducted on 25 April 2013.

Further interviews with public officials:

Interview P, The Ministry of Finance, State Assets Department, conducted on 23 January 2014

Interview R, The National Audit Office of Estonia, Performance Audit Office, conducted on 3 March 2014

Interview Q, The Environmental Investment Centre, conducted on 4 June 2013.

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State Owned Enterprises as Instruments of Innovation Policy

Piret TÕNURIST and Erkki KARO
Tallinn University of Technology, Estonia

ABSTRACT: This article expands the literature on the rationales and governance of state owned enterprises (SOEs). We show that SOEs could be seen as instruments of innovation policies and change agents within broader innovation systems that can overcome many of the conventional challenges of innovation policy and its implementation, from coordination and implementation of policies and innovation system actor networks to financing innovation. We review the existing literature on the rationales of SOEs and extend it to include innovation as a central rationale. Thereafter we provide a taxonomy that reveals the necessary policy and managerial conditions and constraints for using SOEs as instruments of innovation policy. We place some of the better-known innovation-oriented SOE successes and failures into this taxonomy and show that this approach will allow in future research to explore different SOE practices and potential for using SOEs as innovation policy instruments across countries.

Keywords: state owned enterprises, policy capacity, innovation policy, demand-side innovation policy

JEL classification: O20, O32, O38

1. Introduction

The global emergence of innovation policy – actions by public organizations that influence the development and diffusion of innovations – as a complement and in some case also a substitute for industrial policy (Soete 2007), has turned the concept of innovation[1] into a central public policy issue (Block and Keller 2011, Mazzucato 2013). Demand-side innovation policy (i.e. government's demand for currently non-existent technological solutions to specific problems) has become one of the key ways to legitimize and operationalize the role of the state in innovation (see Lember et al. 2014, Edler 2013).

In this paper we look at state owned enterprises (SOEs)[2] as potential instruments of innovation policy and discuss the subsequent governance issues accompanying this rationale for SOEs. This perspective has been largely neglected by innovation policy scholars and until recently by SOE-scholars as well. The latest attempts to discuss the role of SOEs in innovation and innovation policy (see Belloc 2014, Bernier 2014) look mostly at micro or firm level factors – i.e. incentives of managers, public entrepreneurship etc. – as crucial for SOE innovativeness and de-emphasize the macro level governance perspective as a useful analytical focus (especially Bernier 2014). We argue that this simplifies the complexities of innovation that innovation scholars have developed into the 'systems of innovation' concept (see Edquist 1997). In other words, development and successful adoption and diffusion of innovations requires a system of complementary organizations (public and private), institutions and policy instruments. Thus, understanding SOEs as innovation policy instruments requires also a systemic perspective that takes into account the firm-level and system-level (governance)

[1] We follow Schumpeter's (The theory of economic development, 1934) definition of innovation that involves new products, methods of production (technologies), sources of supply, exploitation of new markets and new ways to organize business with the focus on technological innovations.
[2] In this article the definition of SOEs developed by the OECD (2005) is used: by the guidelines SOEs are enterprises where the government has significant control by full or significant majority ownership (usually at least 10% of the voting rights of the company).

factors affecting the processes of innovation.

SOEs can indeed have a wide range of policy rationales surpassing simple profit maximisation and broader social welfare maximisation (Vickers and Yarrow 1988). While the possible ‘public good’ nature of R&D of SOEs has been recognised (Molas-Galart and Tang 2006), we go beyond this focus and propose that SOEs could be considered as prospective drivers of technological innovation. Firstly, SOEs may provide unique institutional settings for the co-evolution of public and private incentives and drivers of innovation by *combining risk-taking and long-term orientation*. Secondly, SOEs may act as *coordinating or direction giving change agents* within broader innovation systems: hence, SOEs can coordinate activities and interactions between different actors necessary for innovation. In this role, SOEs can provide an arena for concentrated and targeted utilizations of various traditional innovation policy tools: investment and coordination of R&D for advancing the techno-economic frontier, market making and signalling, programs tackling the socio-economic ‘grand challenges’ etc. Usually, these policy tools tend to be fragmented between different public and private institutions creating problems of policy coordination, adaptability, and feedback. These roles also require a broader framework and approach to SOE policy rationales and governance. This paper seeks to provide the first steps towards this direction.

Section 2 outlines a general review of prior research on policy rationales and governance of SOEs and ends with the analysis of SOE policy rationales and governance issues from the perspective of technological innovation (and policy). For these reviews, we employed citation searches and the snowball method.[3] Section 3 links SOE research with innovation policy literature and provides a simple analytical taxonomy that combines both policy (state) and firm level perspectives on SOE policy rationales and governance issues. To illustrate the analytical value of the taxonomy, we apply it to discuss some of the best-known cases of innovative and less innovative SOEs in the oil sector. In the conclusion we discuss the implications of our framework for future research.

2. A brief literature review on SOE rationales and governance

While the share of SOEs in industrialized economies has fallen since the 1980s (Guriev and Megginson 2007, 251), SOEs still produce a large proportion of the national industrial output in many countries (OECD 2005b), more so after the economic crisis starting in 2008 (Kwiatkowski and Augustynowicz 2015). Different overviews and survey data show that in OECD countries the average assets of SOEs are around 20-25 percent of GDP and most utilities, social service providers and infrastructure companies still have governments as shareholders (see OECD 2005a, Bortolotti and Faccio 2009, Kowalski et al. 2013, Vining et al. 2014). Moreover, governments as shareholders in partially privatized companies have sometimes more active control over SOEs through corporate control measures and stricter regulation (Ang and Ding 2006, Cruz et al. 2014).

Most of the recent SOE research has concentrated on the issues of efficiency (the influence of ownership on the performance of firms, e.g. Aharoni 2000, Toninelli 2000) and analysed corporate governance and regulation (e.g. Fecher and Lévesque 2008, Goldeng et al. 2008). This research has treated SOEs as regular firms and is rather critical of the role of SOEs as policy instruments; especially given the failure of ‘national champions’ policies in Latin America and elsewhere in the 1980s. Thus, SOEs are perceived as a threats to market competition and seen as causes of inefficiency and wasted resources. Nevertheless, in sectors

[3] First, we carried out an electronic search using the Primo database (http://primo.aub.aau.dk/) for peer-reviewed articles. The search terms we used were [state owned enterprises] or [public enterprises] plus [innovation]; plus one of the following: [R&D], [patents], [innovation policy]. The first search yielded approximately 700 articles, from which approximately 80 were used to find further references in the Google Scholar database (http://scholar.google.com) for the widest range of scientific output. However, in many cases innovative activities turned out to be the by-products of the analysis, not the main theme.

where SOEs have prevailed, governments usually describe them as 'strategic' and with specific and often varying rationales (OECD 2005a, Marra 2007).

2.1 Traditional rationales

SOEs have been created to reach various internal and external objectives from national security to social cohesion (see historical overview in Millward 2010). Historically, the core rationale for establishing SOEs lied in the broad strategic goals rather than short-term productivity or rent collection interests; thus, some scholars do not considers SOEs without a public mission as truly 'public' enterprises (Del Bo and Florio 2012, Florio 2014). Active involvement of governments in the economy through public enterprises has been previously justified through three main rationales: *market failures* (traditional industrial policy argument), s*ocial objectives* (social argument) and *normative welfare approaches* (public value argument) (see Del Bo and Florio 2012, Christiansen 2013).

The market failures argument has been usually limited to solving the problems of constrained capital markets (SOEs can provide long-term, flexible investment for large scale projects (Levine 2005)). This perspective has also justified the existence of natural monopolies (MacAvoy et al. 1989), state governed development banks and capital funds (e.g. Mazzucato and Penna 2014). SOEs can be designed as solutions to investment coordination problems (e.g. need for 'patient' capital (Musacchio and Staykov 2011)). In the more politicized social and welfare approaches, a wide range of non-commercial interest (employment goals, price controls) can come into to play. Consequently, SOEs can also act as employment buffers, social laboratories, and even as measures towards regional socio-economic development (Etling 2009). In sum, the rationales of SOEs vary between economic performance and political strategy (Cuervo-Cazurra et al. 2014).

2.2 Governance issues

The variety of SOE rationales is closely related to the multi-level challenges of governance of SOEs. Bernier (2011) distinguished between 'micro' and 'macro' dimensions: in the micro level, the central focus is on accountability, corporate governance and transparency of SOEs; in the macro level, the central focus is on the public policy purpose of SOEs (and how to compromise between the issues of micro governance of organizations vs systemic governance of policies and policy mixes). Still, most approaches examining governance of SOEs deal with the micro dimension: agency issues, efficiency related goals, transaction costs (e.g. Vagliasindi 2011). The most common theories discussing SOEs from this dimension have been the principal-agent theory, stewardship theory, transaction cost theory, new institutionalism and resource dependence theory. While sometimes contradictory in assumptions, these theories give some insights into the specific nature of SOEs and also into how the interactions between SOEs and innovation are perceived.

The principal-agent theory (see discussion in Bernier 2011) has been the most dominant in SOE literature. The traditional principal-agent argument would presume that due to the lack of control from owners of SOEs there would be no incentive to increase performance within the company (World Bank 1995). However, these problems are also present in private stakeholder-manager relations (Anabtawi and Stout 2008). Nevertheless, several political factors – e.g. the often changing rationales and mandates of SOEs given the electoral cycles and ideological shifts in politics (e.g. DiMaggio and Powell 1983, Ang and Ding, 2006) – make the governance of SOEs distinct from private sector organizations. Due to political meddling multiple, vague and sometimes inconsistent objectives (e.g. profit maximisation vs welfare concerns) can become serious problems for the company (e.g. Dewenter and Malatesta 2001).

Recognizing these issue as central governance challenges, also the stewardship theory has focused on the alignment of management and public sector goals, especially given the increasing competition and autonomy of SOEs. While in the principal-agent theory this would be achieved through increased control over managers, from the stewardship perspective the right (intrinsically motivated) people have to be found to govern SOEs (e.g. Bernier 2014). From this perspective and considering also the perspective of the resource dependence theory, SOEs can also benefit from close links to the state, either by being able to influence regulatory policies and/or by having access to government-owned resources (Xin and Pearce 1996). While there are many concerns related to SOEs dependence on public budgeting, some of these can be offset by potential benefits from total public good (Haney and Pollitt 2013). By having access to additional capital and not being tied to profit-maximization goals, SOEs can have a comparative advantage when dealing with risky innovative projects (Belloc 2014).

2.3 The role of innovation in SOEs literature

Above discussed perspectives on SOE rationales and governance do not totally exclude the possibility of looking at SOEs in the context of innovation and they provide some micro-level perspectives on how key governance issues of SOEs relate also to innovation (see Table 1).

Table 1. Theories on SOE management and innovation

	Core authors	Main considerations	Significance to innovation management
Principal-agent theory	Jensen and Meckling 1976, Ross 1973	▪ CEOs act as self-serving agents ▪ Emphasis on formal rules and incentive mechanisms ▪ Contracts to reduce agency cost, minimize opportunistic behaviour and bare risk efficiently ▪ Informational asymmetry between principals and agents ▪ Different risk preferences of shareholders and stakeholders	▪ Managers have better information about the likely success of R&D ▪ Choice between long-term and short-term pay-offs (moral hazard) creates the need to find the 'right' incentives ▪ Due to the need for extra monitoring and bureaucracy, managers may become less innovative ▪ Assumes a significant relationship between ownership concentration and R&D investments
Stewardship theory	Donaldson and Davis 1991, Davis et al. 1997, Bernier 2014	▪ CEOs act as trustworthy stewards ▪ People are collective minded and pro-organization rather than individualistic ▪ Performance is dependent on the structural situation and the level it facilitates effective actions	▪ Highlights the need for intrinsically motivated managers ▪ Increased levels of management ownership may decrease R&D levels ▪ Assumes a non-significant relationship between ownership concentration and R&D investments
Transaction cost theory	Williamson 1975, Robin 1987	▪ Cost of transactions explains relationships between actors, firm behaviour ▪ Emphasis on the existence of information asymmetries ▪ Imperfect contracting cannot fully deal with asset specificity and opportunism	▪ Outsourcing R&D may come at a high cost ▪ Vertical integration may follow if the contracts are frequently subject to uncertainty and transaction-specific assets
New institutionali	DiMaggio and Powell 1983, DiMaggio 1988	▪ Formal and informal institutions govern firm behaviour ▪ Incentives should be designed based on institutional frameworks ▪ Conformity with institutional norms and acceptance of imposed behaviour	▪ Institutional inertia influences investment ▪ Institutions determine development trajectories

Resource dependence theory	Pfeffer and Salancik 1978, Campling and Michelson 1998	▪ External/internal environments limit choices and influence their institutionalized power ▪ Need to respond to environmental turbulence and organisational resource requirements gives managers an active role	▪ Availability of resources can be a strong impediment to R&D investments and commercialization ▪ Innovation activities require both financial and technological resources ▪ Resource-rich shareholders can help to obtain the required resources for innovation

Source: Authors.

Overall, technology and innovation focused literature on public enterprises has looked at the role of SOEs from the perspective of supplying R&D as part of long-term investments, and also from the public good nature of spillovers (Molas-Galart and Tang 2006, Munari et al. 2010, Musacchio and Staykov 2011).

When innovation and technology are examined, it usually centres on the effect of ownership concentration (e.g. Shapiro et al. 2013), or different ownership structures (Choi et al. 2012, see also Table 1). Ownership status makes a difference in innovative activities of companies (see Munari et al. 2010, Choi et al. 2012, Sterlacchini, 2012): it affects investment decisions, time horizons, legitimacy of actions (Gu and Lundvall 2006) and also the type of technological innovation (Li et al. 2007). Empirical cases following these theories tend to utilise only short-term performance indicators – net income or value added, return on equity, sales or assets, cost savings – when studying ownership effects (e.g. Vining and Boardman 1992, Megginson and Netter 2001) rather than a specific role of the government acting upon long-term policy goals (the macro level perspective). Research of these roles can produce very ambiguous results. For example, depending on the construction of the research – and crucially if in-house R&D or R&D intensity and technical capabilities are considered – it is shown that both private firms (Wang 2005, Lin et al. 2010) and SOEs (Gabriele and Khan 2010, Zhang 2009, Chen et al. 2009) can produce better results in terms of efficiency. Consequently, Belloc (2014) has recently argued that SOEs inefficiency is not intrinsic to the government ownership, but is linked to extrinsic conditions: e.g., management culture, legislation and the degree of political competition and goals (see Victor et al. 2012).

From the empirical perspective, the current research on the links between SOEs and innovation is relatively scant and focuses mostly on the role SOEs or government-linked companies play in Asian innovation systems, e.g. in China, Singapore and Malaysia (e.g. Ang and Ding 2006, Gabriele 2010, Wong and Govindaraju 2012, OECD 2015). Thus, when it comes to more specific factors and measures of innovation (e.g. R&D intensity, patent base etc.), the role of SOEs is mostly researched in the context of China and as part of its peculiar state managed economy (e.g. Guan et al. 2009). The political and institutional differences between China/Asia and the rest of the world make it very hard to expand the research on SOEs in a uniform fashion.

In sum, however insightful, most of the above-reviewed theories do not examine explicitly the conflicting and multidirectional goals and pressures on SOEs. Yet, given the strategic dimension of SOEs (Florio and Fecher 2011) as one of the conceptual rationales for their existence, SOEs can be also linked to a systemic view of innovation/industrial policy that emphasizes institutional complementarities and systemic effects as opposed to simple organizational performance (see also OECD 2012). In the context of innovation, the macro dimensional and wider system-level issues – from policy goals and capacities for policy coordination – become important variables to be unpacked in specific contexts, but existing research seems to have strong empirical (Asia) bias. Thus, the interactions between innovation (policy) and SOEs could be approached from much more systemic and inclusive perspective: i.e. treating SOEs as both *independent innovation actors* and as potential *coordinating change agents* within broader innovation systems.

3. SOEs and innovation policy

While in the (demand-side) innovation policy literature SOEs tend to disappear as distinct policy actors and instruments (Lember et al. 2014, Edler 2013), in theory, SOEs could also play an important role in the demand-side innovation policies and in the so-called 'mission-oriented' and/or societal challenges related policies (e.g. Foray et al. 2012). For example, SOEs could give direction and support knowledge creation as a procurers of innovation (Rothwell 1994) and also accelerate technological adoption and diffusion processes in the economy as lead users (Lember et al. 2014).

3.1 SOEs as innovation policy actors and instruments

Leading innovation policy scholars such as Mazzucato (2013), Block and Keller (2011) argue that the financialization of the economies since the 1980s has turned private sectors towards more short-term oriented and risk averse strategies even in the most developed economies, such as the US and UK. As a result, a new 'policy space' is emerging for governments in the systems of innovation: to support and steer technological development and innovation characterized by profound 'uncertainty' (as opposed to calculable risks). Accordingly, the state may have, at least in theory, policy and fiscal capacities for long-term planning and risk-taking necessary for technological progress and innovation. In existing innovation policy thinking, this role of the state has been so far conceptualized through policy models where the state has specialized innovation agencies or ministries in charge of dealing with clearly visible and explicitly defined market failures (e.g. patient capital to private R&D projects, provision of skilled labour and intellectual property regulations) and also systemic failures (e.g. fostering coordination and networking among actors – e.g. companies and universities – of the system) (see OECD 2005a). The entrepreneurial state and demand-side innovation policy discourses recognize that existing policy models – based on a fragmented system of different policy organizations specializing in specific failures – may not overcome the systemic problems of innovation in a highly financialized global economy.

In this context, SOEs can be treated as an alternative or complementary instrument of innovation policy that has – given its specific external role and unique internal organization in the public sphere – potential to combine into a single organization the traditional public and private roles different organizations play in innovation and thereby to reduce the coordination challenges acutely present in modern innovation policy mixes (Mazzucato and Penna (2014) discuss similarly state-owned development banks). The potential for combining or coordinating R&D expenditures with longer time horizons, procurement for innovation and other demand-based measures, fostering and nurturing collaborative innovation and production networks – all acceptable rationales in the context of innovation policy – may give SOEs a unique role in innovation systems and technological development. Many characteristics of innovation dynamics – increasing returns to scale and clustering, first mover advantage, winner-takes-all markets, externalities, backward and forward linkages and learning effects – already characterize the daily context of many SOEs.

Thus, SOEs could be perceived both as actors and instruments of innovation policy depending on the goals of the policy: either as *independent innovators* (similar to private firms) or as *policy instruments* in a more complex policy mix (making also the performance measurement of SOEs more complex and linking it with systemic effects). Both Gillis (1980) and Eisinger (1988) have previously described these different dimensions in their research. Recently, Belloc (2014) and Bernier (2014) have looked at SOEs mostly as independent innovators. The extent to which these perspectives are present in different countries varies based on the actual policy need, sectoral differences, and also depending to actual policy space (legitimacy) to utilize these rationales. For example, varieties of capitalism literature (Hall and Sosckice 2001) argues that state and private actors have markedly different interaction patterns in different economies depending on the modes of coordination (i.e. liberal vs coordinated market economy models) leading to different risk-sharing and governance arrangements. Thus, while SOEs have by now similar management structures popularized by the OECD (see for example cases in Bernier 2015; also Musacchio and Lazzarini 2014b), their activities and roles in the economy can differ considerably depending on broader, macro-level factors. For example, in Brazil SOEs were used as a fast-track to industrialization (Trebat 1983, Musacchio and Lazzarini 2014a), while in China, the role of SOEs is to maintain control over and develop strategic industries (Chan and Rosenbloom 2010). In Finland and Sweden, the governments have taken a perspective of value creation and 'active' ownership of SOEs based on deregulation and strong strategic choices (Clifton et al. 2006).

In principle, having more direct influence over specific activities of some firms and industries may allow innovation policy makers more policy space (through more intimate and immediate feedback mechanisms between 'state' and 'market') for policy experimentation and for steering innovation processes than through traditionally fragmented innovation policy mixes where ministries and agencies relate to firms indirectly via basic regulations, systems of subsidies, general procurement rules, and other formal and informal interactions. This more immediate interaction can, for example, include direct funding and strategic steering of large-scale R&D projects within SOEs supported by proactive customization of educational, regulatory and procurement policies to support these SOE strategies and projects. However, all of this calls for high levels of policy coordination on the side of the government and the avoidance of transitory policies (e.g. Gosh and Whalley 2008). Overall, this pro-active perspective re-introduces a much wider and systemic rationale of SOEs in innovation policy. It also raises important questions concerning both micro and macro dimensions of governance of SOEs: as this approach attempts to combine into SOEs the different roles public and private organization play in innovation, this may inevitably lead to both intended and unintended consequences. While these macro and micro dimensions contributing to SOE innovation capabilities may be operationalized quite similarly to traditional SOE governance perspectives discussed above, innovation and innovation policy literature emphasizes that in addition to issues such as organizational efficiency, transparency and other traditional concerns, also 'learning' and risk-taking/experimentation capabilities need to be sustained for SOEs to act as innovators; and this can be guaranteed through either systemic or just organizational level factors.

From the *macro dimension*, treating SOEs as instruments in the broader innovation policy mix re-introduces several policy coordination and governance questions, e.g.:

- *clarity of policy goals* (long term strategies and goals communicated by the state as the 'owner'; or convergence of policy goals between different public and private 'owners');
- *general governance capacities: substantive autonomy* granted to SOEs to pursue these policy goals (e.g. fiscal and strategic autonomy from short-term political considerations) balanced by the *capacity to incentivize, control and regulate* the SOEs (to alleviate the risk of corruption, rent-seeking, and general inefficiencies);
- *systemic coordination capacities* (e.g. maintenance of relevant interactions and innovation capabilities of the other actors of the innovation system);

There is ample literature showing that in many cases SOEs are expected to follow conflicting goals of profit maximization, social welfare, and technological capabilities (Kropp and Zolin 2008, Zhang et al. 2010) while also increasing self-sufficiency (Rehan et al. 2014) and/or private-sector like performance (Liu and Sun 2005) and also carrying large amounts of national budgetary burden with potentially negative impact on long term strategies (Lumpkin and Dess 2001). Thus, macro governance issues relate not only to politics-SOE linkages, but also to more institutional questions of policy and administrative capacities of ministries, agencies and regulators relevant for the technological and economic sectors and innovation systems where specific SOEs function (see also Karo and Kattel 2014).

From the *micro dimension* and compared to SOEs with more traditional rationales, SOE as an innovation actor may need to establish highly specific management practices or systemic public entrepreneurship skills (Bernier 2014). Given the complexity of technological innovation, innovation scholars (see Nelson and Winter 1982) focus on key organizational routines in firms that combine into dynamics innovation capabilities combining learning and management/implementation capabilities, e.g.:

- *ownership control and concentration* (motivation of controlling shareholders towards appropriate levels of risk bearing and benefit sharing for innovation);
- *performance incentives of managers and workers* (emphasizing cost-efficiency vs supporting risk taking and innovation);
- *financial management routines* (e.g. scope of financial autonomy to fund R&D, transparency of funding, time frames of financial accountability that allow investment into R&D and innovation);
- *personnel management routines* (intrinsic and extrinsic motivational factors; importance of R&D and innovation related skills in recruitment and training practices, ability to recruit public entrepreneurs and guarantee the quality of boards);
- *organizational design routines* (balancing between organizational variety and dynamism necessary for innovation and learning and organizational coordination and control necessary for strategic agility and implementation).

