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ORIGINAL ARTICLE

# Requirements for innovation policy in emerging high-tech industries

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**Abstract** Innovation policy can never be fully technology-neutral and policies often align to support incumbent technological regimes obstructing the development of new industries. In this paper, two fields are analyzed: the life sciences industry and the solar energy industry to evaluate the Finnish innovation policy's capabilities to promote emerging industries. Qualitative research methods are used for this exploratory study. The data consists of 29 semi-structured interviews and two workshops. The interviewees were chosen with snowball sampling. The data is analyzed using a scheme of functional technological innovation system analysis to identify blocking and inducement mechanisms within the industries. The performance of key processes (functions) of the life sciences and solar energy innovation systems are evaluated. Functional analysis is used to identify underlying mechanisms which induce and hinder system performances. Many similar mechanisms are found to affect both of the industries. Limited commercial experience, scarce venture capital, weak local and global networks, and poor legitimation hinder their development. High-level research and education, good infrastructure, and public R&D support are identified as promoting mechanisms. According to the results, Finnish innovation policy performs insufficiently in facilitating the growth of new industries. We suggest that in addition to the general innovation policy measures, technology-specific measures should be designed to create growth trajectories for emerging technologies. New communication and knowledge exchange channels are needed to support these trajectories.

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## Introduction

Globalization and climate change pose great challenges for the future of the European countries. New sources of growth are needed as the global competition weakens the profitability of the existing industries. Global warming creates additional constraints for economic activities, but may also generate new opportunities as the customer preferences and technological development are increasingly guided by environmental concerns.

Forecasting and assessing the evolution of new technologies have long been focal parts of the discipline of futures studies [3, 32, 52]. According to Jim Dator's [15] First Law of the Future, the future cannot be predicted but alternative futures can be forecasted and preferred futures should be implemented. Recently, linkages have formed between futures studies and a growing research field on sustainable transitions (see *Technology Forecasting and Social Change 2012, 79/6, Special Section*). The literature on transitions concentrates on radical changes in the systems of production and consumption and encompasses social, economic, technological, and political dimensions. Farla et al. [24] argue that because of the long-term orientation and prospective nature of transition processes, the transitions literature is closely connected to technology forecasting and futures analysis.

The goal of innovation policy is to select a desirable future and facilitate its realization [28]. Promoting futures which encompass the desired technologies require the identification of barriers, bottlenecks, and blocking mechanisms which prevent them from gaining ground and developing [70]. Recent studies [6, 30, 44] have shown that requirements for innovation policy vary between industries. Different technologies and sectors have needs that should be addressed in the context of the particular industries. General innovation policy (e.g., tax reliefs for R&D) may provide good starting points for many fields but their growth is often hindered by factors that are specific to one or a few industries. Dynamic capabilities of recognizing and removing bottlenecks which prevent industries from reaching their full potential are needed for comprehensive innovation policy.

Life sciences/biotechnology[1] and solar energy are industries which have recently attracted lots of positive attention in the Europe. Life sciences and biotechnology are considered to create significant opportunities for European societies and economies [27, 39]. Solar energy, especially the photovoltaic (PV) technology, has been identified as a desirable future technology for Europe [7, 10, 38, 68] and acknowledged also by the European Commission [17, 18, 34].

In this paper, we analyze the life sciences industry and the solar energy industry to evaluate the Finnish innovation policy's capabilities to promote emerging industries. We identify mechanisms which hinder the development of these industries to shed light on the obstacles that lie in the way of realizing their full potential. These two industries were chosen for their similarities in their identified desirability at the European level, their high-tech knowledge base, and start-up firm base. They differ in their stage of development, the life sciences industry being more mature, which gives us tentative knowledge on how the obstacles are related to the maturity of the industry.

## Theoretical framework

Innovation systems consist of three components: actors, institutions, and networks which contribute to the generation, diffusion, and utilization of technology [9]. The approach thus acknowledges not only the exploration of new technological and business opportunities but also their exploitation. It covers the creation, diffusion, and use of radically new products and their continuous improvement by incremental innovation. The framework may be used to analyze both incumbent and emerging technologies [49]. Innovation systems can be delineated by national borders [48], regions [14], sectors [42], or technologies [43]. In this paper, the life sciences and solar energy fields in Finland are handled as technological innovation systems (TIS).

The actors in innovation systems may be organizations such as firms, universities, financial institutions, governmental agencies, groups of organizations, or individuals, e.g., consumers, entrepreneurs, and scientists. They interact through different forms of communication, exchange, cooperation, competition, and command [42]. Institutions encompass the "rules of the game": laws, technical standards, regulations, norms, routines, and shared expectations that guide and regulate interactions and relations between actors. Institutions can be coherent but there are often conflicts between different elements [19]. Networks define how different actors are interrelated and can be either formal or informal [6]. Bergek et al. [6] propose seven functions as tools for analyzing the performance of a TIS: knowledge development and diffusion, entrepreneurial experimentation, influence on the direction of search, market formation, legitimation, and resource mobilization.[2] These all contribute to the overall goal of the system: the development, diffusion, and utilization of innovations. The implicit thought is that different processes in the TIS are complementary. To function properly, all aspects of the innovation processes must be taken care of.

Bergek et al. [6] argue that in order to prosper, emerging technological innovation systems require interplay between institutions and the actors' needs. In different stages of development, the systems need different kinds of support. Functional analysis can be used to identify the most important targets for development. According to Faber & Frenken [23], the institutions should develop in a co-evolutionary relationship. The policies should adjust to emerging technological paradigms and the paradigms to policies. Below, the six functions used for TIS analysis are introduced.

### Knowledge development and diffusion

A TIS is fundamentally about the creation and diffusion of knowledge and information. The width and depth of the knowledge base and the diffusion of knowledge between various actors form the basis of a TIS. Knowledge is not limited to a certain type, such as technological knowledge, but various types of knowledge are required for a technology to prosper. Different actors have access to different kinds of knowledge, so comprehensive networks are important [6].

According to Cohen and Levinthal [13], R&D activities have a twofold function. First, they generate new knowledge. Secondly, they improve an organization's *absorptive capacity*, i.e., the ability to exploit outside knowledge. Taken on a national/regional level this implies that some level of own

[1] Life sciences has no universally accepted definition, and the term is often used together with biotechnology or even interchangeably. We define life sciences as functional foods, drug development, diagnostics, biomaterials, bioinformatics, and medical design and technology.

[2] Bergek et al. [6] include also *the development of positive external economies* as a seventh function which deals with synergy benefits such as pooled labor markets, availability of specialized goods and knowledge spillovers, which arise as the TIS grows. We have omitted this function from our analysis on the grounds of simplicity as we believe the externalities may be discussed in the context of the other functions. VINNOVA (the Swedish Agency for Innovation Systems) has also decided similarly.

research capacity has to be maintained to follow and take advantage on research conducted elsewhere even if the resources were too limited to significantly contribute to new breakthroughs.

Borrás [8] associates different components with different knowledge-related processes. Knowledge creation benefits from universities, education system, testing laboratories, and research subvention schemes. The diffusion of knowledge, on the other hand, relies on creating connections between relevant actors, and stimulating knowledge sharing. Actors, e.g., technology transfer centers, bridging organizations, and institutions such as the social and corporate praxis about the diffusion and sharing of knowledge, play a significant role here. In many cases, the knowledge created cannot be exploited commercially because of weak relationships between universities and firms. Major business opportunities may remain untapped if the scientific knowledge cannot be developed into products because of insufficient knowledge transfer [40].

