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Radar report

Indicators of energy innovation systems and their dynamics

A review of current practice and research in the field

2013

Mads Borup, Antje Klitkou, Maj Munch Andersen, Daniel S. Hain, Jesper Lindgaard Christensen and Klaus Rennings

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The report can be obtained from www.eis-all.dk or by contacting DTU Management Engineering, Technical University of Denmark, Building 424, DK-2800 Lyngby, Denmark, (+45) 45 25 48 00, www.man.dtu.dk.

Preface

This report on indicators of energy innovation system is produced in the context of the “EIS – Strategic research alliance for Energy Innovation Systems and their dynamics – Denmark in global competition” as collaboration between some of the researchers participating in the alliance. The activities in the EIS alliance are funded by the Danish Council for Strategic Research, the Programme Commission on Sustainable Energy and Environment, primarily, and by the involved research organisations.

The authors of the different Chapters are as follows: Chapter 1-3: Mads Borup (DTU) and Antje Klitkou (NIFU). Chapter 4A: Antje Klitkou, Chapter 4B: Klaus Rennings (ZEW) with contributions by Mads Borup, Chapter 4C: Maj Munch Andersen (DTU); Chapter 4D: Mads Borup; and Chapter 4E: Daniel S. Hain and Jesper Lindgaard Christensen (Aalborg University).

1. Introduction

The purpose of this ‘radar report’ is to give an overview of the state of the art concerning indicators of energy innovation systems and their dynamics. As part of this, it is the aim to discuss current challenges and efforts made by researchers and other professionals working in the field. Through this, the radar report shall contribute to the discussion of how the field might develop in the future; both for the sake of understanding the dynamics of energy innovation systems in general and, more specifically, for the sake of understanding the role energy innovation systems play for moving towards more climate-friendly and sustainable energy systems.

The analysis behind the radar report builds on a search and review of research literature, databases, statistics schemes, etc., on indicators of energy innovation systems as such and on relevant connected issues. In addition, it builds on assessment and insights from experienced researchers in the field. It is the intention with the report to communicate knowledge from researchers to other interested parties; not only to other researchers, but also to stakeholders more broadly, e.g. interest organisations, policy makers, statisticians, etc. However, a one-way communication picture is not entirely correct. Not only do researchers in many cases build on nationally or internationally recognized indicator schemes and databases established by governmental bodies, statistics agencies or international organizations like the OECD (Organisation of Economic Cooperation and Development) and the IEA (International Energy Agency). Researchers are also in a number of cases involved in establishment and development of official indicator schemes for example by acting as advisors or carrying out background studies. The interaction between research and practitioners is complex, and it makes little sense to address scientific research activities only, without taking into consideration the broader picture of indicator schemes. What we researchers most obviously can contribute with compared to other professional bodies in the field, is an explicit theoretical analysis perspective, in this case based on innovation system theory. Through this we can hopefully point out issues and raise questions that would otherwise not have been addressed.

1.1 Why indicators?

Knowledge about the characteristics and dynamics of innovation systems in the energy area is of central importance for understanding change processes in the energy sector and the opportunities for moving towards more climate-friendly and sustainable energy systems. The knowledge can for example provide insight in the relations between market-based and non-market-based activities in connection with efforts to establish new energy solutions. It can give insight in the patterns of learning and competence development. And it enables us to better understand the connections between on the one hand socio-technical changes in the energy systems and in the practices of production and consumption of energy, and on the other hand commercial and industrial developments including creation of new businesses and jobs.

Different dimensions of human activities and conditions have long been subjected to measurement. Measurements, for example, can allow comparisons over time and between populations. Compiling measurements can be a useful means in taking stock and in determining the extent of change that may be due to different given factors. In terms of innovation, cross-country comparisons can be used to posit an empirical relation between e.g. knowledge accumulation and growth of output or productivity. Juxtaposition of measurement results for different indicators can lead to new insight and understanding.

Hence, establishment of sets of indicators covering a number of different indicators, instead of just one, can be fruitful.

Use of measurements can be done at different levels, for example, at the level of an individual organisation or firm, or at societal levels of sectoral, national or international strategic planning and policy development. When we here talk about indicators of energy innovation systems it is done in a society perspective primarily. The target groups for the radar report are analysts, researchers, planners, policy developers and strategic decision makers dealing with issues of energy change and energy innovation on societal or sector level, or on the level of an energy technology area as such. But many of the indicators may also be useful for others as well. The indicators mentioned in the report contribute to a general picture and overview of energy innovation systems and their dynamics rather than giving insight in the details of energy innovation. Apart from use in the further research and conceptual-methodological development in studies of energy innovation systems and their dynamics, it is an aim of our analyses to contribute input to the development of new indicator standards, national energy technology scoreboards or similar in the field.

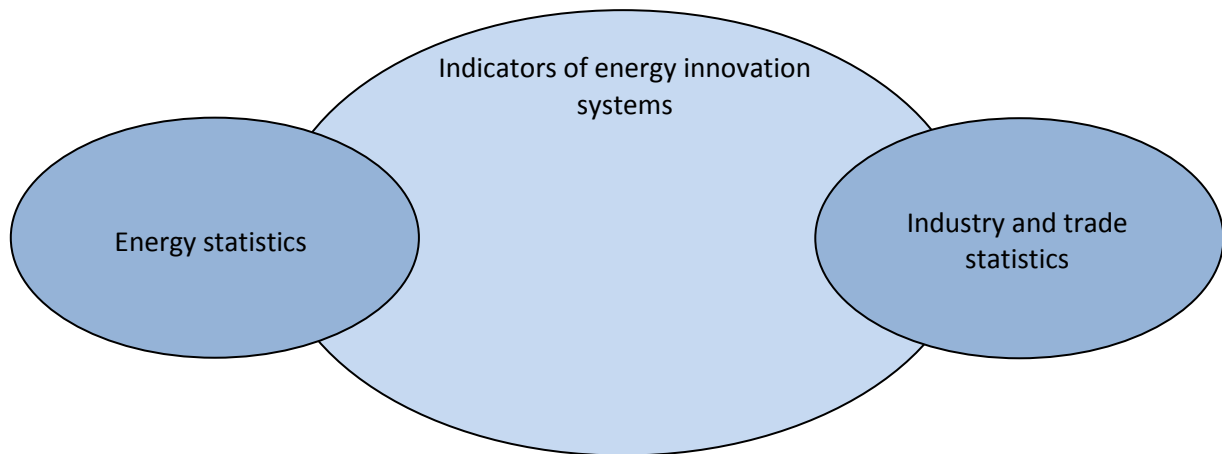
There are some initial caveats of measuring which should be noted. A general one is that sometimes the zeal to measure can obscure or blind one to the purpose of the exercise in the first place. Both individuals, organisations, and communities can be trapped in this. A second caveat is that some activities and conditions lend themselves better to measurement than others (Verbeek et al., 2002). Even seemingly straightforward measures, such as measurement of energy consumption, can pose difficulties. The measurement of energy technology development and innovation is a far more challenging area that poses a set of general challenges both in terms of defining, collecting and interpreting data.

Attention is given to data sources that are as 'official as possible', preferably part of general statistics offered by recognized national or international institutions, up-dated annually over a longer time period, etc. This is however to some extent a utopian ideal picture. Many official statistics do not offer sufficient insight in energy innovation and are too general. Moreover, it is not always that the general, international databases have the best and most complete data. Therefore, a number of indicators are addressed even though they are not officially established and not up-dated on a regular basis.

1.2 Between energy statistics and industry statistics

In the pursuit of useful indicators of energy innovation systems, two existing fields of statistics constitute main pillars of references where insight can be drawn from: 1) Energy statistics; and 2) Industry and trade statistics. Energy statistics is well-established in many countries. It monitors the energy systems and their development over the years. Apart from general figures on energy consumption and energy production, the national energy statistics in many countries also include data on energy sources, climate emissions, and energy production by different energy technologies – renewables as well as others. On international level, the national statistics are gathered by a.o. Eurostat and the International Energy Agency. Well-established R&D statistics are available in many countries and data on public R&D budgets within different areas of energy technology in a number of countries is collected by IEA.

Figure 1: Energy statistics and industry & trade statistics as important sources and reference points for sets of energy innovation system indicators.



Through the industry and trade statistics, a.o.t. the domestic and international trade of products and the classification of firms in different industrial categories can be measured. However, what limits the use of the trade and industry statistics for our purpose is that they only to a limited extent cover energy technology products as individual product categories. For example, many renewable energy technologies do not have their own product categories in these statistics. Moreover, the industrial classification categories are only to a limited degree defined in ways that are suitable for monitoring energy innovation. Similar limitations exist in connection with the industrial innovation statistics that have been established in the latest decades, see below.

1.3 Structure of report

The structure of the report is as follows: Chapter 2 introduces the innovation system perspective and describes a number of indicator frameworks that have been suggested in connection with innovation systems, both in general and concerning energy innovation systems specifically.

Chapter 3 shows examples of measurements of individual indicators. This is done in order to be a bit more concrete about what is actually available today and where the limitations are. The selection of examples is partial and in no way complete. For simplicity reasons the chapter is organised in three sub-chapters on 1) Output indicators – measuring the current performance of energy innovation systems, 2) Input indicators and actor landscape; and 3) Throughput indicators. The examples are given very briefly. Often, the examples are about Denmark or other Nordic countries, reflecting that some of the authors have been involved in research projects about these countries.

Chapter 2 and 3 together make up background for Chapter 4. Chapter 4 addresses five major challenges facing indicator work on energy innovation systems at present. In five thematic sub-chapters, the following challenges are discussed: a) The challenge of classifications of technologies and products; b) The challenge of energy efficiency innovations; c) The challenge of greening of markets and supply chains; d) The challenge of measuring the innovative interaction patterns; and e) The challenge of investments and investors. Finally, in Chapter 5, a number of cross-going conclusions are made.

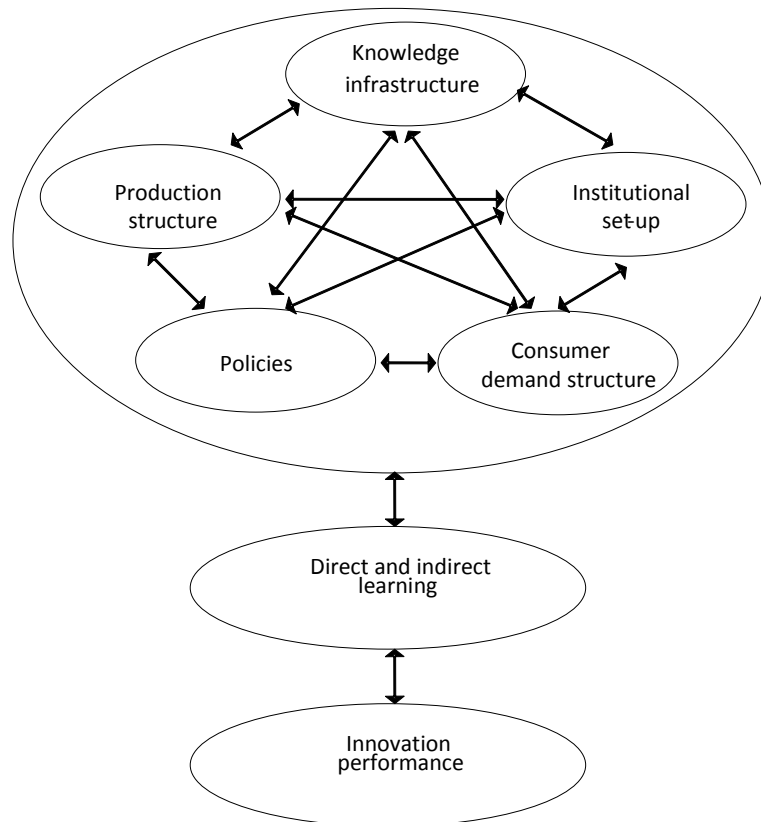
The technological focus is on low-carbon technologies for sustainable energy systems, primarily renewable energy technologies like wind energy, bioenergy and solar energy, or energy efficiency technology. In some cases also other technologies are covered, e.g. conversion technologies like fuel cells.

2. Innovation systems and the sustainability challenge

Analyses of innovation systems have over the last 20 years documented that patterns and conditions of innovation are not identical across the world. They vary from country to country as well as between sectors and technology areas (Edquist, 1997; Edquist and Hommen, 2008; Hekkert et al., 2007; Lundvall, 1992; Malerba, 2002; Nelson, 1993, Borup et al. 2008).

Differences between the innovative performances of innovation systems can be ascribed to differences in the specific constitution of the learning and knowledge production, in the industry and market structures, and in the policies and institutional set-up. This is illustrated in the figure below. The capability of change and innovation can usually not be explained by one factor alone, e.g. by science and research alone, by market forces alone or by policies alone. On the contrary, the system character of innovation systems refers to the fact that development and innovation appear in complex interplay between numerous actors, e.g. companies, their customers and sub-suppliers, research and educational institutions, authorities, interest organisations, etc. and through a multitude of activities and interaction processes.

Figure 2: Innovation systems and their innovation performance.



Source: Gregersen and Johnson (1997)

The complexity makes it a big challenge to establish a useful set of indicators for energy innovation systems as well as for innovation systems in general. It points to that the quality of an innovation system cannot be measured by one, single measuring dimension only. It seems obvious that a combination of indicators must be employed.

In addition to the actors and institutions involved, central constituents of innovation systems are the networks, the infrastructures established, e.g. communication and knowledge systems, energy and transportation systems, the market structures and standard and certification systems. In its' most general sense, an innovation system can be defined as "the elements and relationships, which interact in the production, diffusion and use of new and economically useful knowledge" (Lundvall, 1992, p. 12). Knowledge is hence central, but not in a narrow, scientific sense only. By employing the term learning, innovation system analyses ensure a broad inclusion of knowledge and competence build-up, ranging from market-based learning, learning-by-using and learning-by-doing over entrepreneurial experimentation and industrial product development, to formalised knowledge production, research and educations at universities. This makes it a further challenge to establish indicator sets.

2.1 Innovation system indicators

Many innovation studies include quantitative indicators as part of their methodology. The literature study behind this report shows, however, that the number of studies that address the possibility of establishing a comprehensive set of indicators to evaluate the performance and dynamics of innovation systems is relatively small. Moreover, there does not currently exist a complete innovation system indicator scheme that there is full international consensus about. Neither concerning innovation systems in general, nor concerning energy innovation systems specifically. However, a number of suggestions and attempts have been made with contributions from policy institutions, statistics agencies and researchers. Three overall main perspectives can be identified in these:

1. Research focused perspective
2. Firm focused perspective
3. Change focused perspective

Table 1 shows the main perspectives, their general characteristics and some of the approaches that are used in connection with them. For a general overview and introduction see for example Speirs (et al. 2008) and Deliwe (1999).

The research focused perspective can be said to describe the early years of innovation system indicators and the historical context in which innovation system research developed in the beginning of the 1990s (Lundvall 2007). While science policy and technology policy were relatively well-established fields, innovation policy was still young and under development. The OECD's 'Frascati Manual' on measuring of R&D was a central point of reference at that time. It focused on basic research, applied research, knowledge-based experimental developments and connections to main fields of technological science (OECD 1963, 1981, 1994a, Godin 2008). With emphasis on input indicators like R&D expenditures, R&D personnel and science and engineering education, the Frascati Manual resembles the linear understanding of innovation where science and technology push is seen as the central driving force of innovation and economic development. Though described as an input-output approach, the input indicators were the most

formalized in the manual, while output indicators, e.g., patents, licensing, and technological balance of payment, were merely suggestions that were not generally acknowledged.

Table 1: Main perspectives of indicator schemes for innovation systems.

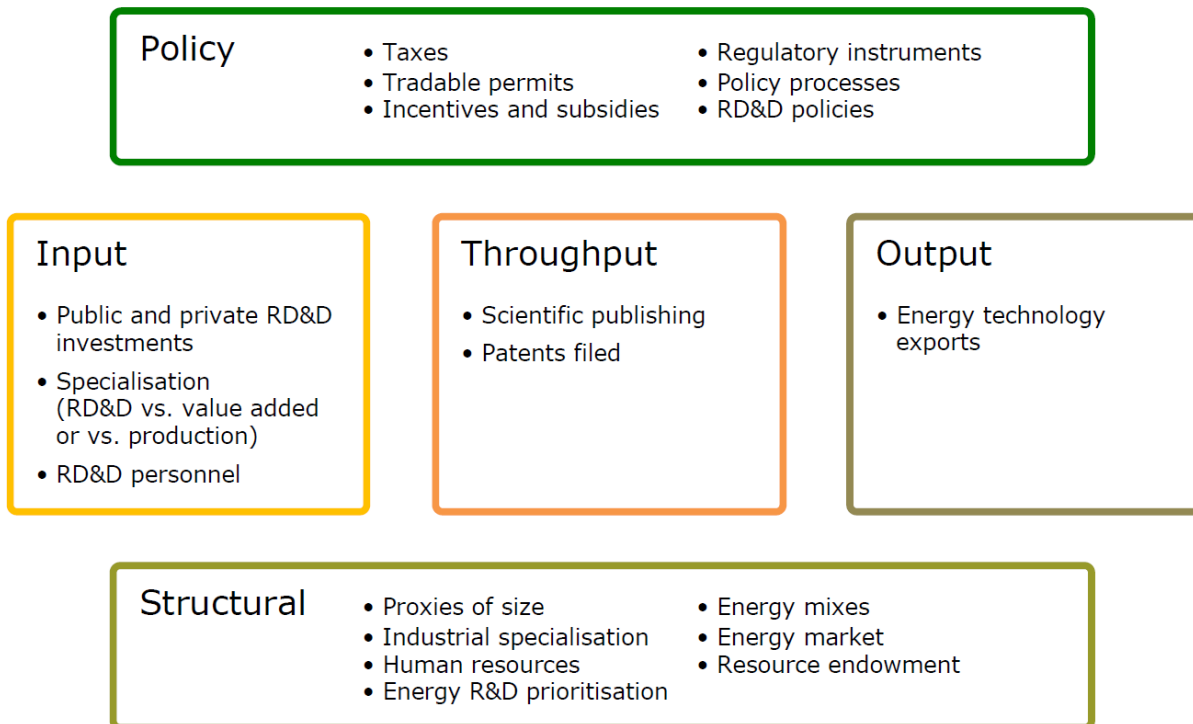
Perspective	Characteristics
1. Research focused Input-output approach	Science push/technology push understanding: Research is the driving force of innovation
2. Firm focused Firm innovations Firm cooperation, information sources Framework conditions – general national innovation systems	Individual firms’ innovations; eventually their context and their interaction, e.g. with universities and other R&D partners. Economic.
3. Change focused Functions of innovation systems Actors and interaction approach Sustainable innovation and greening of economy	Innovation as an issue of change on sector level or societal level; establishment of new technologies

The linear model is interesting for historical reasons primarily. It has been rejected by several branches of socio-economic studies of science, technology and innovation, including innovation system studies. Firstly, this model does not recognize that other factors than R&D can be driving factors for innovation, e.g. industrial competences, market demands, policies, articulations of needs in industrial supply-chain networks, user groups, interest organisations, etc. The model does not acknowledge that innovation can occur at actors that do not engage in formalised R&D activities. Secondly, it underestimates the complexity of innovation processes and the role of interaction and feedback in the processes (see e.g. Jensen et al. 2007).

For similar reasons, the input-output model in a narrow, R&D focused sense is rejected by many. Also this model does not recognize the complexity of innovation processes and the many interactive elements of innovation. It assumes that there is a clearly significant relation between input and output and hence the role of the input is over-estimated in favour of the role of the existing industry and market structures of which innovation often to some degree grows out from and is shaped by: “Innovation systems have an organic life of their own, influenced but not determined by inputs” (Deliwe 1999).

Addition of ‘throughput’ indicators, that is, measures that attempt to capture intermediate products of innovation processes has been suggested, also already before research on innovation systems and their dynamics was well-established and well-developed (Grupp and Schwitalla, 1989). In the decades since, innovation system research has improved the understanding of not least the industrial and market dynamics considerably. In the energy area, Klitkou et al. (2010) recently suggested an indicator set building on an expanded input-output model, see Figure 3. Scientific publishing and patents filed are suggested as throughput indicators and energy technology exports as output indicator. In addition national structural indicators, e.g., energy mixes, energy markets and general industrial specialisation and policy indicators (market-oriented as well as others) are suggested.

Figure 3: Indicator set suggested in the report Nordic Energy Technology Scoreboard (Klitkou et al. 2010).



The firm focused perspective

From the 1981 edition of the OECD's Frascati Manual, innovation was mentioned, not as included in R&D, but as a related matter. Up through the 1980s, more and more attention was directed to innovation and its' role for countries' competitiveness and economy. Under the OECD auspices, this in 1992 led to establishment of a new manual, the 'Oslo Manual', with guidelines for collecting and interpreting technological innovation data (OECD 1992). The Oslo Manual became a new reference for development of innovation statistics. It has amongst other things guided the European Community Innovation Survey scheme (CIS), that apart from in most European countries is used (with modifications) in e.g. China, Japan, Korea, Russia and South Africa (López-Bassols 2011, Smith 2005). The later editions of the Oslo Manual are joint efforts by OECD and the European Commission / Eurostat (OECD and EC 1997, 2005).

Though there was collaboration between innovation system researchers and OECD on integrating the innovation system perspective (Godin 2007), the Oslo Manual and CIS scheme are strictly speaking not innovation system indicator frameworks, but frameworks that address innovation at the level of firms:

"The Manual is concerned with the collection of innovation data at the level of the firm. It does not cover industry- or economy-wide changes such as the emergence of a new market, the development of a new source of raw materials or semi-manufactured goods, or the reorganisation of an industry." (OECD and EC 2005, p. 16.)

The framework in its latest version covers four types of innovations at firm level: product innovations, process innovations, organisational innovation, and marketing innovations. Diffusion of innovations is covered primarily as "new to the firm" (OECD and EC 2005, p. 11-20). The manual provides conceptual background and guidance, but not a template or list of specific indicators. In practice, it has led to a CIS indicator scheme that focuses on the number of innovation active firms, i.e. firms that introduce

innovations of the four different types to markets or internally in the firm (or firms that have tried to do it). In addition to a row of background indicators for the firms, e.g. industry sector, turnover, number of employees, main geographical market, engagement in R&D activities and public funding, a row of innovation indicators for the firms are addressed, see Table 2 (Eurostat CIS 2010, EC reg. 995/2012 and 1450/2004). Not all countries employ all indicators.