3.3 A taxonomy of SOE roles in innovation

The different rationales and dimensions of governance paint a complex and possibly conflict-prone picture of institutional and organizational factors affecting innovation potential of SOEs. As in general with SOEs, it is highly likely that different strategic interest/goals may collide: goal and incentive incompatibilities between state expectations and SOE management; shorter-term political interest and public opinion on the one side and the need for reliable investments for high-risk strategies and development activities linked to innovation management on the other side. At the same time, it is also feasible (though, empirically more rare) that different interests and institutional factors combine into 'pro-innovation' context where SOEs can act as key drivers of innovation in specific innovation systems. Many of these considerations – especially the macro dimension – are currently not discussed in SOE and innovation policy literature and we propose a simple analytical taxonomy to comprehend the macro and micro dimensions affecting SOEs as innovators. From the previous discussion two main dimensions potentially influencing innovation performance of SOEs can be brought out:

a) ***Strategic policy capacities to set and coordinate SOE and innovation policy goals*** *on the macro level*: government strategic policy goals in relation to SOEs can range from short-term 'traditional' goals (profit maximization and/or servicing government budgetary and societal needs) and reach to establishing innovation orientated strategies (from maintaining firm-level technological capabilities to contributing to the broader development of the national innovation system as a whole). The actual implementation of these goals depends also on the state capacities to coordinate (via supervisory boards, legislative and regulatory tools etc., i.e.

balancing between SOE autonomy and control) that SOE adheres to set goals and that other actors and institutions of the system support SOE strategies.

b) ***Strategic organizational capabilities of SOEs*** *on the micro-level*: the crucial determinant is whether SOE's autonomy (from macro-level interference – political or bureaucratic control – in organizational strategic management) has allowed the development of entrepreneurial capacities or organizational routines (in organizational design, financial, personnel and performance/accountability management) that are supportive of the strategic goals of innovation. While SOE research tends to look for global best practices of organization routines (especially in terms of efficiency and in comparison to private sector benchmarks), if we link organizational capabilities with the system-level strategic policy capacities and forms of coordination, one could also expect that the 'best practice' routines fitting the latter context may also be more diverse across different innovation systems and types of capitalism.

In our view, existing research on SOE rationales and governance fails to make sufficiently explicit linkages between these levels and thus ends up in rather simplistic (single variable) explanations of SOE performance. Thus, instead of looking only at SOE corporate governance issues and/or types of state-SOE interactions as in traditional SOE literature, we propose to look systematically both at the *micro-level managerial capabilities* and at the *macro-level policy capacities*. The co-evolutionary interactions between these layers, in turn, determine the *forms of embeddedness and complementarities* between state goals and SOE practices. The taxonomy presented in Figure 1 tries to capture both the extent to which innovation-oriented goals of SOEs can emerge in specific innovation systems (through policy coordination capacities) and also the extent to which SOEs possess strategic 'tools' (entrepreneurial capabilities and routines) to follow and implement these goals. The interaction between macro and micro dimensions determines whether the innovation capabilities of the SOE are *systemic* (SOE as a policy instrument), or *organizational* (SOE as an independent innovator). While the entrepreneurial or innovative capabilities of the SOE in terms of actual organizational routines are *sine qua non*, paradoxically, these capabilities can emerge from two policy contexts: SOEs can focus on innovation because of clear strategies and sufficient coordination by the state, or because of lack of such control and coordination.

Firstly, if both the state and SOE emphasize innovation as central policy and strategic goal (Quadrant A in figure 1), SOEs can become *systemic innovation actors* embedded in the broader innovation system. Thus, the state has consciously granted strategic autonomy to pursue innovation by the SOE (and enforces it through control of the SOE via regulation and supervision) and the SOE builds and maintains its internal innovation strategies and organizational routines. Further, the state coordinates the SOE and other systemic policies (education, regulation, procurement).

Secondly, it can also be possible (Quadrant B) that the SOE builds consciously its own internal innovation strategies and organizational routines and has gained significant autonomy (either as a conscious policy choice to shield the SOE from other interest, or due to the general weaknesses of the strategic coordination capacities), but without supportive systemic policies and coordination (e.g. in the context of strict procurement and other regulations imposed on the SOE, limited overall innovation policy coordination to link the SOE with other actors of the system). In this case the SOEs may act as *independent innovators* with more limited systemic impact (weak backward and forward linkages) in terms of technological spillovers and development of innovation system (e.g. the firm can act as domestic enclave having more linkages and spillovers in and impact on foreign innovation systems). Thus, innovation orientation can be both intended and unintended consequence of public policies in the case of SOEs. Therefore, understanding the policy issues and macro governance of SOEs is crucial for understanding the long-term sustainability of the innovative performance and capabilities of specific SOEs. Quadrants C and D reflect the issues found in traditional critique of SOEs discussed in earlier sections of the paper.

Figure 1. Taxonomy of SOE innovation potential and constraints

Clear and long-term innovation related policy goals and coordination by the state

Weak autonomy and routines for innovation in the SOE	D: SOE as a managerially failing actor Cases: NIOC, NNPC etc.	A: SOE as a systemic innovation actor Cases: Statoil, Petrobras since 1980s	Explicit autonomy and routines for innovation in the SOE
	C: SOE as a 'shadow' actor of government or managerially failing actor Cases: PDSVA post-2000s; Pemex, Petrobras since 2010s	B: SOE as an independent innovator with competing rationales Cases: Petrobras in 1970s, PDSVA pre-2000s	

Weak/vague innovation oriented policy goals and coordination by the state

Source: Authors

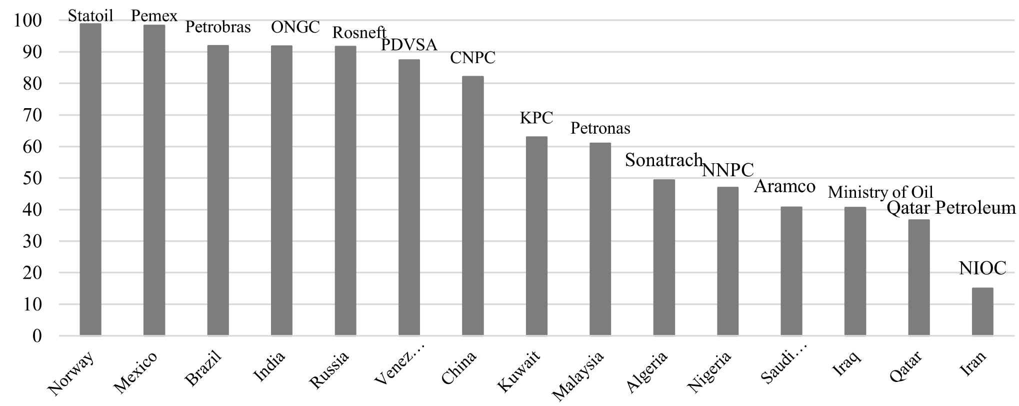
In sum, as in most countries SOEs have not been considered as central instruments of innovation policy, turning SOEs into instruments of innovation policy (i.e. conceptualizing SOEs in quadrant A) seems to require a new focus both on the macro-level coordination and governance (what is the institutional – political, policy, resource – context of SOEs in the innovation system) and micro-level governance (what are the internal routines and drivers of management and performance of SOEs). How this can be achieved is a context-dependent process of either reforming existing SOEs, or nurturing their growth and development over long-term. In other words, SOEs should not be treated as universal entities with similar characteristics (and best practices), but as sectorally and nationally diverse policy instruments. Our analytical taxonomy seeks to provide a framework to advance the SOE research from this perspective.

To illustrate these issues, a short analytical overview of some of the more illustrative oil industry SOEs and their relations to innovation (policy) is presented below. The cases analysed in detail are also placed into Figure 1 (among the 'Cases') and summarized in Table 3 below in terms of more detailed macro and micro level governance variables. SOEs in different sectors have different innovation potential. The oil industry is chosen because there are SOEs across the world with similar size and significance. Furthermore, in countries where they are present their 'strategic' nature is rarely refuted, their role in the economy is usually outlined and documented, and usually the companies deal specifically with technological innovations (the focus of our study). Thus, we do not have to legitimize the expansion of SOE rationales and can concentrate on the analysis of the macro and micro level governance of these companies.

3.4 SOEs as systemic innovation policy instruments in the oil industry

Based on the Fortune Global 500 ranking, the largest number of SOEs (both by number and share) is in the resource sector (Kwiatkowski and Augustynowicz 2015). Particularly in the oil sector a noticeable change of control has happened in the last decades: from the dominant control of the sector by the 'Seven Sisters' to SOEs owning almost three-quarters of the world's crude-oil reserves (Bremmer 2008). Based on the Resource Governance Index (RGI) and its specific SOE score compiled by the Revenue Watch Institute, the standards by which natural resources are governed across countries vary considerably (see figure 2 below). While indicative of the variety in management performance, RGI SOE score still concentrates only on the micro level capabilities – primarily transparency and accountability of SOEs – and does not tell us much about the performance of SOEs as innovative actors. Hence, a high score on the aforementioned does not equate to an overall high performance (e.g. in the case of Pemex – second highest score on the RGI SOE score in figure 2 – the overall performance is rather weak (Pargendler et al. 2013)).

Figure 2. Selection of RGI SOE scores (2013)



Source: Authors based on data from http://index.resourcegovernance.org/ (retrieved 2.07.2015)

It is difficult to assess 'innovativeness' of SOEs as it is related not only to their managerial capabilities but also to their productive context and technological development trajectories (e.g. the easier it is to extract and refine specific type of oil, the less complex technological innovations may be needed, though, incremental innovations may be still necessary). For example, Gay (2014) claims that classic indicators of innovation such as patents may be misleading for assessing the innovativeness of oil sector SOEs, especially in comparison to private sector performance as most SOEs have emerged through nationalisation or through following private firms into the oil sector (e.g. between 2008-2012 Shell and Exxon Mobil had respectively 3.5 and 19.5 times more patents than Brazil's Petrobras with its 431 patents). Thus, SOEs are often adopters/emulators or incremental adjusters of key technologies as opposed to original innovators and most of their innovation is often either incremental and/or not patentable.

Looking at other cases, while Chinese CNPC and others have become increasingly international, many studies show that competitive Chinese SOEs act as important vessels to build up innovative capabilities over a longer period of time across the innovation system (e.g. Chen et al. 2009, Gabriele 2010, Hou and Mohnen 2013). These SOEs have complex networks within the innovation system comprised of universities, research institutes and other public enterprises and privately owned and foreign-funded industrial firms (Gabriele and Khan 2010, Niosi 2008). Furthermore, they can be sources of foreign direct investment and risk arbitrators between foreign companies and high-risk, frontier ventures (Nolan and Thurber 2012). Thus, in addition to being potentially independent innovators, SOEs can act as strategic customers of domestic supply chains that buy a number of products and services (including technology and R&D) from the private sector (Toninelli 2000). This has been also documented in the case of Gazprom (Goldman 2008), although the overall performance of the company on the lower side (see Table 2 below).

Consequently going beyond the micro level management is problematic. Victor et al. (2012, 890, 919) conclude that while the micro-level characteristics (managerial practices and capacities of the SOEs) play a role in the eventual performance of the companies, the macro-level characteristics – especially the goals of the state, the institutional configuration of the state (forms of state-SOE interactions, or embeddedness; especially the coherence and capabilities for control) and contextual characteristics (e.g. nature of resources used in production processes) – are more important for differentiating the performance of SOEs. Taking into account these criteria, Victor et al. (2012) develop a composite ranking (they use traditional financial performance data and also expert assessments similar to peer review) and taxonomy of oil sector SOEs that first looks at hydrocarbon performance (i.e. how 'good' are the SOEs perceived to be in oil extraction, processing and sales) and links this with non-hydrocarbon related burden (related to both social and public goods – domestic subsidies, employment, social programs – and private goods – rents, elite employment and patronage – that these SOEs may have to deliver). See table 2 below for a variety of cases classified in accordance to the aforementioned approach.

Table 2. Performance of SOEs in the oil sector

Performance	**Non-hydrocarbon burdens**			
	High	Upper-middle	Lower-middle	Low
High			PDSVA (pre-2002) (Venezuela) Petrobras (Brazil)	Statoil (Norway)
Upper-middle			CNPC (China) Pteronas (Malaysia) Aramco (Saudi Arabia) Sonangol (Angola)	ADNOC (Abu Dhabi)
Lower-middle	Gazprom (Russia) Rosneft (Russia)* PDVSA (post-2002) Pemex (Mexico)	Sonatrach (Algeria)	ONGC (India)	
Low	NIOC (Iran) NNPC (Nigeria) Ministry of Oil (Iraq)* Qatar Petroleum (Quatar)*	KPC (Kuwait)		

Source: Revised version of Victor et al. (2012, 902). *SOEs added by the Authors listed in the Forbes "World's biggest oil companies – 2015."

To exemplify our own framework concentrating specifically on micro and macro factors of SOEs as innovative actors, we will use the analysis of Victor et al. (2012) to select the cases for our analysis. In their assessment the most capable SOEs in the sector (of the cases they analysed) are Statoil, Petrobras, and PDSVA (pre-2000s) of which Statoil has the most autonomy (least non-hydrocarbon burdens) while the other two represent more mixed cases (see also Musacchio and Lazzarini 2014b). These SOEs are also considered as world leading companies in developing deep-water technologies (Petrobras and Statoil), natural gas processing/transport and carbon capture/storage technologies (Statoil), and also heavy oil extraction and processing technologies (Statoil, PDSVA) (see also Oliveira 2012, Thurber and Istad 2012). These technological skills seem to be all related to relatively high uncertainty and risk related to oil extraction and production in specific geographical contexts into which private actors have yet to enter. In addition, similarly to Gay's (2014) arguments about Petrobras, it is also recognized that the innovation strengths of the Norwegian oil sector in general and of Statoil in particular are not presented through patent statistics, but more through applied engineering skills used for domestic development and customization of oil industry technologies (Thurber and Istad 2012). Yet, all are linked also to specific innovation capabilities. Table 3 presents a succinct comparative analysis of the cases by the micro and macro level capabilities and the analytical framework presented in sections 3.1. In the following sections we will we will analyse the three SOEs depending on their status as systemic innovation actors.

Table 3. Unpacking SOEs as innovation actors

	Statoil	**Petrobras since 1980s**	**PDVSA pre-2000s**
Descriptive data	Founded 1972 Employees 22,516 Sales $95.14 B Reserves 4.3 bboe* Fixed asset turnover**[4] 1.61 Listed SOE (since 2000) Ownership structure: partial (67% state owned)	Founded 1953 Employees 80,908 Sales $143.66 B Reserves 11.1 bboe* Fixed asset turnover** 0.70 Listed SOE (since 2001) Ownership structure: partial (state direct ownership 54% and indirect ownership10%)	Founded 1976 Employees 110,000 Sales $105.3 B Reserves 104.4 bboe* Fixed asset turnover NA Not listed SOE Ownership structure: 100% state owned
Macro dimensions			
Clarity of goals	Low non-hydrocarbon related goals; clear emphasis on developing technological capabilities	Macro-economic and developmentalist goals mixed with non-hydrocarbon goals	Weak steering by the state; implicit non-hydrocarbon related goals
General governance capacities	Balanced system of autonomy and external control/regulation	Evolution from developmental agency (in 1970) to partly regulated entity in 1990s	A 'state within the state': weak control and steering by the state
Systemic coordination capacities	Node of sectoral innovation network	Lead actor of the innovation networks following national policy goals	SOE-led innovation networks with limited systemic policy coordination
Micro dimensions			
Performance incentives	Organizational autonomy within state goals (strong corporatist coordination) and competitive context	Organizational autonomy within the macro-economic and developmentalist goals	Organizational autonomy gained from weak oversight
Financial management	Complete budgetary autonomy also to pursue innovation investments; however; external audits (ex-post control and feedback on the use of autonomy)	Autonomy to pursue innovation investments, although, some investments need to approved by the government; some trans-parency and accountability concerns; external audits	Autonomy to pursue innovation investments; however, post-2000s dividend policy unpredictable; transparency concerns (no external audits)
Personnel management	Strong meritocratic system; 7 of 10 board member are external, no government officials on the board; motivational packages for CEOs (shares of the company)	Meritocratic system with varying pressures for patronage; most board members appointed by the government; motivational packages for CEOs (shares of the company)	Network of private organizations with independent practices; board members appointed by the government (incl. government officials), no external members

[4] Net fixed asset turnover is calculated as total revenue divided by net fixed assets. It is used to evaluate industries with heavy capital investment. Generally, higher fixed asset ratios show that a company has less money invested in fixed assets for each dollar of revenue or sales.

Organization al design	Coherent corporate entity with outreaching R&D networks	Coherent corporate/ bureaucratic entity (also own R&D centre)	Fragmented network of independent entities (also own R&D centre)
Dynamic innovation capabilities	Systemic innovation actor	Evolving from independent innovator to systemic innovation actor	From independent innovator to gradual erosion of innovative capabilities

Source: Authors based on the analysis and Forbes 2000 data (2015), Musacchio and Lazzarini 2014b; * Petroleum Intelligence Weekly (2003) and Stock Analysis on Net (2012).

4.3.1 Petrobras and Statoil as systemic innovation actors

The detailed comparative analysis of risk management practices (by governments) related to these SOEs (Nolan and Thurber 2012) show that Petrobras and Statoil stand out as SOEs whose rationale seems to contradict the conventional logic of creating and managing SOEs.

From the macro level dimension, in both of these cases the rationale for establishing SOEs as the key actors in the oil sector stemmed from rather broad macro-level political needs (reducing the reliance on foreign currency imports in Brazil; maintaining national control of resources and macro-economic development in Norway) that could be supported and maintained through autonomous technological capabilities. Socio-political acceptance of these needs provided to the state the capacity, or policy space, to tolerate risks related to creating indigenous technological capabilities in deep-water and rough-sea oil exploration and value chains. This state-level risk tolerance was achieved in different political systems (authoritarian military system favouring state capitalism in Brazil and social democracy in Norway) and varieties of capitalism Brazil's military rule and its preference for state capitalism created a legacy of using SOEs for fast-track to industrialization (Trebat 1983, OECD 2015, Musacchio and Lazzarini 2014a). At the same time, the Scandinavian governments are traditionally 'active' owners of SOEs with a clear focus in value creation implemented via deregulation and clear strategic choices (Clifton et al. 2006).

In the Brazilian case, the capacities for this role were initially mostly concentrated into Petrobras itself that enjoyed strong autonomy in the oil sector (i.e. the SOE acted almost as the ministry, regulator and innovation oriented developmental agency), although the rulers intervened in the organization in times of macro-economic difficulties. Petrobras started to move towards a more 'modern' SOE with explicit balance between managerial autonomy and external control (through new regulatory arrangements and corporate governance changes) only in 1990s when Brazil intensified attempts to privatize its vast SOE sector and open the oil industry for competition (Oliveira 2012, OECD 2015, Musacchio and Lazzarini 2014a). In the Norwegian case, this expertise was from the start embedded in tightly-knight expert networks and separation of tasks between different institutions (political strategies, regulation, SOE and its value chain) thereby balancing autonomy and control of the company (Thurber and Istad 2012). For example, although the Norwegian Petroleum Directorate (NPD), the regulator of Statoil, is subordinate to the government (Ministry of Petroleum and Energy) it has acquired high levels of technological capabilities which help to keep it functionally autonomous and strong (Musacchio and Lazzarini 2014b). In comparison, the National Oil Agency (ANP) in Brazil is relatively weak and the de facto regulator of Petrobras is the Ministry of Mines and Energy opening it up to also political interference from the heads of the executive branch, including the President of Brazil (ibid.). Furthermore, as both Statoil and Petrobras are publicly traded companies the institutional investors are active in controlling executive decisions and thus play a strong role in monitoring the SOEs. While initially both SOEs performed rather modestly in conventional efficiency terms, over time they have become world leaders in specific deep-water and rough-seas oil operations performing closely similarly to international private corporations.

From the micro level perspective, these macro level characteristics were initially supported by strong meritocratic bureaucratic and managerial expertise and routines consciously nurtured in both countries (policy and administrative levels) and in SOEs (see table 3 above). Both SOEs emphasized rather strong Weberian managerial routines (merit based recruitment and career systems – up until the 1980s in the case of Petrobras (Musacchio and Lazzarini 2014a)) characterizing also public management systems of the time. While in the case of Statoil, previous CEOs have had political backgrounds, their strong technical backgrounds have not been refuted and nor has their appointment been dependent on electoral cycles (Musacchio and Lazzarini 2014b). As Evans and Rauch (1999) famously argue, these routines may be instrumental for devising and implementing long-term investment strategies and projects in the catching-up phase of emulating more developed peers (characteristic of the early development context of both SOEs) while arriving closer to the techno-economic frontier may demand more experimental and learning oriented routines as found in more traditional private innovators (Nelson and Winter 1982).

Over time, the technological and innovative capabilities have become highly interlinked with the domestic innovation systems and networks turning SOEs not only into indigenous technological actors and innovation-oriented entrepreneurs, but also into critical nodes or actors in the broader innovation system. That is, in both countries SOEs provide demand and collaborative networks for domestic value chain development. In Brazil, Petrobras has gradually created since the 1980s its own domestic supplier networks of universities and other companies to develop new skills and technological solutions for the needs of the company (see de Britto Pires et al. 2013, Furtado and Freitas 2000, Dantas and Bell 2011). In Norway, Statoil has acted in a similar way, but through a more open, dispersed and mutual adjustment based collaboration network of actors both on the policy level (other industrial policy actors, regulators) and on the operational level (universities, competitors, value chain partners) (see Engen 2009, Klitkou and Godoe 2013).

In sum, both the Petrobras (in specific period) and Statoil in general fit rather well into the category of *SOE as a systemic innovation actor* of our taxonomy into which they were consciously developed through public policy efforts, but following different institutional models. Given the more unstable political environment in Latin America, in the early years Petrobras was also a tool of state capitalism following more mixed rationales. Since the 2008 global financial crisis the pressures to use the SOE for price controls (together with scandals related to patronage and corruption) (see also OECD 2015) indicate the much more fragile macro level context of the Latin American type of capitalism (Musacchio and Lazzarini 2014a). It is also debatable whether their role as systemic actors will further diminish after their partial privatization and increasing global reach of strategic activities as they may become increasingly detached from domestic context and networks they have created. Namely, it is found that when the companies with lowering domestic resources increasingly internationalize – e.g. ONGC (India), CNPC (China), and Petronas (Malaysia) – they can become less and less attached to the national innovation system and remain autonomous, 'entrepreneurial' or even 'shadow' actors with a high level of fiscal, but low domestic (innovation) policy importance (Nolan and Thurber 2012, Victor et al 2010, see also Tõnurist 2015 for a similar case study result).