### Entrepreneurial experimentation

Schumpeter [57] described the nature of capitalism as "creative destruction" in which the market environment evolves by destroying old structures and giving birth to new ones. This creates considerable uncertainty about the future. TISs must be able to adjust and adapt to the changing surroundings. The best way to reduce the uncertainty is constant entrepreneurial experimentation, which consists of finding new business opportunities from emerging technologies and applications. Many of the experiments are bound to fail but some might succeed. In addition, the search process induces a social learning process into the whole system [6]. This function can be evaluated by the number and variety of firms, used technologies and applications [5, 64]. Pajarinen et al. [50] argue that entrepreneurial experimentation is a needed—and often missing—link between the creation and diffusion of knowledge and their welfare benefits.

### Influence on the direction of search

Technological innovation systems require a certain mass of actors with different knowledge and skills in order to develop. This is because the search for innovation opportunities is a costly process and actors differ in their ability to recognize and valuate them. Numerous actors are needed in the system in order to increase the chances of finding a feasible direction to pursue [6]. High number of participants provides the TIS more resources and new actors may legitimate a new field by their very entry [11].

Total value created by an innovation network is dependent on how well the partners' objectives are aligned to each other [65]. Thus, it is in the policy maker's interest to design incentives for the relevant firms and organizations to join the network. The function "influence on the direction of search" consists of these incentives, as well as activities which direct the search within the system, covering the choices between different competing technologies, applications, markets, business models, etc. [4, 6].

Meijer et al. [46] emphasize the effect of policy uncertainty on the attractiveness of an industry. In their study of the bioenergy industry in the Netherlands, they found out that uncertainty about future restrictions and continuity of existing financial subsidies hindered the development and implementation of biomass gasification significantly. Setting long-term societal goals grant legitimacy to a field and stimulate the allocation of resources for R&D.

### Market formation

Market formation embodies relationships between users and producers and is a prerequisite for emerging technologies to compete with the incumbent ones. In many cases, actors in new technological innovation systems are not aware of the needs and wishes of potential customers, there might not exist any market places and the price-performance ratio may be poor [6]. Functioning markets are a necessary part of innovation. It provides a platform for entrepreneurial experimentation, creates an incentive for firm entry, and facilitates the diffusion of knowledge [33].

Markets usually form through three stages. First new technologies require a "protected space," a niche, which acts as an "incubation room" in which actors form relationships and may learn and shape their expectations. The space may form from a need for a specific type of technology that the existing technologies cannot fulfill. Policy makers can also support the growth of a new technology by providing subsidy schemes and investment grants, helping the technology cross the "valley-of-death" between research and market introduction [6, 25, 54]. Niche markets may evolve into bridging markets with higher volumes and more actors, and finally into mass markets [6]. Emerging technologies typically suffer from a low adoption rate, which is partly due to a lack of customer experiences. The potential customers tend to share information about the new product through interpersonal networks which reduces the risk of adopting the product. When a critical mass of users has adopted the product, its diffusion curve "takes off" and it no longer needs outside support [55].

### Legitimation

Legitimation can be described as social acceptance and compliance with relevant institutions. Technologies need to be seen as feasible and adequate for actors to take interest in them. Legitimacy is closely linked to the function "influence on the direction of search" since legitimacy has an impact on expectations among managers and therefore on their strategy. Legitimacy is acquired through a legitimation process which is the result of sustained conscious efforts of different actors. It usually aims to adjust the institutional framework to support the development of the system better. Another goal is to overcome the stigma of new technology in the eyes of relevant stakeholders [6].

Emerging technological systems usually compete with existing systems that try to defend their position and the related institutions. Often, the best way to break through is to form advocacy coalitions with the actors in the sector and take concerted actions [56, 69]. Jacobsson and Bergek [33] identify institutional weakness taking place when existing institutions are unsuitable and difficult to amend, and network weakness when there are not enough actors forming political consortia to advocate their demands.

### Resource mobilization

The viability of a technological system depends on the availability of required resources. The resources include human capital, i.e., education and scientific knowledge in the related fields, financial capital in the forms of seed and venture capital and diversifying firms, and complementary assets like products, services, and infrastructure [6]. The availability of resources is necessary for all innovative activities and can be provided by, e.g., government or venture capitalists [64]. Human capital may remove barriers to communication between actors by decreasing cognitive distance between them through education. Financial capital relaxes budget constraints and enables all types of economic activities.

## Data and methodology[3]

The data of the study consists of a total of 29 semi-structured face-to-face interviews. The interviewees, chosen with snowball sampling, include policy makers (11), consultants (2), researchers (4), R&D directors (3), senior executives (3), entrepreneurs (5), and a PR manager. Twenty-four of the conducted interviews concern the life sciences industry and were conducted between March 2010 and December 2010. Five interviews concern the solar energy industry and were conducted between November 2011 and December 2011. The interview questions were designed to elicit open-ended responses from participants and to encourage them to provide personal stories and perspectives to emerging industry trends, challenges, and opportunities. Questions were organized into several categories, including networking, collaboration, university–industry relationships, industry trends and dynamics, regional changes, customer interface, funding, and industrial policy.

In addition, the interviews are supplemented with data from two workshops. A 2-day foresight workshop was conducted in the spring of 2010 with 29 representative members from the Finnish life sciences community. During the workshop, participant's inputs on emerging insights, regional concerns, and promising opportunities for long-term success were gathered. In the winter of 2011, a solar energy seminar was organized by the Finnish funding agency for technology and innovation (Tekes). The seminar included a workshop with around 200 participants. The workshop's aim was to identify the inducement and blocking mechanisms of solar energy in Finland and design proposals for action for relevant actor groups. The authors attended the workshop and afterwards received a summary of the results for analysis. Qualitative data is backed by quantitative indicators of the industries in question.

In this paper, the technological innovation system framework is used to analyze the dynamics and functionality of the life sciences and solar energy innovation systems in Finland. More specifically, a functional evaluation method of a TIS presented by Bergek et al. [6] is used. The interviews were transcribed and coded. The coding was made according to the six above-mentioned functions. Every theme or topic was coded with one or more functions according to their fit. The topics which were acknowledged by multiple interviewees or whose importance was supported by complementary data are reported in the results section. Many of the topics were linked with more than one function and had causal links and feedback loops to other functions. In these cases, the topics are discussed under the function considered the most suitable for them. The functional analysis is used to identify the underlying mechanisms which induce and hinder the performance of the systems.

## Results

### Actors, networks, and institutions

In this section, the main constituents of the Finnish national innovation system are briefly outlined. Although technological innovation systems may cross national and sectoral borders [44], the aim of this study is to identify shortcomings in the Finnish innovation policy which puts the emphasis on the actors, networks, and institutions at the national level.

[3] The technology field referred to as solar energy should be understood as comprising different photovoltaic (PV, solar panel) technologies in the context of this paper. The life sciences field encompasses functional foods, drug development, diagnostics, biomaterials, bioinformatics, medical design, and medical technology. Most available data is about the related and overlapping biotechnology field and may not accurately represent the life sciences field.