Table 2: CIS innovation indicators (left). The right column shows the sub-categories used within the two indicators 1) innovation cooperation and 2) sources of information (optional) (EC Reg. 995/2012 and Eurostat CIS 2010).

Innovation indicators	Types of innovation cooperation partners / information sources
No. of innovation active enterprises	Other enterprises within own enterprise group
No. of innovating enterprises that introduced new products (new to market/new to enterprise)	Suppliers of equipment, materials, components and software
Turnover from innovation , related to new products (new to market/new to the firm only)	Clients and customers
No. of innovation active entrpr. involved in innovation cooperation	Competitors and other enterprises in same sector
Innovation expenditure	Consultants, commercial labs, private R&D institutes
No. of entrpr. facing innovation hampering factors	Universities and other higher education institutions
No. of innovation active entrpr. with own innovation / co-innovation with others	Government and public research institutes
No. of innovation active entrpr. that indicated important sources of information for innovation (optional)	<u>Cooperation only</u> : Partner country: national, European, USA and rest of the world
No. of innovation active entrpr. important objectives of innovation (optional)	<u>Info. sources only</u> : a) conferences, trade fairs, exhibitions; b) scientific journals, trade/technical publications; c) Professional and industry associations

As the table show, the OECD/CIS framework in its recent versions contains elements of interaction seen from the firms' perspective. The cooperation indicator is mandatory, while the indicator on information sources is optional. The indicators are not fully harmonized and can vary between the individual surveys. For analysing information linkages the Oslo Manual moreover proposes the following types of linkages: 1) open information sources which do not require the purchase of IPR, such as R&D journals, standards, professional conferences, public regulations etc.; (2) acquisition of knowledge and technology either embodied in capital goods (machinery, equipment or software) or acquisition of external knowledge (e.g. licenses, designs, trademarks, etc.); or services provided by commercial or public sources including engineering services, designing and testing.

The firm focused perspective – with general framework conditions

Building on indicators from the Community Innovation Survey combined with indicators from e.g. European/OECD science & technology statistics and the general statistics on economy, trade and industry, a number of innovation scoreboards have been produced, e.g. European Innovation Scoreboard / Innovation Union Scoreboard (most recent: 2011 (EC 2012)). The scoreboards sum up the results on European and national levels. OECD produces the Science, Technology and Industry Scoreboard. In this, there is still considerable emphasis on science and formalised knowledge production, but in the recent versions, the

industrial dimension is developed. It now includes an element of collaboration in business value chains (OECD 2011a).

In addition to indicators on firm level, a number of studies of national innovation systems suggest inclusion of macro scale indicators of general framework conditions and of main structures in industry and knowledge production. For example Bitard et al. (2008), in a comparison of ten countries' innovation systems, employ the indicators shown in Table 3.

Table 3: Comparison of ten 'small country' national innovation systems. Indicators used as statistical basis (Bitard et al. 2008).

National characteristics:	Size and population GDP and other human development indicators Literacy and educational levels
Economic structure and performance:	Sectoral composition of industrial production (total output, value-added, employment and exports in high, med.-high, med.-low, and low-tech industries) Labour productivity Growth Openness of economy and globalization (import, exports, inwards/ outwards foreign investments, cross-border ownership of patents)
Science and technology profiles:	Science profiles (publications in main areas) Technology profiles (patenting in main areas)
Innovation:	CIS data (product and process innovation, in SME or large enterprises, and in macro-sectors (manufacturing, KIBS, trade, finance) etc.)

Another model that includes framework conditions and structural factors as product-market conditions, factor-market conditions, education and training system, communication infrastructures, macroeconomic regulatory context and supporting institutions has been suggested (OECD 1999 p. 23). To our knowledge, this model has not been directly translated to a set of quantitative indicators. In their continued work with the innovation system perspective, OECD later suggested the indicators in Table 4. There is considerable emphasis on science, research and science-industry linkages. The authors point to that the coverage of aspects of demand, infrastructure and framework conditions is not complete and could be improved considerably. They call it "very partial!" as it is in the version they present (OECD 2005, p. 84).

The change focused perspective

While the firm focused indicator frameworks presented above are primarily concerned with economic development and connected aspects as industrial competitiveness and job creation, another group of studies are explicitly focused on addressing innovation as a matter of change on sector or society level. A number of these studies deal with the energy area and the climate and sustainability challenges it is facing. The change focused studies show that usually a broader set of actors, and not only firms, are important when innovations of societal significance are created. A broader set of activities than individual firms' innovation activities and interplay on a more aggregated level are important to consider. This calls for other types of indicators of the innovation systems.

Table 4: Short list of indicators used for assessing STI performance of national innovation systems (OECD 2005).

Innovation in the company system:	Innovation expenditures Patents SMEs' share of national R&D performance Employment - in medium and high tech manufacturing Employment - in high tech services Stock of inward foreign investments Business expenditure on R&D Governmental funding of business R&D
Knowledge generation through education and research system:	New science-&engineering graduates PhDs Publications Basic research (percentage of GDP) Share of government budget allocated to research
Industry-science linkages:	Business-financed R&D performed in higher education Business-financed R&D performed by government Share of innovative firms co-operating with other firms, universities or public research institutes
Absorption capacity (aspects of demand, infrastructure and framework conditions):	Population with tertiary education Participation in life-long learning Investments in knowledge (percentage of GDP) Seed and start-up venture capital
Overall performance:	Share of innovative firms (in manufacturing and in services) Labour productivity Growth of value added in high and medium tech (compared to growth of GDP) Growth of employment in high and medium tech (compared to growth in total employment)

Many of the studies at the same time point to that indicators on general sector level are not sufficient to give insight in the change processes. Data about the sector level will often primarily illuminate the current paradigm and normal way of doing things in the sector, including current core technologies, system organisation and infrastructure of the sector. It will not to a sufficient degree give insight in innovation activities that contribute to changing the sector. In addition to general sector data, indicators about alternative technologies, niche developments, and efforts for transforming these into more widespread mainstream solutions are needed. In line with this, technology-specific innovation system approaches have appeared, including suggestions of indicators that illuminate the dynamics and processes of new technologies becoming more well-established parts of the sector.

Concerning the energy area, a number of special characteristics and conditions have been pointed out as important when considering innovation and change (see e.g. Grupp 2004). Firstly, the sector to a considerable degree has system and infrastructure character. Innovations and technologies in the sector are often not stand-alone units. They are connected to and dependent on other, complementary elements and technologies in the energy systems. A prerequisite for change in one place is often complementary and coordinated changes in other parts of the systems. Measures of interaction and cooperation in systemic perspective are therefore important. The systems and infrastructures are today in many countries build-up

around fossil fuel technologies (gas, oil and coal). This is the case both concerning heating, electricity, and transport. The entry barriers, entry costs, uncertainties and risks for renewables and other low-carbon technologies to become a part of the systems are often higher than for innovations that fit into the fossil fuel systems. Hence, there is a certain degree of lock-in ('carbon lock-in'). Indicator schemes for energy innovation systems should be able to take this into consideration, for example as Grupp (ibid.) suggests: include e.g. R&D budget for fossil fuels as indicator of carbon-lock in.

A connected aspect of innovation in the energy area is that changes normally take a long time. Development and integration of new energy technologies typically take decades rather than just a few years. Monitoring of the development in the innovation output in sense of resulting changes so far on niche and sector level for the individual areas of low-carbon technologies is here important. It is central for measuring of not only the state of affairs, but also of how much learning and competence build-up about application and system integration of the technologies there have appeared.

Finally, an important feature of the energy area as innovation area is the public or semi-public character it has in many countries. Energy systems are often subjects of policies by national governments and public authorities on different levels. The area is typically publicly regulated. Moreover, energy systems in many countries are partly (or fully) publicly owned. Innovation in the energy area is hence also a matter of innovativeness in public policy and regulation and of public procurement that supports further development of low-carbon energy innovations. Such aspects should also be measured.

Gallagher et al. (2012) take up this challenge on an overall level and use financial investment in a broad sense as indicator of energy technology innovation system activity. Four types of investments are considered: 1) Public research, development and demonstration; 2) Private research, development and demonstration; 3) Market formation investments (including private and public niche market investments, public market support and public procurement); and 4) Diffusion investments comprising investments into energy supply and energy end-use components of energy systems. An assessment on global level is made distinguishing between six broad energy technology categories: 1) End use and efficiency; 2) Fossil-fuel supply; 3) Nuclear; 4) Renewables; 5) Electricity (generation, transport and distribution); and 6) Other/un-specified.

Carlson et al. (2002) suggested a set of innovation system indicators with focus on knowledge and emerging technological systems, see Table 5. The framework on some points resembles the linear model, however interaction aspects are addressed, e.g., in the sense of partners and distribution licenses, regulatory acceptance, and technological diversity. The latter indicator covers the competition and synergies between different technologies.

Table 5: Performance indicators (Carlsson et al. 2002, pp. 241-243). Identification of the actors is an initial step before use of the performance indicators.

Generation of knowledge	Diffusion of knowledge	Use of knowledge
Number of patents	Stage of development (maturity)	Employment
Number of engineers or scientists	Regulatory acceptance	Turnover
Mobility of professionals	Number of partners/number of	Growth
Technological diversity	distribution licenses	Financial assets

This indicator framework also addresses the influence of the maturity. The dynamics of innovation systems differ between mature areas where industrial networks and market applications are well developed, and immature areas where the networks are scattered and market application has not, or only to a small extent, been reached (ibid; see also Foxon et al. 2005; Jacobsson and Bergek 2004). In mature areas,

industrial companies, consumers, markets and industrial interest organisations are usually central, and the number of actors is high. In immature areas, other types of actors, e.g., policy makers, public agencies, research communities, environmental interest organisations or public movements can often be more central and the number of actors will typically be smaller.

Table 6: Functions of innovation systems for establishing new technologies for sustainability (Hekkert et al. 2007, Bergek et al. 2008) and examples of indicators (our amendment based on the sources). The third column shows an alternative set of indicators suggested from an event analysis methodology used on renewable energy technologies (Hekkert & Negro 2009).

Functions:	Examples of indicators	Event categories (pos/neg)
Entrepreneurial activities	<ul style="list-style-type: none"> - Experimental projects - New product introductions - New businesses 	<ul style="list-style-type: none"> - Projects (started / stopped) - Contractors provide turn-key technology - Lack of contractors
Knowledge development (learning)	<ul style="list-style-type: none"> - Scientific publications - Technology application (learning-by-using) - Learning curves (cost development) - R&D projects - Patents 	<ul style="list-style-type: none"> - Desktop-, assessment-, feasibility studies - Reports - R&D projects - Patents
Knowledge exchange in networks	<ul style="list-style-type: none"> - Collaboration patterns - Demonstration projects - Knowledge and experience networks - Conferences and debate meetings - Interest organisations (industrial, environmental etc.) 	<ul style="list-style-type: none"> - Conferences - Workshops - Platforms
Guidance of the search	<ul style="list-style-type: none"> - Policy action plans - Shared strategies and roadmaps - Debate activities 	<ul style="list-style-type: none"> - Expectations on renewable energies (pos/neg) - Regulation by government on renewable energies (pos/neg)
Market formation	<ul style="list-style-type: none"> - Market application, market shares - Public market support - Niche markets - Standards and certifications - Trade and exports - Environmental impacts 	<ul style="list-style-type: none"> - Feed-in rates, environmental standards, green labels - Lack of feed-in rates, of env. standards, of green labels
Mobilization of resources	<ul style="list-style-type: none"> - R&D funding - Investments - Personnel - R&D / employment in general 	<ul style="list-style-type: none"> - Subsidies - Investments
Legitimacy / Advocacy coalition¹	<ul style="list-style-type: none"> - Public opinions on energy technologies and systems - Regulatory acceptance and integration 	<ul style="list-style-type: none"> - Lobby by agents to improve technical, institutional, financial conditions for particular technology - Expressed lack of lobby agents - Lobby for other technology that competes with particular technology - Resistance to change by neighbours (NIMBY attitude)

¹ Hekkert & Negro (2009) address 'Advocacy coalition' instead of 'Legitimacy'.

The differences between mature and immature areas are a challenge for establishment of a set of indicators of energy innovation systems, not only in the sense of measuring whether it is mature or not, but also in the sense of being able to detect dynamics and characteristics in both kinds of areas. Change from an immature to a mature situation is, moreover, a complex and usually long-lasting process. This is a further measuring challenge.

The difference between mature and immature areas is addressed in a number of analyses of technology-specific innovation systems. In connection to the maturity discussion, it is identified that in order for new technologies to move towards a more well-established and mature situation, a number of activities, or 'functions' in the innovation system are typically important (Hekkert et al. 2007; Jacobsson & Bergek 2004). The functions are activities considered on a relatively general level. They overlap and should not be understood as mechanical building blocks. Table 6 shows the functions together with suggestion of indicators that are relevant in connection to the individual functions. The column to the right shows indicators that have been suggested using an event analysis methodology where events, positive and negative to a specific energy technology, are counted.

Change-focused perspective - actors and interaction approach

Inspired by the technology-specific and the general (national) innovation system approaches, Borup et al. (2008) suggest a set of indicators with seven main categories of actors in energy innovation systems and an attention to interaction patterns, see Table 7. The concept of need integration is used for addressing connections between demand-pull and technology-push aspects.

Table 7: Actor categories and indicators in Borup et al. 2008.

Actors	Learning interaction	International significance
1. Energy companies (energy suppliers, energy grid operators, etc.)	Cooperation in R&D projects	Scientific knowledge
2. Business companies – technology supply industry	Learning by using / application based learning	(papers/citations) Patents
3. Universities and other research org.	Need integration through regulation	Governmental R&D
4. Public authorities	Need integration through broad discussion	Market (domestic application)
5. Industry associations, labour unions and other professional org.		Industry (share of world market)
6. NGOs (environmental, consumer organizations, citizens groups)		
7. Finance and investment institutions		

In parallel to this framework, surveys on innovation activities and interaction patterns in the energy innovation system in Denmark are developed with additional sub-categories of business actors (e.g. technology suppliers, component/material sub-suppliers, service suppliers, consultancy companies and providers of technological test & certifications.) and measuring of a row of activities by different actors, interaction between them, and driving forces of market developments and innovation (Tanner et al. 2009, Borup et al. forthcoming). Between six and fourteen low-carbon technologies are covered, including energy efficiency technology.

Change-focused perspective - sustainable innovation and greening of economy

An increasing number of studies about development of indicator systems for sustainable innovation and greening of the economy have appeared in recent years (e.g. Horbach 2005, Kemp & Pearson 2007, OECD 2011b, Eco-innovation observatory 2012). These studies stem from the acknowledgement that existing indicator schemes do not cover sustainable innovation well. The studies often point out that other and additional indicators are needed for indicator schemes for sustainable innovation than has traditionally been used for innovation, e.g. in the sense of indicators that can monitor resulting effects of innovation also with respect to environmental impacts. Usually those indicator schemes include measures of the environmental impacts either in absolute terms or in relative sense, e.g. as resource and energy efficiency or resource and energy productivity.

Horbach suggests an indicator system for sustainable innovation building on a broad comprehension of the innovation system including three overall levels: 1) Determinants of sustainable innovation, 2) Description of the innovation; and 3) Ecological, economic and social impacts, see Table 8 (Horbach 2005 p. 4-17).

Table 8: Levels of analysis of an indicator system for sustainable innovation (Horbach 2005).

Level of analysis:	Examples:
Determinants of sustainable innovation	Market demand, “fitting” time window, environmental policy measures, path dependencies
Description of the innovation	Product and process innovations, organisational and institutional changes, end-of-pipe versus integrated environmental innovations
Ecological, economic and social impacts	Emission reductions, income distribution, employment effects

Building on review of a row of innovation system approaches, Speirs et al. (2008) propose a set of eco-innovation indicators within five overall categories: 1) The Firm, 2) The Conditions; 3) The Linkages, 4) Radical/incremental innovation; 5) Overall performance. The indicators within each of the overall categories are shown in Table 9.

Table 9: List of proposed eco-innovation indicators (Speirs et al. 2008). Data sources are known for most of the 24 indicators at least in some countries. Two of the indicators require new data collection (no. 3 and 9) and four requires changes in CIS data or reanalysis of them (no. 4, 13, 17 and 24).

Category	Indicator
The Firm	<ol style="list-style-type: none"> 1. R&D expenditures for environmental protection in industry 2. % of firms with EMAS or ISO140001 3. % of firms with environmental mission statements and/or officers 4. Managers opinion of eco-innovation
The Conditions	<ol style="list-style-type: none"> 5. 'Green Tax' as a percentage of government budget 6. Government expenditures on environmental R&D as: 1) % of total R&D expenditure, 2) % of GDP 7. Uptake of environmental subsidies for eco-innovative activity 8. Financial support for eco-innovation from public programmes 9. Demand for eco-innovative products 10. Environmental expenditure in college/university research 11. Number of environmental graduates, Mscs or PhDs 12. Waste management costs (landfill tariff etc.) 13. Executive opinion on environmental regulation (Stringency and transparency) 14. Attitudes towards eco-innovation
The Linkages	<ol style="list-style-type: none"> 15. Frequency of eco-innovation workshops/conferences and number of people attending 16. Value of "green funds" made available by financial institutions for innovating companies 17. Managers perceptions of overall quality of environmental research in scientific institutions
Radical/incremental innovation	<ol style="list-style-type: none"> 18. Ratio of eco-start-ups to incumbents in the market 19. Frequency of new entrants to the market 20. Diversification activities of incumbents, investments in smaller operations outside core business 21. Seed and start-up venture capital for eco-innovative firms (investments per 1000 GDP)
Overall performance	<ol style="list-style-type: none"> 22. Eco-patents in triadic patent families per million population 23. Material productivity of eco innovative firms (TMR per capita or GDP) 24. Share of eco-innovative firms as a percentage of all firms (may need to divide into manufacturing and services)

Building on, amongst other things, some of the above mentioned research projects, a European eco-innovation indicator scheme have now been institutionalized in the European Eco-innovation Scoreboard (Eco-innovation observatory 2012). The overall structure of the Eco-innovation Scoreboard is showed on Table 10. The 16 indicators that are used for measuring the performance profile are listed below.

Table 10A and 10B: Indicators in the European Eco-innovation Scoreboard. A: Overall structure; B: Specific indicators (Eco-innovation observatory 2012).

	Structural profile	Performance profile	
	<i>General determinants</i>	<i>Eco-innovation inputs and activities</i>	<i>Eco-innovation outputs and outcomes</i>
Environment	<i>Environmental trends</i> (material consumption, energy consumption, GHG emissions, etc.)		<i>Environmental outcomes</i> (material productivity, energy intensity, GHG emissions intensity, etc.)
Socio-economy	<i>Socio-economic trends</i> (industrial profile, infrastructure, political framework, social context)	<i>Inputs</i> (funding of eco-innovation, etc.) <i>Activities</i> (eco-innovating companies, etc.)	<i>Socio-economic outputs</i> (patents, etc.) <i>Socio-economic outcomes</i> (employment, exports, etc.)

Category	Indicator
Eco-innovation inputs	1.1 Governments environmental and energy R&D appropriations and outlays (% of GDP) 1.2 Total R&D personnel and researchers (% of total employment) 1.3 Total value of green early stage investments
Eco-innovation activities	2.1 Firms having implemented innovation activities aiming at a reduction of material input per unit output (% of total firms) 2.2 Firms having implemented innovation activities aiming at a reduction of energy input per unit of output (% of total firms) 2.3 ISO 14001 registered organisations (per min population)
Eco-innovation outputs	3.1 Eco-innovation related patents (per min population) 3.2 Eco-innovation related academic publications (per min population) 3.3 Eco-innovation related media coverage (per numbers of electronic media)
Environmental outcomes	4.1 Material productivity (GDP/domestic material consumption) 4.2 Water productivity (GDP/water footprint) 4.3 Energy productivity (GDP/gross inland energy consumption) 4.4 GHG emissions intensity (CO ₂ /GDP)
Socio-economic outcomes	5.1 Exports of products from eco-industries (% of total exports) 5.2 Employment in eco-industries (% of total workforce) 5.3 Turnover in eco-industries

The OECD work on establishing an indicator set for green growth does not explicitly build on an innovation system perspective, but the suggested indicators are mentioned here for comparison reasons. Indicators in five overall groups are proposed: 1) The socio-economic context and characteristics of growth; 2) Environmental and resource productivity; 3) Natural asset base; 4) Environmental quality of life; and 5) Economic opportunities and policy responses. Number 2 and 5 are especially of interest for our purpose and the indicators in these groups are shown below.

Table 11A and 11B: OECD indicators for monitoring progress towards green growth (OECD 2011b).