4.3.2 PDSVA: Failing to become a systemic innovation actor

The large-scale study by Victor et al. (2012) highlights also different facets of potential failures of SOEs as individual and systemic innovation actors in case they lack some of the macro or micro level ingredients we have identified. Probably the most notable case of failures in relation to systemic innovation rationales is Venezuela's PDSVA.

PDSVA was created in 1976 through the nationalization of several companies. The new entity maintained many of its private sector managerial routines through the federal model (where each nationalized entity maintained its autonomy and existing managerial practices, e.g. merit based recruitment) and regulation by the commercial code. These micro-level characteristics allowed it to maintain efficiency within separate units, but at the same time it developed also its internal R&D capabilities (INTEVEP centre) and domestic innovation networks. Thus, PDSVA was establishing itself as one of the leading companies in extra-heavy oil exploration activities while also building its own sectoral innovation system of private sector supplies and partners, and foreign linkages. At the same time, the government opted for weak political control of the company as ownership was deemed sufficient for control and no countervailing institution and policy and coordination capacities were consciously developed. This autonomy allowed PDSVA to develop substantial efficiency and technological and innovative capabilities within the company, but also raised political criticism of the company especially in the 1980s (as a state within the state). This limited its potential role as a more general actor and coordinator of the Venezuelan innovation system. PDSVA has almost 3 times more patents than Brazil's Petrobras; yet, the latter is considered more innovative and better performing indicating that patent ratios may be driven by various factors (i.e. lack of strategic supervision of R&D departments, SOEs acting as 'universities' etc.). Thus, in our taxonomy, pre-2000s PDSVA had the micro-level organizational capacities for innovation allowed for by rather weak policy coordination and steering. In comparison to Statoil and Petrobras, it did not function as clearly as a systemic innovation policy actor, but as an *independent innovator* mainly because of the lacking macro-level policy coordination capacities on behalf of the state to steer and coordinate the other actors of the innovation system.

Since early 2000s and given the changes in the macro level dimensions of political goals and coordination (during Chavez presidency of Venezuela (1999-2013)), PDSVA has turned into multiple-goal political entity (operating company, development agency, political tool, government 'cash cow') (Hults 2012, Mares and Altamirano 2007) losing its self-created policy autonomy and shifting towards the role of shadow actor. Similarly, most other SOEs in the oil sector have not enjoyed policy or fiscal autonomy at all and thus, have remained 'cash cows' for the government without distinguishable macro level incentives (e.g. Pemex in Mexico (Pargendler et al. 2013), NNPC (Nigeria), Sonatrach (Algeria) and most SOEs in the study by Victor et al. 2012 would in fact fall into quadrants C or D).

4.3.3 Summary

These cases seem to confirm that while innovation supporting micro level dimensions of SOE governance and management are *sine qua non* for developing innovation capabilities in SOEs, it is the macro level dimensions that determine the most fitting forms of micro level governance mechanisms and also the eventual systemic impact of SOEs and the sustainability of their internal capabilities development. Further, socio-economic differences between different regions and economies and also phases of technological development lead to varied forms of complementarities between SOEs and innovation policy. In other words, if SOEs function as instruments of innovation policy, there are no universal micro and macro level best practices of SOE governance. Rather SOEs become parts of the innovation system adjusting its internal organizational routines to fit the broader governance of the innovation system.

4. Conclusions

This article has discussed the role of state owned enterprises in economic development and has argued that SOEs can also be rationalized as instruments of innovation policy, both as *independent innovation actors* and as potential *coordinating change agents* within broader innovation systems. Looking at SOEs from this rationale requires a broader and more contextually embedded approach to SOE governance than usually used in SOE research. While some scholars have argued that the organizational level characteristics (capabilities and routines) of the SOE matter most for using SOEs as innovation policy instruments, we argue that given the complexities of innovation – that innovation scholars have operationalized into the systems of innovation concept – we still need to grasp the macro level conditions (especially policy and coordination capacities) as well, as these determine whether the SOE acts as a sustainable systemic innovation actor or individual innovator.

To conceptualize this new approach, we have summarized the macro and micro level dimensions of SOE governance into a simple analytical taxonomy that highlights the generic conditions necessary for the SOEs to contribute to national innovation policies. This is the main contribution of the article. We exemplify the approach and the taxonomy through a concise analysis of the oil sector and the examples of Petrobras, Statoil and PDSVA. This discussion shows that the institutional blueprints still remain highly contextually dependent on national or industry-level differences. The discussions of the necessary conditions of macro and micro level governance also show that SOEs as innovation actors exist as a relative exemption given the current state of SOE management practices.

Yet, within the spreading 'entrepreneurial state' and demand-side innovation policy rhetoric, SOEs could act as important instruments for fostering a more pro-active and targeted role of the state in innovation. At the same time, given the legacies of SOE rationales and governance over the last decades, this rediscovery of SOEs as innovation policy instruments may in most instances be a challenging case of policy reform, both at the macro level of economic and innovation policy – through changing the policy orientation of SOEs towards R&D and networking within the innovation system (and also shifting innovation policy more closely towards SOEs) supported by newly developed coordination capacities – and also at the micro level of SOE governance – through changing the internal managerial practices, incentives and performance orientation of SOEs.

To comprehend these challenges in more detail, we need much more detailed case studies of the few success stories of SOEs as innovation entrepreneurs and to compare these to the more extensive accounts of SOE failures for comparative lessons. In these studies both the micro level governance factors and the macro level policy goals and governance factors should be analysed together to provide a more objective account of both the positive and negative effects of ownership structures in the long-term.

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Market Liberalization and Innovation in the Energy Sector: The Case of Belgium and the Netherlands

Piret Tõnurist[1], *David den Besten, Pieter Vandeven, Xinhui Yu, Dalia Paplaityte*[2]

Abstract

Electricity markets in Europe have gone through several rounds of liberalization reforms since the 1950s and 1960s. In recent decades these reforms have also been justified with non-optimal levels of innovation and research and development (R&D) in the energy sector. This article examines the effect electricity-market liberalization has on innovation in the sector and argues that market structure has an influence on the outcomes of these reforms when R&D and innovation diffusion are considered. This is usually not discussed during policy deliberations concerning electricity-market reforms. The case studies of Belgium and the Netherlands are used to exemplify the argument. The findings of the paper are relevant to policy discussions regarding innovation diffusion in the energy sector and the spread of renewable energy technologies. Furthermore, the new market context should be taken into account when designing energy-technology policies.

Keywords: electricity-market liberalization, renewable-energy policy, innovation diffusion, Belgium, the Netherlands

1. Introduction

Historically electricity-market liberalization[3] in Europe started in the 1950s and 1960s. Its main goal was to diminish restrictions on in- and out-flows of electricity from national boundaries (De Jong 2006). Thus, policies during the first round of liberalization developed though the help of technology push as large electricity

[1] Ragnar Nurkse School of Innovation and Governance, Tallinn University of Technology, Akadeemia tee 3, 12618 Tallinn, Estonia; Corresponding author. Phone: +372 620 2657; fax: +372 620 2665. E-mail address: piret.tonurist@ttu.ee.

[2] Den Besten, Vandeven, Yu and Paplaityte all Katholieke Universiteit Leuven, Oude Markt 13, 3000 Leuven, Belgium.

[3] In this article the concept "electricity market" is used interchangeably with the "energy market" – if the latter is used in a broader sense (including the heating and the gas market) it will be specified in the text.

capacities (via outsized nuclear power plants) were built and their output surpluses had to be absorbed and transmitted. Nevertheless, cost-efficiency decisions were still made in national states, as the interconnected energy systems only provided safety valves for seasonal flows of energy for the utility grids, but did not have any measures to stimulate energy production at the lowest (including environmental) cost (COM(88)238). Affordability, reliability and security of energy systems in Europe took precedence (e.g. Surrey 1992). After 1985, the liberalization process has been concentrated on opening energy networks to third parties, unbundling the system and increasing competition across borders (Jamasb and Pollitt 2005; 2008; Serrallés 2006; Lagendijk 2011). Thus, from the 1980s onwards, the European Commission has promoted reforms to increase trade in electricity across Europe using the pillar of the free movement of goods to gradually expand regulation on electricity markets (Padgett 1992). Common investment in energy infrastructure and a smaller number of internationalized electricity companies with a better competitive positions were deemed more efficient (Clifton et al. 2010).[4] In 1996, the policy momentum culminated in the directive on the internal market for electricity (96/92/EC) which called for the opening of electricity markets starting with bulk consumers (Eising 2002; see also Jamasb et al. 2014).

Consequently, in the second round of liberalization reforms, the efficiency arguments became more important and started to include research-and-development (R&D) efforts. The reasoning was that R&D expenditures in publicly owned companies were not transparent: they were considered ill-directed (over-engagement with fundamental science with little connection to the market) and not geared towards profit maximization (see, e.g., Chesshire 1996; Mulder et al. 2006). Furthermore, it was argued that there was a myopic bias in R&D funding in state-owned companies: e.g. more than half of public R&D funding in all OECD countries after the oil crisis went to nuclear energy in the 1970s (Grubler and Riahi 2010). While the debate regarding the inefficiency of state owned enterprises has been rather one-sided, the activities of state-owned energy companies are dependent on the role the government has assigned to public enterprises (Tõnurist 2015).Thus, also the productivity and innovativeness of state-owned energy companies can vary considerably across countries (Tõnurist and Karo 2015).

Nevertheless, in the midst of rising electricity demand, the governments had to socialize the risks associated with R&D in thermal and nuclear power production. Thus, the effects of electricity-market liberalization were seen as very positive (e.g. IEA 2005), and after the liberalization R&D levels were also expected to increase (Erdogdu 2013). However, since the mid-1990s work on the unintended effects of market reforms on R&D, patents and renewable energy (RE) started to surface about the US with other research following (GAO 1996; Dooley 1998). Hence, the previous debate on the effects of market liberalization and increase in competitiveness

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[4] The interests of France and Germany have been seen as instrumental in promoting the idea of an internal market in the union and arriving at the "buyer model" (i.e. all energy generators will sell energy to a singular party that distributes electricity imports and exports; Lagendijk 2011). During this period Belgium and the Netherlands (among others) opposed the idea of third-party access to energy systems (Eising and Jabko 2001); however, later the Dutch government became a strong advocate of ownership unbundling (Torriti 2010, 1066).

was found to be dependent on a static understanding of the technological environments (Porter and Van der Linde 1995). There are still gaps in this academic debate, and one of them relates to the effectiveness of market mechanisms – here liberalization – in the context of different market structures and hence also technological mixes and the influence it has on innovation in the energy sector.

This article discusses how energy-market liberalization has influenced R&D and innovation in the energy sector and the development of renewable technologies. A short review of previous research is presented in the theoretical part of the paper. We argue that these effects are at least partially dependent on energy-market structures prior to liberalization. To exemplify this argument and propose new research avenues, we compare the electricity markets in Belgium and the Netherlands prior to and after liberalization and the effect of reforms on incumbent energy producers' R&D and strategic goals. Belgium and the Netherlands were chosen for case studies, because both countries opened up their electricity markets at a relatively similar time, meaning that the effects of economic fluctuations can be minimized. Furthermore, while both countries have distinct energy-sector structures, they still belong to the same general energy and environmental policy context as part of the older EU member states. After an outline of the empirical cases, we will also discuss the need for hierarchical and network-based policy measures in different settings, and we conclude with the theoretical and policy relevance of our study.

2. Theoretical considerations

Public policy has been found to play an important role in innovation transitions in the energy sector (e.g. Lewis 2011; Ru et al. 2012). In any policy field there are different policy mixes and coordination measures to choose from – most broadly speaking these can involve the use of market mechanisms, hierarchies and networks (Wollmann and Bouckaert 2006; in the context of innovation policies Karo and Kattel 2010). However, ambiguity on what is desired from the policy mix and the instrument interactions has, thus far, not been studied very well (Rogge and Reichardt 2013). Therefore, policy measures can be inconsistent, counter-productive and work against each other (Kern and Howlett 2009, 396). Here we concentrate on the use of market mechanisms and market liberalization in particular in these policy mixes.

As outlined above, at first, energy-market liberalization was not tied to the R&D and innovativeness of the sector, but the risks and uncertainties characterizing the process were soon found to influence also the innovativeness in liberalized electricity markets (Markard and Truffer 2006; Künneke 2008). It became clear that policies which at first glance did not seem to be technology- and R&D-oriented presented a complex relationship between innovative activities and desired goals in the energy sector (e.g. Jørgensen 2005). Parallel to liberalization, the sector was also confronted with societal challenges coming from the climate-change debate and thus, policy (incl. market-based measures) was increasingly put into the context of technological change and innovation (Tõnurist and Valdmaa 2015).

Consequently, the main idea in the energy sector (besides the increased use of market mechanisms) is to raise competition levels through which selective efficiency could be enhanced (Gaffard and Quéré 2006). Hence, in this context market mechanisms – in addition to other governance forms – should be aimed at creating the desirable growth conditions. This can be done through (1) deepening of the market (enhancement of existing product functions), (2) widening of the market (adding new functions to the product), (3) drifting (change of product usage) and (4) emerging of markets (solutions for new problems) (Moore et al. 2007). However, when we are talking about the nature of electricity production – non-unique, interchangeable and infrastructure-dependent product – some of the former market-development models become more difficult to achieve. There are studies about the relationship between liberalization and technological capabilities (Basant and Chandra 2002; Pamukcu 2003; Figueiredo 2007) but little consensus over the direction of the effect. Consequently, free trade does not automatically enhance the accumulation of knowledge and R&D (Cimoli et al. 2007). Therefore, no automatic positive response regarding the growth of innovation should be expected following the liberalization of the energy market.

What is known is that electricity-market restructuring influenced the overall R&D expenditure levels within the industry and affects the levels of technological innovation (Jamasb et al. 2008). R&D investment levels in general have been wavering over the last two decades in the energy sector. This has been ascribed – at least in part – to the process of privatization and liberalization in the energy sector (Sterlacchini 2012). Consequently, also the creation of a wholesale market for electricity is associated with the drop of R&D spending (Kim et al. 2012). As such, between 1990 and 2004 investments in electricity-utilities R&D fell by 62% (45.5% directly relating to electricity research) in Europe, as companies have been abandoning long-term research projects with fundamental and general-purpose technology concerns (Sterlacchini 2012). The same trend holds for the US, especially after the liberalization reforms carried out in 1993 (Sanyal and Cohen 2009). Moreover, going through the unbundling process, the size of the electricity-utility companies and the overall R&D budgets have decreased, meaning a loss in the ability to scale up projects (Jamasb and Pollitt 2008). This points to an overall push towards decentralization in open market conditions, which is also expected to create the momentum for the prevailing technological regime change (e.g. Jacobsson and Bergek 2004). However, Bell and Schneider (1999) describe this process as the "Balkanization" of R&D, in which deregulation is undermining collective research efforts and leads to duplications, which publicly funded technology programmes cannot compensate for. Furthermore, liberalization, unbundling and privatization in the energy markets all contribute to the increased importance of the financial performance of energy companies searching for cost-saving and efficiency gains (e.g. Markiewicz et al. 2004). Consequently, Sanyal and Cohen (2009) found a deep decline in R&D expenditures after restructuring in the electricity markets. The decrease is cyclical: meaning that companies reduce their expenditures very early in the stages of restructuring, followed by a recovery phase and another dip after the market regulation is enacted. This has been tied to the decline in R&D intensity and the suboptimal investment levels in the electricity industry (Jamasb and Pollitt 2006). This also means that R&D budgets in general can decrease through market-based measures in the energy sector, and the configuration and mixes of technologies in the market have a tendency to stabilize after reforms (Munari and Sobrero 2003; Sanyal and Cohen 2009; Jamasb and Pollitt 2008; 2011; Gugler et al. 2013; Cominato Boer et al. 2014).

On a more technical-organizational note, the existing spot markets do not allow hedging based on spot-prices and forward prices – this complicates investment decisions because hardly any informational quality is currently attributed to the aforementioned (Defeuilley and Meunier 2006; also Finon 2008). Moreover, due to the homogeneity of electricity the free-rider problem raises its head when electricity production is a competitive activity, but R&D investments become an "optional" spending for the firm (Grubb 2004; Thomas 2007). On the whole, this means that it is difficult to create high levels of innovative competition in a uniform product markets through market-based measures alone, and the effects of market liberalization policies can be unforeseen (see further on the effects of low competition in energy markets in Schimitt and Kucsera 2014). Thus, in liberalized market conditions regulatory quality – re-regulation – is assumed to be key in inducing adequate investment levels from private players (Joskow 2008). At the same time, regulators in Europe are found to be rather ineffective: for example Ugur (2009) shows that there is no correlation between *ex-ante* regulatory quality and *ex-post* performance indicators in liberalized EU-15 network industries.

Consequently, when we just look at research funding then R&D budgets for RE technology have increased substantially in the 1970s and the early 1980s, but from then on remained broadly constant in OECD countries (Jacobsson and Bergek 2004). The stagnation of R&D funds is in conflict with the increased attention on environmental goals (Johnstone et al. 2010; da Graça Carvalho 2012; Tõnurist and Valdmaa 2015). Various government policies (e.g. tradable renewable energy certificates, feed-in tariffs, production quotas and tax credits) have been introduced in an effort to reduce costs and accelerate market penetration, but also further investment in R&D is needed. Hence, the advisory group of the European Commission has urged to increase the levels of investment in the energy technologies to a level similar to the proportions of 25 years ago (Advisory Group on Energy 2005).[5]

At the same time, R&D expenditures cannot be recovered in the same magnitude from customers anymore (Sterlacchini 2012; Moreno et al. 2012): stable income from the markets to recover costs from guaranteeing a reliable electricity supply has disappeared, and profit margins have become limited due to increased competition.[6] As a result, companies see possibilities for dividends at the expense of advancement in technology (see e.g. Salies 2010; Clifton et al. 2010), especially after the decline of state funding (Schimitt and Kucsera 2014). Some examples of technology fields that are found to require more investment than is currently available are tidal turbine systems, biomass gasification, carbon capture and storage, fuel cell batteries and photovoltaic technologies (Salies 2010). This means that business-oriented goals start to dominate with very little long-term strategic perspective (see also Tõnurist and Valdmaa 2015).

5 For example, while 6.5 billion Euros of the Horizon 2020 are set aside for research and innovation under "secure, clean and efficient energy" the new version of the programme "Intelligent Energy – Europe" was initially not included in the aforementioned, and only later the programme "Market uptake of energy innovation" was added to it (see Climate Allegiance 2012; the opinion of the Committee of the Regions on the Horizon 2020 (2012/C 277/14)).

6 Thus, many larger electricity-utility companies (especially from larger economies) have selected an aggressive strategy towards cross-border acquisitions and internationalization to increase their size in the market that is characterized by monopolistic competition (e.g. the emerging dominance of EDF, ENI, E-ON, Vattenfall in the European energy markets) (Clifton et al. 2010).

Furthermore, electricity companies are not in general terms R&D-intensive companies (Nemet and Kammen 2007; Jamasb and Pollitt 2011). However, the intensity and quality of R&D (measured by patent data) has also declined in the connected industries (e.g. Sanyal and Ghosh 2013). Nevertheless, it does not mean that all innovative activities have stopped. Markard and Truffer (2006) found, after studying the effect of liberalization on the 4th-generation energy technologies (nuclear energy, fuels cells, wind power etc.), that while prior innovations were incremental, "slow" and technology-oriented, after structural changes in the market, companies tended to switch to more customer-oriented, organizational and more rapidly executed innovative activities. That means that energy companies have put the weight of innovative activities on the customer end of the value chain dealing with intelligent networks, smart grids etc. (Jamasb and Pollitt 2008). Therefore, through the process of liberalization in a network-bound system customers are re-involved with the service through the changing strategic actions of power utilities (e.g Vliet 2012). Consequently, re-shuffling of the energy market and creating institutional discontinuity affects both basic and applied activities of energy firms – the first seems to decrease and the second to increase (Calderini and Garrone 2002). Thus, innovation has moved in the energy sector more towards how electricity is consumed rather than how it is produced.

Consequently, in the context of the adoption of renewable energy sources there are considerable "system failures" that are outlined also in connection to market structures, infrastructure and institutions (Negro et al. 2012). While Johnston et al. (2010) show that public policy and especially the environmental restrictions and the passage of the Kyoto Protocol spurred on patent applications in the field of renewable energy, large-scale criteria, the dominance of incumbents and incremental/near-to-market innovations still play a role. High sunk costs become large barriers to market reconfigurations (Paulun 2008; Grubler 2012), and if surpassed too fast, technological up-scaling can lead to inferior technology choices (Kamp 2008; Verbong and Geels 2007). Hence, uncertainties created through market restructuring may affect investment in general, investment in R&D in particular and thus also the technological direction in energy sectors (Sanyal and Cohen 2009; Sirin and Erdogan 2013). Consequently, spurring competition through the liberalization of energy markets might increase the possibility of technological breakthroughs and their diffusion (Szabó and Jäger-Waldau 2008), but without substantial initial public stimulus and stability of investment it is difficult for RE companies to break through (Jacobsson and Bergek 2004; Nemet 2010; Jamasb and Pollitt 2008). Furthermore, the smaller the energy suppliers are in the electricity market (as is the case for the UK and the US) the more difficult is the task to support collaborative R&D projects (Sterlacchini 2012). Consequently, a U-shaped relationship between innovation and completion has been previously discussed (Aghion et al. 2005). However, there is no direct and uniform connection between the two: Tishler and Milstein (2009) argue that it depends on the sector/technology, strategic choices of firms and differences in existing competition. In the infrastructure-bound system of electricity generation this seems to become even more important.

Thus, more competition to the energy sector may create market failures in the electricity system or uncover them, but based on current evaluations it is difficult to see the full extent of the former. As mentioned above the market structures and technological mixes become important factors in the ongoing R&D and innovation dynamics. Thus, market structure may strongly influence technology penetration (Moore et al. 2007). Tsoutsos and Stamboulis (2005), furthermore, argue that different players in the market should be made to participate in R&D activity or at least contribute to it, because knowledge creation needs to be sustained throughout the evolution of the system. For this reason, even the initial degree of decentralization (with existing linkages, networks and possibilities for technology spill-overs; Dantas et al. 2007) in energy markets prior to the introduction of market measures can become very important: previous experience in integrating decentralized sources of energy to the network helps collaboration (Lehtonen and Nye 2009). Consequently, Jamasb et al. (2005) argue that the initial sector structure predetermines the reform trajectory and following key decisions. Furthermore, the distance from the technological frontier becomes a factor in how companies deal with increased competition (Aghion et al. 2002; Carlin et al. 2004). This, however, is more postulated in single-case-study approaches, rather than empirically analyzed. As argued above, prior analyses have been more static and have not accounted for the dynamic and developing nature of markets. This is the topic where the current article tries to make a contribution: we will compare the market structures and market incumbents' strategies over time in Belgium and the Netherlands in the following sections to explore the significance of market structures on innovation and R&D through the process of electricity-market liberalization.