There are several actors playing an important role in the Finnish national innovation system. The list and description of the actors is not comprehensive, but constructed to contain those actors that based on interviews seemed to be the most relevant. The networks are largely formed around these actors.

The Finnish Ministry of Employment and the Economy oversees Finland's technology and innovation policy and energy policy. The Finnish Ministry of Education and Culture is responsible for the country's science policy. Key issues are coordinated by the Research and Innovation Council, chaired by the Prime Minister. At regional level, the national technology policy is implemented by the Centers for Economic Development, Transport and the Environment. Tekes (Finnish funding agency for technology and innovation) is the main public funding organization for applied research, development, and innovation. Another big public financier, the Academy of Finland, concentrates more on funding academic basic research. Sitra, the Finnish Innovation Fund, is an independent public foundation under the auspices of the Finnish Parliament. Sitra's activities are financed by the yield from its endowment capital and the return on its venture capital investments.

Laws, standards, and regulations play an important role in the innovation environments of the life sciences and solar energy fields. Many of the laws and regulations are based on EU directives, but some national institutions also have a strong effect on the emergence and development of the technologies. Institutions related to university–industry relationships and taxation issues were seen highly important in the interviews.

The university–industry relationships have been crucial for the emergence of both of the industries. The legal and structural changes related to these relationships were seen highly central. Especially three changes with major impacts on the Finnish university–industry relationships were mentioned in several interviews. In a chronological order, the first change is the University Inventions Act from January 2007. The objective of the act is to promote technology transfer from universities to industry. The second change is the establishment of the Strategic Centers for Science, Technology and Innovation (CSTI, Finnish acronym SHOK). They are new public–private partnerships and their main goal is to promote collaboration between universities, research institutes, and industry and to facilitate radical innovations. The CSTI of Finnish energy and environment sector (Cleen Ltd) was established in 2008 and the CSTI of Health and Well-being (Salwe Ltd) operating in life sciences sector started on April 2009. Third change is the new Universities Act which came into force on the first of January 2010. The objective of the renewal was to give universities a more autonomous position in terms of financing and overall management, and to offer universities better premises to fulfill their three central assignments: research, education, and societal interaction (Fig. 1).

In addition to the university–industry relationships, taxation issues were considered critical in fostering innovation. Taxation has an important role in creating growth-friendly environment where venture capitalists, business angels, and companies feel comfortable in investing. In 2005, 70 % of OECD member countries, excluding Finland, had tax incentives for R&D investments [16]. In year 2012, the Finnish government has decided to test R&D tax incentives for a 3-year period [67]. The public R&D money for Finnish companies as well as the tax incentives are below the average of OECD countries [49].

## Functions

### *Knowledge development and diffusion*

In *knowledge development*, one of Finland's biggest strengths is the high quality of research. This was identified important by interviewees from both sectors. The knowledge base was considered notable in the life sciences by the interviewees. In a national ranking of clinical medicine research 2001–2011, Finland was among the top ten countries on citations per research paper [62]. In the solar energy field, the interviewees rated the research highly but criticized the field for lack of focus. The number of patent applications (7) and the RTA-index (0.2) which measures technological specialization were both very low in the solar energy field during the period 2000–2007 [36].

Because of the small population of the country, total resources for research are on a quite modest level. There is a significant trade-off between the depth and width of the knowledge base. If the resources are divided between all research fields within life sciences or renewable energy sources, none of the subfields will benefit much. On the other hand, some level of knowledge should be maintained in a variety of fields for the researchers and firms to be able to follow and understand research made somewhere else. Concerns were expressed that both of the fields lack concentration. The knowledge bases are currently quite wide but mostly not deep enough to achieve significant results. The resources should be focused on one or few areas instead of dividing them among many research themes.

Public policies play an important role in supporting networking and the *diffusion of knowledge*. In research-intensive areas like the life sciences and solar energy sectors, the university–industry relationships play a critical role in knowledge diffusion. Tekes and EU funding require university–industry collaboration which facilitates networking, partnering, and gaining important knowledge from the field. However, based on interviews the collaboration works sub-optimally because academic projects are guided more by an

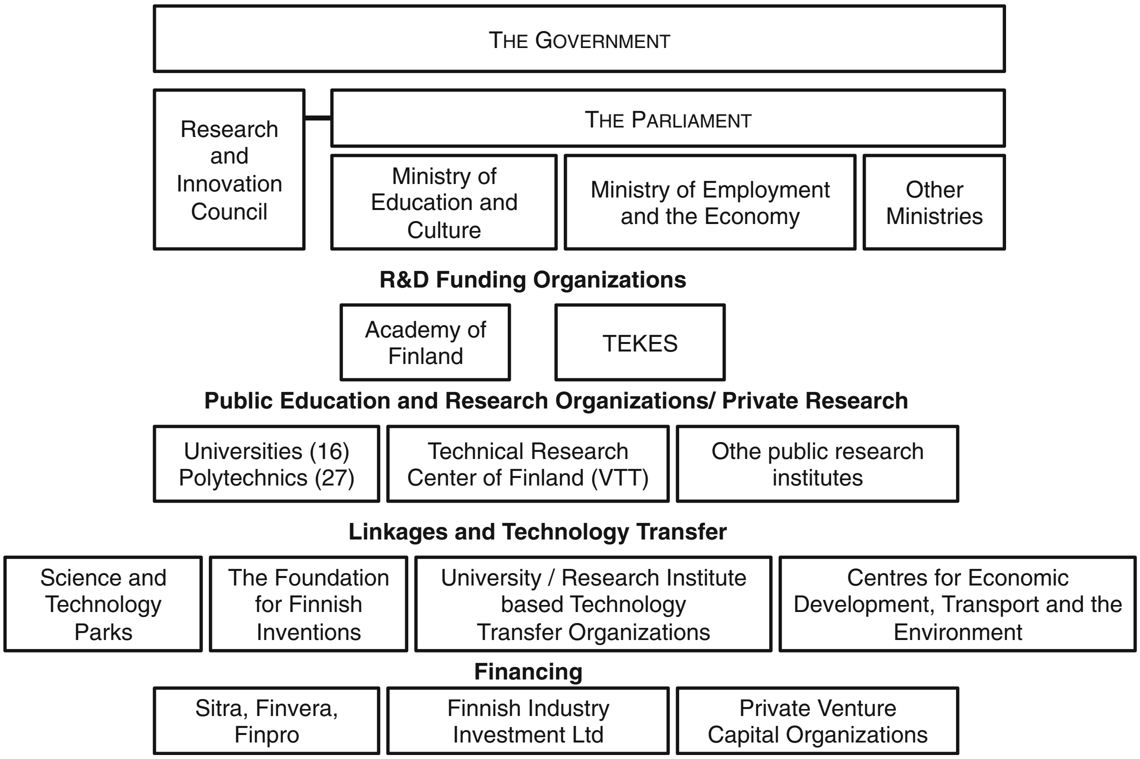


**Fig 1** Actors in the Finnish innovation system (based on [67])

opportunity to acquire research funding than a genuine interest in collaboration. This prevents knowledge diffusion between academia and industry. "The research groups start calling firms to take part in their projects two weeks before the Tekes deadline," one interviewee described the standard way of cooperation. "We rarely find ourselves with anything useful after a project ends," a firm representative commented joint R&D projects. The best results are usually achieved when the universities and firms plan the projects together, collaborating right from the start.