Environmental and resource productivity	
Carbon & energy productivity	<p>1. CO₂ productivity</p> <p>1.1. Production-based CO₂ productivity GDP per unit of energy-related CO₂ emitted</p> <p>1.2. Demand-based CO₂ productivity Real income per unit of energy-related CO₂ emitted</p> <p>2. Energy productivity</p> <p>2.1. Energy productivity (GDP per unit of TPES)</p> <p>2.2. Energy intensity by sector (manufacturing, transport, households, services)</p> <p>2.3. Share of renewable energy in TPES, in electricity production</p>
Resource productivity	<p>3. Material productivity (non-energy)</p> <p>3.1. Demand based material productivity (comprehensive measure; original units in physical terms) related to real disposable income</p> <ul style="list-style-type: none"> • Domestic material productivity (GDP/DMC) <ul style="list-style-type: none"> - Biotic materials (food, other biomass) - Abiotic materials (metallic minerals, industrial minerals) <p>3.2. Waste generation intensities and recovery ratios By sector, per unit of GDP or VA, per capita</p> <p>3.3. Nutrient flows and balances (N,P)</p> <ul style="list-style-type: none"> • Nutrient balances in agriculture (N, P) per agricultural land area and change in agricultural output <p>4. Water productivity VA per unit of water consumed, by sector (for agriculture: irrigation water per hectare irrigated)</p>
Multi-factor productivity	<p>5. Multi-factor productivity reflecting environmental services (comprehensive measure; original units in monetary terms)</p>
Economic opportunities and policy responses	
Technology and innovation	<p>16. R&D expenditure of importance to GG</p> <ul style="list-style-type: none"> - Renewable energy (in % of energy related R&D) - Environmental technologies (in % of total R&D, by type) - All purpose business R&D (in % of total R&D) <p>17. Patents of importance to GG in % of country applications under the Patent Cooperation Treaty</p> <ul style="list-style-type: none"> - Environmentally related and all-purpose patents - Structure of environmentally related patents <p>18. Environment-related innovation in all sectors</p>
Environmental goods and services	<p>19. Production of environmental goods and services (EGS)</p> <p>19.1. Gross value added in the EGS sector (in % of GDP)</p> <p>19.2. Employment in the EGS sector (in % of total employment)</p>
International financial flows	<p>20. International financial flows of importance to GG (in % of total flows; in % of GNI)</p> <p>20.1. Official Development Assistance</p> <p>20.2. Carbon market financing</p> <p>20.3. Foreign Direct Investment (tbd)</p>
Prices and transfers	<p>21. Environmentally related taxation</p> <ul style="list-style-type: none"> - Level of environmentally related tax revenues (in % of total tax revenues, in relation to labour related taxes) - Structure of environmentally related taxes (by type of tax base) <p>22. Energy pricing (share of taxes in end-use prices)</p> <p>23. Water pricing and cost recovery (tbd)</p> <p><u>To be complemented with indicators on:</u></p> <ul style="list-style-type: none"> • Environmentally related subsidies (tbd) • Environmental expenditure: level and structure (pollution abatement and control, biodiversity, natural resource use & management)
Regulations and management approaches	<i>Indicators to be developed</i>
Training and skill development	<i>Indicators to be developed</i>

3. Examples of current measurements

The purpose of Chapter 3 is to briefly show a set of examples of actual measurements of indicators of energy innovation systems. This supplements the previous chapter with a more practically based picture of the state of affairs, the types of data used, etc. Chapter 2 and 3 together constitute the background for Chapter 4 with its five thematic discussions of central challenges in current measuring of energy innovation systems and their dynamics. The selection of examples here in Chapter 3 is partial and not a complete coverage. Denmark and other Nordic countries are used as example in most cases. For simplicity reasons the chapter is organised in three sections: 1) Output indicators – measuring the current performance of the energy innovation systems; 2) Input indicators and actor landscape; and 3) Throughput indicators.

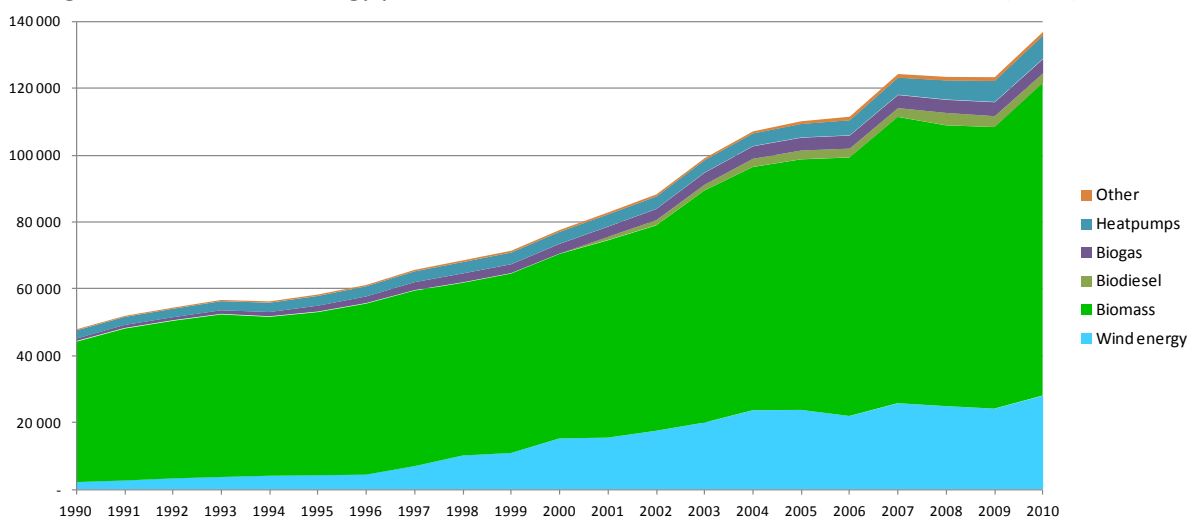
3.1 Output indicators – measuring the current performance

Application of low carbon technologies – domestic use

Market application of new low-carbon technologies and products is among the most direct indicators of output from the energy innovation system. It can be measured in economic terms, as it is done in the exports and trade statistics shown later. Or it can be measured in technical terms, e.g., in the number of energy technology units brought to use, in the amount of installed energy production effect by different low-carbon technologies, or in the amount of energy produced by the different technologies.

National energy statistics make up a good source of data for the latter type of indicators, as they in many countries include data on the use of different types of energy production technologies in the domestic energy systems. Figure 4 shows the development in the use of different types of renewable energy technologies in the energy production in the Danish energy systems over the latest decades. It appears that biomass energy and wind energy constitute the majority of renewable energy production. In the ‘Other’ category hide e.g. solar cells and geothermal energy.

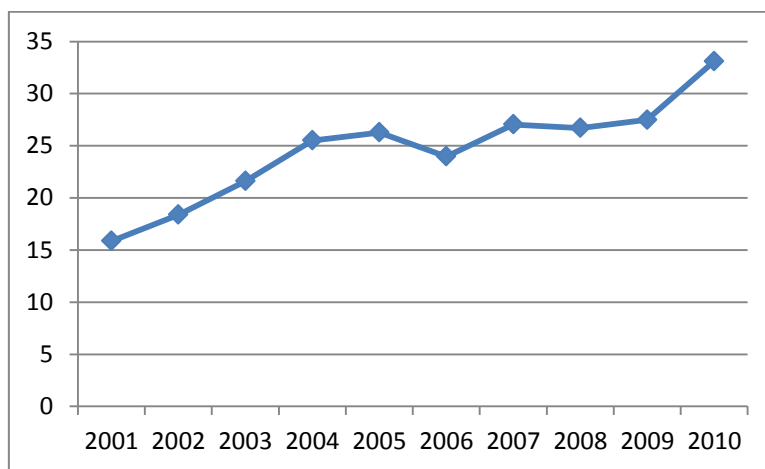
Figure 4: Renewable energy production in Denmark, TJ, 1990-2010. Source: ENS (2011).



Though the production of renewable energy has increased significantly since 1990, the relative share of renewable energy in the primary energy production has only increased from around 11% to 14% in

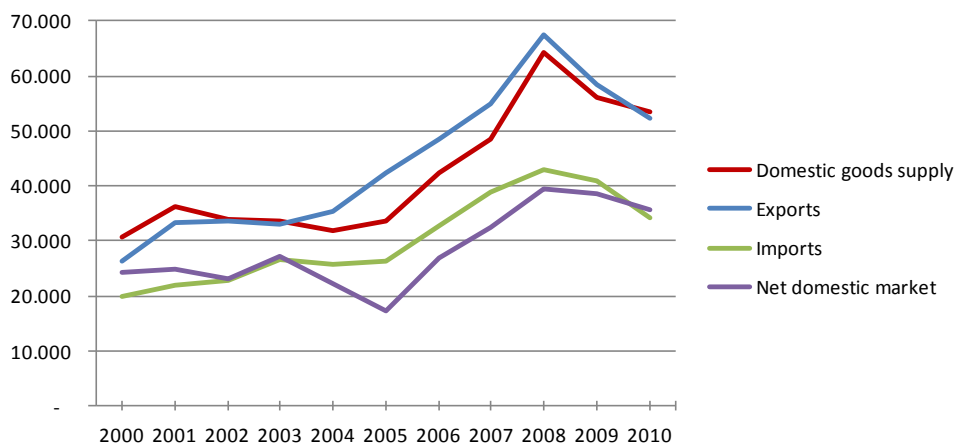
Denmark over the period, due to increase in also other types of energy production, not least natural gas (ENS 2011). A significant amount of gas and oil is exported. If one considers the greening of the national energy systems as an output indicator of the energy innovation systems, it can also be relevant to look at the share of renewable energy in the total consumption of energy. This has increased significantly from 6-7% in 1990 to around 20% in 2010 (ENS 2011). Figure 5 shows the development in the percentage share of electricity generated from renewable sources in Denmark. As appears, there has here been a significant development. The renewable sources in 2010 account for more than 30% of the electricity. It is worth noticing that measurement of market application of new energy technologies is not only an output indicator but also an indicator of application-based learning and competence build-up (hence a through-put indicator).

Figure 5: Electricity generated from renewable sources in Denmark, percentage of total. Source: Eurostat.



In economic terms, the size of the domestic market and trade of energy technology and equipment in Denmark have been measured in the Energy industry statistics (ENS et al. 2011). It is based on Eurostat’s (Comext database) nomenclature for commodities with some adaptations (Dræbye 2010). As appears from Figure 6, the size of the net domestic market is in the order of 35-40 billion DKK.

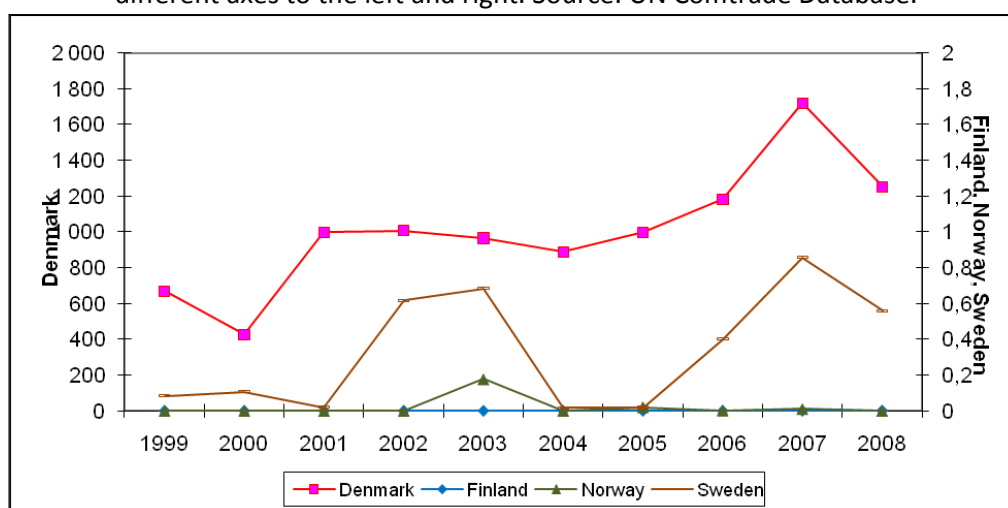
Figure 6: Goods supply, imports/exports, and market for energy technology and equipment in Denmark. Mill. DKK. Domestic market = Domestic goods supply + imports – exports. Source: ENS et al. (2011).



Exports

Energy technology export is another output indicator for the energy innovation systems. The development in exports of energy technology in general from Denmark is shown in the figure above. A significant increase has appeared over the latest decade. Figures for individual areas of energy technology are not published in that statistics, though a distinction between 'green' energy technology and other energy technology is made in the most recent version. As will be discussed in Chapter 4, there are different suggestions of which product classifications to use when measuring energy technology trade. The opportunities for measuring individual areas of energy technology constitute an important challenge. Here, we will just mention the example of measuring energy technology exports through the UN database Comtrade. The list of commodities included in this database does not allow coverage of all energy technologies. There are commodities which address *wind power* (HS 850231) and *hydropower* (HS 841011-13, 841090). As has been pointed out by Johnstone and Hascic (2009b), *solar photovoltaic* technology may be covered by HS 8541.40, but the commodity group includes not only photovoltaic devices but also light-emitting diodes and semiconductor devices and is therefore far too broad. Figure 7 shows the results concerning wind technology exports from the Nordic countries building on this database.

Figure 7: Wind technology export from the Nordic countries. Mill. USD. Please note the different axes to the left and right. Source: UN Comtrade Database.



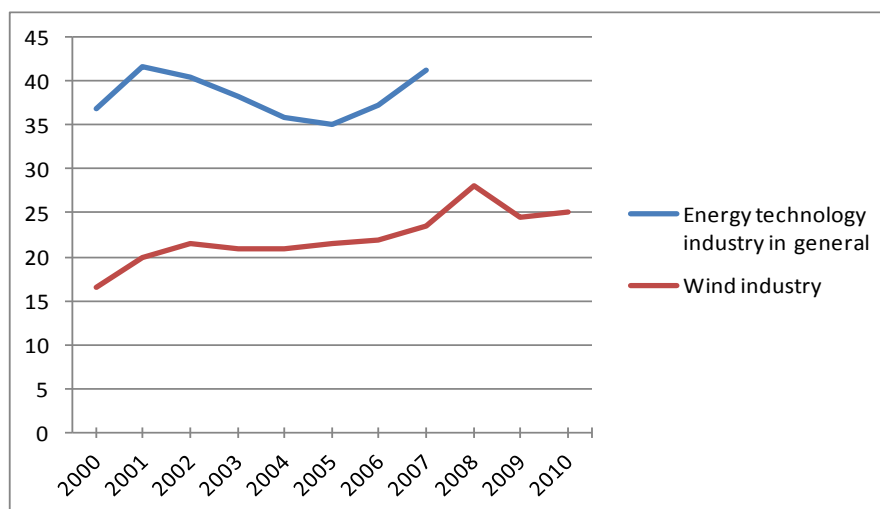
Another type of indicator that offers insight into the international competitiveness of a country's innovation system with respect to a specific area of energy technology is the share of the world market by the country's technology-supply industry in the area. Apart from in economic terms, this can be measured in energy terms, e.g., share of the globally installed energy effect in a year stemming from local technology manufacturers, or share of the number of new-established energy production plants. Data availability is often a problem here, but in some cases trade literature and reports from international institutions and industry observers make accounts of market shares by different manufacturers in different countries (see Borup et al., 2008 for examples).

Employment

Employment in the energy technology industry is another important output indicator of the energy innovation system. For Denmark, figures from the Energy industry statistics (ENS et al., 2011) are available for the period 2000–2007, see the graph below. The figures cover the energy technology industry in general

and show an employment in the industry in the order of 35–40.000 persons, increasing in the period from 2005 to 2007 to around 41.000 persons after some years of decrease since 2001. In addition, figures for the wind technology industry up till 2010 are available from the Danish Wind Industry Association. These figures show a generally increasing tendency in the employment from around 16.000 employees in the wind industry in the beginning of the millennium to 25.000 a decade later. Juxtaposed with the general employment data, it is clear that the wind area make up a considerable share of the total employment within the energy technology industry in Denmark. Around half of the employment is in the wind energy area, and the share has been increasing.

Figure 8: Employment in the Danish energy technology industry in general and in the wind industry (in thousand employees). Sources: ENS et al. (2011) (general) and Danish Wind Industry Association (2011) (on wind industry).

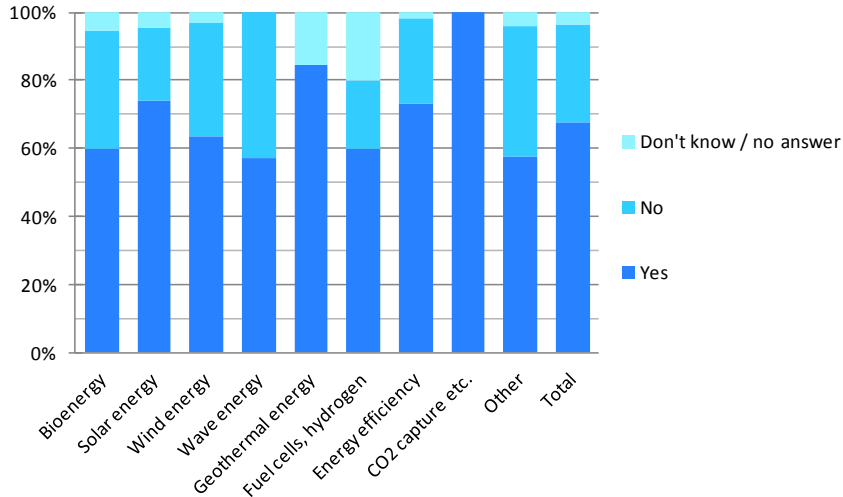


The employment figures show the total employment, independently of what the work activities more specifically consist in, and whether they have to do with innovation and development activities or not. This is why we here mention them as output indicator from the energy innovation system. However, if we focus on only employees that directly work with innovation and development activities or have an innovation and R&D oriented education, the employment figures can also be considered as input or through-put indicator. There are examples of measuring of such indicators from industry statistics, however to our knowledge it has not been done for the energy area specifically.

Market introduction of new technological products and services

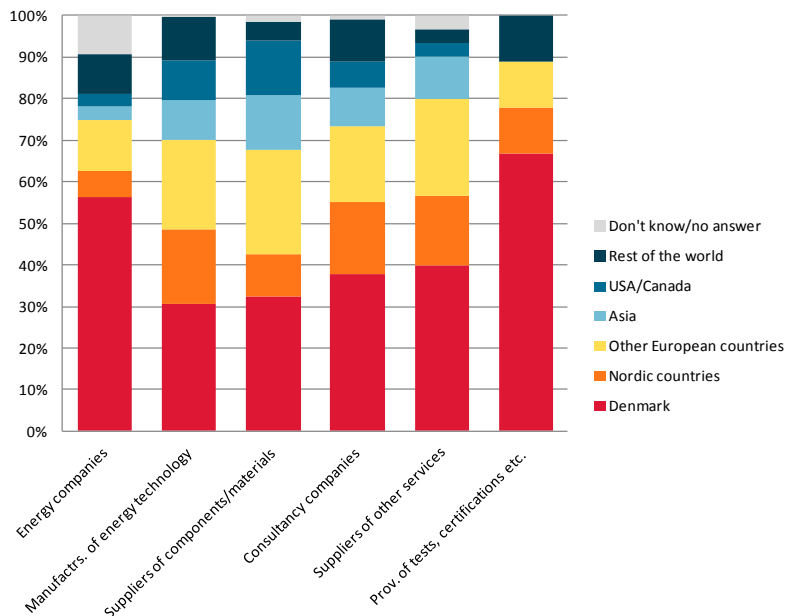
Market introduction of new technological products and services is another industry-related output indicator of energy innovation systems. The frequency of introduction of new products and services is measured e.g. in the Danish 'EIS Survey of innovation activities and interaction patterns' (Borup et al. 2012). The measuring method makes the results directly comparable with the general national and European innovation statistics, CIS (the CIS does not cover the energy area separately). As it appears from the Total column in Figure 9, 2/3 of the companies in the Danish energy innovation system introduced new energy technology products or services in the period 2009 to 2011. This is a higher share of companies than seen in the Danish industry in general.

Figure 9: Introduction of new energy technology products or services in the period 2009-2011 by companies in the Danish energy area, N=314, EIS Survey 2011.



There is variation between the technology areas, e.g. with more than 70% in the area of energy efficiency technology and around 60% within bioenergy and wind energy. The data on geothermal energy and on CO₂ capture build on a limited amount of cases. The markets on which the new products and services are sold appear in Figure 10. The result are here shown by different types of companies.

Figure 10: Markets on which the new energy technology products and services are sold. (Companies with product/service introductions in 2009-2011), N=213, EIS Survey 2011.



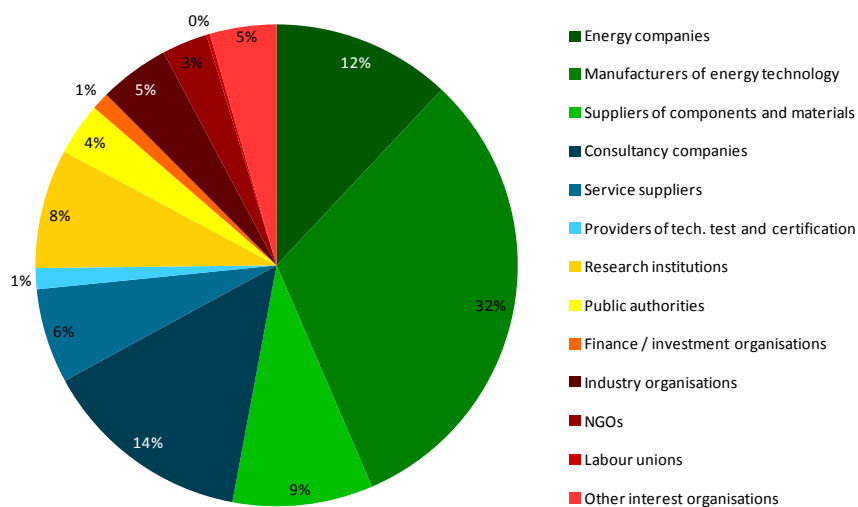
3.2 Input indicators and actor landscape

Actors

An energy innovation system consists of many different actors. It is difficult, however, to obtain a complete and 100% exact picture of the actors in the system. One reason is that there are no official databases of this and it is a difficult task to make complete lists of the actors. Another reason is that the borders of energy innovation systems are fuzzy to some extent, not only because some actors disappear over time and new actors appear, but also because some actors are influencing energy innovation through some of their activities, but not through all them. They are what one might call ‘part time’ involved in the energy innovation system. This can for example be sub-suppliers of central, specialized components of energy technologies (e.g. suppliers of solar cell materials for solar cells systems, or suppliers of gear components for wind turbines) who sell, say, 40% of their production to the energy technology industry while the rest is sold to other industries. It can also be, e.g., finance and investment organisations that in part of their activities have energy investments as a focus area, or policy makers that establish general, new regulations that influence conditions for energy innovation. Hence, there will always be a degree of uncertainty about which actors are included in the energy innovation system, and which are not.