3. Market liberalization and innovation: the case of Belgium and the Netherlands

The paper adopts a comparative research design juxtaposing the energy sectors in Belgium and the Netherlands throughout the process of market liberalization. While the countries are different in their policy-implementation structures (federalism, centralism) and policy measures to promote R&D in the energy sector (see, e.g., Table 2 in the Appendix), the countries were chosen due to their relatively similar timing of reforms, similar size and dependence on (albeit different) non-renewable energy sources. Both countries belong to the same regional wholesale market, and they have relatively strong, single-sector national regulatory agencies (at the time of the analysis; the Netherlands has integrated national regulators into a multi-sector regulator since 2013) (Glachant 2014). While it is impossible to minimize all challenges that comparative research designs present – causality issues, identification of net effects and confounding factors – triangulating evidence gives us the possibility to study the effects of market structures and the liberalization of electricity markets on innovation in the sector and propose new research avenues. However, we have to note that the relative overall time span of 20 years of market liberalization is too short for an in-depth analysis of the success or failure of radical innovations and their connection to market reforms.

In the following sections we will outline the structures of the energy sectors in Belgium and the Netherlands, analyze the reform trajectories towards market liberalization and the effects the former had and look at the change in R&D investments during this period. To get a better picture of the actions of the electricity-production companies in Belgium and the Netherlands and illustrate the effect of market structures on innovative activities, we will look at the changing strategic positions of significant incumbents in the markets (> 1% market share). This is based on the qualitative analysis of the authors based on annual company reports (from 2001 to 2011) from the database Amadeus. Not to be influenced by the diverging availability levels of recent data, we cap the year of analysis with 2011. Following that we will proceed with two chapters to describe the context of electricity-market reforms in Belgium and the Netherlands and the policies applied to make the energy sectors "greener" before proceeding to the discussion of changes in R&D and innovation levels within the two markets throughout the process of liberalization.

3.1 Electricity market reforms in Belgium and the Netherlands

The starting points of the electricity-market reforms in Belgium and the Netherlands have been arguably different in terms of sources of energy for electricity production. While the increase in electricity-production capacity and the total production levels of electricity in these two countries have been historically quite comparable (despite the Netherlands having an understandable size advantage; see Figure 1 below), the composition of the electricity production structures have been relatively different (see Figures 2 and 3 below). Since the mid-1970s the dependence on oil and coal for electricity production has diminished in Belgium due to the introduction of nuclear energy. Currently (according to the data from 2010 from the World Bank), the biggest energy resources for electricity production are nuclear energy (50%), natural gas (32%), coal (8%) and renewable energy (6%). In the Netherlands, the electricity production since the late 1960s has been dependent on natural gas. At the moment, natural gas constitutes 62% of the total electricity production, followed by coal (22%), renewable resources (10%), nuclear energy (4%) and oil (1%). Further differences in the market structures and the potential impact on R&D and innovation within the sectors are discussed below.

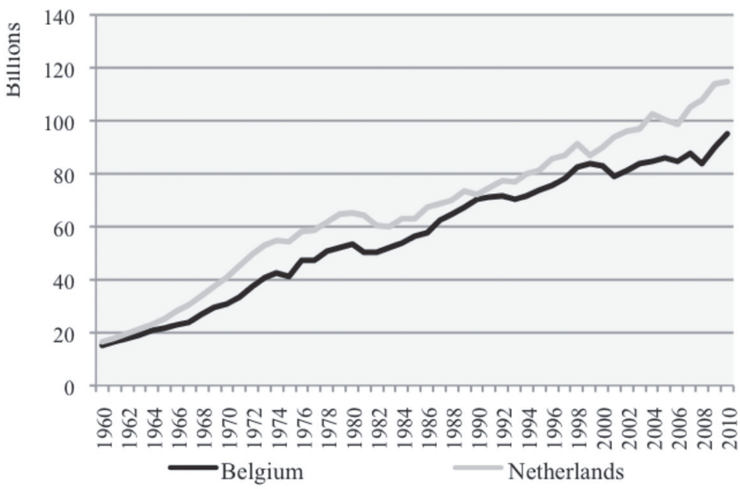

Figure 1. **Electricity production (kWh) in Belgium and in the Netherlands**
Source: Authors. World Bank Development Indicators.

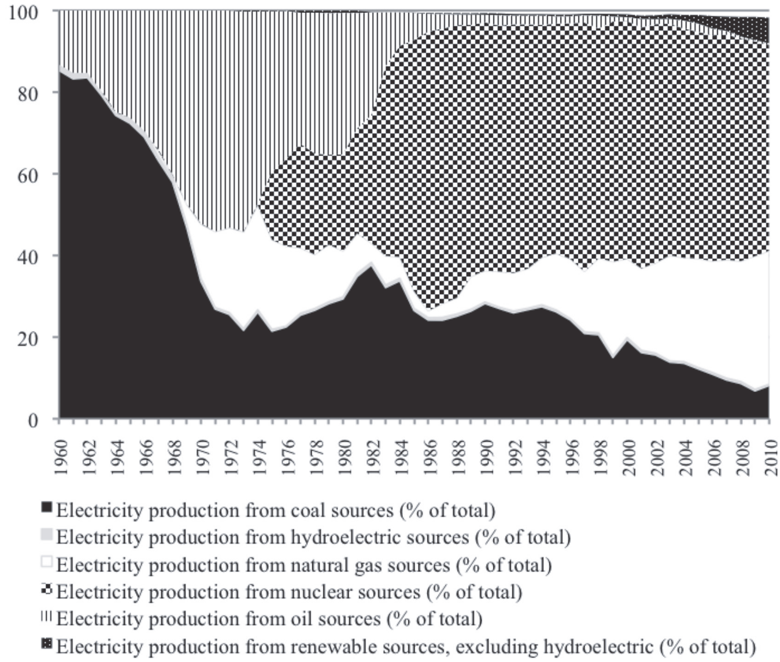

Figure 2. **Electricity production structure in Belgium by source of energy 1960-2010**

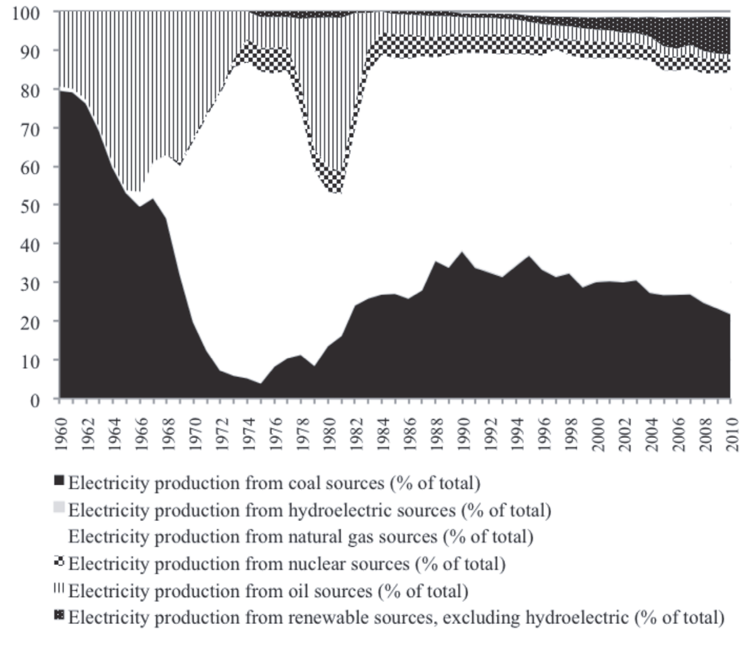

Figure 3. **Electricity production structure in the Netherlands by source of energy 1960-2010**
Source: Authors. World Bank Development Indicators.

3.1.1Market structure and reforms in Belgium

The previously mentioned EU directive (96/92/EC) was the first impulse to start the liberalization of the Belgian energy market (Deconinck and Gillard 2004), and the Electricity Act was introduced in 1999. Before the process of the liberalization, the Belgian market structure was highly concentrated, especially in the production or generation segment and the transmission segment (De Jong 2006). At the end of the 1970s, only three large private companies remained: Ebes, Unerg and Intercom. These private generators merged into Electrabel in 1990 and gained a market share of 91%. The other market shares belong to CPE, a fusion of small public generators, and some diminutive autonomous producers (Verbruggen and Verstappen 1999). In 1995, Electrabel and CPE formed the Coordination of Production and Transport of Electricity (CPTE),[7] which served as a participative company for the coordination and the management of their activities in the generation and transmission segment (Verhoest and Sys 2006). Since then, CPTE has dominated the transmission segment of the market (Huveneers 2005). The distribution and supply segments were in the hands of the municipalities. The first segment was controlled by both municipal and inter-municipal companies. Some inter-municipal companies joined forces with private partners in order to have a better organization of their activities. By the end of 1995, Electrabel was the private partner of 33 "mixed inter-municipal companies" and served 87% of the municipalities (IEA 1997). Therefore, it is easy to conclude that Electrabel dominated the whole Belgian energy market (see Table 1 below).

Table 1. **The Belgian and Dutch energy market: before and after the process of liberalization**

	Before the process of liberalization		**After the process of liberalization**	
	Belgium	**Netherlands**	**Belgium**	**Netherlands**
Supply/sales	*Concentrated*: Domination by Electrabel (91% market share) and nuclear energy – publicly owned (encompassing generation, transmission, distribution and supply) SPE (6.5% market share; public) – company in public hands (generation, transmission and supply)	*Less concentrated*, but controlled by large-scale producers: Electrabel (33% generation capacity in 1999; of which 85% was gas-fired), Reliant, Essent, E.ON; EPZ	*Concentrated*: Generation and supply: market control of Electrabel + SPE (98% in 2006) Electrabel private for profit company – bought by Suez (France) RWE and EDF emerge	Acquisitions, *concentration* in the market: RWE, E-On etc. sold to MNCs; Essent buys up CHP companies and concentrates production
Distribution	*Centralized*: CPTE created by Electrabel and SPE (public-private elements)	*Centralized control*: SEP – transmission company owned by main producing companies	*Centralized, public control increased.* CPTE►Elia (transmission systems operator public (30%), Electrabel (ca 27%) and SPE (6%); rest stock market.	*Centralized, public control.* SEP►Tennet Nationalized and in public ownership
Transmission	Public and partially private: municipal and inter-municipal companies + Electrabel (obligation to buy electricity from company)	Distribution-grids-regulated local monopolies (Nuon, Eneco Energie and Essent biggest owners)	Same + Elia, BIAC Public and partially private (Electrabel ca 30% in 2006 mixed-municipal companies)	Some consolidation and emergence of new distribution companies (incl. Enexis)
Generation	Electrabel + SPE (38%), municipal (1%) and pure (12%) and mixed inter-municipal companies (with Electrabel 49%)	Large number of municipal and local energy sellers and suppliers; however, dependence on main electricity suppliers (Nuon, Essent, Electrabel, Eneco Energy)	Increase in the number of smaller companies in the Belgian market: including E.ON Belgium, Luminus, RWE, Essent Belgium, Wase Wind etc. (however, entrance to the market through purchase of regional utilities)	Rapid acquisition processes, number of suppliers decreases (when looking at subsidiaries) (e.g. under Essent)

Source: Authors based on the overviews by Verhoest and Sys (2006) for Belgium and De Jong (2006) for the Netherlands.

[7] Electrabel holds 91.5% of the shares, the remaining 8.5% of the shares are property of CPE.

The Electricity Act of 1999 served as the translation of the EU directive 96/92 at a federal level. This law would have initiated the opening of the market by legally unbundling the distribution and transmission segments from the generation and supply segments. This unbundling was realized by creating a legal monopoly for the former segments (Gusbin and Kegels 2003). CPTE accommodated their high-voltage transmission infrastructure in their subsidiary Elia, which was established in 2001. This operator was chosen in 2002 by the Belgian government as the national Transmission System Operator and gained a market share of 94% in the transmission segment. The municipal and inter-municipal companies were also obligated to exit the supply segment to fulfil the regulations of the Electricity Act (Huveneers 2005). Several measures were taken by the government to breach the monopoly of Electrabel in the supply segment, and the process was speeded up by the Royal Decree of 11 October 2000. This decree stated that all large industrial consumers are free to choose their suppliers. The full market opening for all other consumers had to take place from July 2004 onwards. Furthermore, the dissociation of CPTE and the auctioning of parts of the generation capacity of Electrabel have intensified competition (De Meulemeester et al. 2006).

It took several years after the Energy Act of 1999 to see some limited changes in the Belgian market structure (see Table 1 for the situation in 2006). Only two new players, RWE and EDF, entered the generation market, but they made no impact on the dominant position of Electrabel. The transmission segment stayed under the control of one company. The distribution segment stayed more or less as before the liberalization process. Municipalities retained their legal monopoly, and only two new players entered: Elia and BIAC. The biggest changes took place in the supply segment, where over 40 new companies entered the market. This seems very impressive, but the impact was rather limited with their combined market share of 14.2% (Verhoest and Sys 2006). The legal unbundling separated the distribution and supply activities, and municipalities had to leave the supply segment. The new law created a monopoly again for Electrabel with an 85.8% market share.

On the whole, the Belgian liberalization process was characterized by two different stages and the speed of the market opening. The energy-market opening was officially completed by July 2003. The energy market of the Walloon and Brussels region opened at a slower pace. According to the directive of the European Commision (2003/54/EC), these markets opened completely for industrial customers in July 2004 and for household customers on 1 July 2007. Thus, in Belgium a defensive strategy was at work: by delaying the market opening in different regions, Electrabel pursued an ambitious internationalization programme between 1999 and 2006 (Clifton et al. 2010, 1001). The fears of the government were proven correct, but the delayed strategy failed, and the company was bought by Suez and later merged with Gaz de France to form one of Europe's largest multi utilities (for an overview on the evolution of the French electricity policy in this regard see Bauby and Varone 2007). It is a general conclusion that the liberalization of the Belgian energy market was not successful either in promoting cost-efficiency or in diminishing the almost oligarchic control of one energy company (or the legislators' preference for the latter) in the market.

3.1.2 Market structure and reforms in the Netherlands

The opening of the Netherlands energy market took place also after 1996, when the direction of the EU policies changed and the Energy White Paper was introduced for the liberalization of Dutch energy markets. However, the electricity-market structure in the Netherlands is at its core different from the market structure in Belgium. Where the former was very concentrated, the Dutch electricity market had decentralized suppliers and less state regulation (Larsen et al. 2006, 2865). Thus, during the 1990s, the Dutch energy sector faced a different set of problems (for an overview see De Jong 2006). First, there were numerous players in the energy market. In reaction, the Dutch government decided to limit the number of suppliers to 50 within ten years in 1996 and integrate electricity with gas distribution to achieve more economies of scale (ibid.). Secondly, another set of problems (perceived by the policy maker) was the failure of the Electricity Act of 1989, which was mainly concerned with pricing and planning of electricity. It was responsible for the creation of a network of four power generators controlled by one institution SEP (now Tennet – see also the overview in Table 1 above). It was owned by the producing companies and was in charge of the capacity decisions in the Dutch electricity market. In 1999, 69% of the electricity-production capacity was in the hands of the large-scale producers of electricity: Electrabel had 4.7GW (33%) with 85% gas-fired, Reliant 3.7GW (26%) with 80% gas-fired, Essent 3.3GW (23%) with 60% gas-fired, E.ON 1.7 GW (12%) with 65% coal-fired, and EPZ had 0.85GW (6%), this includes a nuclear station of 450MW and the rest was in the hands of the industry (combined heat and power (CHP) units) (da Silva and Soares 2008, 342). The lack of completion created by the structure was a major concern for consumers and suppliers of electricity (ibid.). Thus, prior to market reforms, energy distributers in the Netherlands were looking for a way to become less dependent on the main electricity suppliers (Eising 2002).

The reform of the energy sector was greatly influenced by the Electricity Act of 1998, which gave the consumers the right to choose their own energy company (a large part of the consumers of electricity would be able to choose suppliers by 2002, other commercial users would get this possibility by 2004 and households in 2008). The rights were, at first, reserved for green-energy providers only, but the possibility was quickly expanded (Vliet 2012, 271). The unbundling of the electricity sector followed the EU electricity directive (2003/54/EC), and the separation of the transmission and distribution of electricity from production, trade, metering and sales started. The main goal of the reform was to diminish market power and to remove market entry barriers for new electricity producers that would bring new technologies and energy sources to the electricity sector. However, electricity companies Delta, Eneco, Essent, Nuon and Rendo were quickly bought up in the market. What now is Tennet was nationalized and made into a system operator and manager for the establishment of the national grid (Van Damme 2005). Next to that, network oversight was established, which is carried out by a regulatory authority DTe (Association of Electricity Producing Companies). Since the 2000s, intermediary companies have come to the market selling energy in “green”, “grey” or “cheap” packages from various national and international energy producers (Vliet 2012). In 2007, the state required energy companies to separate the distribution and production of energy into separate companies by 2011. This has led to shares of regional energy companies being sold to multinational enterprises (RWE, E-ON) and to the creation of new distribution network companies (e.g. Enexis; this already started in 2005-2006; De Jong 2006). Consequently, unbundling in the Netherlands created a situation where transmission networks remained in public ownership, but all other commercial activities privatized and concentrated (Künneke and Fens 2007). Table 1 above describes the processes succinctly: showing the concentration in both electricity generation and sales, however, as the starting point was much more decentralized compared to Belgium, the consolidation process was less centred on single companies.

3.2 R&D and innovative activity after market liberalization

How does the above-described market-reform and market-structure analysis tie in with R&D and innovation in the electricity sector? As shown in the theoretical framework liberalization can produce adverse effects for R&D expenditures and innovation in the energy sector. While it is deemed important how the reforms are implemented in the context of different market structures, there are few studies that concentrate on the former. This is so because, in general, R&D investment data for the electricity sector is very scarce. Only the country-level data submitted to the International Energy Agency (IEA) is available and thus can be comparatively analyzed. Data on corporate R&D expenditure, especially for the technology field, is very difficult to obtain – in this article available annual company reports (2001-2011) were analyzed to evaluate the commitment of electricity producers to RE technologies and R&D before and after the market liberalization in the Dutch and Belgian markets. Additionally, as indicative proxy for research activity, data from the Research Framework Programmes (CORDIS database and SET projects; ending 2011) was analyzed to identify R&D partners and especially direction of research of incumbent firms.

Our analysis shows that the variations in the starting conditions prior to the reforms have led to slightly dissimilar outcomes in Belgium and the Netherlands. The differences can be found both in terms of the technology base used in the dominant electricity-producing industries and also in terms of incumbents' power in the electricity market. The production and supply of energy was far more concentrated in Belgium with one dominating firm, while in the Netherlands, the market power was shared among several companies, and the local supply system was decentralized. This means that also in the Netherlands, the technology base was wider, and there were smaller companies in different RE technology fields and more interconnected networks. Thus, R&D was more diversified compared to Belgium. In Belgium nuclear energy dominates when it comes to R&D. Between 1989 and 2007 only R&D in solar energy and bio-fuels showed a slight increase in R&D-spending in Belgium, while in all other RE technology fields, R&D has remained relatively the same with no noticeable difference since 1970 (see Figure 4 below). Thus, despite the slight increase in R&D-spending in solar energy – demand of which was highly subsidized in the last decade – the energy-liberalization reforms in Belgium have not produced a significant diversification of R&D in the direction of RE technologies.

The prior momentum from the nuclear-energy orientation is still in place and is mostly funded by public sources. Nevertheless, there are R&D projects connected to RE technologies and diffusions in Belgium: for example, the construction of wind farms in the Belgian part of the North Sea (De Mulder 2008). However, funding for R&D in wind energy is so miniscule in Belgium that usually in international comparisons it cannot be displayed on graphs of the same scale graphs as other better performing EU countries (incl. the UK, Germany, the Netherlands, Denmark etc., but also the Czech Republic, Portugal, Hungary; see Technology Map 2009).

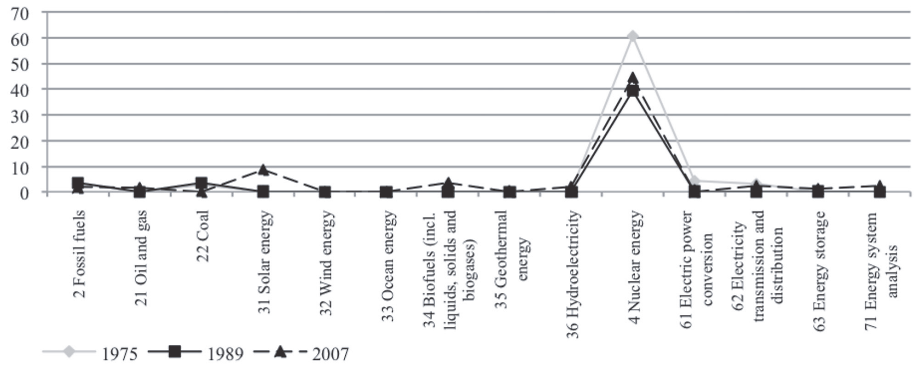

Figure 4. **Total RD&D in Million NC (nominal) in Belgium**[8]
Source: Authors based on IEA data (2012 edition)

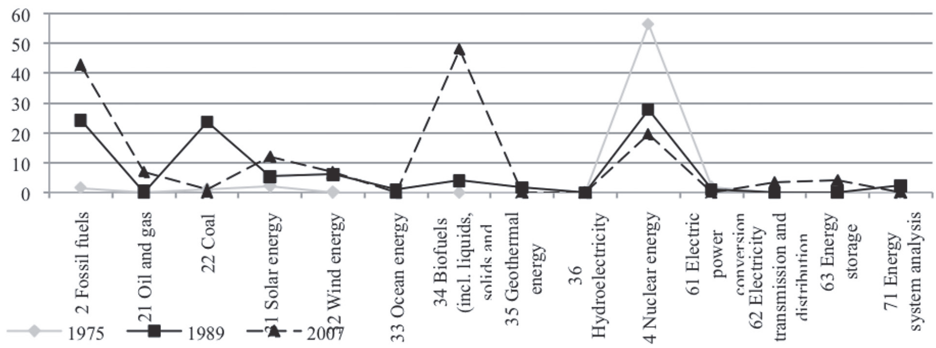

Figure 5. **Total RD&D in Million NC (nominal) in the Netherlands**
Source: Authors based on IEA data (2012 edition)

Consequently, in Belgium, only low-technology-based RE technologies have diffused. The biomass and biogas technologies in addition to PV solutions are not produced in the country itself. Here we cannot assign all of the changes in technology to market-liberalization processes alone, although the former was the single process

[8] For Belgium, data for the years 2000-2006 and 2008-2010 is missing.

which affected the incumbent companies the most. An overview of the policies and processes outside of the market liberalization is presented in Table 2 in the Appendix. However, in the 20-year-old solar thermal industry in Belgium, not many companies have survived the liberalization – at the moment only 4 to 5 companies have survived the competition with the largest supplier of equipment, HVAC (Verbunt 2011).