Only recently, changes in the innovation policy have brought academia and industry closer to each other, changing the attitudes gradually more positive towards commercialization. The companies would like to be involved in the university projects already in the planning stage, but academic researchers worry that a closer university–industry partnership may shift the focus excessively towards applied research. Compared with the national R&D effort, Finland's overall EU project participation rate is very poor [20]. This is the case especially in the energy industry, where the actors have traditionally found most of their partners from within Finland. Global networking is needed to keep up with the latest advancements in the fields and the poor participation rate is to be considered weakness of the knowledge development and especially the diffusion function.

The development of the technology transfer offices in promoting the commercialization of university inventions is crucial. To recognize the commercial potential of the inventions is challenging, and to find a working model for the technology transfer from university to industry requires continuous development as well as mechanisms to develop early phase products and methods to a more mature state. A comment: "The Finnish life sciences sector has potential that somehow cannot be realized. The invention phase as such works but thereafter the process stalls" represents a pretty typical answer in the interviews. Organizations or funds to assure the development of the inventions further and facilitate more efficient exploitation of university inventions are needed in Finland.

*Entrepreneurial experimentation*

The number of firms in the whole biotechnology and life sciences sector grew sharply until the beginning of the millennium but after that it has stagnated [31]. There are roughly 200 companies operating in life sciences sector in Finland including consulting companies and distributors. Diagnostics and drug discovery stand out as the most important branches. Around 25 % of the companies are operating in the diagnostics sector and 25 % in the pharmaceutical sector, biomaterials cover around 10 % and bioinformatics 5 % [66].

In the pharmaceutical sector, there are a few domestic producers of which Orion is the biggest one with around €850 million annual net sales. In addition, there are some small players with less than €20 million net sales and a few, quite young, originally Finnish drug development companies with a few molecules in the product pipeline. Multinational companies Bayer and Santen also have production facilities in Finland [21]. The total pharmaceutical sales in Finland were around 2 billion euros with wholesale prices in 2011 [51]. Diagnostics was regarded as the most dynamic field within life sciences with moderate development times and relatively long history compared with many other branches. In the diagnostics sector, there are around 30 companies and €350 million yearly net sales [29]. Big multinational companies Thermo Fisher Scientific and Perkin Elmer have facilities through acquisitions in Finland and are actively operating in the diagnostic sector.

When exploring 5-year periods 2002–2006 and 2007–2011, the number of established companies in the life sciences sector has declined 30 % from 50 to 35. Around 60 % of the new companies were small service providers. The size of the personnel in Finnish life sciences companies is modest and around 30 % of them are one person businesses (personal communication, Kai Lahtonen, Senior Advisor).

Pöyry Management Consulting Oy [53] identifies 74 companies operating in the Finnish solar power innovation system. The companies are either Finnish or do business in Finland. Companies associated with photovoltaics are much more common than those who concentrate on solar thermal. Many of the companies are not specifically concentrated on solar power but do business in construction, real estate, or property management. Those who focus solely on solar power are typically recently founded and technology oriented. In another study [36], the number of companies was identified as 97 with the following positions in the value chain (Table 1).

The growth of the companies is slow and high-growth enterprises are largely missing from both sectors. Many of the companies are small science-based university spin-offs. The researchers who establish businesses do not have entrepreneurial experience and also fail to utilize know-how from other sectors. Some of the companies have truly original products and are able to grow and prosper by themselves. Others are unable to develop beyond a certain point regardless of their potential. These firms are often sold abroad. In these cases, the government does not fully benefit from the public investments made in the companies. Long-term tax and employment effects are not achieved.

**Table 1** Value chain categorization of Finnish solar energy companies [36, p. 108]

| | SMEs | Enterprises | Foreign parent company | Total |
|---|---|---|---|---|
| Energy company | – | 1 | – | 1 |
| Device and component manufacturing | 14 | 12 | 4 | 26 |
| Import and sales | 31 | 2 | 2 | 33 |
| Planning and project management | 7 | – | – | 7 |
| Installation | 19 | – | – | 19 |
| Maintenance | 5 | – | – | 5 |
| Research | 2 | – | – | 2 |
| Sector associations | 2 | – | – | 2 |
| Other | 2 | – | – | 2 |
| Total | 82 | 15 | 6 | 97 |

The dilemma is that small businesses are supported by public policies, but their impact on the development of the field is not very high. Companies which aim to expand their business often find to be on their own. In the life sciences sector, long-term financing is limited. In the solar energy sector, the next step would be to conduct pilot and demonstration projects to gain credibility and references. These projects are typically very expensive and funding is scarce. According to Pöyry Management Consulting Oy [53], there are 19 ongoing or finished development projects utilizing solar energy in Finland. Most of these are building projects or area development projects. Municipalities play an important role in these projects and bureaucracy in the municipalities often prevents solar projects from taking place.

Taxation, lack of funding, and attitudes towards risk are among the top factors that hinder investments by Finnish firms. Foreign investments are hampered by taxation, small domestic market size, lack of knowledge about Finland and its strengths, and distant location [58].

The general attitude towards entrepreneurship is quite discouraging. According to an evaluation by Murray [47], the ranking of the entrepreneurial climate in Finland is 1.6 on a scale of 1 to 5. In comparison, the ranking of the UK is 3.9 and the USA is rated 4.9. Entrepreneurship as a career choice is not valued highly in Finland. In addition, the ambition and willingness to take risks are quite modest with those who have started their own businesses. This was noted also by the interviewees in the life sciences sector: “Many Finns have low ambition; they are content with funding their own laboratory for the next 5 years with some subsidy.” Another interviewee commented: “I think the situation is similar to Finnish sports: if you aim to finish 33rd at the Olympics, you will never win. The lack of ambition and greed results in mediocrity.” Risk averting and low ambition restrict the growth of Finnish companies which are often satisfied with a steady income for a few employees.

### *Influence on the direction of search*

The actions by policy makers may have a big influence on the *attractiveness* of a technology field. They should be predictable to reduce political risk [46]. The life sciences sector in Finland has suffered from a realized political risk. At the beginning of the last decade, the life sciences sector was booming and it was hoped to become a new pillar to the Finnish economy. The attitudes however changed and the amount of public financing decreased drastically. This in turn influenced the private investors.

In the solar energy sector, Finland does not have a feed-in tariff to subsidy the production, like many other EU countries. The tariffs have boosted the growth of the solar sector in the EU, but the late economic downturn has in many cases led to decisions of running down the existing tariff systems. This is extremely troubling because the investment times in the energy business are very long. The existence of this kind of political risk in Finland and in EU generates considerable uncertainty, which reduces the effectiveness of all policy measures as their continuity cannot be fully trusted.