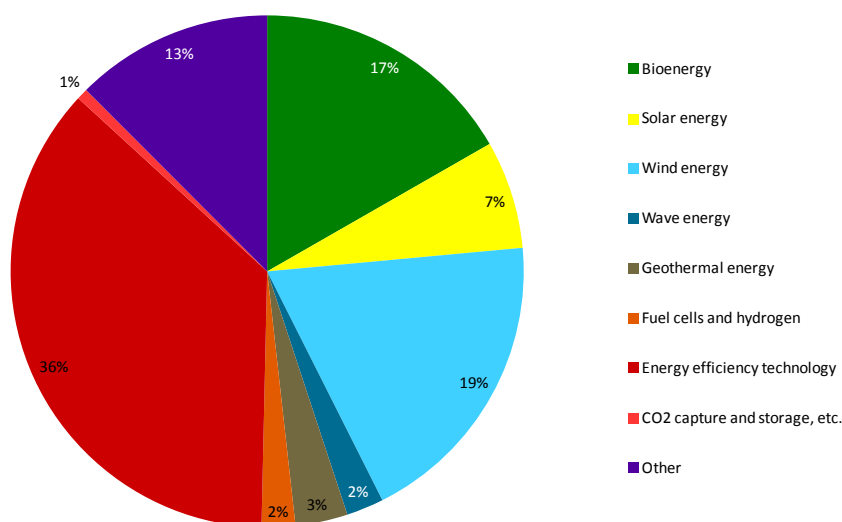
In case of the Danish energy innovation system, the EIS survey (Borup et al. 2012) gives an overview picture of the landscape of actors in relation to renewables and low-carbon technologies. According to this analysis, the energy innovation system has in the order of 1500 actors. Building on a gross list of these actors, 425 actors answered the survey’s questionnaire. The results indicate a distribution of types of actors as shown in Figure 11. Around 75% of the actors are companies of different kinds. The remaining 25% are public research institutions and authorities, finance and investment actors and different types of interest organisations. Energy consumers, politicians and media organisations were not included in the survey. 12% of the actors are energy companies, including energy-net operators. Another observation is that in the order of half of the actors are companies that supply energy technologies or different types of components and services in connection to energy technology.

Figure 11: Types of organisations, EIS Survey 2011, N=425.



The EIS survey also includes data about which areas of renewable and low-carbon energy technologies the actors work with, see Figure 12. Wind energy, bio energy and energy efficiency technology constitute the relatively large areas in Denmark with more than hundred actors, while solar energy, geothermal energy, wave energy, fuel cells & hydrogen technology and CO₂ capture & storage are smaller with less than hundred actors.

Figure 12: Primary technology area of the organisations, EIS Survey 2011, N=425.

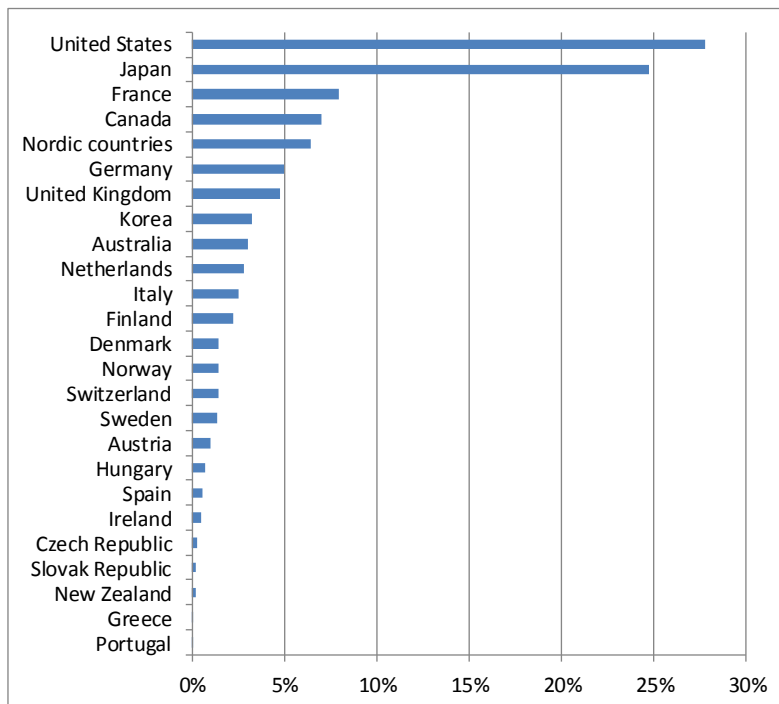


Public RD&D investments

As example of input measures, the report will feature expenditures on research, development and demonstration activities (RD&D expenditures). The IEA energy RD&D statistics are used for this. The IEA RD&D statistics are collected from government RD&D funders. They use a scientific/technical nomenclature and are publicly accessible. The expenditures are reported on a level of detail that makes it possible to distinguish between a number of relevant energy technologies. The IEA database is an OECD database and covers a.o. 17 EU Member States. All Nordic countries, with the exception of Iceland are included in the database. The database allows for an analysis of public energy RD&D investments over a long time period. The figures below cover values from mid-1970 to 2010.

On top of traditional research and development budgets the IEA database covers *demonstration budgets*. Demonstration projects are large “test” projects which are not yet operating on a commercial scale. Demonstration budgets are, however, scarcely reported in the database. Most IEA member countries do not provide data on funds for demonstration or do not report them separately (Wiesenthal et al. 2009). Demonstration budgets are typically available since 2004. For the Nordic countries some data are available, but the systematic reporting and collecting of demonstration budgets need to be improved further.

Figure 13: Public energy RD&D budgets as percentage share of estimated total IEA budget in 2010. Source: IEA.



Note: Four IEA member countries did not report: Belgium, Luxembourg, Poland, and Turkey.

Japan and USA together constitute more than 52.5% of the total IEA energy RD&D funding in 2010 (see Figure 13) while the Nordic countries in total count for about 6.4%. This can be seen as an argument for that international research cooperation is essential, especially for small countries in order to increase their access to a larger pool of resources and strategic knowledge, generate synergies and avoid duplication.

In the next figures trends in RD&D budget distribution over the main groups of energy technologies are illustrated for Denmark and Norway, following the classification by the IEA:

Table 12: Classification of main energy RD&D groups in IEA RD&D statistics.

I.	Energy Efficiency
II.	Fossil fuels
III.	Renewable energy sources
IV.	Nuclear fission and fusion
V.	Hydrogen and fuel cells
VI.	Other power and storage technologies
VII.	Other cross-cutting technologies or research

For Denmark, Figure 14 shows dominant position of public funding of RD&D on renewable energy sources, hydrogen and fuel cells and other cross-cutting technologies, while funding of RD&D on fossil fuels and nuclear fission and fusion is marginal. For Norway the picture is different (see Figure 15). Here RD&D on fossil fuels dominates, and to a lesser extent renewable energy. (For Sweden and Finland the focus is on energy efficiency and renewable energy sources.)

Figure 14: Denmark, Mill. €. RD&D budgets for main groups, 1975-2010. Source: IEA.

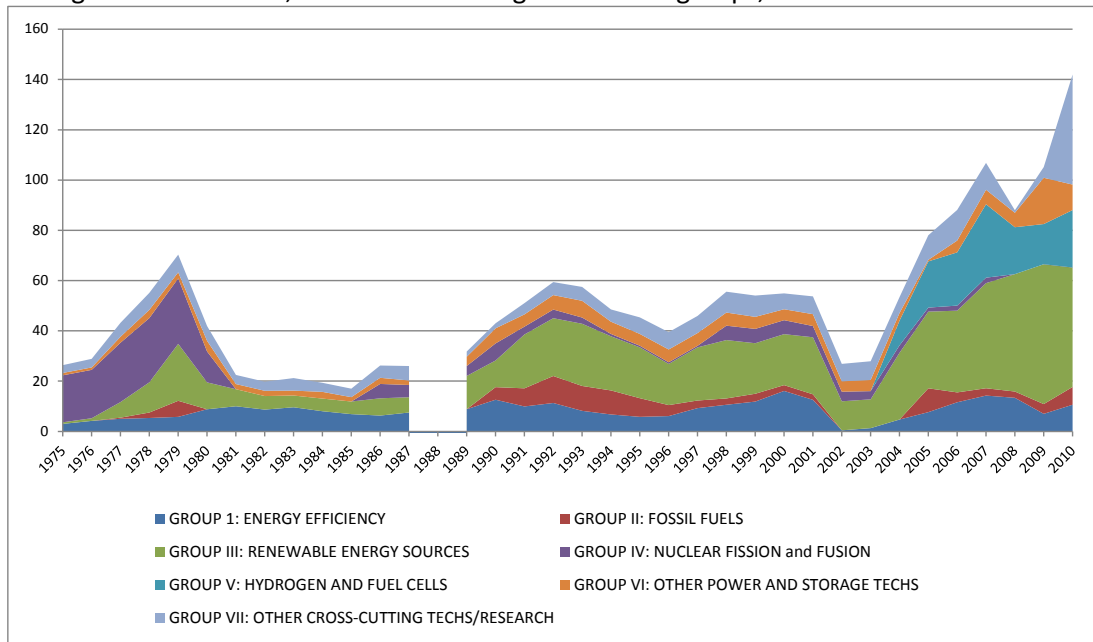
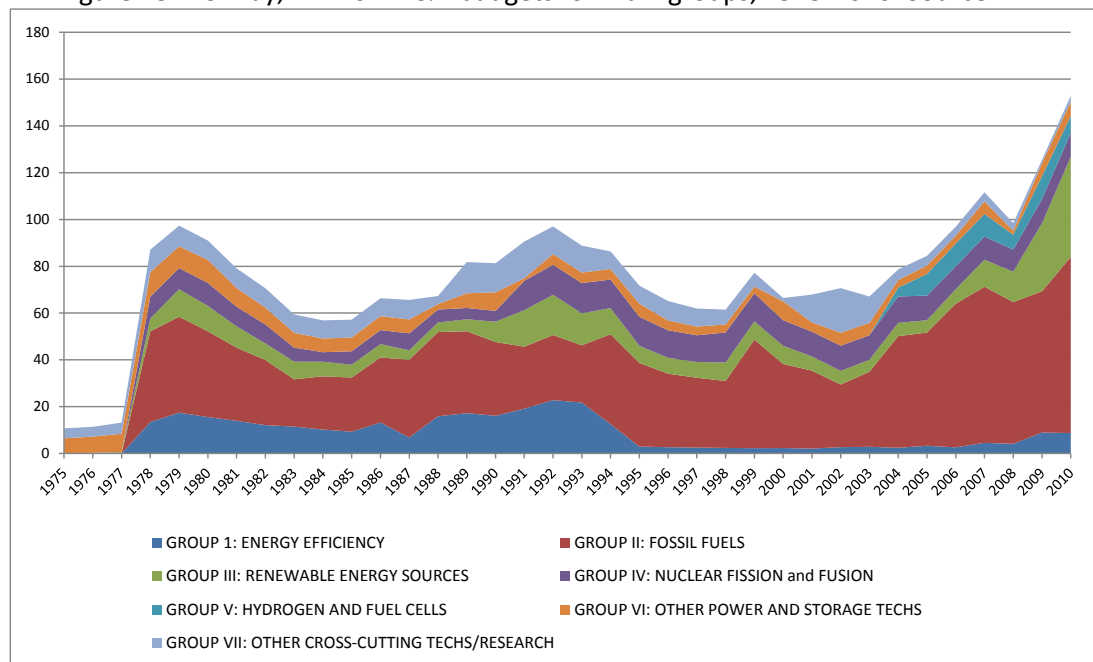


Figure 15: Norway, Mill. €. RD&D budgets for main groups, 1975-2010. Source: IEA.



The advantage of the IEA database is that it provides public RD&D budgets by energy technologies over a relatively long time period. This means that it is possible to compare trends in budget distributions by different renewable energy sources, energy efficiency areas, power and storage technologies and carbon capture and storage. The figures presented below illustrate budget developments in the period 1970-2010, where data has been available. The technologies are classified by the IEA in the following way:

Table 13: Classification of (selected) energy relevant sectors in IEA RD&D statistics.

- I.1 Energy efficiency - Industry
- I.2 Energy efficiency: Residential & commercial buildings, appliances and equipment
- I.3 Transport
- I.4 Other energy efficiency
- II.3 CO₂ Capture and Storage
- III.1 Solar Energy
- III.2 Wind Energy
- III.3 Ocean Energy
- III.4 Biofuels (incl. liquids, solids and biogases)
- III.5 Geothermal Energy
- V.1 Hydrogen
- V.2 Fuel cells
- VI.1 Electric power conversion
- VI.2 Electricity transmission and distribution
- VI.3 Energy storage

In Denmark the focus over the years has been primarily on wind energy and biofuels, but in recent years also fuel cell technology has gained substantial attention in public RD&D budgets. Energy efficiency has been addressed continuously over almost all years.

Figure 16: Denmark, Distribution of low carbon energy RD&D budgets, Mill €. 1975-2010, Source: IEA.

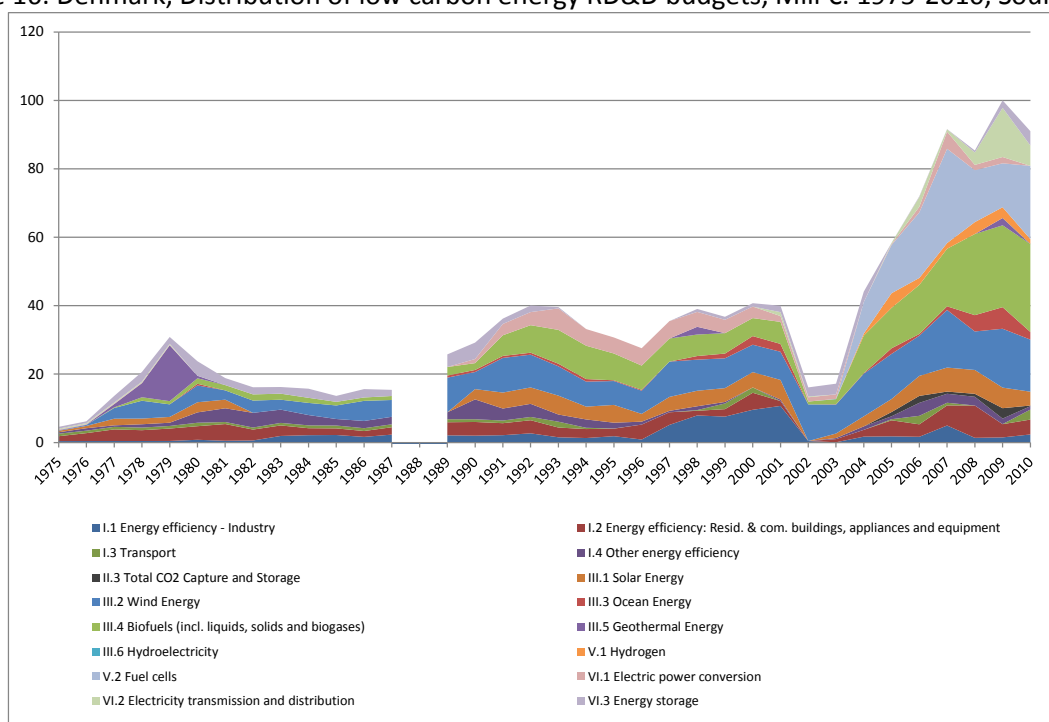
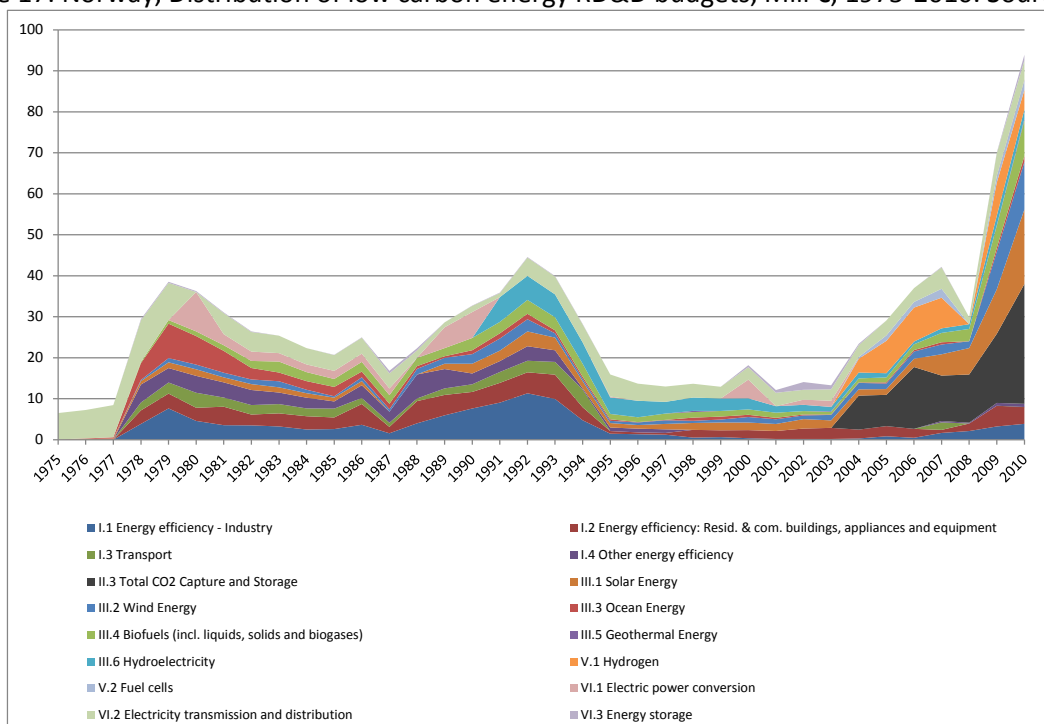


Figure 17: Norway, Distribution of low carbon energy RD&D budgets, Mill €, 1975-2010. Source: IEA.



In Norway there is a long tradition for funding of energy efficiency in industry, but this field received much less attention from the middle of the 1990s. Carbon capture and storage received substantial funding since 2004. In the field of renewable energy solar energy, wind energy and biofuels are prioritised. RD&D on electricity transmission and distribution, and hydrogen have been prioritised as well.

3.3 Throughput indicators

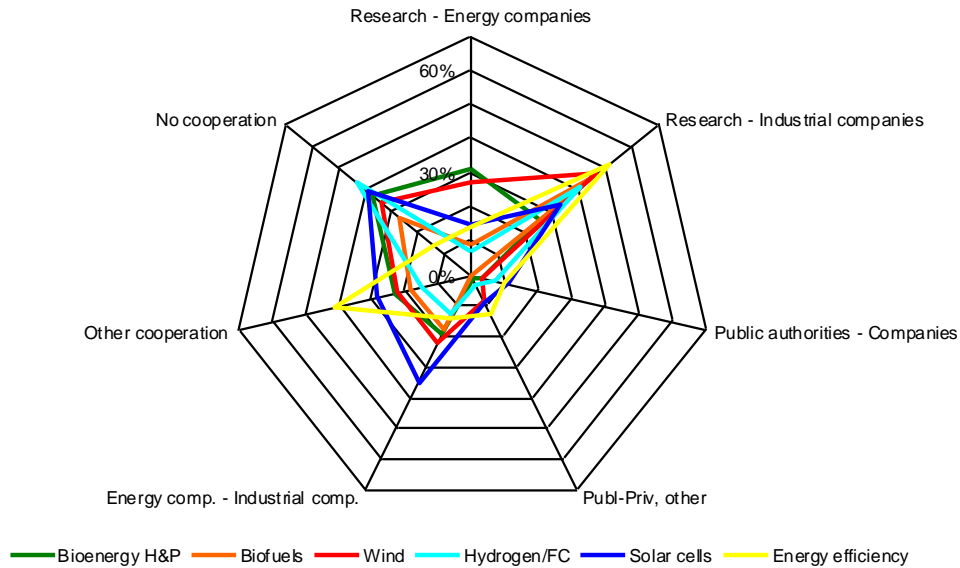
As examples of throughput indicators we will here show four types: Cooperation in R&D projects; market developments as driving factors for innovation; bibliometric measures of scientific publishing; and patents.

Cooperation in R&D projects

Cooperation patterns in connection to publicly funded R&D activities can be measured by analysis of participants in the projects in the public R&D programmes on energy (Borup et al., 2008). The analysis builds on the DENP project database supplemented with additional material about projects and participating organisations. In the analysis, attention is given primarily to public-private and other cross-going cooperation. The results in different areas of energy technology are shown in the following figure. It appears that the cooperation pattern in the publicly funded R&D activities varies between the different technology areas. A considerable amount of projects include public-private cooperation in the sense of cooperation between research institutions and industrial companies. Compared to this, the share of projects with cooperation between research institutions and energy companies is smaller. This is the case in all the covered technology areas apart from bioenergy for heat & power.

Figure 18: Cooperation pattern in the public energy R&D programmes in Denmark. Share of projects with cross-going cooperation between actors of different type. Running projects 2007-2008. N=492.