In the Netherlands R&D spending has shown some indication of diversification: from 2005 onwards, non-governmental R&D spending has increased from a basically non-existent position (see Table 3 in the appendix). However, private spending has been highly irregular, and the most noticeable increase has been in the field of bio-fuels. Governmental spending in the field has risen considerably since 1996. Resources for wind energy are higher now, but during the last decade, they have been wavering in the Netherlands (remaining on a level comparable to the period 29 years ago; see Figure 5 above). During recent years, the non-governmental part in the R&D expenses has increased (see Table 3 in the appendix). In the last decade, the total R&D resources allocated to the research of solar energy have improved. Fossil fuels have slightly improved (see Figure 2 above). However, as many projects started prior to market liberalization, it is hard to make a causal link between the two. Having transmission rights under public control may have led to smaller decentralized companies having access to a larger market base.

As such, there has not been a large shift in the direction of R&D spending in either Belgium or the Netherlands after the opening of the market and the unbundling of production, transmission and supply services. However, as there has been an increase in the proportion of electricity production from renewable energy sources in both Belgium and the Netherlands, the companies' commitment to using RE technologies for the production of electricity after liberalization processes is worth considering. The authors of this paper examined annual company reports and websites for companies having more than 1% market share in Belgium and the Netherlands for electricity production for this purpose. The subsequent list of the 6 energy producers in Belgium and the 5 energy producers in the Netherlands is presented in Table 4 in the appendix. While electricity-producing companies actively use the existence of RE sources in their production portfolios in marketing, the commitment towards RE sources and R&D, however, was not apparent in their annual reports. In line with the R&D spending overview presented above, use of RE technologies and investment in R&D are rarely presented in these company reports, meaning that for the largest incumbents in the Dutch and Belgian market at the moment, sustainable energy production is not a considerable factor for prospective investors (for it to be included in the reports) or a large-scale commitment for the firms themselves.

Nevertheless, there were some notable aberrations. First, Essent in the Netherlands, the largest energy producer in the Dutch market after Electrabel Netherlands, E.ON, Essent NV and Nuon NV, reported to have produced 17.9% of the energy generated from sustainable sources (accounting for 23% of the total RE produced in the Netherlands). In 2010, Essent was acquired by the leading electricity and gas company, RWE Group (German), which has tried to expand its portfolio towards RE sources in recent years. The main RE fields in Netherlands are biomass and wind energy. However, Essent did not become the biggest player in the Dutch cogeneration market (biomass) through building up capacities from the ground up, but through a merger between two CHP production companies and several distribution companies (Hekkert et al. 2007, 4685). Furthermore, E.ON, EPZ, Electrabel and Vattenfall-NUON own co-firing biomass capacities (see also report on bio-energy by Schwarz et al. 2011). As such, the second exception, based on company reports, is Nuon Belgium N.V. It is a fully renewable energy producer (large electricity-production capacity from a wind farm in the Antwerp dockland area) with a market share of 5.1% in 2011. Nevertheless, this company (as well as the previously mentioned Essent) has been subjected to larger multinationals expanding their production portfolios: from 2011 onwards the company operates as the subsidiary of Eni S.p.A., an Italy-based energy firm engaged in exploration, production, marketing, distribution and sale of oil and natural gas (see Deloitte 2011). Thus, multinational companies have bought market shares in RE production in Belgium and the Netherlands rather than entering the market as new entrants. Looking at the incumbents, this means that in both countries, through the process of liberalization and opening-up of markets a small group of large multi-nationals has emerged. Their activities cover North-Western Europe, which makes their R&D activities hard to distinguish and dependent on the groups' interest. For the largest incumbent in the Belgian energy market, it was noted in the annual reports since 2004 that the Belgian subsidiary of Electrabel (acquired shortly after the market liberalization by the French GDF Suez) has no considerable R&D commitments in RE technologies or else. In line with the conclusions from Markard and Truffer (2006) discussed in chapter 2, a direction towards customer-oriented innovations was chosen in Electrabel in 2006, after the opening of the market. This is also true for Luminus, which has participated in two projects of intelligent networks since 2009 with KU Leuven (Electa, CUO) and others (SET projects data; CORDIS 2012). Established companies in the Netherlands, as well, are further along with the "smart metering" than other R&D projects (Technology Map 2011).

This does not mean that energy technologies are not developed outside of the electricity-production sector. As mentioned before, most of the R&D in the energy sector is carried out outside of the companies producing energy. For this, the authors mapped the SETIS projects in the EU: for example, in Belgium there is a world-class wind-turbine producer, Hansen Transmissions International, that makes equipment for a German manufacturer, ZF Friedrichshafen AG, and 4Energy Invest NV, which invests in biomass-related projects (however, neither is a major electricity producer, the former has a capacity of 503MW and the latter has 18MW; Deloitte 2011).[9] In the Netherlands, there is a large R&D project in wind energy, INNWIND (the counterpart of the famous UpWind research). It has a technology-oriented electricity producer with the involvement of ECN (SET projects data; CORDIS 2012). But again, the established companies in the market (see Table 3 in the appendix) were rarely represented in these joint R&D projects (SETIS), apart from the above-mentioned "smart" solutions for energy networks and also in projects not directly connected to RE technologies, but prior to production capabilities. For example, E.ON

[9] Estimated installed generation capacity in Belgium is around 19,627MW (in mid-2011) (GREG 2011), of which according to VREG data CHP constitutes 1491MW, hydropower 1MW, solar energy (PV) 977 MW, onshore wind 264MW and other (including biogas and -mass) 623MW.

Benelux Netherlands/Belgium and Electrabel Netherlands are involved with several projects connected to CO_2 capture and storage, and Nuon is involved with low-emission gas-turbine technology (SET projects data; CORDIS 2012). Thus, in line with the theoretical considerations, in the exemplifying cases we did not see considerable changes in commitments of electricity producers themselves. What happened is that the incumbents started to support low-technology-based RE-technology solutions and customer-oriented innovation. This is especially true for the Netherlands (Raven 2006; Negro et al. 2008), because the market was already considered to be highly mature (with high levels of decentralization to begin with), and since 1998 larger capacity developments were made by mostly national and foreign energy companies who built CHP plants for their own supply and had large surplus of electricity to sell on the market (Finon 2008, 155).

4. Discussion and conclusions

The focus of this paper has been on the market structure of energy markets and its influence on innovative activities in the process of liberalization. In addition to the theoretical overview, we used two cases – Belgium and the Netherlands – to exemplify the arguments made. From the review of previous research and the exemplifying cases we can conclude that market-based measures are not enough for transformative innovations in the energy sector to emerge. In both countries, the market opening has led to restructuring, and a small group of large multi-nationals has emerged whose activities span across North-Western Europe, which makes their R&D activities hard to be distinguished and dependent on the groups' interest. As there is demand for green energy from the government side, larger multinational companies have chosen to acquire market shares within these countries from the existing incumbents and their RE projects (e.g. Essent and RWE in the Netherlands) rather than to establish themselves as "new" entrants in the market. For the incumbents, RE or other larger technology commitments are hard to find, while customer-oriented innovations have soared. This is not wholly problematic because most R&D and innovations in the electricity sector are conducted outside of the production companies themselves, although large sunk costs of existing infrastructure can become a large market-entry barrier. However, it is very difficult to ascertain causality between policies and outcomes – liberalization and R&D increase/decrease – because the policy mixes are widely different and complex and furthermore, there are very varied market mechanisms in use (see also Jaffe et al. 2002; 2004). This makes not only the analysis complicated, but also the policy context; hence, it is not surprising that in the overall goals R&D and innovation diffusion policies in the energy sector have failed.

When R&D-related rhetoric is brought into the market-liberalization reforms it seems to, furthermore, simplify the debate. It is not always clear if the governments understand that deregulation and liberalization reforms alone do not have the desired effect on R&D in the energy sector. At the same time, prior research has shown that regulators are largely ineffective in influencing the performance and investments of market incumbents throughout liberalization reforms (e.g. Ugur 2009). As such, there are barriers created by policy and regulatory frameworks that stand in the way of regime shifts: unclear messages about the need for new technologies and their role in the energy system result in uncertainty about the future of market development and regulatory barriers to the deployment of new technologies. There is also risk aversion at play from the side of the public sector: governments do not risk change in the face of the political cost of vested interests (Tsoutsos and Stamboulis 2005). At the same time, it is highly unlikely that a process away from the market-based mechanisms (back towards more hierarchical measures) will be taken in the EU in the near future to regulate the sector. This means that the policy options regarding the increase of R&D and innovation in the electricity sector (especially towards renewable and clean energy sources and away from the use of fossil fuels) should first take into account the market dynamics which by now characterize the sector (for a similar argument see Jamasb and Pollitt 2008) and also the need of investment outside of the production firms hinting at the increased importance of network-based solutions between R&D organizations and the industry.

The main policy challenge here is the slow diffusion of RE technologies within the sector. The construction of the electricity sector plays an important role for the introduction of RE technologies, and the effect of the market structure should be addressed in liberalized market conditions. Hence, different policy approaches should be constructed depending on how fragmented or concentrated the market is (see the differences for Belgium and the Netherlands) and based on ownership structures (foremost, public or private, but also multinational ownership). Nevertheless, increase in funding alone will not guarantee innovation in electricity production, nor will automatic incentives such as tax breaks. It may require more specific measures depending on the technology field and the number of competitors present in the market. Consequently, the actual technology push in the liberalized energy market needs to be reconsidered, as relying primary on market demand may not be the most beneficial direction towards the diffusion of RE technology. Thus, not only are public subsidies to RE development needed, but there is also a need to deal with the diffusion of clean technologies among private market participants.

The main contribution of the paper is to highlight the importance of factors in large-scale reform processes and their indirect effects. The latter seem to disappear in the overall rhetoric of high-level policy making. This is dire in the context of the need to have high levels of private-sector involvement to employ renewables, CO_2 capture and storage and other green technologies on a massive scale in the upcoming years due to the climate challenge. Compared to the scale of the issue, the cases of Belgium and the Netherlands presented in the article were, at most, illustrative, but hopefully they will exemplify the need to analyze market structures, incumbents and network partners in the energy sector in more detail when also planning market-based measures.

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Appendix.

Table 2. **Greening of energy in Belgium and the Netherlands – overview of parallel activities to liberalization**

Belgium	The Netherlands
In 1997 Belgium was at the bottom of the EU15 with the production of only 1.1% RES-E (Renewable Electricity Standard for Europe) of gross electricity consumption. Together with the Energy Act of 1999, the government has since been promoting the use of renewable energy sources and energy efficiency. For the promotion of "green" energy, mainly market mechanisms have been used, while the public spending in the R&D field of 3rd nuclear-energy reactors still dominate over all other research fields (including outside of the energy sector). The facility is scheduled to be completed in 2014, and the total construction cost over the period 2010-2013 is budgeted at approximately €960 million (see SETIS 2012). For the ESNII-2 MYRRHA project 40% come from the national funding (15% from other European countries, 5% from non-EU countries and 30-35% from EU grants and incentives and 5-20% (open) from an EIB loan (Baetan 2011). This also means that the nuclear research reactor (MYRRHA nuclear fission research infrastructure) in Belgium is considered part of the new EU research infrastructure for wind, solar and nuclear energy within SETIS.	In the Dutch electricity sector natural gas still plays a substantial role. The country has large domestic natural gas reserves that contribute to the countries' energy security. Thus, the promotion of the adoption of RE technologies could have been hindered from the start; however, the feed-in tariffs were introduced to the electricity sector already with the 1989 Electricity Act. Nevertheless, the high generation costs of RE and the tariffs on their own made it hard to have a market for the technologies, although wind-energy technologies received the largest share of R&D contribution for RE from the government at the beginning of the 1990s (Agnolucci 2007, 870). The adoption of RE goals into the Dutch policy framework can be dated back to the White paper of 1996, which introduced the goal of a 10% share of renewable energy of the energy production of the Netherlands and the promotion of increase in energy efficiency (see De Jong 2006; Junginger et al. 2008). Green electricity was specifically defined in regulations as energy from biomass, hydro-electric solar-cells and windmills (Reijnders 2002; Agnolucci 2007) – the latter was already mentioned in the 1989 Electricity Act.
This in an unusual situation where a conditional agreement has been made by the government to close three nuclear reactors by 2015 and phase out nuclear energy altogether (Deloitte 2011). Here, it is good to note that in Belgium, nuclear-related R&D (fusion and fission) is under federal responsibility, namely through the DG Energy by the FPS Economy, while administration of non-nuclear-related R&D activities is the main responsibility of the regional governments and coordinated through regional authorities (Technology map 2009). This means that all other "greening" measures (also the electricity certificates discussed shortly) are under the control of three different regions (Walloon region, Flanders and Brussels), all of which have slightly different targets and implement their own regional market measures.	Indirect measures, such as the regulatory energy tax (eco-tax) (Van Rooijen and Van Wees 2006; Junginger et al. 2008), were used to subsidize green energy use in the Netherlands (Agnolucci 2007). Within a few years, the number of green-energy users increased substantially (by the end of 2002, it amounted to 1.4 million), and the demand for green energy outnumbered the national supply, mea¬ning that it had to be imported from other countries (Van Sambeek and Van Thuijl 2003; De Jong 2006). This resulted in a situation where Dutch tax money was used to buy green-energy certificates from neighbouring countries and the actual exchange of RE did not take place (Van Rooijen and Van Wees 2006). In 2003 the policy changed, however, from demand subsidy to supply promotion: while smaller tax breaks for consumers remained, producers of green energy in the Netherlands now had a guaranteed subsidy for 10 years (Van Damme and Zwart 2003). As the criteria within the eco-tax law were not well specified, it was modified in 2012 to include physical imports of green electricity from countries with a liberalized energy market to receive the tax break (Reijnders 2002).
The main tool to stimulate the "greening" of the electricity production in Belgium is a system of so-called tradable green-electricity certificates or TGC's, combined with penalty-enforced quotas on electricity-supply companies (VREG 2012ab). A second governmental tool is used to stimulate energy efficiency with a similar system of cogeneration certificates. The system of cogeneration certificates works with same type of penalty-enforced quotas (Deconinck and Gillard 2004). As such, in Flanders, since the mid-2000s, the number of green certificates has increased substantially, mostly from the technologies linked to the use of biomass and slightly from biogas (VREG 2012ab).	Throughout the mentioned measures offshore wind technology and biomass technology were clearly favoured (Dinica and Arentsen 2003; Jacbosson and Bergek 2004; Van Damme and Zwart 2003), while several other green industries were not able to survive in liberalized circumstances (an example of the latter is the Dutch CHP market; Hekkert et al. 2007).

At the same time, the number of certificates given out to wind energy has increased since 2005, but has remained relatively the same since. Also, after 2009, the number of certificates issued to solar energy has started to rise. This can be seen in parallel to the deployment of solar-energy subsidies, and the latter has decreased in recent years. Thus, stimulated by TGC's, green-energy diffusion has been led on the company level by larger industrial enterprises installing some green-energy- and electricity-producing measures to their production process. The Antwerp Port Authority and the Left Bank Corporation, for example, have decided to invest in up to 100 wind turbines to be constructed in 2013 (Deloitte 2011). With the latest market-based measures, the Flemish government guaranteed a fixed price for 10 years for tradable green certificate for wave/tidal energy (Technology map 2009).	Thus, the development of different RE fields – incl. the favoured wind energy – were fought with several system failures (see, e.g., Junginger et al. 2004; Negro et al. 2012) and also resistance from larger electricity companies (Bergek and Jacobsson 2003). Even though there were several market-stimulation instruments introduced, such as investment subsidies and taxation on electricity, the difficulty in obtaining buildings permits or public support slowed down the diffusion rate of the technology, and the new RE technologies did not diffuse quickly in practise (e.g. Kamp 2008; Negro et al. 2008).

Source: composed by authors.

Table 3. **Energy R&D spending in the Netherlands: government (G) and non-government (NG) resources compared (Million NC (nominal))**[10]

	1996		1997		1998		1999		2000		2001		2002		2003		2005		2006		2007		2008		2009		2010	
	G	NG	G	NG	G	NG	G	NG	G	NG	G	NG	G	NG	G	NG	G	NG	G	NG	G	NG	G	NG	G	NG	G	NG
2 Fossil fuels	10.9	0	11.5	0	9.4	0	8.1	0	8.6	0	7.8	0	18.3	0	13.1	0	8.6	4.9	10.8	1.8	11.0	31.7	13.1	1.1	16.4	2.7	21.2	10
21 Oil and gas	7.9	0	8.9	0	7.6	0	7.4	0	8.4	0	7.7	0	15.9	0	10.9	0	3.5	0.2	5.7	1.1	6.4	0.4	7.1	0.7	5.9	0.6	2.7	0
22 Coal	3.0	0	2.5	0	1.8	0	0.7	0	0.1	0	0.1	0	2.3	0	2.2	0	1.7	0.3	2.5	0.3	0.3	0.5	0.5	0	0.0	0	0.0	0
31 Solar energy	13.7	0	19.0	0	20.8	0	17.4	0	11.9	0	15.9	0	17.5	0	15.0	0	12.3	0.8	10.4	0.6	11.3	0.7	14.2	0.6	25.6	2.3	26.3	3.2
32 Wind energy	4.9	0	7.1	0	6.3	0	8.4	0	7.8	0	12.4	0	11.8	0	10.0	0	4.4	0.4	4.2	0.9	5.5	1.2	4.7	1.6	9.4	0	21.4	9.8
33 Ocean energy	0.0	0	0.1	0	0.1	0	0.0	0	0.2	0	0.2	0	0.0	0	0.0	0	0.0	0	0.0	0	..	0	..	0	0.3	0	0.1	0.8
34 Biofuels (incl. liquids. solids and biogases)	5.9	0	6.6	0	9.3	0	12.1	0	10.6	0	12.4	0	11.6	0	23.5	0	9.7	12.3	14.5	16	20.1	27.8	22.0	3.9	18.5	4.1	49.5	16
35 Geother-mal energy	0.0	0	0.3	0	0.5	0	1.0	0	0.0	0	0.0	0	3.0	0	0.0	0	0.0	0	0.0	0	..	0	..	0	0.1	0	1.0	0
36 Hydro-electricity	0.0	0	0.0	0	0.0	0	0.1	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	0.0	0	..	0	..	0	..	0	0.0	0
4 Nuclear energy	14.6	0	17.8	0	13.4	0	14.7	0	22.5	0	21.5	0	18.0	0	18.5	0	13.8	0.9	14.6	0.9	18.7	0.9	15.2	1.6	12.4	0	17.9	0
61 Electric power conversion	10.0	0	10.8	0	8.1	0	7.3	0	8.1	0	7.3	0	5.8	0	6.0	0	0.0	0	0.0	0	0.1	0	0.0	0	0.0	0.8	0.1	0
62 Electricity transmission and distribution	5.0	0	3.9	0	2.5	0	1.9	0	0.3	0	0.5	0	3.4	0	4.6	0	4.0	0.1	5.9	0.1	2.8	0.7	6.7	0.3	9.9	0	2.6	0
63 Energy storage	0.3	0	1.2	0	0.5	0	0.3	0	0.8	0	0.9	0	0.5	0	0.0	0	0.2	0	0.5	0	2.9	1.1	1.7	0.4	0.4	0.6	0.5	0
71 Energy system analysis	5.4	0	7.12	0	7.12	0	5.4	0	1.2	0	4.1	0	0.2	0	0.36	0	0.4	0	0.9	0	0.6	0	1	0.1	0.7	0	4.2	0

Source: Calculated by the authors based on IEA data (2012)

[10] Similar data from IEA for Belgium is not available as the country stopped giving data in 2000 to the organization on R&D (with the exception of 2007)

Table 4. **Overview of energy production companies in Belgium and the Netherlands (>1% market share)**

BELGIUM												
		2001	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**
Essent Belgium (RWE before 2006, private)	R&D exp.				0	0	0	0	0	0	0	0
	Firm size	NA	NA	NA	18,169,000	29,512,000	36,455,057	55,404,387	83,974,218	56,486,078	76,709,690	83,691,427
	Profits (EBIT)	NA	NA	NA	-8,123,000	-6,603,000	-22,058,746	-16,995,791	-3,965,761	-16,132,289	-2,796,459	-6,123,281
	Market share (%)	NA	NA	NA	2.9	1.7	<2	2.3	2.3	2.1	1.8	2.1
E.ON Belgium (private)	R&D exp.	NA	NA	NA	0	0	0	0	0	0	0	0
	Firm size	NA	NA	NA	5,156,000	6,609,000	14,089,058	75,944,471	128,985,161	170,437,578	67,525,346	104,927,712
	Profits	NA	NA	NA	459	366	468,274	766,396	-1,002,614	-9,704,435	-5,669,299	298,547
	Market share (%)[11]											
Nuon Belgium[12] (private)	Firm size	NA	NA	NA	92,996,000	115,291,000	118,182,897	167,948,604	213,727,220	257,872,995	240,053,796	214,426,785
	Profits	NA	NA	NA	25,024,000	243	-24,349,013	89,703	12,744,054	16,153,107	17,073,687	16,484,975
	Market share (%)	NA	NA	NA	2	2.8	3.2	3.2	3.3	3.7	4.6	5.1
EDF Luminus[13] (from 2006 private, before SPE=public)												
	Firm size	NA	NA	NA	1,001,347,000	1,104,593,000	1,315,478,642	1,290,439,792	1,272,110,152	1,635,805,616	1,791,772,006	1,810,287,764
	Profits	NA	NA	NA	26,645,000	-29,024,000	-1,294,446	34,902,283	69,712,921	118,412,713	174,898,650	226,103,589
	Market share (%)	NA	NA	NA	9	13.7	13.1	12.6	12.2	13.7	15.2	17.5

11 Only available for N.ON Benelux – see further in the table.
12 From 2011, Eni S.p.A., the listed Italy-based energy firm has agreed to acquire Nuon Belgium N.V. (Deloitte 2011).
13 SPE NV before 2011; SPE+Luminus+ EDF Belgium before 2006.

Electrabel (private)	R&D						R&D for better performance			R&D through subsidiaries; goal: better performance and non-polluting technologies		
	Firm size	NA	NA	NA	18,874,757,000	19,597,061,000	20,241,074,976	37,448,710,475	41,975,019,160	45,454,904,414	47,650,593,578	46,244,721,771
	Profits	NA	NA	NA	727,887,000	784,075,000	725,456,567	855,316,663	772,702,741	1,141,551,654	1,009,512,497	1,122,780,762
	% RE of product.	NA	NA	NA						2.77		
	Changes in strategy	NA	NA	NA			Emphasis on customer service			Stronger emphasis on sustainable development		
	Market share (%)	NA	NA	NA	34.8	33.6	31.5	31.8	30.1	27	28.8	28.1
Electrabel Costumer Solutions (private)	R&D exp.											
	Firm size	NA	NA	NA	1,899,992,000	2,237,528,000	1,925,951,461	2,824,434,935	3,608,517,757	2,766,479,610	2,898,485,052	3,017,071,868
	Profits	NA	NA	NA	74,121,000	126,061,000	100,215,947	104,667,138	67,560,642	27,621,746	141,453,143	106,461,003
	Market share (%)	NA	NA	NA	31	32.3	33.3	42.9	42.5	43.6	40.4	38.3
NETHERLANDS[14]												
Elsta[15] (private)	Firm size	NA	NA	NA	230,342,000	265,810,000	251,061,000	226,336,000	212,374,000	191,910,000	178,506,000	
	Profits	NA	NA	NA	36,454,000	34,059,000	32,850,000	35,018,000	32,337,000	31,641,000	28,392,000	

14 Capacity shares instead of market shares are calculated due to lack of data using available electricity production capacity of the company (in MW). The total installed generating capacity of electricity in The Netherlands is used as a basis. Source: Energie in Nederland 2011.