Companies in both of the sectors are mostly very small and few have much influence. Actors in the fields are too scattered to gain from the synergy benefits of joint activities. By joining their forces, companies could increase their competences, offering, and visibility. In the solar energy sector, large companies have strong connections to the Ministry of Employment and the Economy which is responsible for the energy regulation and standardization. The relationships are either direct or via industrial associations. The ministry's connections to solar energy researches and SMEs are however poor. Because of limited resources, the ministry cannot follow the field closely and lacks the latest knowledge and understanding about the sector. A concern was expressed that it is extremely difficult to foresee all effects of regulative actions because of communication barriers between regulative policy makers and the developers of technology. Large companies and industrial associations encompass only some of the relevant actors and their views may be more conservative than the others.

The *direction* of the life sciences sector is strongly guided by technology-push mechanisms. New products originate from scientific developments and the lack of customer orientation is considered a weakness. Companies find it hard to acquire knowledge of the demand factors and cannot guide their search with respect to it. With no clear shared goals, the research has divided among many different subfields. Synergy benefits from clustering and knowledge exchange are largely missed.

The EU climate and energy package has a strong influence in the direction of energy research in Europe. The package was agreed in December 2008. It is binding to all EU member countries and includes significant reductions in greenhouse gas emissions and increases in the use of renewable energy by 2020. Finland tries to reach the 2020 targets mainly by supporting the production of bioenergy accompanied with wind and water power. Solar power does not hold a strong position in the national energy policy [61]. As a result, creating regulation to support the development and utilization of solar power technology and services is a low priority. At the EU level, Finland is associated with bioenergy as Germany is with solar power and Denmark with wind power. Limited resources have to be divided among different energy sources and solar is not at the top of the list.

A pervasive view that came up in the interviews was that Finland needs shared goals concerning the development of life sciences and solar energy. Actors should form tight networks and decide on the direction to pursue. Input from producers, researchers, government agencies, municipalities, and users are needed for this. The creation of business clusters was suggested as a good way to share knowledge and boost collaboration.

*Market formation*

Recently, a concern has been expressed that the TIS framework does not take geographical issues sufficiently into account [12, 63]. A distinction between domestic and global markets has to be made when thinking of the market formation. The domestic markets are not nearly big enough to support many firms. The target markets are global. As there is no local demand, Finnish companies need to go global at a very early stage.

The know-how and business competence are gradually accumulating, as the life sciences industry is becoming more mature. Although many Finnish life sciences firms have been forced to sell their innovations abroad at a quite early stage, some older companies have survived and acquired valuable experience. In the absence of long-term funding, the companies have to find alternative ways of income before the actual product is on the market. That means new, innovative, business models, virtual companies, combining service and product development, etc. Also, the bigger players have not taken an active role in market formation.

The SMEs in the solar sector think that a domestic market would support their business significantly. It would give them a chance to gain reputation, credibility, and experience in a familiar environment. Without project references and experience in conducting projects, competing against global players is very difficult. Another widespread view among the companies is that although solar energy will not play a big role in Finnish energy production, there is business potential that could be unleashed with a little policy support. Finland has enough skilled actors to start producing turnkey solar panel systems for households and firms, but because of hampering regulation and lack of subsidies, there are not enough incentives to do so. "Finns are technology enthusiasts. They would get solar panels if it was only possible to buy them," commented one of the company representatives at the solar energy seminar. Turnkey solar systems which require no expertise or effort from the customer were considered critical in the formation of domestic PV markets. The electricity prices in Finland are 15.2 % lower for households and 26.7 % lower for industrial customers compared with EU average [22]. This makes the opportunity cost of producing energy with solar panels higher than in most countries. Producing solar energy for household's or firm's own use could nonetheless be profitable since consuming electricity on the spot saves the electricity distribution costs.

Global partnering is necessary to succeed abroad. The global life sciences market is well-formed but Finnish actors are largely disconnected from the relevant networks. Amir-Aslani and Negassi [1] state that small life sciences companies need partners to share risk and to access financial resources leading to the formation of strategic alliances. Our study supported this view that small companies often lack skills and resources to form relationships in order to penetrate the foreign markets. Moreover, the Finnish financiers may be unable to help either as they are not specialized in the life sciences area. Participation in EU projects could help in connecting to professional networks but is currently an underused channel.

Small start-ups often have funding only for a few months ahead, and have thus limited resources to contact potential partners. Furthermore, public funding is often not allowed to be spent on traveling and marketing. Language and cultural differences, geographical distance, and legal frameworks form challenges in partnering. Good business plans, patents, concepts, and unique products are not enough to attract global investors to Finland. Policy support and actions, such as tax incentives, new funding instruments, and national patent pools are also needed.

*Legitimation*

The legitimation of the life sciences sector faced a downturn in mid-2000s when Sitra (the Finnish Innovation Fund) withdrew from the capital markets. In its footsteps, other investors started to reconsider their investments also, and after since the appeal of the sector has been quite low among investors. Actors in the field are concerned that the industry has not gained as much positive publicity as deserved. Especially, the Finnish media was criticized for a negative attitude towards the life sciences industry. Negative publicity in Finnish media may have an unfavorable influence on foreign investors. Moreover, the entrepreneurial climate, legislation, and taxation system were not regarded as highly supportive in Finland.

Finland has some advantages in the pharmaceutical sector, as Finnish health care is well-managed and well-documented, the infrastructure is good and the citizens are willing to participate in clinical trials which facilitate product development. The public attitudes towards research in life sciences sector are positive, thus promoting the adoption of new techniques and innovations among users and customers [41]. However, slow permit and reimbursability processes in healthcare prevent big pharma investments, even though Finland has a long track record in clinical trials.

Based on the interviews, the lack of legitimation is one of the biggest obstacles in the development of the solar innovation system in Finland. In principle, the solar energy technologies, especially PV, have strengths that could ease their acceptance. For example, PV panels do not reshape the landscape the same way wind power generators do. They do not rely on the economies of scale in size unlike wind turbines: small rooftop panels are as efficient as big power plants. Small panels can be built without taking building regulations into account. Small-scale solar production also fits well into the recent trend of building and developing smart electricity grids, which facilitates distributed energy production. The life cycle of a PV panel is long and they require little maintenance. Despite these points, solar power is not seen attractive in Finland. Most of the arguments against it concern the country's light conditions. However, according to Šúri et al. [60], the yearly sum of irradiation in southern Finland is approximately at the level of Germany and the UK.

Actors who do not follow the development of the solar field closely are at risk of having false understanding and misconceptions. Information acquired 2 years ago is inevitably outdated. Thus the limited resources of policy makers hinder the legitimation process. This point is notable because the solar energy actors in Finland do not have an advocacy coalition to lobby for their interests. The policy makers receive conflicting information about the profitability and development of the solar energy technologies while the firms and researchers seem to be unanimous. Actors in the solar energy field are sometimes referred to as "solar believers." This indicates that they are considered overoptimistic about the technology.

The solar regulation supports distributed energy production by relaxing some of the bureaucracy and requirements for small scale activities. For example, the owners of below 2 MVA solar power systems cannot be charged for the costs of strengthening the power grid when they connect to it. Also, electricity produced to one's own use by small systems is not taxable. Several interviewees however noted that in practice it is not easy to connect solar panels to the power grid. Bureaucracy and technological requirements make connecting difficult. Selling surplus electricity can also be hard. Finding a buyer for energy supply that is fluctuating and small in scale is rarely easy. Regulation also prevents selling electricity directly, e.g., to one's neighbors. Energy must always be transferred via a transmission system operator.