Cooperation patterns in R&D programmes - Denmark



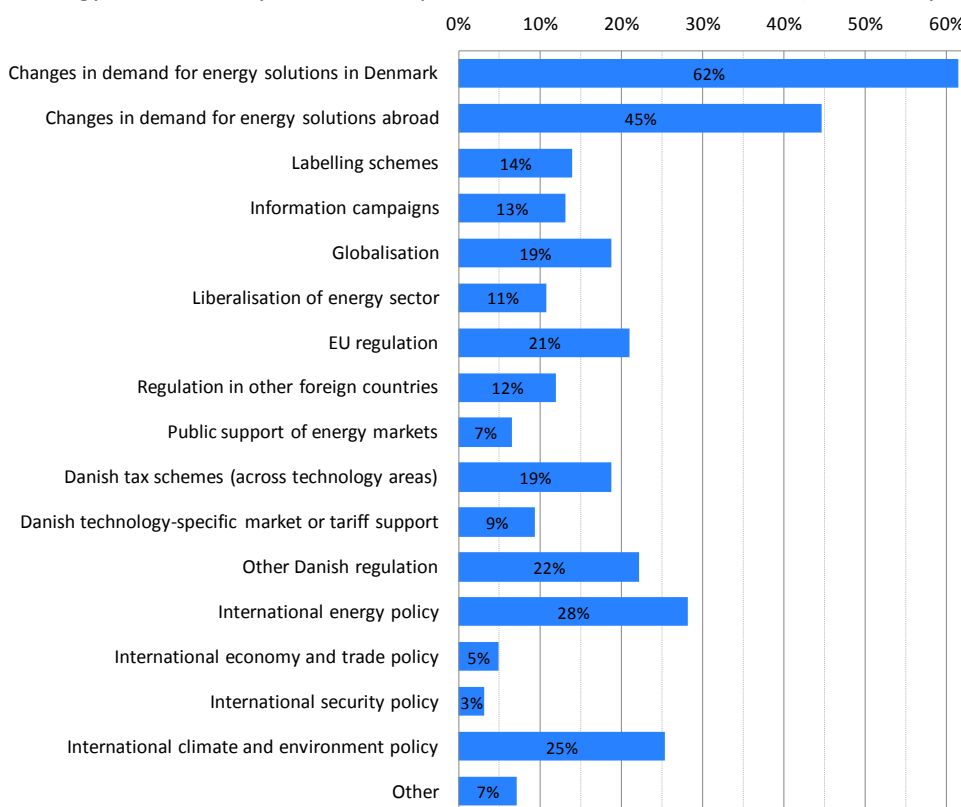
Source: Borup et al. 2008. The figure is read clockwise starting by 12 o'clock. Biofuels are here defined as biomass based liquid fuels for transportation purposes.

The figure also shows that the majority of projects contain some kind of cross-going cooperation. 'No cooperation' appears in less than 50% of the projects. This finding is especially significant within energy efficient technology where less than 15% of the projects have no cross-going cooperation, i.e., there is cross-going cooperation in more than 85% of the projects.

Market developments as driving factor for innovation

Developments in market demands can be an important driving factor for innovation. This type of throughput indicator is analysed in the EIS Survey (Borup et al., 2012) where sources of market developments in recent years (2009-2011) are illuminated, building on identification by the actors in the Danish energy innovation system. The majority of the actors (2/3) experienced a significant development in the market in connection to their activities on energy technology development. The sources of the market developments are identified as shown in the following figure. It appears that developments in demand on the domestic market are more important than developments on foreign markets. Of the more specific sources behind the market changes, the international policies on energy and on climate and environment are the most important ones, followed by developments in regulation on national and EU level.

Figure 19: Sources of market developments as driving factor for innovation. (Share of actors in the Danish energy innovation system that experienced the different sources.) EIS Survey 2011, N=351.



Bibliometric-based measures of scientific publishing

Bibliometric data is traditionally based on scientific publications and includes information on the type of publication, title, authors and their location, etc. Bibliometric data provides insight into the production of scientific literature in a given field and can be used to gauge the contributions in a given discipline by scientists working in a given country. It is an established throughput indicator as bibliometric-based measures explore the intermediate production of the innovation process, especially those resulting at early stages of the innovation process. Compiling and comparing data of relevant literature published by national scientists provides the basis for other indicators, in addition to intermediate production of the innovation process. For example, the concentration of publication in given fields can be used as a further measure of the intensity of scientific activity; the degree of citations of given articles can be used as a measure of scientific impact; and the co-authorship patterns can be used to investigate collaboration and cooperation.

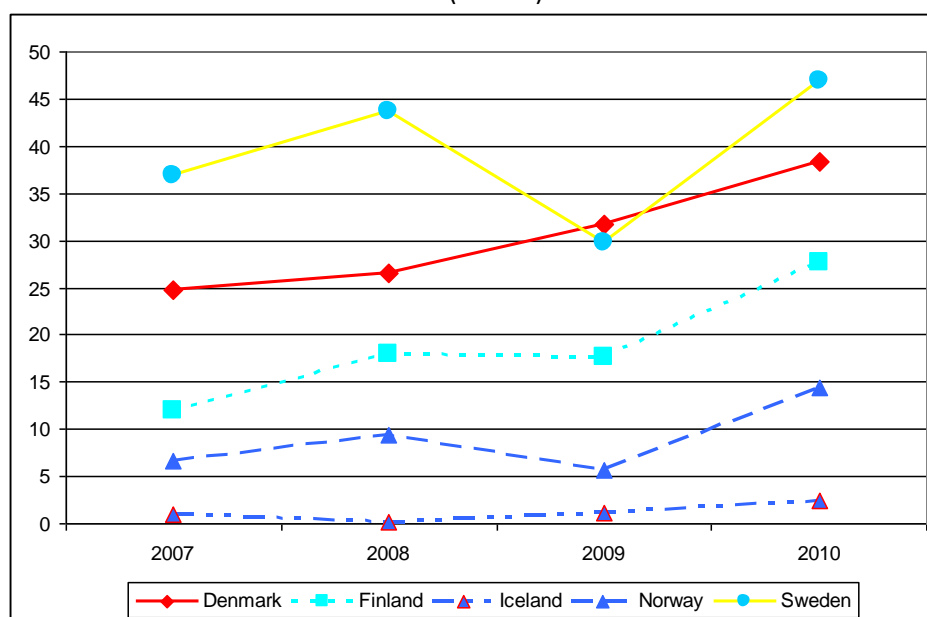
In the example below, bibliometric data have been extracted from the ISI Web of Science of Thomson Reuters using keywords tailored to each technology field. We propose to use the Science Citation Index and Social Science Citation Index and to include the following document types: article, editorial material, proceeding paper and review. The application of bibliometric data hinges on the definition of keywords. We propose to apply revised search strings based on key words for each technology field as they have been developed in 2007 for the eNERGIA project (Klitkou et al., 2008a), but have been updated for this project. The keywords are used to check titles, author keywords, abstracts and keywords added by the database provider. Fractionalized counts of publications are used. This means that every paper counts only once and different author addresses receive their respective share of this paper. If the article lists two addresses, each address receives 0.5 points, for three addresses every address receives 1/3 points a. s. o.

Table 14: Scientific publishing 2007-2010. Sources: ISI Web of Science. Based on fractionalized counts.

	2 nd generation bio-fuels	Fuel cells	Photovoltaic	Wind
Denmark	121,3	148,9	299,3	318,8
Finland	75,2	56,4	496,0	62,8
Norway	36,1	71,9	203,4	95,6
Sweden	157,3	0,8	853,7	152,5
Iceland	4,8	99,8	3,4	0,8

Note: Included document types: article, review, proceeding paper, editorial material.

Figure 20: 2nd Generation bio-fuels: Publishing for the Nordic countries 2007-2010. Based on fractionalized counts (N=509).



Authors with at least one Danish address published 155 articles on 2nd generation biofuels, 54 or 35% were internationally co-authored (numbers are based on total counts). The main co-authoring countries are Germany and the US. Table 15 shows co-authoring figures also for fuel cells, photovoltaic energy and wind energy.

Table 15: Co-publishing of scientific publications by Danish authors: Top 10 countries of co-authorship. Based on fractional counts (Klitkou et al. 2012).

Biofuels	N=54	Fuel cells	N=65	Photovoltaics	N=197	Wind	N=111
USA	4,2	USA	6,5	Germany	21,5	Germany	7,7
Greece	3,4	Switzerland	5,4	USA	13,8	P R China	7,2
Cuba	2,5	Germany	5,3	UK	8,9	USA	6,1
France	2,4	P R China	4,6	Peoples R China	7,5	UK	5,2
Spain	2,4	France	2,9	Spain	7,1	Spain	4,8
P R China	2,0	Finland	2,5	Sweden	6,3	Sweden	3,1
Sweden	1,8	Sweden	2,5	Switzerland	4,8	Ireland	2,5
Germany	1,8	South Korea	1,2	France	4,3	Norway	2,4
UK	1,2	Netherlands	0,8	Norway	3,5	Italy	2,1
Austria	1,2	Iceland	0,7	Australia	3,3	Australia	2,0

Patents and low-carbon energy technologies

A patent is an indication of inventive activity that has yielded a technological feature that is new to the field and that has an assumed commercial potential. Patenting is not an everyday activity to most actors in the energy innovation systems. It must be considered more an exception than the rule, and in this sense patents as an indicator is a relatively indirect measure that only captures a small fraction of the innovative activities in the innovation systems. Moreover, it is a disputed indicator, as there can be both significant advantages and disadvantages in patenting. An OECD study (2004) highlighted that patents play a decisive role in a few industries, such as biotechnology, drugs development, chemicals and machinery and computers, while other industry sectors use other means to protect their intellectual property, such as “secrecy, market lead, advance on the learning curve, technological complexity and control of complementary assets” (OECD, 2004, p. 9). While the energy sector is not among the documented patent-intensive industries, low carbon energy technologies encompass many different fields of advanced technological knowledge: e.g. biotechnology for producing biofuels and chemistry for carbon capture towards material science for technologies. It can be assumed that the role of patenting varies between the fields.

Despite the limitations, patents are a much used type of indicator within innovation studies. It can indicate that there are some activities going on e.g. in industrial companies, in research organisations, and, in some cases also, on the boundary between research and industry or other kinds of collaboration. A quality of patents as indicator is that there are well-developed and complete databases of patents available. Patent data do however not reflect the commercialisation of the patents. Therefore they are throughput indicators. An earlier Nordic project provided a comprehensive overview of patenting activities within different energy technologies for the Nordic countries. For Denmark, for example, a high activity level is seen in two of the studied technology fields: wind and second generation biofuels – and in addition, also in hydrogen & fuel cells (Klitkou et al., eNERGIA report Part 2, p. 103). See Chapter 4a for overview figures of patent applications in different energy technology areas (WIPO 2009).

The most promising and comprehensive approach so far comes from EPO – the European Patent Office. The following results are based on a study with data from the of EPO Worldwide Patent Statistical Database (PATSTAT, the Fall 2009 version).² The table shows the results for bio-energy. They confirm the identified strengths in bioenergy technology in the eNERGIA study, even though only patenting for second generation biofuels was addressed and not bioenergy in general.

Table 16: EPO applications in bio-energy. 1999-2008.

	Denmark	Other Nordic countries	Other EU27	Other countries	Unknown	All
1999	4	3	12	17	2	37
2000	4	1	21	27	11	62
2001	5	4	20	32	9	65
2002	3	6	25	41	9	72
2003	4	5	31	42	9	82
2004	8	8	37	69	2	116
2005	14	9	24	102	3	142
2006	10	6	60	126	6	201
2007	8	5	101	179	10	284
2008	5	12	86	203	5	289
Total	65	59	415	835	65	1 349

² <http://forums.epo.org/epo-worldwide-patent-statistical-database/topic586.html>

4. On-going efforts and debates: Five measuring challenges

4A The challenge of classifications of technologies and products

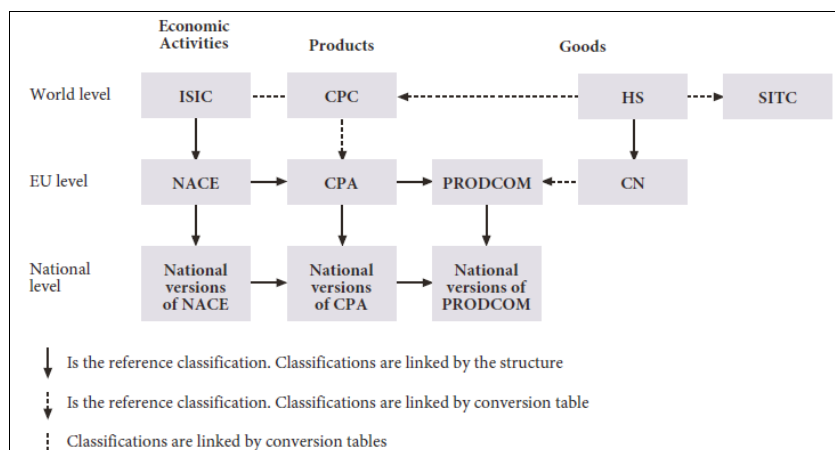
Antje Klitkou

In this chapter we discuss challenges related to different types of classifications of industrial activities and technologies which are widely used and relevant for analysing energy innovation systems. We distinguish between industrial classifications, product and service classifications, and patent classifications.

4A.1 Industrial classifications

There are several challenges related to the use of industrial classifications for analysing industrial activities related to energy innovation: (1) energy relevant classes are spread throughout the classifications, (2) classes mostly, with some exceptions, do not cover only energy relevant technologies but also other technologies, (3) services are not addressed sufficiently in these classifications, (4) a complicated system of concordance tables between different versions of the International Standard Industrial Classification of All Economic Activities (ISIC), the Statistical Classification of Economic Activities in the European Community (French: Nomenclature des Activités Économiques dans la Communauté Européenne, abbreviated to NACE), the North American Industry Classification System (NAICS) and the Central Product Classification (CPC) is needed to allow comparative analyses, (5) larger firms tend to list several codes because they are characterised by either vertically integrated activities or horizontally integrated activities, which makes an analysis difficult. The classification systems require applying those codes which account for the largest share of the firm's value added. This makes it difficult to identify intra-firm niche activities, relevant for an analysis of renewable energy innovation systems. Industrial classifications have been developed by international institutions, like the United Nations Statistics Division (ISIC) or the European Commission (NACE), for studying economic phenomena and by applying a standard classification improving international comparability of data, but also as guidance for attempts to develop national statistics. Beside these international classifications there exist also national classifications, such as the Standard Industrial Classification (SIC) developed by the United States, and classifications developed by private actors, such as the Global Industry Classification Standard (GICS) developed by MSCI and Standard & Poor's. That means that these classifications have been developed for rather different purposes, which makes it difficult to compare the outcomes. The international classifications are linked either by their structure or by concordance tables (see Figure 21).

Figure 21: The international system of economic classifications (European Commission, 2008:13).



Explanation of abbreviations not listed before:

- CPC: United Nations' Central Product Classification
- HS: Harmonized Commodity Description and Coding System, managed by the World Customs Organisation
- CPA: European Classification of Products by Activity
- PRODCOM: Classification of goods used for statistics on industrial production in the EU
- CN: Combined Nomenclature, a European classification of goods used for foreign trade statistics

National industrial classifications

ISIC and NACE have been adapted by national statistical authorities to national economic conditions and needs for economic analysis. Examples for this are the Norwegian Standard Industrial Classification (2008), the Standard Industrial Classification (SIC) developed in the United States and used also in the United Kingdom, and the North American Industry Classification used in Canada, Mexico and the United States. The Norwegian Standard Industrial Classification (Statistisk sentralbyrå, 2008) is based on the NACE Rev. 2, but is more specific by introducing sub-classes at the 5-digit-level. This is especially relevant for renewable energy production. In the Danish Standard Industrial Classification DB07 (Danmarks Statistik, 2007) there do not exist such sub-classes for renewable energy production.

Private industry classifications

Two examples of private industry classifications are (1) the MSCI Global Industry Classification Standard (GICS), a classification jointly developed by Morgan Stanley Capital International and Standard & Poor's for their financial market indexes, and (2) the Industry Classification Benchmark (ICB), a classification maintained by Dow Jones Indexes and FTSE Group. GICS consists of 10 sectors, 24 industry groups, 68 industries and 154 sub-industries into which S&P has categorized all major public companies. GICS is used as a basis for S&P and MSCI financial market indexes in which each company is assigned to a sub-industry, and to a corresponding industry, industry group and sector, according to the definition of its principal business activity. ICB consists of 10 industries, 19 super-sectors, 41 sectors, and 114 subsectors, allowing a detailed analysis (FTSE, 2012).

4A.2 Product and service classifications

Beside classifications of economic activities there exist also classifications of products and goods. Recently, also services have been included in the United Nations Product and Service Code. Major challenges for applying product and service classifications for studying energy innovation are related to (1) to define sufficiently fine-grained energy technology products, (2) to distinguish between "green" energy technology products and services and "non-green", and (3) international comparability.

International product classifications

As examples we compare here the United Nations Standard Products and Services Code (UNSPSC), the Harmonized Commodity Description and Coding System (HS) and the newly developed Standard Inter-

national Energy Product Classification (SIEC). According to the guidelines of UNSPC the United Nations Standard Product and Service Code is the “classification framework for products and services bought, sold or otherwise exchanged in the global marketplace” (UNDP, 2004). At its broadest classification level, the UNSPSC currently consists of 55 Segments, each spanning multiple industry sectors. Together, they are intended to encompass all goods and services exchanged in world marketplaces.

Figure 22: UNSPSC at the highest level, the segment level (Source: UNSPC Guidelines).



There is a basic unifying logic in the UNSPSC that operates horizontally across segments. It can be viewed as a transformation continuum of product categories ranging from basic raw materials in the first group of segments to industrial equipment and a wide-range of manufactured items derived from raw materials in the middle group of segments to a similarly wide-range of discrete services in the last group of segments (Figure 22). Energy relevant products and services are located in all segments but the fourth.

HS is a classification of products and was designed for international trade purposes. The detailed HS categories have been used as the main building blocks for the Central Product Classification (CPC). HS is being revised on a 5-year schedule, with recent revisions in 2002, 2007 and most recently in 2012 (United Nations Department of Economic and Social Affairs Statistical Division, 2011). Here we have the challenge that the product codes are very broad. For example it is difficult to measure trade of photovoltaic equipment because it is grouped together with light emitting diodes (HS code 854140 Photosensitive Semiconductor Devices; Light Emitting Diodes).

To amend these challenges – the spread of energy relevant products over many segments in UNSPSC and the lacking differentiation between energy technology products and other technology products – the Standard International Energy Product Classification (SIEC) was developed in 2011 by the Statistical Division of the United Nations. It is a classification of products relevant for energy statistics, and it is the first internationally agreed classification of energy products (United Nations Department of Economic and Social Affairs Statistics Division, 2011a, 2011b; United Nations Statistics Division, 2011). The classification has ten classes distinguishing between coal, peat and peat products, oil shale and oil sands, natural gas, oil, biofuels, waste, electricity, heat and nuclear and other fuels n.e.c. (United Nations Department of Economic and Social Affairs Statistics Division, 2011b:32). This classification will allow the creation of internationally comparable data sets on energy technology products, but it does not include energy services and the classification scheme is still not fine grained enough for comparing between different renewable electricity technologies, for example.

Danish statistic of energy industry

The Danish statistic of energy industry was developed as a national attempt to capture the span of Danish industrial activities in the energy sector. The first statistic was developed in 2007 and the methodology has been revised in 2009/2010 (Dræbye, 2010). The main framework for the compilation of the statistics was the identification of relevant industries, processes, products and services (Figure 23). This compilation combines extraction, processing and distribution of *solid energy fuels* (biomass, coal), petroleum and natural gas, the production and transmission, distribution and storage of *energy services*, such as electricity,

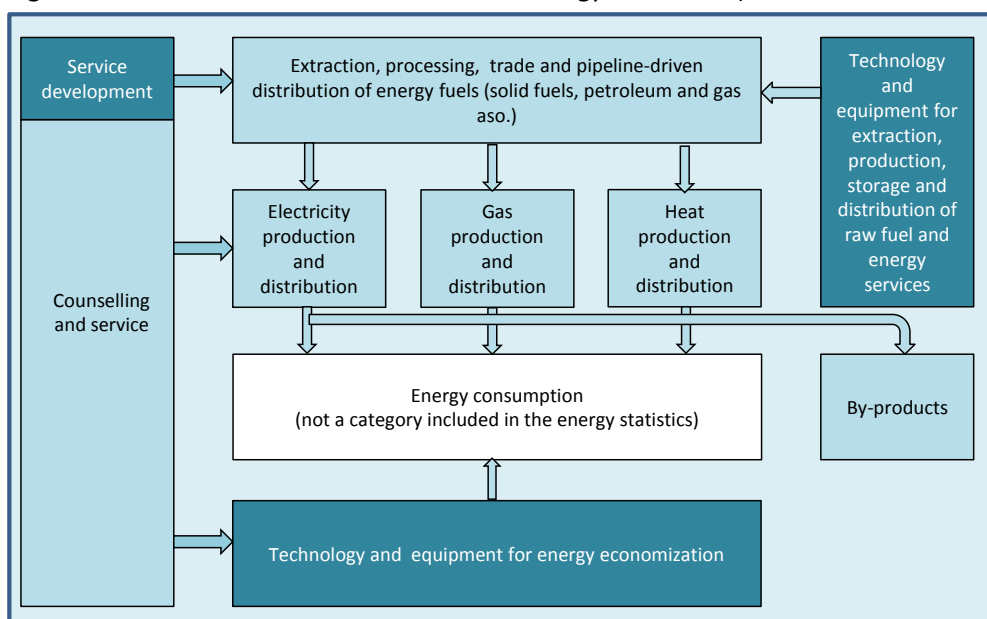
heat, natural gas and hydrogen, *technology and equipment* for extraction, processing, production and distribution of energy services, including internal heat and electricity distribution in buildings, and specialised energy efficiency technologies, such as insulation material and thermostat for regulation of temperature, and finally, counselling and service for extraction and processing of energy fuels, production, distribution and storage of energy services and execution of energy economization.

Two sources have been used for the compilation of the data, (1) Eurostat’s ComExt and (2) Danish enterprise statistics 6-digit DB07 which is based on NACE Rev. 2. Out of ComExt about 650 product codes have been identified as relevant. If the selected products have been produced in the energy industry the energy products have been included, while they have been excluded if they were produced in firms outside the energy industry. The industry sectors have been assessed based on the identification of the export value of the 25 top products of this industry. The industry enterprises have been scrutinized following this principle: If at least 85% of the export value of the industry was based on energy related products this industry was labelled as energy industry. If less than 15% of the export value was from energy related products this industry was discarded as energy industry. For industries which have an export value between 15 and 85% a distribution key was applied.

For us this methodology has some advantages and some drawbacks. An advantage is the innovative attempt to combine product codes, export data and industry classification. However, when scrutinizing the product table and the applied distribution key, it seems that this has been done very roughly, and a repetition in other countries is almost impossible. Also the comparability over time is in question. Therefore, we would prefer to apply the new Standard International Energy Product Classification and not a more home-made Danish classification.

In the most recent analysis the identified ComExt product codes have been classified into two groups: “green” energy technologies and other energy technology. “Green” energy technology is defined as either (1) usage of renewable energy: products and technologies related to wind power (onshore and offshore), processing of biomass to bioenergy, geothermal energy, wave power and solar energy or (2) more efficient usage of energy: electricity saving products and technologies, energy management and energy storage, green transport solutions, combined heat and power technology, heat pumps etc.