15 Owned by AES (50%), DELTA Nutsbedrijven (25%) en Essent (25%)

	New strategic direc.	NA	NA	NA	CHP							
	Capacity share (%)	NA	NA	NA	NA	NA	NA	NA	NA	NA	6.07%	6.07%
Essent (since 2010 part of RWE)												
	Firm size	8,680,000,000	8,975,000,000	8,525,100,000	8,580,300,000	6,507,500,000	6,558,600,000	8,204,000,000	7,829,600,000	12,377,000,000	10,605,400,000	
	Profits	414,000,000	311,000,000	389,000,000	417,000,000	526,000,000	761,000,000	935,000,000	1,069,000,000	4,400,300,000	763,100,000	
	% RE of product.											11%
	Cap. (%)	NA	NA	NA	23%	23%	23%	23%	23%	23%	23%	23%
EPZ [16] (public)												
	Firm size	518,936,000	480,670,000	510,855,000	468,007,000	491,510,000	521,417,000	495,618,000	490,129,000	565,913,000	556,443,000	595,963,000
	Profits	6,263,000	32,209,000	26,770,000	20,686,000	15,666,000	28,873,000	29,625,000	23,895,000	46,728,000	33,556,000	33,438,000
	Capacity (%)	NA	NA	NA	NA	NA	NA	NA	3.75%	3.75%	3.75%	3.75%
Intergen N.V. [17] (public)												
	Firm size	5,711,695,000	6,680,839,000	6,630,172,000	4,920,974,000	4,596,219,000	3,957,201,000	3,137,884,000	3,391,806,000	3,394,673,000	3,541,369,000	
	Profits	-49,440,000	-197,222,000	-18,762,000	-598,385,000	492,939,000	118,226,000	-47,557,000	149,512,000	98,205,000	137,913,000	
	Capacity share (%)	NA	NA	NA	3.2%	3.2%	3.2%	3.2%	3,2%	3.2%	3.2%	3.2%
Electrabel Inter. Holdings												
	Firm size	NA	NA	NA	1,277,983,000	1,343,501,000	NA	1,332,679,000	1,520,436,000	1,704,902,000		
	Profits	NA	NA	NA								
	Market share (%)	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	19.7%
EON Benelux [18]												

16 2008 production: Nuclear energy 515MW, Coal and bio-energy 427MW, Wind energy 12MW. In 2012 in total 7 wind turbines 55.000 (MWh) green energy per year. DELTA Energy B.V. en Energy; Resources Holding B.V. have 70% and 30% of shares since October 2011.

17 Owner of Rijnmond Energie.

18 EON Benelux has annual reports available for the EON Group, information on Belgium and The Netherlands separately is not available.

	Firm size	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Profits	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
	Capacity share (%)	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	7,3%
NUON (Nether-lands)												
	Firm size	NA	NA	10,553,000,000	10,225,000,000	11,183,000,000	10,875,000,000	11,601,000,000	9,478,000,000	7,816,000,000	8,685,000,000	6,848,000,000
	Profits	NA	NA	536,000,000	532,000,000	1,098,000,000	849,000,000	1,114,000,000	399,000,000	196,000,000	721,000,000	554,000,000
	Market share (%)	NA	NA	NA	NA	NA	14.6%	14.6%	14.6%	14.6%	14.6%	14.6%

Source: Comprised by authors based on annual company reports and database Amadeus.

Piret Tõnurist is a junior research fellow at Ragnar Nurkse School of Innovation and Governance and her research topics include innovation policy, energy technologies and social innovation. She has worked for the State Audit Office of Estonia as a performance auditor in the field of innovation and entrepreneurial policy. **David den Besten**, **Pieter Vandeven**, **Xinhui Yu and Dalia Paplaityte** were colleagues of the main author in KU Leuven between September 2012 and June 2013 and helped with the collection of empirical data for the article. Correspondence: Piret Tõnurist, Ragnar Nurkse School of Innovation and Governance, Tallinn University of Technology, Akadeemia tee 3, 12618 Tallinn, Estonia; E-mail address: piret.tonurist@ttu.ee.

APPENDIX (article V)

V Tõnurist, P. and K. Valdmaa. 2013. “Impact of Climate Change Policy Discourse on Energy Technology Research: the Case of Estonian Science and Industry Linkages.” Revised version of the paper presented at the 6th Annual Conference of the Academy of Innovation and Entrepreneurship “Innovation and Entrepreneurship for Inclusive and Sustainable Development.” Oxford, UK, 29-30 August 2013. (5.2)

Impact of Climate Change Policy Discourse on Energy Technology Research: the Case of Estonian Science and Industry Linkages

Piret Tõnurist and Kaija Valdmaa

Abstract

This article examines how climate change discourse has led to a new policy paradigm and also to diverging trajectories in industry and science collaboration and related innovation outputs. Institutional narratives that are not technology-specific, change participatory networks in complex, non-linear ways. The article suggests that discursive changes on the level of global climate change policy have not only influenced the direction of energy technology policy and research at a national level, but have also contributed to multi-directional industry-science linkages and have had unintended consequences that influence future policy choices (e.g., the large expansion of incremental innovation towards energy efficiency). The arguments are exemplified through a case study of industry-science linkages in the field of energy technologies in Estonia and how these have altered in line with the influence of global climate discourse, and the changes it has induced on the national policy level. This article calls for more comprehensive studies on how policy practice and policy implementation change due to global climate change discourse.

Keywords: climate discourse, cleantech, clean energy, science and industry linkages, policy implementation, energy technologies

1. Introduction

Social construction of problems and the following policy change in a non-positivist tradition have become widely discussed, especially in the area of climate change (Dayton, 2000; Reusswig, 2010). Exceedingly popular post-structuralist discourse theory (e.g., Howarth, 2010) and the theory of cultural political economy (e.g., Jessop, 2010) maintain that policy comprehension requires an understanding of the inter-subjective meaning behind them. This paper takes a step further and maintains that when narratives are introduced to policy fields, they change policy governance and participatory networks in complex, non-linear ways with various, unintended consequences. The paper aims to analyze the consequences brought by global climate change discourse and the subsequent changes in national policy contexts on a policy field in a specific policy domain. As the solutions to climate change are high-technology-centered (Wesselink *et al*., 2013), the science policy domain has been selected (Shackley and Wynne, 1995; Demeritt, 2006). The field of energy technologies was chosen because it is the most important sub-field (as a major contributor to the burning of fossil fuels) of clean technologies, a special type of environmental technologies (ETs) in global climate change policy discourse (e.g., Kuehr, 2007; Ekins, 2010).

By and large, climate change policy discourse has been preoccupied with science policy and this has led both academics and policy makers to focus on technology transfer (Brewer 2008; Murphy et al., 2014) as part of low-carbon, renewable technology diffusion (e.g., Karakosta *et al*., 2010). However, the mutual interdependence of the industry and R&D facilities is usually neglected in this debate. Related literature leaves a 'black box' in the analysis of the interactions between the broad range of actors who influence technological development at country level (policy makers, enterprises, research institutes, universities, etc.) and the actual innovative activities that are influenced by the global discourse (Taylor, 2008). Even if steps are taken to fill this gap in evolutionary economics (Schmidt *et al*., 2012), research is too general or piecemeal when it comes to the interdependence of R&D goals and the direction of search. Furthermore, climate change discourse is also part of a wider sustainability discourse (Wilson and McDaniels, 2007; Beg et al., 2002; Swart et al., 2003; Tschakert and Olsson, 2005) and has thus been used in different competing narratives of development from a pure environmental problem solving to a more business-oriented approach – both of these influence policy governance and policy implementation in their own way.

In discourse analysis in general, only transformative moments in time are usually analyzed and consequently, much weight is thrown behind the presumed change on the policy/program level without verifying or examining it in the policy field. Very little attention is also paid to policy feedback and implementation. From previous research it is clear that global discourse also changes policy priorities and power relations between different actors (Newmann, 2005). Yet it is much less observed how interpretations of the discourse influence policy implementation at different governance levels at a later stage; current contributions concentrate on a very broad policy level. In order to compact the research and to analyze the effects in the longer run, we zero in on the science policy domain and look at the dynamics in industry-science linkages (ISL). This synthesis is exemplified through the case of Estonia, which presents an opportunity to explore the effects of global policy discourse changes in a small country, in a simple polity context, which firstly, did not have any significant environmental policy prior to the 1990s; and secondly, had a mono-technological energy sector with a very high GHG impact until the beginning of the 2000s.

To analyze these effects, main trends relevant to the scientific networks in energy technologies are identified based on a review of the global discourse. We highlight how the national policy context has altered through the change in global discourse and aim to draw a comprehensive picture of how these changes affect the research networks in the field of energy technologies. The main argumentative turns and their possible effects are presented in Section? 2. Consequently, the section ends with main propositions from the theoretical review for an analytical approach. In Section 3, we present the methodology and in Section 4 the specific policy environment of Estonia and the main findings of our analysis are discussed in light of the theoretical considerations. The article ends with discussion and conclusions.

2. Global climate change discourse, technology mitigation and shift in national policies

The rise of global climate change discourse in general (from bottom-up initiatives involving not only in the public sector, but also NGOs, enterprises and other local stakeholders (e.g., Caprotti, 2012; Wittneben *et al*., 2012;)) and especially the Kyoto Protocol as a lead in a series of international environmental agreements, have increased the funding of and attention to public policy and the private sector's interest towards environmentally-led technologies and science policy, which mitigate climate change (for literature overviews of environmental policies effects on innovation, see e.g., Kemp and Pontoglio, 2011; Fischer and Preonas, 2010).

The shift has been towards more resource-efficient technologies (also called cleaner and clean technologies or simply *cleantech*) that have a reduced or zero effect on the environment.

With clear social goals – at least when it comes to GHG reduction – it is somewhat surprising to find an ambiguity in global climate change discourse in regard to defining the space around innovation and clean, green or even ecotechnology (e.g., UNCED, 1992; OECD, 1995; Kuehr, 2007). Within the innovation debate led by 'climate crisis the former terms are sometimes used interchangeably (Kuehr, 2007; Carrillo-Hermosilla *et al*., 2010; Schiederig *et al*., 2012), while they may actually signify very different strands in the discourse. As the current public discussion is strongly led by social goals, the nuances of e.g., business profit-centered approach of *cleantech* lie outside of the immediate interest of policy makers. This means that while the goal is the reduction of GHGs, very little differentiation has been made in climate-policy-led innovation policy in practice. While it is clear that these policies – influenced by global climate change discourse – shape technological development (e.g., del Rio González, 2009; in the context of industrial policy, see Johnson, 2015), the actual impact is not that clear-cut. Innovation can lead to very different results both in terms of cost efficiency and ethical concerns (equity across generations in terms of available energy resources).

The previous discussion can be summarized by the main shortcomings of the dominant global climate change discourse. First, through the Intergovernmental Panel on Climate Change (IPCC) and the Kyoto Protocol the dominant discourse has become very linear and focused on science policy (e.g., Pielke, 2010; Beck, 2011). Thus, it was argued that a simple 'technical fix' was possible from an objective, value-neutral scientific approach (Wesselink et al., 2013, Friman and Linnér, 2008) with little attention to various policy goals, political commitment, uncertainty over the process itself, allocated means, etc. Secondly, it was framed as a global issue, in need of global solutions (Miller, 2004) and ofre-thinking the whole system (Johnson and Suskewicz, 2009), which of course increased ambiguity at a national policy level. Below, we will discuss the main trends and effects for scientific networks/ISL in the field of energy technologies in detail.

2.1. Diversification of research agendas

With the rise of global climate-led discourse both in academia and entrepreneurial activity, new ETs have crossed over a wide range of technological areas (e.g., from smart ICT systems to renewable energy/green chemistry). Hence, it is difficult to compare the studies in the field: if some general definitions have been brought out (see UNCED, 1992; OECD, 1995; Kuehr, 2007; Ekins, 2010), it has rarely been stated clearly, which technologies were included or which were not (and why). In the majority of cases, most technological innovations are assumed to render some environmental benefits. This means however, that researchers usually define their own industry and technology categories to describe the 'green' or 'clean' sector. While a cause of ambiguity, it is also a distinct characteristic of the climate-led technological change, which leads us to our first observation. Namely, a diversification effect in terms of research areas (in energy studies), collaboration networks and ISL can be expected due to the multi-disciplinary nature of technologies under the umbrella of climate change. Furthermore, the construction of varied environmental problems connected to climate change has led to twinned discursive strategies – moral and technocratic –, which deal both with environmental problems from the perspective of a crisis situation and business opportunity. These interwoven interests may also make scientific research more politically oriented (Bailey *et al*., 2011; Bailey and Wilson, 2009), because the interest towards solving specific problems while obtaining the largest social benefit is justified within an environmental problem.

The ambiguity problem of 'clean' or 'environmental' fields has spread to the policy field, as technology programs cannot concentrate on specific technologies in ETs, which poses a challenge to traditional mission-oriented government policies and also science funding. This means that there are usually only a few specific large-scale public projects, little public research infrastructure or public procurement geared specifically towards clean technologies (Yang and Oppenheimer, 2007; Jaffe, 2012). Stringent regulations can lead to premature decisions and lock-in into suboptimal technologies in a value-neutral science-based global discourse (e.g., Yarime, 2003). Indeed, it is usually argued that governments need to distribute R&D funds among different technologies so not to pick the 'wrong winners' that are backed merely by business interests, as clear research priorities are also a must (Azar and Sandén, 2011). At the same time, it is not entirely clear how this discursive shift has affected scientific research and funding. At most, the climate crisis debate has increased the role of the so-called sustainability science (Komiyama and Takeuchi, 2006), but this is more notable in the fields of environmental ethics, *greentech* rather than in the global discourse of *cleantech* (see next section). Some find that the discourse led by global climate change has formally not changed the academic world to a large degree by maintaining that by and large, environmental innovation research is still in its infancy (Andersen, 2008: 3). However, due to its multi-disciplinary nature, the actual effects may be subsurface at the moment.

2.2. New business models and corporate influence

It is important to differentiate between the newest concept addressed above, i.e., '*cleantech*' and other environmental technologies (historically focused on environmental 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 with traditional ETs first popularized in the 1970s and 1980s (Schot, 1992). Examples of the latter can also be end-of-pipe technologies (pollution treatment) (Yarime, 2003) or environmental additive equipment that may actually speed up resource depletion under increasing restrictions (Frondel *et al*., 2007). However, the rapid emergence of the concept of *cleantech* in the US in the beginning of the 2000s can be linked to the purposeful activities of a small range of institutional entrepreneurs within global climate change discourse, who promote a 'business model' that pulls together a range of technologies that have both economic and environmental value (Cleantech Group, 2007; O'Rourke, 2009). As the new sector relies strongly on networks and several interdependent institutions, it presents interesting propositions in terms of the analysis of this paper, clearly exemplifying the multi-disciplinary nature of climate change mitigation technologies.

Consequently, very diverse firms may take up 'greening' activities (e.g., *cleantech vs*. environmental protection) in response to climate change discourse, signaling their own interests to policy makers and introducing specific goals, motivation and technical capabilities to ISL (Kemp and Foxon, 2007; van den Hove et al., 2002). The last decade has witnessed a strong emergence of a firm-centric and market-driven approach to value capture, which is a highly profit-oriented approach – '*do well by doing good*' (Richtel, 2007). From the social perspective, it is not important, which reasons lay behind the adoption of clean technologies – be these purely environmental or more profit oriented – and thus, the motivations of firms are not regularly discussed in the analysis 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, incentives to invest, technologies and time-frames), this can play a considerable role. While the differences in culture and objectives between academia are well known, different global discourses within environmental technologies also suggest very different cultures within the private sector.

2.3. Direction of innovation: incremental versus radical change

Due to the '*linear*' and '*value-neutral*' technical approach of global climate change discourse (Wesselink *et al*., 2013) and the multi-disciplinary nature of ETs, much more attention has been paid to the rate of innovation rather than the overall direction of innovation (Johnstone, 2005: 21). With the 'Porter hypothesis' (Porter, 1991; Porter and Van der Linde, 1995) one would assume that clean technologies(paving the way for more profound change and cost cutting as measures of reducing restrictions) would be one of the best routes for businesses, but it is far from so. A distinction between incremental and radical innovations should be made in assessing the change produced by global-climate-discourse-related policy momentum. As such, environmental technologies are found to encompass both product innovations (Ekin, 2010) and additive (end-of-pipe) and process-integrated technologies (Hemmelskamp, 1997). These may have very different effects on the long-term direction of innovation. For instance, end-of-pipe technologies in energy technologies such as the carbon capture and storage (CCS) may reinforce lock-into fossil fuels (Unruh and Carrillo-Hermosilla, 2006; Markusson, 2011). As argued above, *cleantech* is found to go beyond end-of-pipe, regulation-inspired technologies and sustaining technologies – they should be at the side of radical innovations (Markusson, 2011; Hellström, 2007) or as has also been claimed, *cleantech* 'needs' more radical innovations than end-of-pipe technologies (Kuehr, 2007: 1320; Hellström, 2007).

This means, however, that compared to the broad range of activities under ETs, clean technologies may require large up-front investments. As such, it should present more lucrative business opportunities to begin with, but on the other hand, it would also be much more capital-intensive and such investments would entail longer time-frames, which can be far from commercialization. Hence, although radical by nature, many *cleantech* start-ups are university spin-offs rather than established by market subsidiaries (e.g., van Geenhuizen and Soetanto, 2012). Furthermore, non-emitting technologies have far steeper learning curves (Junginger, 2010). Additional measures are required in order to catch up with the present profitability of current technologies (Azar and Sandén, 2011). And, there should also be a balance between exploration and exploitation. In the OECD countries, a shift towards cleaner production can be seen and this means that end-of-pipe technological solutions are not the most important ones in tackling environmental issues (Frondel *et al*., 2007). However, this is not uniform across all countries and sectors (Unruh and Carrillo-Hermosilla, 2006). The problem is most critical in infrastructure-dependent industries, such as the energy sector in which clean energy can be regarded as a sub-category of *cleantech* (Moore and Wüstenhagen, 2004).

When it comes to the specifics of the energy sector, the 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). Further, it is not among the sectors with rapid technological changes (as ICT or pharmaceuticals) and it is characterized by one of the lowest innovation intensities in the world (Jamasb and Pollitt, 2011) and where similar technologies have dominated the sector over a century. This makes the long-term direction of R&D more essential than the level of innovativeness that is generally analyzed in connection with ETs. Nevertheless, *cleantech* has also strongly entered the field of energy technologies and is one of the largest fields for the new multi-disciplinary technology sector (around 30% of *cleantech* investments are in the field of 'clean' energy (Young, 2009)). Furthermore, when it comes to energy technologies, these are usually addressed from the angle of a technology-centric approach (e.g., technology innovation systems (e.g., Gallagher *et al*., 2012)), which does not fit in with the *cleantech*/ETs multi-disciplinary logic (especially as regards clean technologies, these multi-disciplinary scientific networks are rarely studied and the sole emphasis has been put on company collaborations (Caprotti, 2012)). However, there has been a significant discursive change that has been shown to be directly linked to the technological and economic response to notions of climate crisis (*ibid.*). Subsequently, arguments away from incremental efficiency efforts have been presented (Murphy and Gouldson, 2000), but there is a substantial problem with translating radical changes and results from basic science into workable solutions in a sector with many network barriers. The multitude of systemic problems of technology diffusion in the energy sector is well described in Negro *et al*. (2012).

2.4. Shift in national policies– main propositions

In previous paragraphs, the discursive shifts in ETs as part of global climate change discourse and their effects on energy technology policies, scientific networks and ISL were outlined (the summary of the former is provided in Figure 1 below).

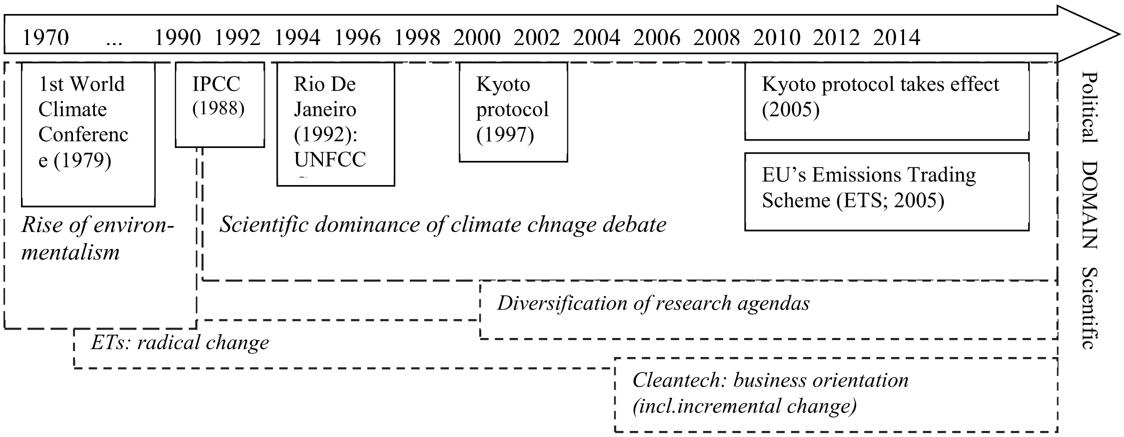

Figure 1. Climate change: main political agreements and evolution of scientific agenda

By summarizing the prior discussion, the following propositions can be made:

(1) First, a diversification effect in terms of research areas, their collaboration networks and ISL can be expected due to the multi-disciplinary nature of clean technologies and overall ETs.
(2) Second, scientific research is becoming more political; we can also presume changes in science funding, which influences ISC. On the one hand, this means that new research groups are expected to emerge in the areas of 'pure' clean technologies (proposition 2.1). On the other hand, this may also mean that traditional energy research groups alter their activities to include ETs (if not fully clean technologies) to respond to funding incentives (2.2).
(3) Third, the qualitative nature of ISL can considerably differ depending on the motivation and nature of the collaborating company (variety originates from environmentally motivated 'traditional' green technology and the more recent, business model-based *cleantech*). 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 in question (3.1). And on the other hand, the effect may also be contradicting due to the strong business nature of *cleantech* ventures – meaning a push for ready-to-market collaboration with research units and therefore also short-term contracts (3.2). This can also imply that these collaborative projects may produce non-optimal technological solutions to the energy sector. When the ETs in question within ISL are additive and efficiency-related, collaborations close to the market can be expected (3.3).

(4) As innovation differs depending on specific conditions of existing completion, the strategy and maturity of technologies involved, and ultimately and most importantly, depending on the nature of the technology researched – incremental and radical – different direction of innovation (and also socio-economic impact) can also be expected from ISLs in the energy sector. Research groups in traditional energy fields (previously connected to fossil fuels), who have incorporated ETs goals into their agenda as part of their response to climate-change-led policy agenda, can be expected to contribute to possible 'sailing effects' of traditional energy technologies (4.1). With some reservations we can also propose that the socio-economic impact of clean technology-oriented ISL could be influential if a project secures return on investment and has strong public support in order to mitigate long-term risks (4.2).