*Resource mobilization*

Finland is one of the most research-intensive countries in the world. Finnish national R&D expenditure is 3.8 % of GDP [59]. Seventy percent of these R&D investments are covered by private sector and 30 % comes from the public sector [59]. However, the private sector figures are dominated by the ICT sector. Nokia covered about half of the private R&D investments in Finland in 2011 [35]. Based on the interviews, Finland stands out with its good educational system, high-quality basic research, good infrastructure, and internationally recognized technological competence. High-quality education lays the foundation for building expertise and world-class innovations.

The public health care system provides an advantage compared with other countries in the life sciences sector. The Finnish health care system has comprehensive patient registers, which may increase the potential of clinical studies. Further, Finland has committed resources to develop a biobanking infrastructure that is hoped to improve the health care in Finland, provide opportunities for international collaboration and research services, and help to integrate its research infrastructure with the EU's efforts [26].

A smart electricity grid is an update to the traditional electricity grid infrastructure. It acquires information on the supply and demand factors and gathers and distributes electricity accordingly. Two-way communication and transmission make it possible for small energy producers to sell their power back to the grid. This increases the attractiveness of residential solar panels. Therefore investments in smart grid infrastructure may be considered complementary to investments in PV technology. The smart grid infrastructure is being developed in a large scale. In 2013, smart electricity meters will be installed in 80 % of Finnish households. Smart grids are also researched, e.g., in the Smart Grids and Energy Markets programmes in CSTI Cleen Ltd and in Tekes's Sustainable community programme.

Finland's pervasive weakness in all sectors is the absence of venture capital. Public R&D funding is on a relatively high level but cannot account for all of the needs. EU funding is available but not much of it ends up in Finland. In 2008, the total amount of VC investments for start-up companies was €127 million which was divided among 196 growth-stage companies. In 2009, the amount decreased to €93 million for 167 companies [45]. This was considered a critical barrier for the development of the industries by practically all of the interviewees. The lack of business know-how stands out as weakness in the human capital stock. The entrepreneurs originate mostly from the academia and lack skills and experience required in penetrating global markets.

*Summary*

The analysis shows that there are several bottlenecks that prevent both of the industries in focus from developing further. These are gathered in Table 2. Most of the bottlenecks concern barriers to growth that fresh start-up companies face. The observed combination of weak performance in high-growth entrepreneurship and the high level of research and notable R&D investments per capita is sometimes called "the Finnish paradox" [2].

Despite Finland being a small country in terms of population, actors in both of the fields are quite scattered and unconnected. The research areas and product offerings are divided into many detached segments. This deprives the actors from synergy benefits such as the economies of specialization, technological spillovers, and pooled labor markets [6, 37]. Without shared goals, their visibility and influence over policy makers will stay low. This in turn affects resource mobilization by reducing the amount of both public and private funding. The university–industry relations still have room for improvement which reduces the amount of inventions that are tried in the markets.

The remote location of Finland at the outskirts of Europe creates additional difficulties in forming connections to global networks required to penetrate the global markets. The problem exists both in the academia and in the industry but is more significant in the latter. Finnish universities do not attract many foreign researchers and participation rate in international EU projects is low. The real problem however is the obstacles companies face in gathering investments from abroad and getting their products in global markets. Language and cultural differences, geographical distance (travel costs, time zones) and varying legal frameworks make it more difficult for a Finnish firm to break through than for instance a firm from the USA.

Public attitudes towards an emerging industry have a strong effect on market formation, the amount of researchers and companies willing to join the field as well as the financier's interest in investing in it. Both of the case study industries suffered from a bad public image resulting from overoptimistic expectations (life sciences) and prejudices and false information (solar energy). Emerging industries typically have little means to widely affect their public perception.

Small firm size may act as a barrier between policy makers and firms. Policy makers are informed of the regulative needs of firms mostly via big enterprises and advocacy coalitions. In the life sciences and solar energy sectors, most of the companies are very small and the policy makers are not aware of their needs. This has an effect on the design of incentives and regulations.

The point above is related to the observation of technology-specific policy needs. The life sciences sector, especially the pharmaceutical sector, has very long and costly development periods and the current public funding system seems to fail to take this into account. The resources are shared between many small projects while it would arguably be more useful to fund few big projects instead. The development of the Finnish life sciences and PV markets is also hindered by regulative issues. Limited understanding about the industry's leading to

**Table 2** Summary of the blocking mechanisms

| Mechanism | Weakens the function[a] | Description |
|---|---|---|
| Low level of domestic collaboration | a, b, c, f | Low connectedness of the actors hampers the development of shared goals and decreases synergy benefits from collaboration. |
| | | Absence of advocacy coalitions limits the visibility of the fields and reduces influence over policy makers. |
| | | Poor university–industry relationships hinder knowledge transfer. |
| Remote location | a, b, d, f | Geographical, institutional and cultural distances from global networks make knowledge transfer, attracting funding, and commercialization difficult. |
| Public image | a, b, c, d, e, f | Poor public images discourage actors from joining the fields which creates negative feedback loops that decrease the performances of all functions. |
| Small firm size | c, e | SMEs are lacking communication channels with policy makers who in turn are unable to acknowledge their needs. |
| Technology-specific policy needs | a, e, d | Insufficient regulation and legislation generate difficulties in the commercialization of the products. |
| | | Differences in research and development times are not acknowledged in public funding. |
| Lack of business know-how | b, f | Lack of commercialization experience hinders the market introduction of new products |

[a] Functions: (a) knowledge development and diffusion, (b) entrepreneurial experimentation, (c) influence on the direction of search, (d) market formation, (e) legitimation, (f) resource mobilization

insufficient actions is currently a significant bottleneck in Finland. Dynamic capabilities to develop institutions in co-evolution with the industries are missing.

The companies in both of the sectors are often university spin-offs and tend to lack know-how to commercialize their technologies. Getting products into markets is hindered by the lack of employees with adequate experience in commercialization. In other words, the life sciences and solar energy fields are hindered by the absence of the right kind of human capital.

## Discussion

Many of the results concern difficulties in creating growth trajectories for emerging knowledge-intensive industries. In Finland, the knowledge creation processes are in good shape but the knowledge is poorly exploited. Start-ups get founded but high-growth entrepreneurship is very rare. According to this study, the most immediate causes are limited resources and poor international commercialization skills. These problems arise from the facts that there are no shared goals concerning the future of the industries. Academia, industry, and policy makers should together define clear targets for future developments and act accordingly. At the moment, lots of potential and effort is wasted because the actors in the innovation systems are not aligned to support each other. The Finnish economy has previously led by ICT, forestry, metal and machinery industries, and large enterprises. The growth has not been dependent on promoting the growth of SMEs which may have guided the policy makers away from developing institutional settings that support high-growth entrepreneurship.

Low amount of venture capital and remote location are known difficulties for Finnish firms. Different technological innovation systems however face their own special characteristics. We argue that in order to support the growth of emerging industries the policy makers have to increase communication with relevant actors, analyze the strengths and weaknesses in the TISs and react with technology-specific policy measures aiming to remove bottlenecks that prevent the industries from reaching their full potential. Our suggestions for relevant policy measures for the life sciences and solar energy industries include means and incentives for tighter local and global networking, influencing public opinion, eliminating prejudices, raising awareness, and designing needed regulation and demand-based innovation policies to boost domestic market creation.