Figure 23: Identification and delineation of energy industries (translated from Danish, Dræbye, 2010).



4A.3 Patents classifications

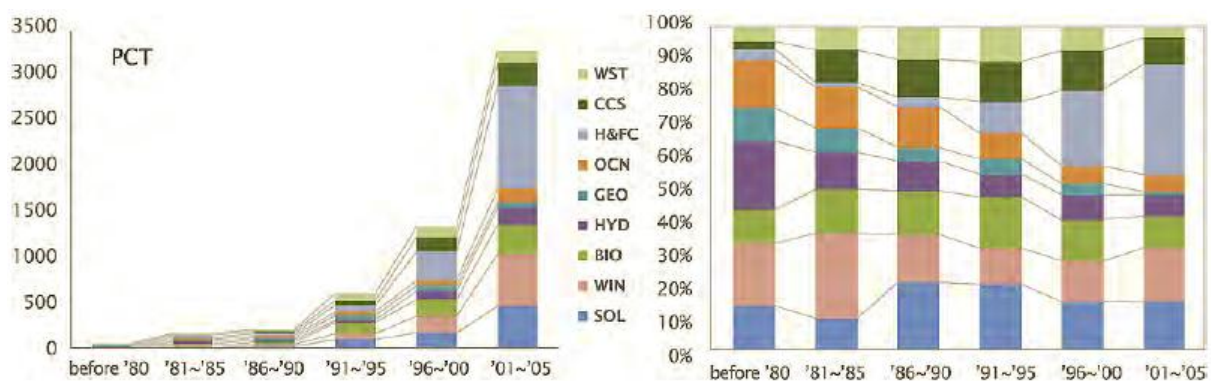
In the following chapter we discuss the challenges of the main patent classification systems, the International Patent Classification (IPC), the European Classification System (ECLA), and Cooperative Patent Classification (CPC). Patent classifications may be a source of problems due to the fact that an invention can be hard to classify precisely in established classification systems because patents in fast-evolving technological fields do not always fit into the existing classes. Therefore “it is best, so far as possible, to work with the most detailed and regularly updated system, such as USPOC for United States patents or ECLA for European ones, or to use keyword searches” (OECD, 1994b:41). Another problem is connected to the fact that in the established patent classification systems often technologies are spread over several sections of the classification. Nowadays, the most updated and for the purpose of studying sustainable energy innovation most suitable classification, the Cooperative Patent Classification (CPC) is the best point of departure (CPC, 2013).

IPC based patent analysis of renewable energy generation technologies

The IPC classification has a hierarchical structure and analysing wind power plants should be investigated not just with one sub-class, but with several. Similar problems we can see in most of the renewable energy generation technologies. In addition, we need to combine IPC subclasses with keywords, in some cases, such as bioenergy, there do not exist satisfactory IPC subclasses. This makes it challenging to define the right combination of IPC codes and keywords to achieve comparability.

In 2009, the World Intellectual Property Organization (WIPO) published a patent-based technology analysis report on alternative energy technologies (WIPO, 2009). Here the patents were identified by a combination of IPC subclasses and keywords (2009:99ff). Here we give some of the results for following technologies: solar power, solar thermal, wind power, bio energy, hydropower, geothermal energy, wave and tidal power, hydrogen and fuel cells, carbon capture and storage, and waste-to-energy. The results are based on patent applications filed from 1978 to 2005 through the Patent Cooperation Treaty (PCT) system. It should be noted that the selection of the IPC classes is not quite convincing, as the rather narrow definition for wind power and the selection of keywords for bio energy show. Over the investigated time line the following technologies have seen a substantial increase in patent applications: solar and wind power and hydrogen and fuel cells (Figure 24).

Figure 24: Applications through the PCT system by technology (WIPO, 2009:31, Figure 12).

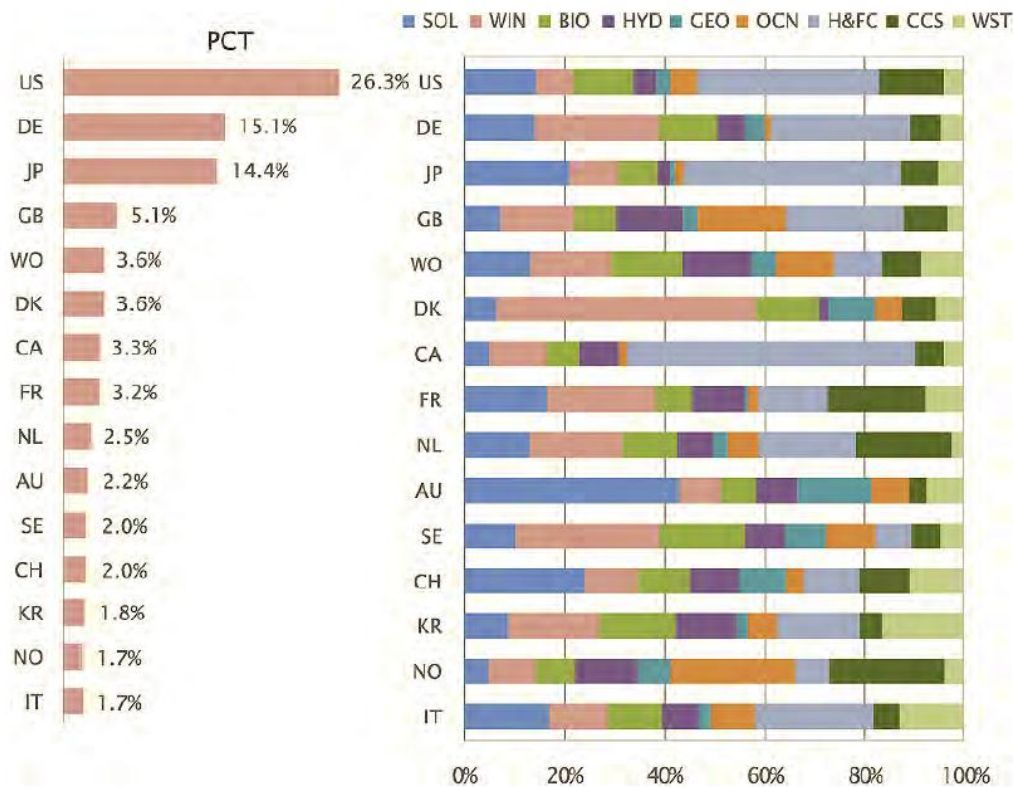


Note: Following symbols have been used for representing the different technologies: SOL: solar power, solar thermal; WIN: wind power; BIO: bio energy; HYD: hydropower; GEO: geothermal energy; OCN: wave and tidal power; H&FC: hydrogen and fuel cells; CCS: carbon capture and storage; WST: waste-to-energy.

Analysing the nationality of the applicants, we see for Denmark for example the clear domination of wind technology (Figure 25). Only one other country is dominated that much by one technology: Canada, which is dominated by hydrogen and fuel cells technology. The two other Nordic countries, Norway and Sweden, display a more diverse pattern of specialisation.

A group of researchers at the OECD Environmental Directorate, Nick Johnstone and Haščič, Ivan, have used patent data for analysing the effect of environmental policies on technological innovation (Nick Johnstone, Hascic, & Popp, 2008; N. Johnstone, Hascic, & Popp, 2010).

Figure 25: Applications through the PCT system by applicant nationality (WIPO, 2009:30, Figure 11).



European Classification (ECLA)

The development of the European Classification System (ECLA) was originally based on the old Dutch classification scheme, but after 1968 it was reorganised on the principles laid out in the first edition of the IPC (Rampelmann, 1998). ECLA has been continuously revised. Main differences to IPC can be summarised as following: (1) too wide IPC classification entries are further sub-divided, (2) unclear IPC classification entries are either modified or not used at all, (3) modifications of ECLA are realised also in the backlog of the system, which means that there exist only one current edition. According to Rampelmann, at the end of 1997, ECLA contained 120,000 groups, while the then in force 6th IPC edition contained 67,000 groups (1998:7). Later a team of patent examiners at the European Patent Office developed a tagging system for tracing patents for climate change technologies (Y02) which has now been implemented into the ECLA and then into the Cooperative Patent Classification (CPC) (see Cooperative Patent Classification (CPC)).

Cooperative Patent Classification (CPC)

The Cooperative Patent Classification (CPC) is the result of a partnership between the United States Patent and Trademark Office (USPTO) and the EPO which “have agreed to harmonize their existing classification systems (ECLA and the United States Patent Classification, USPC, respectively) and migrate towards a common classification scheme”.³ The migration to CPC was developed based in large part on the existing ECLA modified to ensure compliance with IPC standards administered by the World Intellectual Property Organization (WIPO). CPC is jointly managed and promoted by the EPO and USPTO. It is divided into nine

³ <http://www.cooperativepatentclassification.org/about.html>

sections, A–H and Y, which in turn are sub-divided into classes, sub-classes, groups and sub-groups. There exist approximately 250 000 classification entries. CPC will use IPC type numbering, which means that ECLA letters after the “/” will be replaced by digits. The revisions of CPC will be undertaken jointly by EPO and USPTO.

The nine CPC sections are:

- A. Human necessities
- B. Performing operations; transporting
- C. Chemistry; metallurgy
- D. Textiles; paper
- E. Fixed constructions
- F. Mechanical engineering; lighting; heating; weapons; blasting engines or pumps
- G. Physics
- H. Electricity
- Y. General tagging of new technological developments; general tagging of cross-sectional technologies spanning over several sections of the IPC; technical subjects covered by former USPC cross-reference art collections [XRACs] and digests

The most recent versions of the CPC definitions can be found on the webpage of CPC.⁴ There exist concordance tables from ECLA to CPC (static) and from CPC to IPC (dynamic).⁵ In section Y we find the class Y02 Technologies or Applications for Mitigation or Adaptation against Climate Change which has several sub-classes relevant for studying energy innovation systems. These sub-classes give a much better overview of the involved technologies than the former IPC, USPTO or ECLA. The categories in the class Y02 were “defined with the help of experts in the field, both from within the EPO and from the Intergovernmental Panel on Climate Change (IPCC)” (UNEP, EPO, & ICTSD, 2010:88).

Table 17: CPC – Y02 Technologies or Applications for Mitigation or Adaptation against Climate Change

Y02B	Indexing Scheme relating to Climate Change Mitigation Technologies related to Buildings, e.g. including Housing and appliances or related End-user Applications
Y02C	Capture, Storage, Sequestration or Disposal of Greenhouse Gases [GHG]
Y02E	Reduction of Greenhouse Gases [GHG] Emission, related to Energy Generation, Transmission or Distribution
Y02T	Climate Change Mitigation Technologies related to Transportation

Y02E is divided into following groups:

Y02E 10/00	Energy generation through renewable energy sources
Y02E 20/00	Combustion technologies with mitigation potential
Y02E 30/00	Energy generation of nuclear origin
Y02E 40/00	Technologies for an efficient electrical power generation, transmission or distribution
Y02E 50/00	Technologies for the production of fuel of non-fossil origin
Y02E 60/00	Enabling technologies or technologies with a potential or indirect contribution to GHG emissions mitigation
Y02E 70/00	Other energy conversion or management systems reducing GHG emissions

In a recent OECD report on energy and climate policy the more detailed ECLA and the new CPC have been applied on a study of climate change mitigating technologies (Haščič, Watson, Johnstone, & Kaminker, 2012; OECD, 2012). Specialization in individual technology fields within climate change mitigating technologies is documented there. According to their study there is a high specialisation (among the five leading countries) of Denmark in wind technology, for Norway in hydro and ocean power, CO₂ capture and CO₂ storage, and for Finland in biofuels.

⁴ <http://www.cooperativepatentclassification.org/cpcSchemeAndDefinitions/table.html>

⁵ <http://www.cooperativepatentclassification.org/cpcConcordances/CPCtoIP.txt>

4B The challenge of energy efficiency innovations

Klaus Rennings, with contributions by Mads Borup

Measuring application of energy efficiency technology

Application of energy efficiency technologies will often be more difficult to measure than the application of renewable energy production technologies etc. addressed above. One possibility is to identify specific product types and measure the extent of their application either in economic terms (trade of products) or in technical terms (amounts of units installed or in energy consumption or efficiency figures). As energy efficiency issues appear in a lot of different product and application areas, and as energy efficiency is often a relative issue related to the already existing practices in the specific application areas, it is highly difficult to establish a general and homogeneous way of measuring the application of energy efficiency products in total.

An approach focused on the specific application areas and the functions filled by the innovations can be taken. This can be a bottom up strategy where one may succeed in measuring the application on micro and firm level, but where it is difficult to establish a full and consistent macro level picture. An example of a micro-based measuring is the data from the 'Community Innovation Survey' presented briefly in the next section.

Another, opposite, possibility is a macro-level strategy, where one uses macro level statistics on energy consumption and measures the developments in energy intensity, i.e., the developments in energy consumption set in relation to developments in activities. The activities can be measured in macro economical terms like GDP. An example of a macro-database is the new WIOD database which is presented more detailed in section 3. Other examples would include:

- IEA's work on energy efficiency indicators (to a large extent building on energy consumption statistics in different sectors relative to output – not innovation focus, however some attention to best-available-technologies etc. in some sectors),
www.iea.org/publications/freepublications/publication/Indicators_2008.pdf
- IEA's database on energy efficiency policies and measures,
www.iea.org/policiesandmeasures/energyefficiency
- EU policies, e.g. energy efficiency watch which is a survey on policy efficiency
www.energy-efficiency-watch.org/index.php?id=88

Micro-level: Energy efficiency in the EU Community Innovation Survey

In the European innovation statistics, the 'Community Innovation Survey', an eco-innovation module has been introduced that contributes valuable insight into energy efficiency innovation on a statistical level. One of the advantages is that it is directly connected to the general statistics on innovativeness of European enterprises. Amongst other things, figures are found on the proportion of innovative enterprises that introduce new energy saving products or services, i.e. innovations with reduced energy consumption at the end user. Moreover, there are also figures about the proportion of enterprises with energy efficient process innovations. In both cases, the shares of enterprises that introduce these types of innovations are considerable. The following table shows examples of the available figures.

The eco-innovation module is experimental in character and not established as a permanent and fixed part of the innovation statistics. Moreover, as appears from the figure, it is not adopted by all EU countries. The advantage of the database is that it includes large innovation-relevant information of a firm, and thus allow

for causal analysis. For example, Horbach et al. (2012) found that cost reduction is a main driver of energy efficiency innovations, while in general eco-innovations are largely driven by government regulation. Another source of micro-level data for energy efficiency innovations can be patent statistics as described in the previous chapters.

Table 18: Proportion of innovative enterprises introducing innovations with reduced energy use in 1) end use of products/services (to the right), and 2) the production of products/services (to the left). (2008, % of innovative enterprises) (Eurostat 2011, CIS6).

	Reduced energy use per unit of output				End-user benefits, reduced energy use			
	Total	With 10 to 49 employees	With 50 to 249 employees	With > 250 employees	Total	With 10 to 49 employees	With 50 to 249 employees	With > 250 employees
Belgium	30.3	26.3	37.9	56.5	27.0	25.0	31.5	37.8
Bulgaria	13.6	11.4	15.5	24.4	8.8	8.3	8.2	15.0
Czech Republic	33.1	28.4	40.8	53.1	30.7	29.3	33.2	36.9
Denmark	.	.	.	.	.	.	.	.
Germany	46.4	42.9	54.5	60.4	44.0	41.4	49.3	55.9
Estonia	11.7	10.3	14.5	18.4	15.0	12.7	18.8	30.4
Ireland	33.5	28.0	44.7	64.4	33.1	31.8	35.1	43.1
Greece	.	.	.	.	.	.	.	.
Spain	.	.	.	.	.	.	.	.
France	28.2	23.8	35.0	50.5	23.9	21.6	27.0	38.5
Italy	16.5	14.8	22.6	34.8	23.5	21.5	30.8	43.3
Cyprus	13.6	11.5	19.3	28.0	5.4	4.8	7.3	8.0
Latvia	23.5	26.8	13.7	29.7	21.7	26.1	11.4	18.8
Lithuania	29.3	22.7	37.0	51.9	22.9	19.4	28.8	27.9
Luxembourg	24.8	17.5	33.8	54.6	30.1	28.5	28.3	48.3
Hungary	36.3	33.1	36.9	55.7	19.1	19.3	16.5	23.8
Malta	27.0	25.3	25.9	45.0	19.8	17.7	20.7	35.0
Netherlands	21.1	17.6	26.3	41.9	19.8	17.9	23.2	30.2
Austria	30.7	26.8	34.9	53.8	28.9	26.0	32.9	44.2
Poland	25.3	21.5	28.0	40.5	24.8	24.1	24.1	31.4
Portugal	41.5	40.2	43.8	55.9	39.1	40.2	34.7	40.6
Romania	32.8	29.2	37.1	50.6	30.3	28.8	32.3	37.2
Slovenia	.	.	.	.	.	.	.	.
Slovakia	23.7	18.3	31.4	45.5	26.2	24.9	27.7	32.9
Finland	32.9	28.4	38.9	56.5	33.0	29.7	35.7	55.6
Sweden	28.6	25.1	33.4	53.5	28.1	27.3	25.6	46.5
United Kingdom	.	.	.	.	.	.	.	.
Croatia	32.7	29.8	35.7	50.0	32.6	32.2	31.7	40.2

Source: Eurostat (online data code: inn_cis6_eco)

Macro level: Economic growth, structural change, and energy use

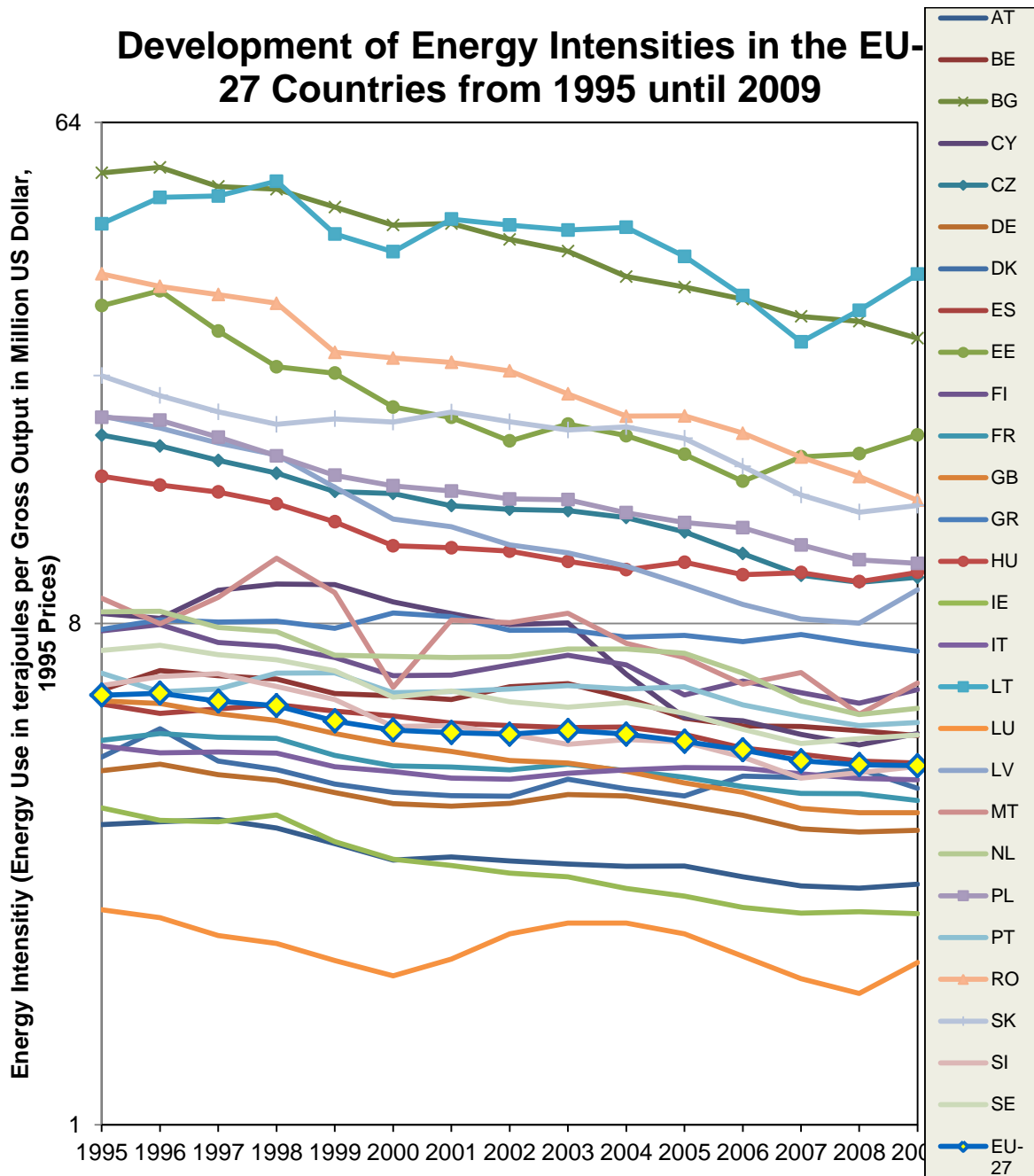
An example of a macro level approach is the World Input Output Database (WIOD; www.wiod.org) which is new and publicly available since May 2012. The WIOD project is a large project funded by the European Union under the 7th framework program. It offers sector level information on produced output, used inputs and it provides information on pollution and energy use. Furthermore, it allows for a so-called index decomposition method that is restricted to the manufacturing sector only. The index decomposition method separates several effects that have influenced the total development of the aggregate energy use.

It is worthwhile to study trends in energy efficiency in different countries on a macro-economic level. WIOD includes the EU-27 countries as well as the world's major economies including the United States (US), Japan (JP) and China (CN). The countries included account for approximately 85 percent of the world's production and report all data on a sectoral disaggregated level of 37 sectors. Moreover, the economic data is linked to environmental accounts and energy use. Energy use (here synonymously used with energy consumption) in the WIOD database considers the use-side of energy. This means that the gross energy use reported in the WIOD data covers the transformation of primary energy to other forms of energy like electricity and heat as

well as the final use of energy. In this sense, gross energy use includes intermediate consumption plus final energy use plus exports of energy, respectively.