3. Methodological approach

First, literature review and secondary data were used to give a brief overview of the main developments and changes in the Estonian energy policy context and legal framework after the changes in global climate change discourse (the change in the discourse was initially observed by reviewing 20 years of parliamentary stenographic records, news articles and reports and later verified through in-depth interviews). A synopsis of this analysis is presented below.

Secondly, to analyze the effects of the policy on real practices through exploring the aforementioned propositions, this paper implements a broad case-study-based approach by looking at how scientific research topics, collaboration and networks and ISL have changed through the influence of global climate change discourse. Other aspects such as the effects of the discursive shift could have also been chosen for analysis, but the authors believe this approach to best describe the relevant change in research and the relationship with the industry. This case-based approach is also found to be one of the better methods to capture factors internal and external in the multi-disciplinary context of ETs (see del Río González, 2009). Furthermore, through an in-depth case study, a variety of data sources also help 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. Both quantitative (network analysis) and qualitative methods (documentation analysis, structured interviews, etc.) are deployed. Reliance only on aggregated, top-down quantitative analysis would mean that most of these dynamics and factors would be missed.

To set clear borders to the analysis, the research was carried out in a small country, Estonia, where the data are available and the network can be described almost in full. The study is advanced within the project *Public funding of research activities in Estonia* conducted by the Ragnar Nurkse School of Innovation and Governance (Tallinn University of Technology (TUT)). The study covered the largest technology-oriented universities in Estonia (TUT, Tartu University, Estonian University of Life Sciences (EULS)) and a separate research institute (National Institute of Chemical Physics and Biophysics). TUT is the main contributor to energy technologies in Estonia, while at other universities, singular RE-centered research units have emerged in the 1990s. As the 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. The research design consisted of three steps:

(1) First a *network analysis* was carried out based on personal and project records of all universities in Estonia between 1998 and2012. A network was created based on all research collaboration, where the nodes illustrated individual scientists and firms and the edges R&D projects and contracts between them (an analysis on the group level – R&D group/institute/department-firm was also run, but organizational aspects are outside the scope of this study). This makes the networks bipartite or

two-mode, as it is important to keep the data on researchers on the individual level, because changes in and the re-formation of research groups are not uncommon. Networks were later weighed against the monetary value of contracts and also against their length in order to check the strength of ties. This constricted the networks and reduced the significance of very small contracts, while the main structure and trends of the network remained intact.

However, as the strength of ties and informal communication are difficult to analyze through project data alone, additional steps to triangulate data were taken. Thus, with additional steps described below (interviews with research groups) 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. And therefore we relied more on the self-reported information of scientists in order to determine the strength of relationships. The following additional steps were taken:

(2) *Document analysis* was carried out to prepare an extensive qualitative profile for each research group. This comprised analyses of government funded research proposals, project reports, co-publication analysis and career data from the electronic database, the Estonian Research Information System (ETIS). These profiles were created in order to get a more detailed overview of the strategic activities of research groups and also to account for shifts in time, as these are difficult to outline solely through network analysis due to the complexity of data – e.g., projects spanning for several years, etc.

(3) For the third-layer verification, 11 most salient science groups in energy technologies were selected for *in-depth interviews*. They were selected based on one criterion: they all had received public funding (public targeted financing) at some point in between 1998 and 2012, which indicates that they also had a high-level scientific component to their work.[1] Extensive in-depth interviews were conducted with the former in order to get further information on their research areas and ISL (incl. other contacts with companies, such as internship programs, lectures, board membership, etc.) and to verify the strength of ties, change in their strategic behavior and the content of their research activities.

The information collected from project descriptions (applications, final and interim reports), network analysis and interviews was later added to the entrepreneurial-based data collected by TUT in 2011 for the Global Vision *cleantech* report, which also included extensive interviews with companies in the ETs/clean technology sector in Estonia (see Valdmaa and Kalvet, 2011).

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

4.1. Estonian energy policy context and the new climate change policy paradigm

Below, we will give an overview of the Estonian energy policy context and the change in the discourse and policy that can be linked to the change in the global discourse in the past 20 years. By and large, Estonia has implemented an environmental policy 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)), which became a strong part of the independence movement in Estonia. This inspired the early adoption of the first environmental protection act in 1990 and the imposition of environmental pollution charges. However, these were not sufficient to change the energy sector that was under the control of the government (Valdmaa, 2014).

[1] Here there is a bias built into the study, because obviously we could not interview and closely profile extinct science groups (even if they were included in the evolution of collaboration in network analysis and their field of activity was known to us).

Estonia is the only country in the world whose principal source of electricity depends on oil shale (kukersite) combustion for as much as 80% (see Table 1). The country has been the largest oil shale producer and consumer in the world since the 1960s, but this has entailed a considerable environmental impact that was the highest in the 1980s and has lowered 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 and since 1998, the energy sector has accounted for more than 85% of all GHG emissions (see Figure 2 below). Additionally, a substantial amount of solid waste (ash) is also generated in the process (Blinova *et al*., 2012) – remaining ash plateaus in Northeastern Estonia may cause environmental problems for several generations to come (Mõtlep *et al*., 2010).

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	132 389	131 999	140 265	162 400	154 123	160 563	155 265	180 852	175 374	172 995	205 080	208 863
... 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
... firewood	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

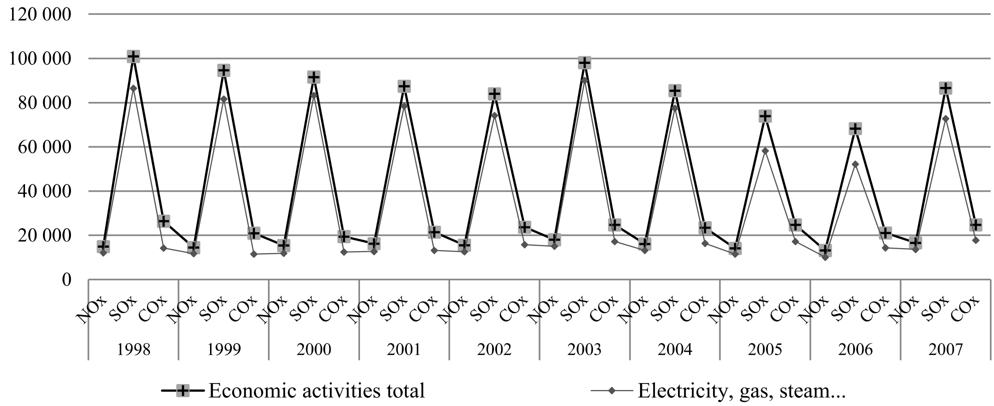

Figure 2. Pollution of air from stationary sources (tons) (Statistics Estonia, 23 June 2013).

In 1995, the country ratified the UNFCCC, but in legal sense, 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 took effect later. The Kyoto Protocol was signed by the country also in 1998 and ratified in 2002. However, the parliamentary debate and oversight in connection with energy between 1992 and 2002 was mainly concerned with energy security and pricing – meaning that environmental concerns were secondary in the local policy discourse as parliamentary debates indicate. The policy discussion in relation to climate change became more prevalent only after joining the EU in 2004: in April 2004, the *National*

Programme of Greenhouse Gas Emission Reduction for 2003-2012 was adopted and it was the first document that also included the Kyoto target as its main objective (previously, the Estonian environmental policy had mostly been concerned with water management and waste treatment). Estonia imposed a CO_2 tax in 2005 and in 2006, 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 (overview of which is available in the Estonia's Fifth National Communication to the UN under the UNFCCC (2009)). Thus, several measures were adopted and alongside the changes, parliamentary debate and the coverage of climate issues also increased in local media. However, in discussions over investments into the energy sector, concerns over energy security still prevailed.

In light of this, the government – while seeking to diversify energy production towards REs due to the pressure from the EU – plans to continue to use oil shale in electricity production. The government has heavily subsidized the production of electricity from oil shale in order to reduce GHGs: second-generation units have been built with higher efficiency rates and fluidized bed combustion (CFB) technology is implemented that is expected to minimize environmental (incl. ash and water) pollution (e.g., Dementjeva and Siirde, 2010). In 2011, the European Commission amended the conditions set up by the Directive concerning integrated pollution prevention and control (2008/1/EC), which rendered it possible for the older-type oil shale power plants to also continue their operations up to 2023. Moreover, there is a clear link between economic development and GHG emissions, which lowered considerably after 1990 during the economic downturn. As seen in Figure 3, the GHG emissions also increased with the rise of GDP between 1999 and2004, and fluctuated with the following economic boom and crisis from 2008 onwards. On the whole, primary energy density has remained very high in Estonia and contributes to considerable environmental impact.

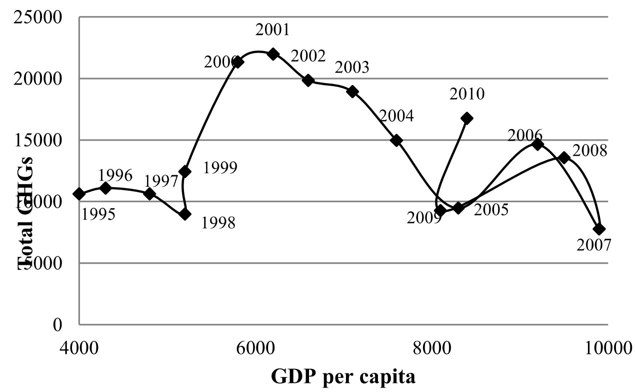

Figure 3. Relationship between GHG emissions and GDP compiled of the data available in Statistics Estonia (23 June 2013).

The possible future decline in the proportion of oil shale is expected to be achieved from the rise in wind energy, use of natural gas and biomass (Roos *et al.*, 2012). This is mostly supported by both scientific efforts and the funding from the government, and parliamentary records indicate that the high technology-centered discourse in policy documents and discussions still prevails. However, it is clear that no new energy production infrastructure will be built in Estonia without a high subsidy from the government. With the reduction of renewable energy charges and fragmented R&D support, no micro-producers or start-ups are expected to influence the current market equilibrium at least in the next 10 years. It is also noteworthy that the subsidies for biogas and solar power are lower in Estonia than in the neighboring countries. (However, photovoltaic research receives the highest funding in energy technologies – reasons for this are discussed in Section 4.2). For less advanced and more common technologies in renewable energy, such as biomass, hydropower and even wind energy, the subsidies range around the average of the countries in the region (State Audit Office, 2012). Therefore, no significant reduction in the importance of oil shale in the Estonian energy system is foreseen at least for the coming 10 to 15 years.

4.2. Change in ISL in energy technologies

Originating from the oil shale-centered energy system described above within the context of a small country, the network analysis showed a heavy concentration of influential research groups in energy technologies at TUT (see Figure A.1 in the Appendix, which describes the whole network by Eigenvector centrality). Through visual inspection of snapshots from different periods of time, institute-based central research groups emerged. There are approximately 15 major research groups in the field of energy technology in Estonia. The network analysis showed that the competence regarding the traditional energy technologies (oil shale combustion and chemistry) lies with TUT, which also has the majority of energy technology research groups. With structural reforms within the university, traditional research groups have moved between three departments (Faculty of Power Engineering, Chemical and Materials Technology and Mechanical Engineering). At other universities, including the University of Tartu and the EULS, energy technology research groups were not found to be closely linked to the field of traditional energy studies – these science 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 (photovoltaic elements in Tartu and biomass at EULS). Next, we will discuss the propositions made in Section 2.4 and will then move on to further discussion and possible policy relevance.

First, a clear diversification effect in terms of research areas was observed after the beginning of the 2000s, when climate change discourse took effect in policy making in line with the new multi-disciplinary ETs (discussed in Section 2.1). This is more apparent among science groups who have more actively been involved in industry contracts. While scientific research itself has been diverse throughout the period (see Figures A.2 and A.3 in the Appendices) and there have been central groups at TUT dealing with ETs and RE (photovoltaic batteries), the collaboration network has clearly diversified and central groups (also in oil shale technologies) have started to also include ETs-related projects. With view to some indications of the direction of innovation, the former trend gives some credence to proposition 4.1. Nevertheless, the interviews showed that research groups in traditional energy fields (oil shale technology), who incorporated ETs goals in their agenda, did not change their main research areas and are thus contributing to the 'sailing effects' of traditional energy technologies. Conducted interviews showed considerable inertia in research fields, even if activities that were more related to ETs, received more attention. 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.

While analyzing the research projects applications and reports in the time period selected and looking at the dynamics of the topics and group members, it became apparent that some current core research groups grew out of basic research in materials technology during the early periods under review with possible applications to the photovoltaic industry. These groups were the main actors who worked towards clean energy before the 2000s. However, most of the RE-related research before 2004 was fundamental by nature and in terms of ISL, the collaboration between the industry and universities was previously clearly one-dimensional – it included only traditional, efficiency and some environmental projects – and changed clearly in the subsequent period by becoming multi-dimensional (see the descriptive Figures A.4 and A.5 in the Appendices). As the goals of the Estonian environmental policy and the local discourse unmistakably changed between 1998 and 2004, research projects started to also include more environmental concerns towards emission reduction and pollution avoidance. Based on the project reports and the interviews, there was a newly found interest from the side of the industry (also oil shale based production facilities) to initiate new collaboration projects with research groups solely based on ETs (in accordance with proposition 2.2). Nevertheless, we did not find a clear connection with proposition 2.1, i.e., due to political funding, new research groups are expected to emerge in the areas of 'pure' clean technologies in response to funding that is based on 'climate change'. While many research groups in more traditional energy technology fields did indeed perceive a bias in funding towards RE, the issue is more complicated, as is mentioned above (in paragraph 5.1). The science group leaders interviewed emphasized that the process was led by the companies and their restriction-based demands towards ETs, but no significant RE R&D goals or preferences were set. The effect of 'political' interference as such is unsubstantiated from the perspective of public projects; if we look at the proportion of R&D funding between clean/environmental technologies and traditional technologies, we can see that the first few receive proportionally more financing than the rest. This may largely originate from the bias in the Estonian research funding system, which favors basic research over applied science – high-technology. And therefore, applied science research groups have been found to weaken and rely on short-term private funding, especially in the energy sector. As no clear goals specific to R&D in energy technologies existed in Estonia, the weight was put on value-neutral scientific activities, very much in line with the global climate change discourse discussed before.

Related with the previous, the third block of propositions argues that the qualitative nature of the emerged networks in scientific collaboration differs depending on the motivations and nature of the collaborating company. If we look at how the cooperation with the industry and enterprises has changed in the longer run (based on the network analysis and content analysis of project reports), we can see that after Estonia had regained its independence in 1991, the majority of traditional energy technology groups experienced the weakening of their ties with industry from the 1990s onward and especially during the period observed (1998–2012).

According to the scientists interviewed, only dominant companies in the market (e.g., a state owned enterprise, Eesti Energia, and Viru Chemistry Group in Estonia) or university spin-off companies were interested in the application of basic research also in traditional fields. However, substantial R&D collaboration in the core areas of energy companies was in general very rare and focused mainly on *cleantech* (e.g., in photovoltaic batteries). To some degree, this supports proposition 3.1 in terms of longer and durable transformative investment, but the variation in the latter was small, as we had only a few cases to describe these long-term relationships. However, as understood by scientists and also supported by the Global Vision data (Valdmaa and Kalvet, 2011), the majority of the companies that have contracts with Estonian research groups want simple environmental impact assessments or solutions that have to be worked out fast and can easily be integrated into existing technology. As the projects were executed in a very short time (maximum 5–6 years in RE), it is not possible to formulate any clear stands on proposition 3.2 (in terms of a difference between green and *cleantech* ventures – as the business orientation of the latter may push for ready-to-market corporation with research units and thus also for short-term contracts). The interviews showed that it is primarily the industry giants who wish to keep themselves informed of the work of scientists in the related area, but on the other hand, companies are not any more willing to pay for basic research that cannot be implemented in the short term (for additional information on the Estonian energy sector, see Tõnurist, 2015)).

In the aforementioned non-traditional energy technology fields, the application of technology may be too far from the market due to the dominance of smaller firms who lack investment capabilities required for the testing of R&D. This might mean that local research in the areas outside of the production of energy from fuel sources may remain just theoretical or wider international networks may be utilized in order to market or sell the results of the latter. Consequently, there was clear evidence in support of proposition 3.3 and also 4.1: when ISL based on additive (sailing-oriented) projects was concerned, the collaboration acquired a very short-term, close-to-the-market format. On the whole, cooperation is generally related to incremental innovation and even more so to rudimentary analyses/testing run for the companies. In general terms, one can expect a direct influence from the structure of the energy sector of the country to the direction of research. Science groups who mainly deal with applied sciences and with more radical innovations are less attractive to the industry because of long periods of development, capital intensity and high uncertainty (also found by Valdmaa and Kalvet (2011)). Due to the novelty of *cleantech* projects, it is yet too early to discuss proposition 4.2 (i.e. the socio-economic impacts of clean technology-oriented ISL are expected to become influential if a project secures return on investment and has strong public support in order to mitigate long-term risks). See the summarized account of the propositions presented in Table 2 below.

Table 2
Summary of main findings

Propositions	Findings
Prop.1 Research diversification effect	Corroborated
Prop. 2 Politicisation of scientific funding due to discursive change	
Prop. 2.1 emergence of pure clean technology oriented research groups	Not corroborated*
Prop. 2.2 inclusion of ETs-agenda in traditional energy technology research groups	Corroborated
Prop. 3 Qualitative difference subsequent collaborative ties between science and industry	
Prop. 3.1Radical change oriented investment implies more durable ISL	Not corroborated
Prop. 3.2 *Cleantech* ventures push for short-term collaborations	Not fully corroborated
Prop. 3.3 Incremental ETs projects imply close to the market projects	Corroborated
Prop. 4 Discursive change and direction of innovation	
Prop. 4.1 Rise of 'sailing effects' in traditional energy technology fields	Corroborated
Prop. 4.2 In case of strong investment return security (public support), expected socio-economic impact of clean technology oriented ISL is high	Not corroborated*

As argued above, the qualitative nature of these collaborative networks can considerably differ depending both on the motivation and nature of the collaborating company, but also the technology at hand. In our sample, companies entered into contracts for the maximum term from six month to one year and wanted immediate results and market applicability or introduction to the production process. Research groups that have worked with and for the industry have usually continued this trend. Only in those cases where public funding was not received, some groups began to more actively cooperate with the industry. However, this was true only if they had previously had some contacts with industry. In a situation, where a research teams are solely dependent on industry contracts, they can function with the help of funding from outside the industry only for a short period of time – it is not sustainable from the perspective of the development of the research field. Doing short-term research which is more applied by nature hollows out the basic research competences of the group and in the long run, this limits/decreases the research group's value also to the industry. Successful applied research has to be grounded on profound basic research capabilities – a core competence of universities.

5. Discussion

Previous analysis has revealed that when dealing with discursive changes in policy – here with climate change – more systematic analysis of the direction and impact of such changes should also be provided, because the impact of the former may contradict the broad-based global discourse. Even with the goal of long-term low-carbon energy production in environmental policy, R&D has not moved hand in hand with the former. The same holds true for industrial policy that is not addressed in compliance with science, technology and innovation policy. This shows that while the broad global climate discourse has assimilated into national policy-making and funding decisions, the impact has not been as profound as expected: value-neutral research policy has strengthened some research groups, but has also left others more dependent on the industry investment. Furthermore, the overall goal, systemic change toward GHG reduction has not emerged.

As is shown in the case of Estonia, without a clear mission-oriented energy technology financing, the area of applied research is left to compete within the general science funding system. While the former has given precedence to new *cleantech* fields, this is not the result of active state policy in the field of energy, and it is highly uncertain, whether the local GHG emission output will diminish (the technology can of course be applied elsewhere with global net benefit, but within the goals of global climate change discourse, internal investment into carbon reduction is also essential). The willingness of companies to implement R&D becomes in many cases the central concern in connection with the actual policy goals in the context of climate change. The nature, magnitude, quality and direction of ISL become also very important here. As investment decisions are not managed centrally, incentives for the advancement of technologies granted to individual electricity utilities in the market become more important. Some of these projects may not attract investments from the private sector and the latter – as shown above – may enforce different dynamics altogether. This indicates that some differentiation in terms of policy should be made from short-term solutions, while energy diversifications could further lead to energy security and greater use of renewable, 'clean' energy. In order to switch from oil shale-based electricity production to 'clean' energy, longer-term commitments are required. Here, the correct policy mix becomes the key to addressing many of the problems not only in R&D, but also within the industry. Henceforth, the highly scientific-oriented and linear understanding will not produce the desired effect in Estonia.

6. Conclusions

Global climate change discourse has influenced policy making at all levels of governance. However, the impact of global discourse on national policies, real practices, interactions of involved actors and the direction of the discursive change has not been sufficiently researched. This paper brings these issues to the forefront and maintains that policy changes based on a broad and high-level global discourse may have unintended and multi-directional consequences both on the related policy field and the broader policy domain. This argument is elaborated through an overview of the main discursive policy changes within the climate change policy debate, and focuses on its effects on science and industry collaboration and also the direction of innovation. In addition, this article develops a more consistent approach of analyzing the impact of social goals and entrepreneurial interest characteristic of the global discourse in a more integrated way and it also outlines the importance of policy feedback. Furthermore, it is shown that while the broad-based policy discourses and changing policies may easily be transferred from one country to another, they can also accommodate diverging, almost conflicting approaches (e.g., *cleatech* versus *greentech*) due to the feedback from interested parties also in the private sector.

In the theoretical framework we explained, how global discourse relates to policy practice and how discursive nodes lead to changing national policies. Based on a review of global climate change policy discourse, we developed four main propositions connected to the change in the research activities in both firms and research institutes (which include the influence on research agenda of R&D groups, form and quality of their collaboration with the industry and possible direction of innovation). In general, the analysis demonstrates the importance of accounting for the long-term and multi-directional effects of discursive policy changes and the need for an adequate policy mix depending both on the technologies in question and the enforcing structure of 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.

To this end, much more extensive research is needed in order to highlight the actual effects of broad-based policy discourse, especially in terms of policy outcomes. However, due to the interdependence between global discourse, international standards and national policy, the causality of changes and following action is hard to delineate, but as we have shown above, it can have very significant effects. While a number of central trends in academic research were identified in the theoretical part of the paper, it is impossible to verify all of them in detail within one study. For one, the selection of research groups in the current study in combination with the mixed method approach may create some bias in the results. Further research is needed in order to describe the business model aspect of *cleantech* and its influence on the direction of technology. The main intention of this study was to outline the principal argumentative turns in global climate change discourse and to show through the industry-science collaboration, how significant these arguments become in reality. Therefore this stream of research would benefit from a comparative study between countries with the aim to analyze, whether the local interpretations of global climate change discourses are different and whether the effects on energy technology ISL and other issues follow similar patterns in different science systems and whether there are also differences in effects under sub-fields of energy technologies.