Technological path-creation by policy makers has a risk of 'picking the wrong winners', i.e., investing in technologies that will not yield commercial or societal benefits. This is not a trivial concern and answering it demands strong forecasting skills. Methods of evaluating emerging technological systems need to be further developed. The functional evaluation model used in this study provides a useful way to divide complex systems into manageable components. However, the functions are not very explicitly defined. Many topics that arise from the data could not be exclusively associated with only one function. For example, the functions influence on the direction of search and legitimation have similarities and overlap with each other. Different functions are interdependent and may affect each other by causal relations and feedback loops. Bergek et al. [6] included a seventh function, *development of positive external economies*, in their original model to capture the interdependencies. We considered it significantly different from the other functions and decided to omit it from the paper and discuss the synergy effects (or their absence) with their appropriate functions. Further development of the theory should focus on designing clear indicators and assessment methods for the functions to enable comparability between different technological innovation systems.

Our data covers qualitative interviews from two emerging high-tech innovation systems. Although the results have been complemented with some quantitative data they should be considered exploratory and preliminary. The life sciences and solar energy fields share some common elements but they differ in their stages of development the life sciences field being much more evolved. While it is interesting to notice that these two fields face problems that are very much alike, more research on industries at different development stages could reveal information on which mechanisms play the most important role in which stages. Further research on other emerging fields would back or contradict our findings and determine their generalizability.

## Conclusions

Finland has been praised for its innovation policy, which has led to success especially in ICT, forestry, and machinery industries. The traditional industries are currently however losing ground and new sources of growth are needed. Innovation policies, technological development, and social practices tend to evolve to support certain industries and provide beneficial synergy benefits and economies of scale and scope. At the same time, they may create barriers for emerging technologies.

This study analyzes the life sciences industry and the solar energy (PV technology) industry in Finland to evaluate the Finnish innovation policy's capabilities to promote emerging industries. Using a functional analysis scheme of technological innovation systems, several shared bottlenecks are identified. Both of the industries do quite well in knowledge creation. Low level of domestic collaboration, remote location, poor public image, small firm size, unmet technology-specific policy needs, and lack of business know-how are mechanisms that prevent the industries from exploiting the created knowledge commercially by reducing available funding and making international commercialization difficult.

Many of the bottlenecks of the technological systems are technology-specific. Based on this, we argue that each industry and their needs should be evaluated individually. Accomplishing long-term competitiveness and continuous development of desirable technological systems is however not a matter of one-time political reform. Arrangements are needed where policy makers are informed of the latest developments and able to adjust their actions accordingly. Supporting the development of emerging industries requires dynamic capabilities from the policy makers. Communication and knowledge exchange between policy makers, firms (especially SMEs who are numerous) and academia needs to be improved in order to design sustainable innovation policy.



## References

1. Amir-Aslani A, Negassi S (2006) Is technology integration the solution to biotechnology's low research and development productivity? Technovation 26:573–582
2. Autio E (2009) The Finnish paradox: the curious absence of high-growth entrepreneurship in Finland. ETLA discussion papers No. 1197, The Research Institute of the Finnish Economy
3. Bell W (2009) Foundations of futures studies: human science for a new era. Transaction Publishers, Piscataway
4. Bergek A, Hekkert M, Jacobsson S (2008) Functions in innovation systems: a framework for analysing energy system dynamics and identifying goals for system-building activities by entrepreneurs and policymakers. In: Foxon TJ, Köhler J, Oughton C (eds) Innovation for a low carbon economy: economic, institutional and management approaches. Edward Elgar Publishing, Cheltenham, pp 79–111
5. Bergek A, Jacobsson S, Carlsson B, Lindmark S, Rickne A (2005) Analyzing the dynamics and functionality of sectoral innovation systems—a manual. In: DRUID Tenth Anniversary Summer Conference 2005: Dynamics of Industry and Innovation: Organizations, Networks and Systems, 2005
6. Bergek A, Jacobsson S, Carlsson B, Lindmark S, Rickne A (2008) Analyzing the functional dynamics of technological innovation systems: a scheme of analysis. Res Policy 37:407–429
7. Berger W (2001) Photovoltaics in Europe in the year 2020. VÖAW, Wien
8. Borrás S (2004) System of innovation theory and the European Union. Sci Public Policy 31:425–433
9. Carlsson B, Stankiewicz R (1991) On the nature, function and composition of technological systems. J Evol Econ 1:93–118
10. Carrera G, Mack A (2010) Sustainability assessment of energy technologies via social indicators: results of a survey among European energy experts. Energ Policy 38:1030–1039
11. Carroll GR (1997) Long-term evolutionary change in organizational populations: theory, models and empirical findings in industrial demography. Ind and Corp Change 6:119–143
12. Coenen L, Benneworth P, Truffer B (2012) Toward a spatial perspective on sustainability transitions. Res Policy 41:968–979
13. Cohen WM, Levinthal DA (1989) Innovation and learning: the two faces of R & D. Econ J 99:569–596
14. Cooke P (2001) Regional innovation systems, clusters, and the knowledge economy. Ind Corp Change 10:945–974
15. Dator J (1996) Foreword. In: Slaughter R (ed) The knowledge base of futures studies. DDM, Melbourne
16. EC (2006) Promoting innovation by tax incentives: a review of strategies and their importance to biotech growth. European Commission, Brussels
17. EC, SEC (2009) 1295 a technology roadmap for the communication on investing in the development of low carbon technologies. Commission of the European Communities, Brussels
18. EC (2011) Photovoltaics and nanotechnology: from innovation to industry. European Commission, Brussels