The WIOD data covers the years 1995 until 2009. Figure 26 illustrates the change in energy intensity at the country-level for 27 European countries. All countries faced a decrease in energy intensity between 1995 and 2009. The countries with the highest energy intensities are Bulgaria (BG), Lithuania (LT), Estonia (EE), Slovakia (SK), Poland (PL), the Czech Republic (CZ), Latvia (LV), and Hungary (HU).

Figure 26:



For Europe as a whole, the situation looks quite different. The reason why Europe as a whole has a low energy intensity compared with the intensities of most of the countries in Figure 26 is simply that the most

energy intensive countries have a low share of the total output produced in the whole Europe. Countries that account for a high share of the goods produced in Europe have low energy intensity.

Other reasons for a change in energy use might be changes in the level of production or changes in the composition of different sectors. In this sense, a so-called index decomposition analysis is carried out that decomposes a change in an underlying index (which is total energy use in manufacturing sectors in this case) in a scale, a composition, and most importantly, in a technique effect. The first accounts for the change in the index that is due to a change in economic activity (overall level of production⁶) holding the composition of an economy's sectors and the technology (energy efficiency) fixed over time. The composition effect indicates how energy use changes if the composition of the sectors within a country changes at a fixed scale (constant gross output) and given a fixed technology. The industry composition measures the share of goods produced in different sectors (that differ in their energy intensity) in the total level of production of a country, or for the sum of manufacturing sectors, as studied here. As a brief example, a negative composition effect would mean that, holding the size of the total manufacturing sector fixed as well as energy intensities of its subsectors, production in subsectors with lower energy intensity would have increased relative to the ones that have higher energy intensities. Finally and most importantly, the technique effect studies how energy use would have changed, had the total level of production (scale effect) and the industry composition remained unchanged over time.

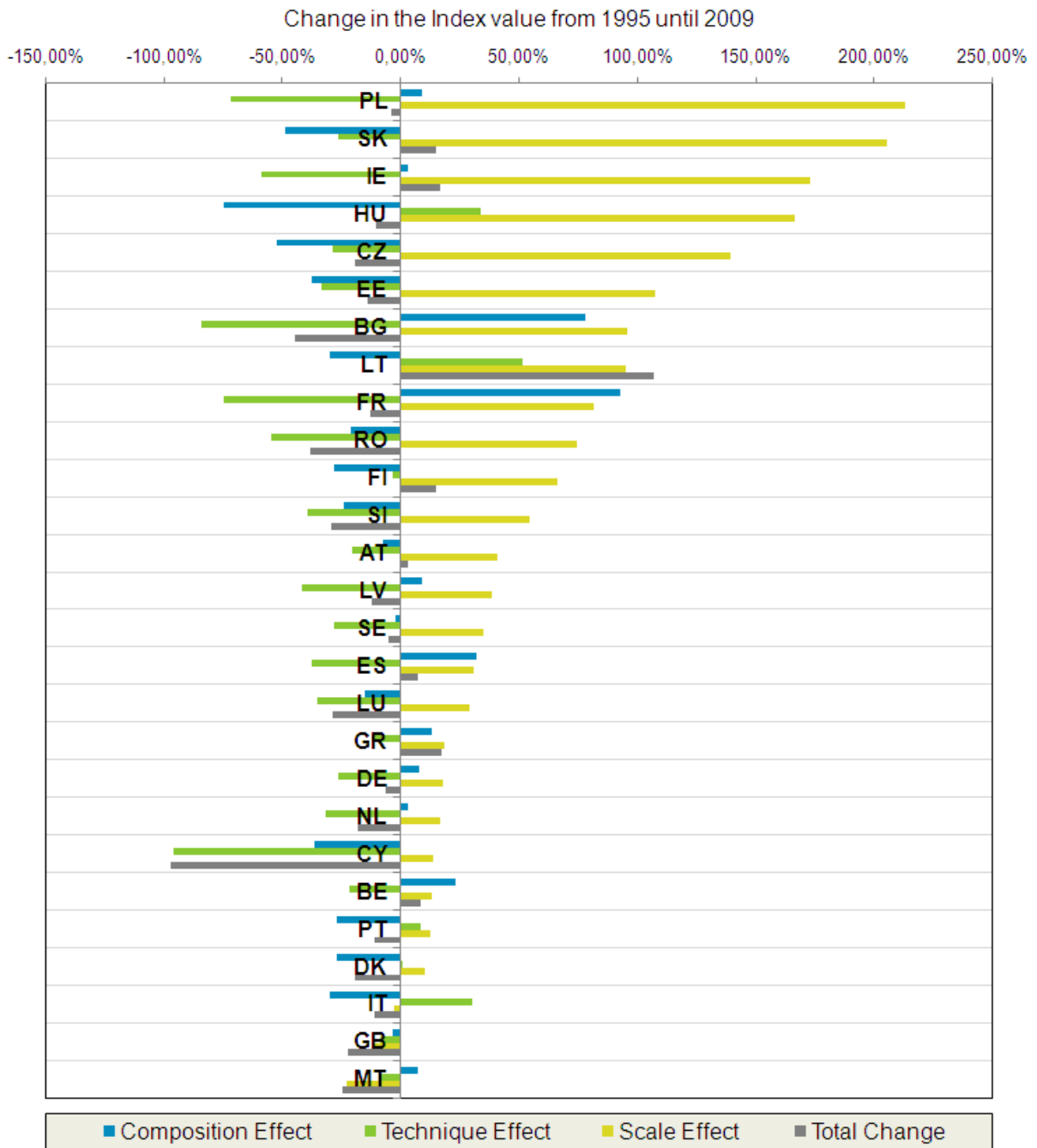
Until now, changes in energy efficiency for Europe have been studied for the EU-27, EU-15, or EU-12 member states taken together. What makes this problematic is simply the fact that, for instance in 2009, the large countries France, the United Kingdom, and Germany account for 53.59 percent of the whole output in Europe's manufacturing sector. Thus, the situation could be quite different in the individual countries compared to the EU-27. Therefore, the index decomposition analysis has been carried out for every country individually. The results appear in Figure 27.

Please note that (as to improve readability) this figure reports the change in the index value and not the index itself. For instance in Estonia, the change in the index value of the scale effect (yellow bar) of approximately 100 percent corresponds to an index value of approximately two in 2009. Thus, had energy efficiency and subsector composition remained constant from 1995 until 2009, Estonia would have consumed more than 100 percent more energy in 2009 compared to 1995 (which is more than two times the value in 1995). Likewise, for Poland, a decrease in the index value of the technique effect (green bar) of approximately 70 percent indicates that the index decreased from 1995 until 2009 from one to approximately 0.3. In other words, had there been no economic growth and had the subsector composition remained unchanged, Poland's manufacturing sector would have consumed in 2009 approximately 30 percent of the energy it consumed in 1995, which is a reduction of 70 percent (and due to an increase in energy efficiency). The composition effect and the total effect can be interpreted in the same fashion. Overall, in most of the EU-27 countries, total energy use in the manufacturing sectors decreased from 1995 until 2009. The grey bars indicate the change in the index of total energy use (where 1995 = 1) in percent. What is interesting is that those countries with a high scale effect (most of them are EU-12 countries) are at the same time those countries that achieved the highest reduction of energy intensity, indicated by the technique effect (holding all other effects constant). This means that economic growth has been accompanied by improvements in energy efficiency.

⁶ The level of production is measured by the gross output of the different manufacturing sectors. The gross output data is converted into 1995 US Dollars as to make a comparison between different countries possible.

Figure 27:

Decomposition Analysis of Total Energy Use in Manufacturing Sectors



What the analyses presented so far allow concluding is that technical change towards the use of more energy efficient technologies occurred in most of the EU-27 countries and also in other major economies.

Conclusions and challenges for measuring energy-efficiency

To sum up the findings of the macro-level data, the effect of technical change in Europe has more than outweighed the increase in energy use from economic growth in most countries, so that energy consumption in manufacturing sectors have decreased in the last decade. These results highlight the importance of eco-innovations on the aggregate country level and show how the eco-innovations introduced by European enterprises have contributed to Europe's energy saving and climate goals. In addition, micro-level data can offer insights into the determinants and impacts of eco-efficiency innovations at the firm level.

A challenge for the future measurement of energy-efficiency will be the consideration of the rebound effect, i.e. the fact that energy consumption increases (due to a reduced price of energy) after the introduction of energy efficiency measures. Up to now the rebound effect is more or less ignored in energy statistics and energy policy. An exception is the UK where energy policy development takes the rebound effect into account (Maxwell et al., 2011). The anticipated energy saving for domestic insulation measures has to be downgraded by 15 %. This can be seen as a good practice for other countries.

4C The challenge of greening of markets and the role of standards

Maj Munch Andersen

4C.1 Introduction

Applying an *innovation system* perspective on energy indicators makes it important to consider how the set of indicators may include demand side aspects and wider changes in framework conditions to a higher degree. Conceptually, the innovation systems literature builds on evolutionary economic theory (Nelson and Winter, 1982). A basic assumption is that innovation is time and space dependent and subject to path dependencies. Positive feedback mechanisms on historical events lead to increasing returns and trajectories that create lock-ins on the system (industry, national or regional) level (Dosi, 1982; Arthur, 1994). The essence of innovation systems thinking is hence the co-evolution of organizations (firms), knowledge, technologies, institutions and markets over time (Lundvall, 1992, 2007b; Nelson 1993). While the recent Oslo manual as well as other innovation indicators (e.g. European Innovation Scoreboard 2010) reflect trends towards a richer innovation concept going beyond formal R&D and including organizational and marketing innovations the focus remains very much on firm level innovation while more economy-wide changes such as the emergence of a new market are not dealt with (OECD 2005). The current dominant focus on input innovation indicators gives, as discussed in chapter two, not just an unfortunate bias towards science based indicators but entails a neglect of investigating the linkage between the creation of variety and selection mechanisms in the indicators. In practice lies the assumption that markets are simply there rather than paying attention to how markets evolve and consolidate through the passage of time. Over time markets grow, mature and become more efficient as information codes, information channels and trust are created between users and producers, none the least essential in B2B markets (Arrow 1962; Lundvall, 1988). More formal standards and labels may support these relational institutions. Only when such market supporting institutions come into place we may see a transformation from emerging markets into mainstream market penetration.

This chapter focuses on the challenges of measuring the emerging, pervasive 'greening' of markets, considering that energy technologies makes up an important part of wider green technologies or 'eco-innovations'. We cannot understand the dynamics of energy innovation without understanding the greening of markets. The chapter particularly looks into the potentialities of using standards and labels as innovation indicators, arguing that these could make up important but neglected throughput indicators related to institution formation of the innovation process. They form a central role for the development of well-functioning green markets and for achieving compatibility between complementary innovations and hence efficient coordination in the value chains. A pilot case on measuring energy efficiency developments related to buildings is given.

In modern innovation systems innovation is not merely a function of simple variety and selection mechanisms. The innovation process is becoming still more institutionalised and institution formation makes up a still more important part of the innovation process (Lundvall, 1992). Formal standards and labels are today key economic institutions and they none the least act as facilitators of efficient R&D (standards) but also efficient markets and trade (both standards and labels) (Blind and Jungmittag 2008).

The greening of markets and the role of standards

Until the mid-zeroes the environment was still largely considered a burden to business (see Andersen, 2009, 2012) and hence the 'green economy', 'green growth' or 'eco-innovation' agenda, here interpreted as synonymous, is only very recent (UNESCAP 2006; OECD 2011; UNEP 2012). It is, however, difficult to

track the emergence of the green economy. There is a lack of statistics and indicators on eco-innovation. The use of trade and industry statistics is limited, as the greening of firms, markets and technologies goes much beyond the traditional 'environmental sector' category covered in these (Kemp and Arundel, 1998; Horbach 2005; Andersen, 2006; Kemp and Pearson, 2007; OECD 2011; EIO, 2012). When it comes to energy technologies, particularly energy efficiency indicators are insufficient (IEA 2012, see also Rennings chapter in this paper). The new 'green economy' agenda is leading to novel intensive work on developing better indicators, see (OECD 2011; United Nations 2011; UNEP 2012). This chapter takes as a starting point that the greening of the economy is a techno-economic paradigm change having economy-wide disruptive effects (Andersen, 1999). Eco-innovation, then, is not a technology or sector but the rise of new green business models and associated green markets where environmental issues are becoming a new value proposition and gradually a selection criterion on the market (Andersen, 2006, 2008, 2012). Interpreting the green market as emerging puts a) attention to the importance of coordination problems and transaction costs along the value chains, costs that standards may lower in important ways; b) attention to the importance of labels for achieving efficient green market communication. 'Greening' is credence characteristic and cannot communicate itself on the market but requires some kind of certification (Andersen, 1999, 2002, 2012).

Standards and labels

Formal standards are targeted norms articulated in a document, achieved through a consensus process by a recognized organ, the standardization bodies. International standards play a key role for innovation in providing harmonized, compatible solutions and access to world markets. Standards provide rules, guidance or characteristic features often related to products or processes but may go beyond these and e.g. refer to terminology, and measurement methods (Gürtler 2011). Labels are, on the other hand, information codes which may be certified or not, directed at the market or stakeholders which inform about the properties of a product or firm. Concerning energy efficiency, energy- and eco-labels are both relevant. Standards and labels are interesting innovation indicators because they potentially relate to the entire innovation process and any type of business functions and products including service products. They hence have the potential to capture also less science based innovation as well as market side aspects. It is here suggested to designate standards and labels as 'throughput' indicators, that is measures that attempt to capture intermediate products of innovation processes (Grupp and Schwitalla, 1989).

Innovation research on standards tend to focus on the competition between competing emerging standards as well as the economic impacts of these, often related to IPR issues and trade restrictions (Blind and Jungmittag (2008), Blind (2011), Bekkers et al. (2012). The speculative novel idea pursued here is to view longitudinal trends in the standardisation process as an indicator of changes in the innovation process itself; more specifically, changes in the thematic *direction* of the standardization process are sought captured. The analysis below seeks to capture when, where and how energy efficiency becomes an issue in Danish and international standardization work using buildings as a case. This entails looking beyond single standardization cases and instead highlighting the uptake of new themes and issues across a wide spectrum of standardization activities. The standardization processes themselves may further reflect important features of how national and regional (e.g. EU) innovation systems work. They could be seen as a new key indicator of the level and quality of institution formation in specific technological or economic areas in national and regional (i.e. EU) innovation systems. An important part of the, so far quite small, and explorative work undertaken has been to investigate methodological opportunities and challenges in using standards for such longitudinal quantitative studies. The institutional set-up and processes related to particularly standardization are highly complicated and a detailed account goes beyond this paper. Here only some main features will be given and sought illustrated via the building case below. Labels may be seen as derived from standards, as the more formalized or important labels often are initiated or supported by standards e.g. using their definitions or measurement recommendations. Labeling is only briefly looked

into, presenting some overview of available data within building relevant labels. The analysis takes a starting point in Danish standardization work seeking to put this into an international perspective.

4C.2 Pilot case: energy efficiency in buildings

Buildings have been chosen as case because of three reasons: First, buildings are the single main user of energy, accounting for around 40% of EU energy requirements, and 32 % at the world level (IEA, 2012). Second, indicators on energy efficiency innovation are quite poor. Third, the construction sector is fairly low tech and very home market oriented meaning that traditional innovation indicators such as R&D investments and trade statistics have less relevance. Expanding on the second factor, the low availability of indicators, the new IEA energy progress report states that 'Assessing the progress of energy efficiency in buildings is a challenge. Data on the deployment of energy efficient technologies are limited, and many different technologies and components contribute to the overall energy performance of buildings. Progress is therefore evaluated by reviewing building energy codes, improvements in appliance efficiency, and deployment of solar thermal and heat pump technologies for heating and cooling. This assessment remains largely incomplete until further global data collection enables better analysis of efficiency in the buildings sector' (IEA 2012 p. 38).

There is, in other words, lacking data on trends in specific building technologies both at the building system level and the building component level. The international data available currently is limited to improvements in the energy efficiency of the overall building stock.⁷ The EU MURE project provides some more specific data and concludes, but for households only, that in EU households, energy efficiency improved by 1.1%/year since 1990. Space heating and large appliances experienced the greatest energy efficiency improvement close to 1.5%/year, each compared to an improvement of 2.1%/year in industry and 0,8%/year in transport.⁸ Despite the registered improvements energy demand from the buildings sector is expected to more than double by 2050 globally, mainly due to population growth and rise in wealth and thereby changing occupancy structures (IEA, 2012).⁹ The lack of more technological indicators is to some degree sought met by a recent European initiative, the BPIE data hub launched in February 2013.¹⁰ The analyses are, however, mainly country wise rather than cross country indicators, the data have a varied character and some countries are lacking.¹¹

Data on labels in buildings

Concerning labelling in the building area related to energy efficiency, which includes energy labels and the somewhat broader eco-labels, the main conclusion of the review undertaken of literatures, webpages and consultancy with experts is that there are quite few international labels but somewhat more national labels, many of these of a temporary or recent nature. But there is a lack of overview over these and no systematic longitudinal mapping of their emergence or market penetration. Overall, relatively few labels are oriented towards buildings and even fewer at building components or –technologies; this also goes for the EU flower and the Nordic Swan. The focus of energy and eco-labels are still predominately on small consumer products which in the energy area largely means appliances.¹² New EU policy signals though

⁷ See IEA data at <http://www.sustainablebuildingscentre.org/pages/beep>

⁸ Data from the ODYSSEE MURE project see http://www.muredatabase.org/query1b_mr.asp and http://en.wikipedia.org/wiki/Energy_efficiency_in_europe

⁹ Average OECD occupancy in the residential sector dropped from 2.9 in 2006 to 2.6 in 2009 while the size of households increased. In the United States, average household size increased from 166 m² to 202 m² between 1990 and 2008, while China's urban houses increased in size from 13.7 m² to 27 m² per occupant between 1990 and 2005 (National Bureau of Statistics, 2007 and IEA 2012).

¹⁰ <http://www.buildingsdata.eu/bpie> The data are based on a big survey from 2010-2011 to EU member states. See the report BPIE (2011) European Buildings under the Microscope'.

¹¹ <http://www.buildingsdata.eu/>

¹² See e.g. <http://wec-indicators.enerdata.eu/>, <http://www.ecolabelindex.com/ecolabels/>, <http://www.muredatabase.org/index.htm>

means that more labels on building components are expected in the coming years.¹³ The 'Eco label index' does look broader and does have a search function for building products but the data are poor.¹⁴

The best indicators on energy efficiency related to buildings are policy indicators. The last years have seen the rise of several new international policy indicator initiatives related to buildings, see noticeably BPIE, IEA, WEC and MURE.¹⁵ These are relevant for tracking developments in the implementation of mandatory and in part voluntary labels but not their market penetration.

The most important international label related to buildings is the Energy Performance Certificate (EPC) on buildings. Derived from the central EPBD (Energy Performance of Buildings) EU directive from 2002, it is mandatory since 2006 to implement Energy Performance Certificates in EU countries. There are analysis on the implementation and distribution of EPBD standards including the EPC, but so far mainly in the form of national reports rather than quantitative analyses.¹⁶ There is quite a varied level of implementation rate and speed so far within EU countries. Denmark has been among the initiators of this scheme together with the Netherlands. Denmark is also among the pioneering countries starting already in 1997 and has also one of the most extensive systems (Hansen et al. 2013). In time EPC is expected to become a good source of data on energy efficiency innovation in buildings and related green market development within the EU countries, but it is likely to take quite some years before the data quality will improve sufficiently across EU countries (CENSE 2012).¹⁷

Illustrating the key role of standards for the greening of the building market it is interesting to notice that behind the EPC scheme as well as the related energy inspections of boilers and ventilation systems in buildings, which together make up the main initiatives of the EPBD, lies no less than 596 CEN standards, illustrating the immense complexity of these tasks and the need for comprehensive European coordination.¹⁸ New Danish analyses show that after a very long difficult introductory period for the EPC, there are finally signs of positive economic effects on the Danish building market; buildings with a high energy performance achieve better prices (Hansen et al. 2013).

4C.2.1 Standards and energy efficiency in buildings

Shortly on standardization

The pillars of the standardization system are the National Standardization Bodies (NSB), in Denmark Danish Standards (DS). These are the main point of access for stakeholders to the international standardization organizations. Standardization processes have changed a lot over time, and have generally grown in importance especially in EU. More and more standards are developed at the international level, for Europe mainly CEN, CENELEC, ISO and IEC.¹⁹ There is a close co-operation between international, regional and national standards bodies.²⁰ New standards are developed in so-called technical committees (TC) or subcommittees (SC) or for more preliminary or new work, in Working groups (WG).

¹³ See <http://www.ecodesign-info.eu/>, for information on the working plan of the ecodesign directive which since 2009 includes initiatives for not only energy using but also energy related products such as several building components.

¹⁴ http://www.ecolabelindex.com/ecolabels/?st=category,building_products

¹⁵ <http://www.buildingsdata.eu/bpie-data-hub>, <http://wec-indicators.enerdata.eu/>, http://www.muredatabase.org/query1b_mr.-asp, <http://www.sustainablebuildingscentre.org/pages/beep>.

¹⁶ See the EU network Concerted Action, <http://www.epbd-ca.eu/country-information>

¹⁷ <http://www.epbd-ca.eu/country-information>

¹⁸ Own analysis based on CEN data. The number of standards are those which have been implemented in Denmark related to the EPBD directive so far.

¹⁹ For Denmark the most important ones being CEN, the European standardization organization, and CENELEC, covering electronic products, the global ISO and IEC, the latter covering electronic products. Since the so-called 'New Approach' in 1985 a large part of EU legislation is implemented via harmonized standards which has led to a marked rise in European standardization.

²⁰ CEN and ISO have a very close technical cooperation; since the Vienna Agreement from 1991 new standards projects are jointly planned between them. CEN further cooperates extensively with other national and regional standardization bodies worldwide.