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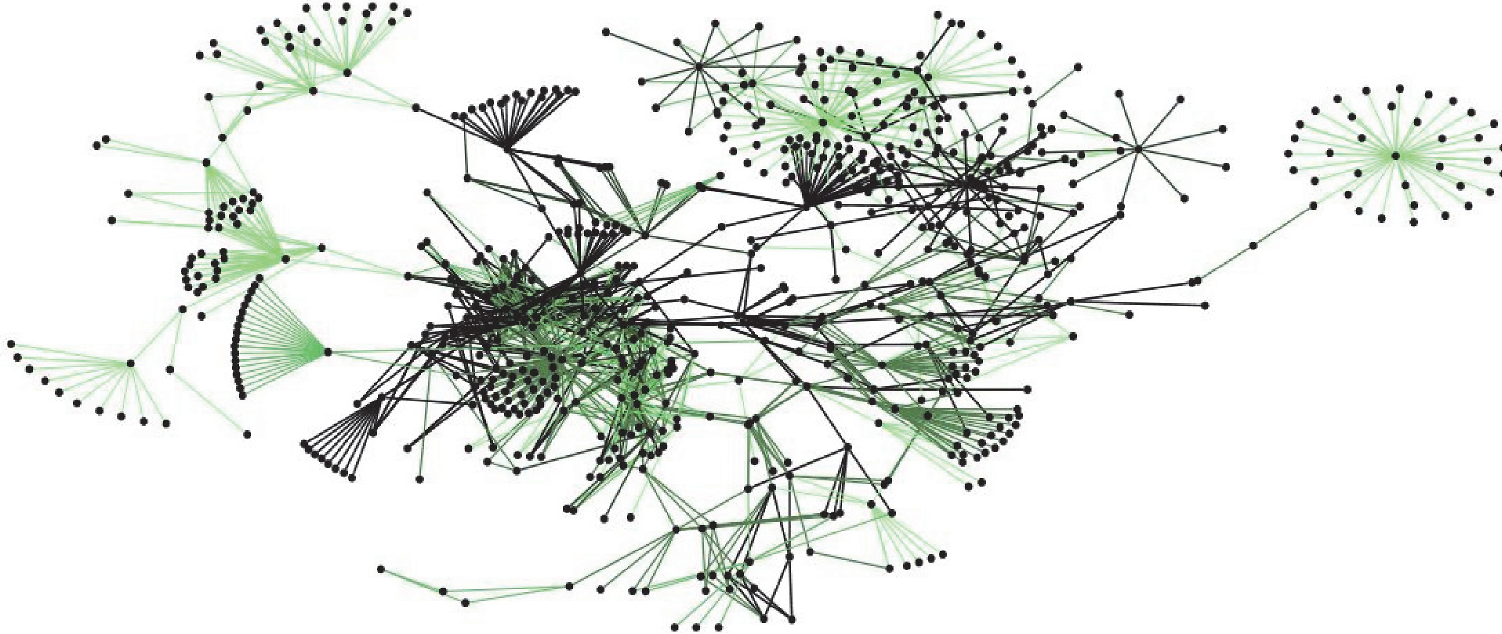
Appendix A. Figure A.1. Energy technology network in Estonia 1998-2012 (based on project information)*

Source: Authors, NodeXL.*Within the descriptive figure the edge color denotes the university (blue and green TUT (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 a 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)



Created with NodeXL (http://nodexl.codeplex.com)

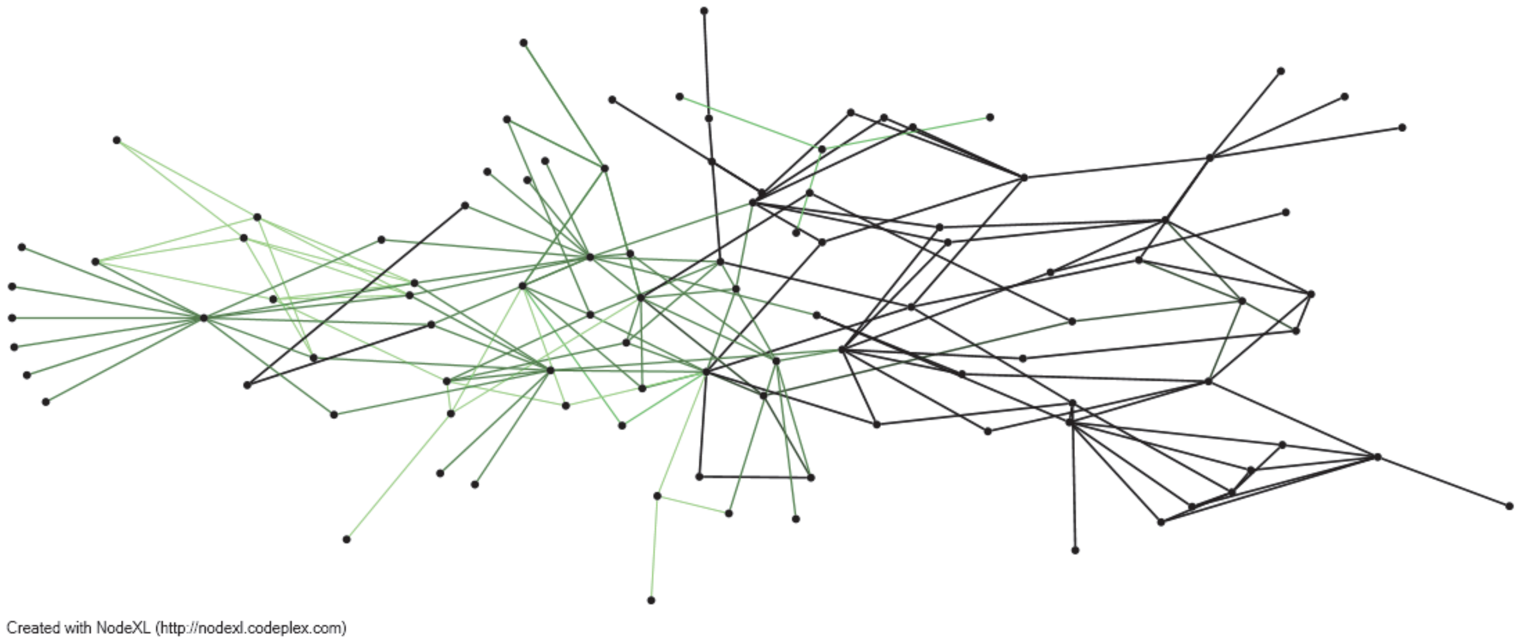


Figure A.4. Energy technology network (contracts with private companies) by type of technology 1998-2004

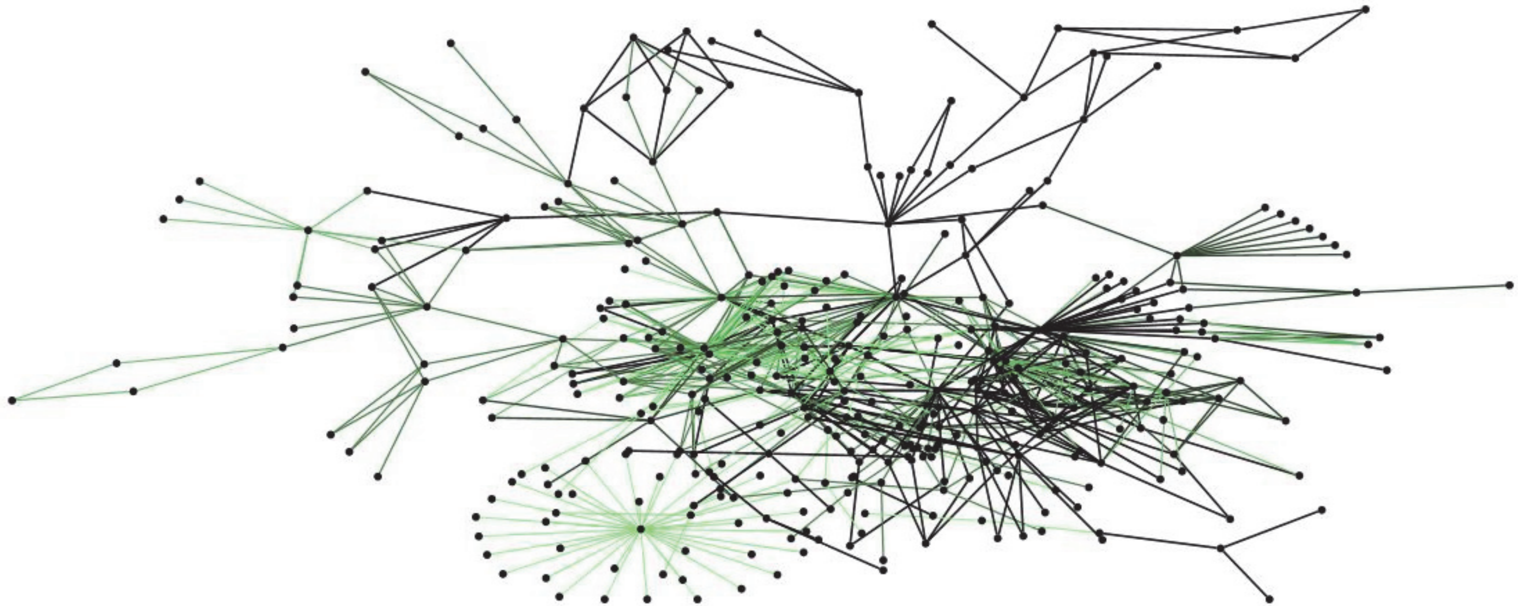


Figure A.5. Energy technology network (contracts with private companies) by type of technology 2005-2012.

CURRICULUM VITAE

Piret Tõnurist

1. **Personal data**

Date & place of birth:	27 December 1985, Tallinn
Citizenship:	Estonian

2. **Contact information**

Address:	Ragnar Nurkse School of Innovation and Governance Akadeemia tee 3, 12618 Tallinn, Estonia
E-mail:	piret.tonurist@ttu.ee

3. **Education and academic degrees**

2009 -	Tallinn University of Technology, Technology Governance, PhD
2010 - 2011	Katholieke Universiteit Leuven, Social Policy Analysis, Master of Science (magna cum laude)
2008 - 2009	Tallinn University of Technology, Technology Governance, Master's degree (cum laude, highest distinction)
2004 - 2007	Tallinn University of Technology, Public Administration, Bachelor's degree (cum laude, highest distinction)

4. **Language skills**

Estonian	native language
English	proficient
Russian	mediate
Dutch	mediate
Finnish	intermediate
French	beginner

5. Employment

2013 -	Tallinn University of Technology , Faculty of Social Sciences, Ragnar Nurkse School of Innovation and Governance, Chair of Innovation Policy and Technology Governance; Junior Researcher Fellow (1.00)
2008 - 2011	National Audit Office of Estonia, Performance Audit Department, Performance Auditor
2007 - 2008	Chancellery of the Riigikogu, Constitutional Committee, consultant

6. Selected scientific projects

2013 - 2017	FP7 research project “Learning from innovation in Public Sector Environments (LIPSE),” researcher
2011 - 2015	Estonian Ministry of Education and Research, the Research and Innovation Policy Monitoring Programme (TIPS Programme), contractual researcher

7. Academic administration

2015 -	Co-chair of the EGPA Permanent Study Group on Behavioral Public Administration
2014 -	Social innovation network, member
2005- 2007	Council of the Faculty of Humanities in the Tallinn University of Technology, member

8. Defended theses

Piret Tõnurist, Master's Degree, 2011, (sup) Dimitris Pavlopoulos, Part-Time Wage-Gap in Germany: Evidence across the Wage Distribution (In English), Katholieke Universiteit Leuven

Piret Tõnurist, Master's Degree, 2009, (sup) Rainer Kattel, Small States, Innovation Systems and Globalization (In English), Tallinn University of Technology, Faculty of Social Sciences, Ragnar Nurkse School of Innovation and Governance

Piret Tõnurist, Bachelor's Degree, 2007, (sup) Margit Kirs (Suurna), European Union as an Innovation System: Baseline for Innovation Policy

Developments (In Estonian) Tallinn University of Technology, Faculty of Humanities

9. Honours & rewards

2010 CEPS/INSTEAD scholarship, Grand-Duchy of Luxembourg and University of Leuven (Belgium)

2005 Kodanikuhariduse Sihtasutus, scholarship

2004 Rotalia Foundation, Bruno and Helge Laan's scholarship

10. Supervised theses

Ly Ferenets, Master's Degree, 2016, (sup) Piret Tõnurist, The role of Cost Models in Collaborative Governance: the Example of Social Services in Estonia, Tallinn University of Technology, Faculty of Social Sciences, Ragnar Nurkse School of Innovation and Governance

Kleiri Vest, Master's Degree, 2015, (sup) Piret Tõnurist, Using the Concept of Co-creation in Public Service Design Process, Tallinn University of Technology, Faculty of Social Sciences, Ragnar Nurkse School of Innovation and Governance

Artur Talihärm, Master's Degree, 2013, (sup) Piret Tõnurist, Technology Transfer in Low-Tech Industries: the Case of Biotechnology and Aquaculture Industry in Estonia, Tallinn University of Technology, Faculty of Social Sciences, Ragnar Nurkse School of Innovation and Governance

Kaire Kesküla, Master's Degree, 2010, (sup) Piret Tõnurist, The Rise of the „Creative Agenda“ in Transition Counties: The Case of Estonian Creative Industries and Industrial Design, Tallinn University of Technology, Faculty of Social Sciences, Ragnar Nurkse School of Innovation and Governance

11. Teaching

2014 Case Studies in Technologies and Industries (Master’s level) and Case Studies in Business, Government and International Economy (Master’s level) (in English)

2013 Post-soviet states in the Caucasus and Central Asia in a transnational perspective (Batchelor's level)

12. **Publications**

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ELULOOKIRJELDUS

Piret Tõnurist

1. Isikuandmed

Sünniaeg ja -koht:	27. detsember 1985, Tallinn
Kodakondsus:	Eesti

2. Kontaktandmed

Aadress:	Ragnar Nurkse innovatsiooni ja valitsemise instituut Akadeemia tee 3, 12618 Tallinn, Eesti
E-mail:	piret.tonurist@ttu.ee

3. Hariduskäik

2010 - 2011	Leuveni Katoliiklik Ülikool, sotsiaalpoliitika analüüs, teadusmagistri kraad (*magna cum laude*)
2008 - 2009	Tallinna Tehnikaülikool, Tehnoloogia valitsemine, magistri kraad (*cum laude*)
2004 - 2007	Tallinna Tehnikaülikool, haldusjuhtimise õppesuund, bakalaureus (*cum laude*)

4. Keelteoskus

Eesti	emakeel
Inglise	kõrgtase
Vene	kesktase
Hollandi	kesktase
Soome	madalam kesktase
Prantsuse	algtase

5. Töökogemus

2013 -	Tallinna Tehnikaülikool, Sotsiaalteaduskond, Ragnar Nurkse innovatsiooni ja valitsemise instituut, Innovatsioonipoliitika ja tehnoloogia valitsemise õppetool; Nooremteadur (1.00)

2008 - 2011 Riigikontroll, tulemusauditi osakond, tulemusaudiitor

2007 - 2008 Riigikogu Kantselei, põhiseaduskomisjon, konsultant

6. Valitud teadusprojektid

2013 - 2017 FP7 uurimisprojekt "Avaliku sektori tingimustes innovatsioonist õppimine (LIPSE)," põhitäitja

2011 - 2015 Eesti Haridus- ja Teadusministeerium, "Teadus- ja innovatsioonipoliitika seire programm" (TIPS), lepinguline uurija

7. Muu akadeemiline töökogemus

2015 - EGPA alalise uurimisrühma "Käitumuslik avalik haldus", kaasesimees

2014 - Sotsiaalse innovatsiooni võrgustik, liige

2005- 2007 Tallinna Tehnikaülikooli Humanitaarteaduskonna Nõukogu, liige

8. Kaitstud lõputööd

Piret Tõnurist, magistrikraad (teaduskraad), 2011, (juh) Dr. Dimitris Pavlopoulos, "Part-Time Wage-Gap in Germany: Evidence across the Wage Distribution" (inglise keeles), Leuveni Katoliiklik Ülikool

Piret Tõnurist, magistrikraad, 2009, (juh) Rainer Kattel, Small States, Innovation Systems and Globalization (inglise keeles), Tallinna Tehnikaülikool, Sotsiaalteaduskond, Ragnar Nurkse innovatsiooni ja valitsemise instituut

Piret Tõnurist, Bachelor's Degree, 2007, (sup) Margit Kirs (Suurna), Euroopa Liit kui innovatsioonisüsteem: alus innovatsioonipoliitikate arengusuundadeks, Tallinna Tehnikaülikool, Humanitaarteaduskond

9. Teaduspreemiad ja –tunnustused

2010 CEPS/INSTEAD stipendium, Luksemburgi Suurhertsogiriigilt ja Leuveni Katoliiklikult Ülikoolilt (Belgia)

2005 Kodanikuhariduse Sihtasutuse stipendium.

2004	Rotalia Fondi Bruno ja Helge Laane (Laan) nimeline stipendium

10. **Juhendatud väitekirjad**

Ly Ferenets, magistrikraad, 2016, (juh) Piret Tõnurist, Kulumudelite roll koostööl põhinevas valitsemises eesti sotsiaalvaldkonna teenuste näitel, Tallinna Tehnikaülikool, Sotsiaalteaduskond, Ragnar Nurkse innovatsiooni ja valitsemise instituut

Kleiri Vest, magistrikraad, 2015, (juh) Piret Tõnurist, Koosloome kontseptsiooni kasutamine Eesti avalike teenuste disainimise protsessi näitel, Tallinna Tehnikaülikool, Sotsiaalteaduskond, Ragnar Nurkse innovatsiooni ja valitsemise instituut

Artur Talihärm, magistrikraad, 2013, (juh) Piret Tõnurist, Technology Transfer in Low-Tech Industries: the Case of Biotechnology and Aquaculture Industry in Estonia (Tehnoloogiasiire madalatehnoloogilises tööstuses vesiviljeluse ja biotehnoloogia näitel Eestis), Tallinna Tehnikaülikool, Sotsiaalteaduskond, Ragnar Nurke innovatsiooni ja valitsemise instituut

Kaire Kesküla, magistrikraad, 2010, (juh) Piret Tõnurist, The Rise of the „Creative Agenda“ in Transition Counties: The Case of Estonian Creative Industries and Industrial Design, Tallinna Tehnikaülikool, Sotsiaalteaduskond

11. **Õpetamine**

2014	Case Studies in Technologies and Industries (Master’s level) and Case Studies in Business, Government and International Economy (magistri tase) (in English) (in English)
2013	Kaukasuse ja Kesk-Aasia post-sotsialistlikud riigid rahvusvahelises perspektiivis (bakalaureuse tase)

12. **Publikatsioonid**

Tõnurist, P.; De Tavernier, W. 2016. The welfare state in flux: Individual responsibility and changing accountability relations in social services. Christensen, T.; Lægreid, P. (eds.) *The Ashgate Research Companion to Accountability and Welfare State Reforms in Europe*. Ashgate Publishing Ltd, *forthcoming*.

Tõnurist, P.; Karo, E. 2016. State owned enterprises as instruments of innovation policy. *Annals of Public and Cooperative Economics*, *forthcoming*.

Surva, L.; Tõnurist, P.; Lember, V. 2016. Co-production in a network setting: Providing an alternative to the national probation service. *International Journal of Public Administration*, *forthcoming*.
Tõnurist, P.; Lember, V.; Kattel, R. 2016. Meta-analysis of LIPSE work packages 1-5. *LIPSE Working papers*, *Forthcoming*.
Kattel, R.; Cepilovs, A.; Drechsler, W.; Kalvet, T.; Lember, V.; Tõnurist, P. 2015. *Public Sector Innovation Indicators: Towards New Evaluative Framework*, European Commission report.
Tõnurist, P.; den Besten, D.; Vandeven, P.; Yu, X.; Paplaityte, D. 2015. Market Liberalization and Innovation in the Energy Sector: The Case of Belgium and the Netherlands. *Halduskultuur - Administrative Culture*, *forthcoming*.
Tõnurist, P.; Kattel, R.; Lember, V. 2015. New Leisure Class and Conspicuous Politics in Urban Regeneration Initiatives. *Working Papers in Technology Governance and Economic Dynamics*, 64, 1 - 24.
Tõnurist, P.; Kattel, R. 2015. Kas TAI poliitikad saavad ületada piire? Põhjamaade ja Baltimaade näide. *Tehnoloogia & Valitsemine: Ragnar Nurkse instituudi poliitikaanalüüsid*, 6, 1 - 30.
Tõnurist, P.; Kattel, R.; Lember, V. 2015. Discovering Innovation Labs in the Public Sector. *Working Papers in Technology Governance and Economic Dynamics*, 61, 1 - 36.
Tõnurist, P.; Pavlopoulos, D. 2015. Part-Time Wage-Gap in Germany: Evidence across the Wage Distribution. *Journal of Income Distribution*, *forthcoming*.
Lember, V.; Tõnurist, P.; Karo, E.; Hanson, R.; Mäekivi, R. 2015. Kuidas konkursside ja auhindadega innovatsiooni hoogustada: maailma tervisesusteemide oppetunnid Eestile. *Tehnoloogia & Valitsemine: Ragnar Nurkse instituudi poliitikaanalüüsid*, 5, 1 - 32.
Voorberg, W.; Tummers, L.; Bekkers, V.; Torfing, J.; Tõnurist, P.; Kattel, R.; Lember, V.; Timeus, K.; Nemec, J.; Svidronova, M.; Mikusova Merickova, B.; Gasco, M.; Flemig, S.; Osborne, S. 2015. *Co-creation and citizen involvement in social innovation: A comparative case study across 7 EU-countries*. European Commission report, 1 - 144.
Tõnurist, P. 2015. Framework for analysing the role of state owned enterprises in innovation policy management: The case of energy technologies and Eesti Energia. *Technovation*, 38, 1 - 14.
Karo, E.; Kattel, R.; Kalvet, T.; Tõnurist, P. 2014. Teadus-arendustegevuse ja innovatsiooni indikaatorid kui kasulik tagasiside poliitikakujundajatele? *Tehnoloogia & Valitsemine: Ragnar Nurkse instituudi poliitikaanalüüsid*, 4, 1 - 27.
Tõnurist, P.; Pavlopoulos, D. 2014. Part-Time Wage-Gap in Germany: Evidence across the Wage Distribution. *AMCIS Working Papers*, 2014/2, 1 - 33.

Kattel, R.; Cepilovs, A.; Drechsler, W.; Kalvet, T.; Lember, V.; Tõnurist, P. 2014. Can we measure public sector innovation? A literature review. *LIPSE Working papers*, 2, 1 - 45.
Tõnurist, P. 2010. What is a „Small State“ in Globalizing Economy? *Halduskultuur - Administrative Culture*, 11(1), 8 - 29.
Laidvee, J.; Tõnurist, P. 2008. Lissaboni lepingu ja Euroopa põhiseaduse lepingu võrdlus: ekspertarvamus. *Riigikogu Toimetised*, 17, 68 - 74.

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