19. Edquist C (2005) Systems of innovation: perspectives and challenges. In: Fagerberg J, Mowery DC, Nelson RR (eds) The Oxford handbook of innovation. Oxford University Press, New York, pp 181–208
20. Edqvist C, Luukkonen T, Sotarauta M (2009) Broad-Based innovation policy. In: Veugelers R (ed) Evaluation of the Finnish national innovation system: policy report. Taloustieto Oy, Helsinki, pp 11–71
21. Espicom (2011) The Outlook for pharmaceuticals in northern Europe
22. Eurostat (2011). Energy statistics. http://epp.eurostat.ec.europa.eu/portal/page/portal/energy/. Accessed 20 Dec 2011
23. Faber A, Frenken K (2009) Models in evolutionary economics and environmental policy: towards an evolutionary environmental economics. Technol Forecast Soc Change 76:462–470
24. Farla J, Markard J, Raven R, Coenen L (2012) Sustainability transitions in the making: a closer look at actors, strategies and resources. Technol Forecast Soc Change 79:991–998
25. Geels FW (2005) The dynamics of transitions in socio-technical systems: a multi-level analysis of the transition pathway from horse-drawn carriages to automobiles (1860–1930). Technol Anal Strateg 17:445–476
26. Genomeweb (2011) Finland Invests $6.7M to Connect Biobanking, Bioinformatics, and Translational Research Resources. http://www.genomeweb.com/informatics/finland-invests-67m-connect-biobanking-bioinformatics-and-translational-research. Accessed 21 Sept 2012
27. Gertler MS, Vinodrai T (2009) Life sciences and regional innovation: one path or many? Eur Plan Stud 17:235–261
28. Grupp H, Linstone HA (1999) National technology foresight activities around the globe: resurrection and new paradigms. Technol Forecast Soc Change 60:85–94
29. Haapalahti, J (2010) Drafting the landscape of the diagnostics industry in Finland. http://www.tekes.fi/en/gateway/PTARGS_0_200_368_859_1841_43/http%3b/tekes-ali2%3b7087/publishedcontent/publish/en_content/campaigns/diagnostics/reports/seminar_materials/joukohaapalahti250510.pdf. Accessed 27 Jun 2013
30. Hekkert MP, Suurs RAA, Negro SO, Kuhlmann S, Smits REHM (2007) Functions of innovation systems: a new approach for analysing technological change. Technol Forecast Soc Change 74:413–432
31. Hermans R, Kulvik M, Tahvanainen, AJ (2005) ETLA 2004 survey on the Finnish biotechnology industry. ETLA Discussion Papers No. 978. The Research Institute of the Finnish Economy
32. Inayatullah S (2002) Reductionism or layered complexity? The futures of futures studies. Futures 34:295–302
33. Jacobsson S, Bergek A (2011) Innovation system analyses and sustainability transitions: contributions and suggestions for research. Environ Innov Soc Transit 1:41–57
34. Järger-Waldau A (2012) PV Status Report 2012. Publications Office of the European Union, Luxemburg
35. Kaitila V, Ylä-Anttila P (2012) Investoinnit Suomessa—Kehitys ja kansainvälinen vertailu. ETLA Discussion Papers No. 1267, The Research Institute of the Finnish Economy
36. Kohl J, Loikkanen T, Hernesniemi H, Simons M, Koljonen T, Nikulainen T, Valovirta V, Talja H, Similä L (2012) Näkymiä Suomen mahdollisuuksista uusiutuvaan energiaan liittyvässä globaalissa liiketoiminnassa. Edita Publishing Oy
37. Krugman P (1991) Geography and trade. Leuven University Press, Leuven
38. Lior N (2010) Energy resources and use: the present (2008) situation and possible sustainable paths to the future. Energy 35:2631–2638
39. Lü L (2009) The value of the use of biotechnology: public views in China and Europe. Public Underst Sci 18:481–492
40. Lundvall B-Å, Borrás S (1997) The globalising learning economy: implications for innovation policy. Commission of the European Union, Brussels
41. Lähteenmäki R (2002) Finnish biotechnology-built on solid foundations. Nat Biotechnol 20:437–440
42. Malerba F (2002) Sectoral systems of innovation and production. Res Policy 31:247–264
43. Markard J, Truffer B (2006) Innovation processes in large technical systems: market liberalization as a driver for radical change? Res Policy 35:609–625
44. Markard J, Truffer B (2008) Technological innovation systems and the multi-level perspective: towards an integrated framework. Res Policy 37:596–615
45. Maula M (2011) Pääomasijoitukset kasvuyrityksiin. In: Kasvuyrityskatsaus 2011. Unigrafia Oy, Helsinki, pp. 46–51
46. Meijer ISM, Hekkert MP, Koppenjan JFM (2007) The influence of perceived uncertainty on entrepreneurial action in emerging renewable energy technology; biomass gasification projects in the Netherlands. Energ Policy 35:5836–5854
47. Murray G (2011) A policy response to the 'Finnish Paradox'. In: Kasvuyrityskatsaus 2011. Unigrafia Oy, Helsinki, pp. 38–45
48. Nelson RR (1993) National innovation systems: a comparative analysis. Oxford University Press, Cary
49. OECD (2010) Measuring innovation: a new perspective. OECD Publishing, Paris
50. Pajarinen M, Rouvinen P, Ylä-Anttila P (2010) Missä arvo syntyy? Suomi globaalissa kilpailussa, Taloustieto Oy
51. Pharma Industry Finland (2012) Statistics and Reports. http://www.pif.fi/frontpage/satistics_and_reports/. Accessed 21 Sept 2012
52. Porter AL, Ashton WB, Clar G et al (2004) Technology futures analysis: toward integration of the field and new methods. Technol Forecast Soc Change 71:287–303
53. Pöyry Management Consulting Oy (2011) The Finnish Solar Cluster. http://www.tekes.fi/fi/gateway/PTARGS_0_201_403_994_2095_43/http%3B/tekes-ali1%3B7087/publishedcontent/publish/programmes/groove/documents/the_finnish_solar_cluster_2012.pdf. Accessed 10 Apr 2012
54. Raven RPJM, Geels FW (2010) Socio-cognitive evolution in niche development: comparative analysis of biogas development in Denmark and the Netherlands (1973–2004). Technovation 30:87–99
55. Rogers EM (1995) Diffusion of innovations. The Free Press, New York
56. Sabatier PA (1988) An advocacy coalition framework of policy change and the role of policy-oriented learning therein. Policy Sci 21:129–168
57. Schumpeter JA (1975) Capitalism, Socialism and Democracy. Harper & Row, New York
58. Seppänen E, Jauhiainen J (2011) Investointeja Suomeen -aivoriihi. Tiivistelmäraportti. http://www.tem.fi/files/31643/Investointeja_Suomeen_aivoriihi.pdf. Accessed 22 Dec 2011
59. Statistics Finland (2012) Research and Development. http://tilastokeskus.fi/til/tkke/index_en.html. Accessed 26 Mar 2013
60. Šúri M, Huld TA, Dunlop ED, Ossenbrink HA (2007) Potential of solar electricity generation in the European Union member states and candidate countries. Sol Energ 81:1295–1305
61. TEM (2010) Suomen kansallinen toimintasuunnitelma uusiutuvista lähteistä peräisin olevan energian edistämisestä direktiivin 2009/28/EY mukaisesti. http://www.tem.fi/files/27405/NREAP_300610_FINLAND.pdf. Accessed 10 Jan 2012
62. Thomson Reuters (2013), Thomson Reuters essential science indicators SM database
63. Truffer B, Coenen L (2012) Environmental innovation and sustainability transitions in regional studies. Reg Stud 46:1–21
64. van Alphen K (2011) Accelerating the development and deployment of carbon—an innovation system perspective. Utrecht University, Dissertation

65. Vanhaverbeke W (2006) The interorganizational context of open innovation. In: Chesbrough H, Vanhaverbeke W, West J (eds) Open innovation: researching a new paradigm. Oxford University Press, Oxford, pp 205–219
66. Villa A, Saukkonen P (2009) Bioteknologia 2020. Edita Publishing Oy
67. VM (2012) Valtiontalouden tarkistetut kehykset vuosille 2013–2016. http://www.vm.fi/vm/fi/04_julkaisut_ja_asiakirjat/03_muut_asiakirjat/20120404Valtio/2013-2016_kp.pdf. Accessed at 1 May 2012
68. Wehnert T, Araguás JPL, Bernardini O et al (2007) European energy futures 2030: technology and social visions from the European energy Delphi survey. Springer, Berlin
69. Weible C (2007) An advocacy coalition framework approach to stakeholder analysis: understanding the political context of California marine protected area policy. J Publ Adm Res Theor 17:95–117
70. Woolthuis RK, Lankhuizen M, Gilsing V (2005) A system failure framework for innovation policy design. Technovation 25:609–619