Standards as innovation indicators on energy efficiency – methodological issues

Longitudinal studies of trends in standardization are very few. The literature on the development of energy saving standards is very scarce and possibly loosely founded, claiming that Poland and North America were pioneering this work in the 1960s and 1970s, although early standards were ‘weak’ and little applied (Wiel and McMathon, 2005). These findings are surprising, given that European countries generally are considered early movers in the energy efficiency area. In the attempt to uncover the emergence and development of energy efficiency issues in standards two types of main indicators are here suggested. These are indicators where the information is relatively easily accessible electronically via the web pages or documents from the standardization organizations. In this case we use information from the core relevant international standardization organizations (CEN/CENELEC, ISO/IEC) as well as Danish Standards. Naturally, more studies could be made if more national standardization bodies were included:

1) The first set of indicators tracks changes in the thematic orientation of the committees, i.e. the evolution and transformation over time of energy efficiency or energy performance issues in Technical Committees, Sub Committees and Working Groups in different standardization bodies. The challenge is to identify the relevant committees/groups. Some are related directly to EU directives, noticeably the central EPBD, (Energy Performance of Buildings Directive) and therefore per definition relevant to the theme pursued, others more generally dealing with energy efficiency, noticeably the EuP (Eco design of products Directive dealing exclusively with energy efficiency issues of energy relevant products). Indicators suggested to measure Danish/national prominence are: A) the secretariat function, (held by a given national standardization body). B) for ISO only, the status of participation i.e. participating (P), observing (O), and non-participating (N) status of member countries of the committees and groups. There is no such registration in CEN where all 33 national members are supposed to be P.

2) The second set tracks the number of standards dealing with energy efficiency related to buildings and building components across the core standardization organizations (CEN/CENELEC, ISO/IEC). The analysis seeks to identify when we see changes in (energy efficiency related) standardization activity but also the diffusion of the energy efficiency themes between the technological building areas and by whom. Did energy efficiency emerge in e.g. insulation materials, windows or at the building system level and how did it diffuse and grow? The analysis is important to track standards outside the core building and energy efficiency oriented technical committees. More studies could be done e.g. looking into the set of participants in the committees but these have not been pursued here because of time and resource constraints.

Some methodological limitations

It has shown to be difficult, and for the time being impossible, to track the history, i.e. the pioneering role of Denmark or specific countries due to the general lack of historic registration in the standardization bodies. Only recently extinct standards are preserved. More in-depth studies into archives may remedy this. The thematic search at the level of standards (used also to identify relevant committees) is quite difficult and very time consuming because of: A) Lack of standardization codes (called ICS) on energy efficiency and lack of key words in the standardization bodies. Both thematic, title, related ICS codes and search by directives have been used to identify the relevant standards; these, however, need to be complemented by expert verification due to discrepancies in the data before findings are rigorous enough to be used as indicators. B) Lack of search tools and software available – data have to be extracted by hand, except for CENELEC. Finally, parts of particularly CEN electronic (Web) data are often difficult to access, despite the fact that they in theory are accessible. Due to these limitations indicators are not yet available at the level of standards (i.e. track two suggested).

Figure 28. The evolution of ISO Technical Committees working with energy efficiency in buildings.

Year	1975	1991	1992	1993	2002	2008	2009	2010								
Relevant Science and Working Groups	TC 163/SC 1, Test and measurement methods	TC 163/SC 2, Calculation methods	TC 205/WG 2, Design of energy-efficient buildings	TC 205/WG 3, Building Automation and Control System Design	TC 205/WG 4, Indoor air quality	TC 205/WG 5, Indoor thermal environment	TC 59/SC 17/WG 1, General principles and terminology	TC 59/SC 17/WG 2, Sustainability indicators	TC 242/WG 1, Energy Management	TC 242/WG 2, Energy performance metrics	ISO/TC 163/WG 4, Joint working group TC 163 & TC 205 Energy performance using a holistic approach	TC 257/WG 1, Definition of a methodological framework applicable to calculation and reporting on energy savings	TC 257/WG 2, General calculation methods on energy efficiency and savings for countries, regions or cities			
	TC 163/SC 3 Thermal insulating materials	TC 163/WG 3, Energy performance buildings	TC 203/WG 3, Methods for analysis	TC 205/WG 6, Indoor acoustical environment	TC 205/WG 7, Indoor visual environment	TC 205/WG 8, Radiant heating and cooling systems	TC 205/WG 9, Heating and cooling systems	TC 207/SC 3, Environmental labelling	TC 207/SC 5, Life cycle assessment	TC 59/SC 17/WG 3, Environmental declaration of products	TC 59/SC 17/WG 4, Environmental performance of buildings	TC 59/SC 17/WG 5, Civil engineering works	TC 242/WG 3, Joint TC 242 - TC 257 WG: Measurement & verification of organizational energy performance - General principles and guidelines	TC 257/WG 3, General technical rules for measurement, calculation and verification of energy savings of projects	TC 257/WG 4, General calculation methods on energy efficiency and savings for organisations and other enterprises	
Number of Countries Represented on TC	25	28	9	22	26	24	78	32	23	13	50	17	18	13		
	Participating Observing		Participating Observing		Participating Observing		Participating Observing		Participating Observing		Participating Observing		Participating Observing			
ISO Technical Committees	ISO/TC 163 - Thermal performance and energy use in the built environment		ISO/TC 203 - Technical energy systems		ISO/TC 205 - Building environment design		ISO/TC 207 Environmental Management		ISO/TC 59/SC 17 - Sustainability in buildings and civil engineering works		ISO/TC 242 - Energy Management		ISO/IEC JTC 2 - Joint Project Committee - Energy efficiency and renewable energy sources		ISO/TC 257 - General technical rules for determination of energy savings in renovation projects, industrial enterprises and regions	

Source: Maj Munch Andersen, based on ISO data.

Some early findings

Figure 28 illustrates the evolution of core identified ISO technical committees related to energy efficiency in buildings (CEN data, an important part of the story, is lacking due to difficulties in getting the time of establishment of their committees). We see the first committee emerging after the oil crisis in the mid-1970s directed at the energy performance of buildings illustrating the early attention to the role of energy efficiency in buildings for solving the at the time just emerging energy crisis. This is followed by a sixteen year gap until more recent relevant committees and subgroups evolve and spreads. We see a change in the agendas of the committees, the energy efficiency agenda becoming still more complex and systemic, moving towards a more holistic perspective on buildings energy performance, which is specifically sought addressed in the ISO JTC joint working group on a ‘holistic approach’ established in 2009.

Figure 29 below illustrates current European participation in main ISO committees identified as relevant for energy efficiency in buildings. Especially Northern European countries have a high level of participation in the committees working with energy efficiency.

Figure 29: European participation level in selected ISO committees.

Code	Description	DK	SN	NO	FI	GE	BE	AU	SW	UK	FR	NL	IT	SP	PL	US	CH	IN	JP	BR	AT	
ISO/TC 163	Thermal performance and energy use in the built environment																					
ISO/TC 205	Building environment design																					
ISO/TC 203	Technical energy systems																					
ISO/TC 59/SC 17	Sustainability in buildings and civil engineering works																					
ISO/IEC JTC 2	Joint Project Committee - energy efficiency and renewable energy sources																					
ISO/TC 257	General technical rules for determination of energy savings in renovation projects, industrial enterprises and regions																					
ISO/TC 242	Energy Management																					
ISO/TC 207	Environmental Management																					
ISO/TC 115	Pumps																					
ISO/TC 77	Products in fibre reinforced cement																					
ISO/TC 160	Glass in building																					
ISO/TC 162	Doors and windows																					

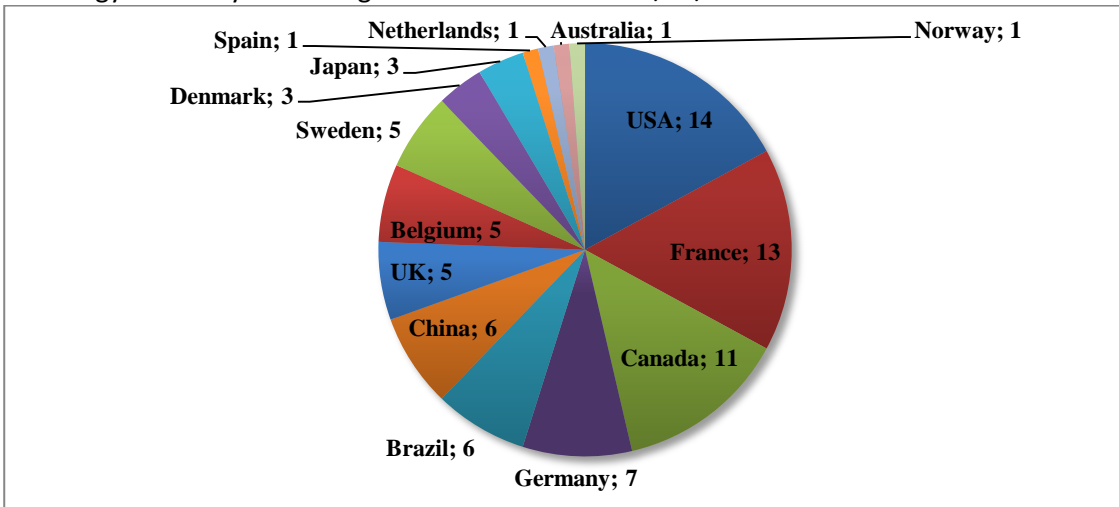
Notes: Countries: DK - Denmark; SN - Sweden; NO - Norway; FI - Finland; Ge - Germany; BE - Belgium; AU - Austria; SW - Switzerland; UK - United Kingdom; FR - France; NL - Netherlands; IT - Italy; SP - Spain; PL - Poland; US - United States; CH - China; IN - India; JP - Japan; AT- Australia.

	Participating
	Observating
	Neither participating nor observing

Source: Own analysis, based on ISO data.

If we look at the important secretariat function of the central relevant committees as a proxy of core national involvement, it is interesting to notice that while Western European countries dominate, two BRICS countries play quite important roles, respectively China and Brazil, illustrating the globalization of the green economy. Denmark is well represented for a small country.

Figure 30: Measuring national prominence – Current distribution of countries holding the Secretariat of the 81 energy efficiency & building related ISO and CEN TC/SC/WG.



Source: Own account based on ISO and CEN data.

Conclusions

The pilot standardization analysis undertaken related to energy efficiency innovation in buildings shows that standards and labels do represent interesting throughput innovation indicators capturing important aspects of the institutional and structural changes related to the emergence of a new (green) market; aspects which are difficult to catch with other data sets and which have been little tried before. It is further possible to trace the uptake of energy efficiency issues, or the lack of this uptake, across all kinds of technologies, products and business practices, also in the difficult energy efficiency and construction area. Standards do present interesting international solid and comparative data very relevant to innovation and none the least our understanding of innovation systems. But there are also some methodological problems and limitations, particularly concerning very long term analyses and lacking ICS codes for energy efficiency and therefore need for further methodological clarification. Other more narrow energy themes where ICS codes are available are likely to be much easier. Concerning energy labelling of buildings and building components, the development of these as well as their use of these as indicators is relatively limited, though growing more lately, reflecting weak market supporting institutions on energy efficiency related to the construction market. An overall conclusion is the need to focus on the labelling and standardization process itself as important features of modern innovation systems and innovation processes.

4D The challenge of measuring interaction patterns

Mads Borup

Official national and international indicator schemes have until now only to a limited extent included indicators of interaction in the innovation systems. This is striking as one of the main points of innovation system research in general is that the patterns of interaction constitute a key factor for the resulting innovative strength and performance of an innovation system. In agreement with this point, also a number of studies of energy technology development and transition processes towards sustainable energy systems have identified that the patterns of cooperation and network interaction are important factors for the outcome of innovation processes.

The influence of interaction activities on the resulting innovation performance is often due to synergies that appear in connection to the interaction. The synergies can appear in different ways and on different levels, for example through combination of competences and resources, through integration of perspectives and goals, through economies of scale, through development of strategic actor alliances, through creation of new opportunity spaces or through establishment of new, additional units and resources that on a system or sector level complement the existing units and resources. Musiolik et al. (2012) show that firms and other actors collaborate in formal networks, not only in order to generate knowledge but also to strategically create and shape supportive resources that can contribute to the innovation conditions for a new technology on a system level. In addition to formal networks, appear less formalized network interaction, interaction in more or less open forums and public media and, of course, interaction on markets and in industrial supply-chains. The different kinds of interaction vary considerably in their specific mechanisms and effects. It is hence a considerable challenge to establish a well-covering set of indicators of interaction.

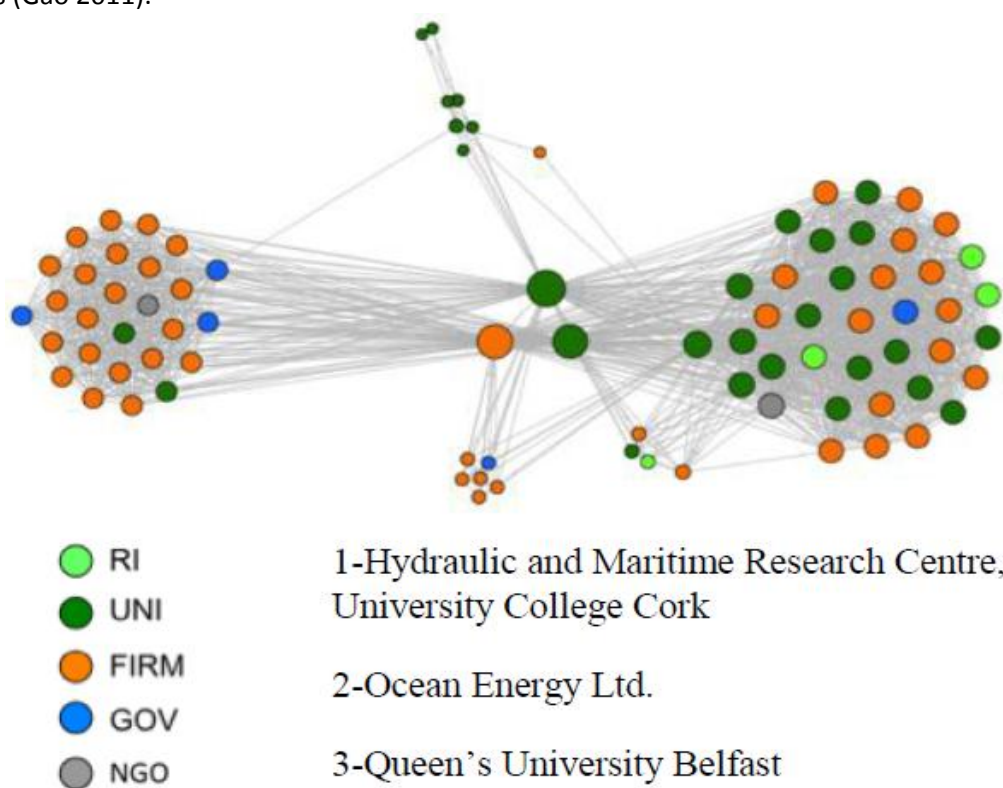
We have in the previous chapters seen that the European CIS scheme and the OECDs STI Scoreboard in their recent versions include a measuring of share of firms that engage in cooperation (but that the industry classifications employed do not address energy technology specifically). We have also seen examples of indicators that address cooperation in connection to research, scientific publications and patenting and selected aspects of market interaction and supply-chain interaction within selected areas of energy technology. However, there is need of further development of interaction indicators. Amongst other things development is needed concerning:

- Actors addressed: A broader set of actors is needed. In addition to firms and public research organisations, e.g., also consumers, investors, interest organisations, public authorities and policy actors are often relevant for the innovation processes. Moreover, there is need of a more detailed distinction between actor types a.o.t. with respect to their role and position in relation to the energy sector and its challenges, e.g., distinction between energy system operators, energy companies, technology supply companies, etc.
- Geographical distribution of interaction connections (national/local versus international/foreign countries)
- Interaction in relation to strategic and long-term oriented networks
- Institutional and regulatory developments and interaction in connection to these
- Less formalized interaction in discussion forums and more or less open arenas
- Media interaction and publications (also other than scientific journals)

The indicators that are presented in the following do on some points show ways ahead concerning the challenges. They do however not answer all of them.

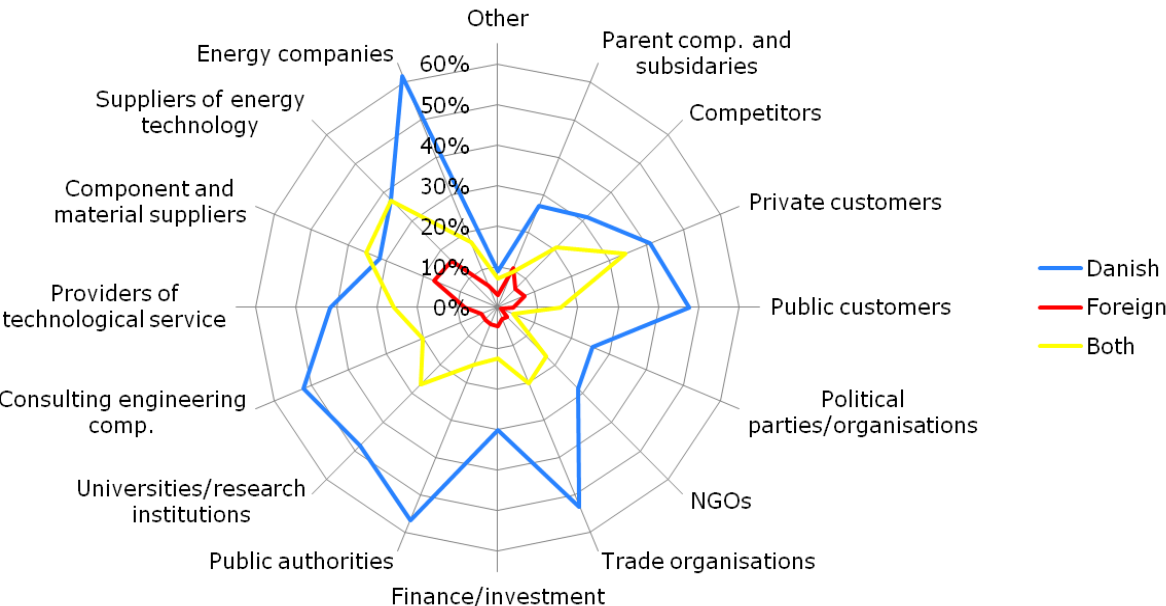
Social network analysis is one of the approaches that can contribute to a picture of the broader set of actors and the interaction between them. The approach has been increasingly employed in recent years also in the energy area, e.g., by Gao (2011) that in addition to firms and public research organisations also includes governmental authorities and NGOs. Central actors and clusterings of actors are identified, see Figure 31. There is no established common standard for the definition of the network connections or how they should be counted and aggregated. Both formal collaboration projects and more informal relations have been suggested as basis for analysis. Supported by different software tools, a number of methodologies for aggregating and characterizing the interaction patterns and network structure have been suggested, e.g., based on the characteristics of the connection types seen from the individual actor, however there is no best practice established.

Figure 31: Social network of Irish ocean energy innovation network. Different types of actors; three central actors (Gao 2011).



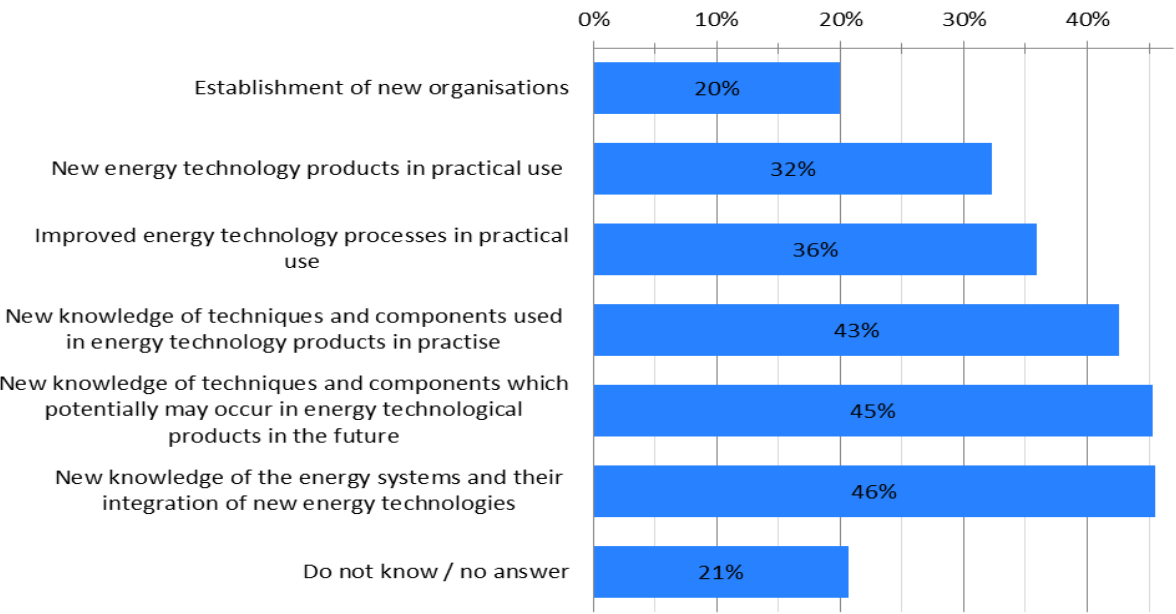
In some studies, databases of projects in public R&D programmes have been used for measuring cross-going interaction between different types of actors; see e.g. Figure 18 in Chapter 3. Also, questionnaire surveys can be used, see for example Figure 32 where the interaction patterns between actors as energy companies, technology supply companies, consultants, authorities, investors, NGOs, customers, and competitors are measured. The survey approach can in principle reach out to a larger group of actors than only those involved in public R&D projects. In the shown example, the differences between domestic (Danish) and international cooperation appear, showing a predominance of domestic cooperation.

Figure 32: Pattern of cooperation in the energy innovation system in Denmark. Types of cooperation partners in 2010-2011, Danish or foreign partners (EIS Survey 2011, N=391).



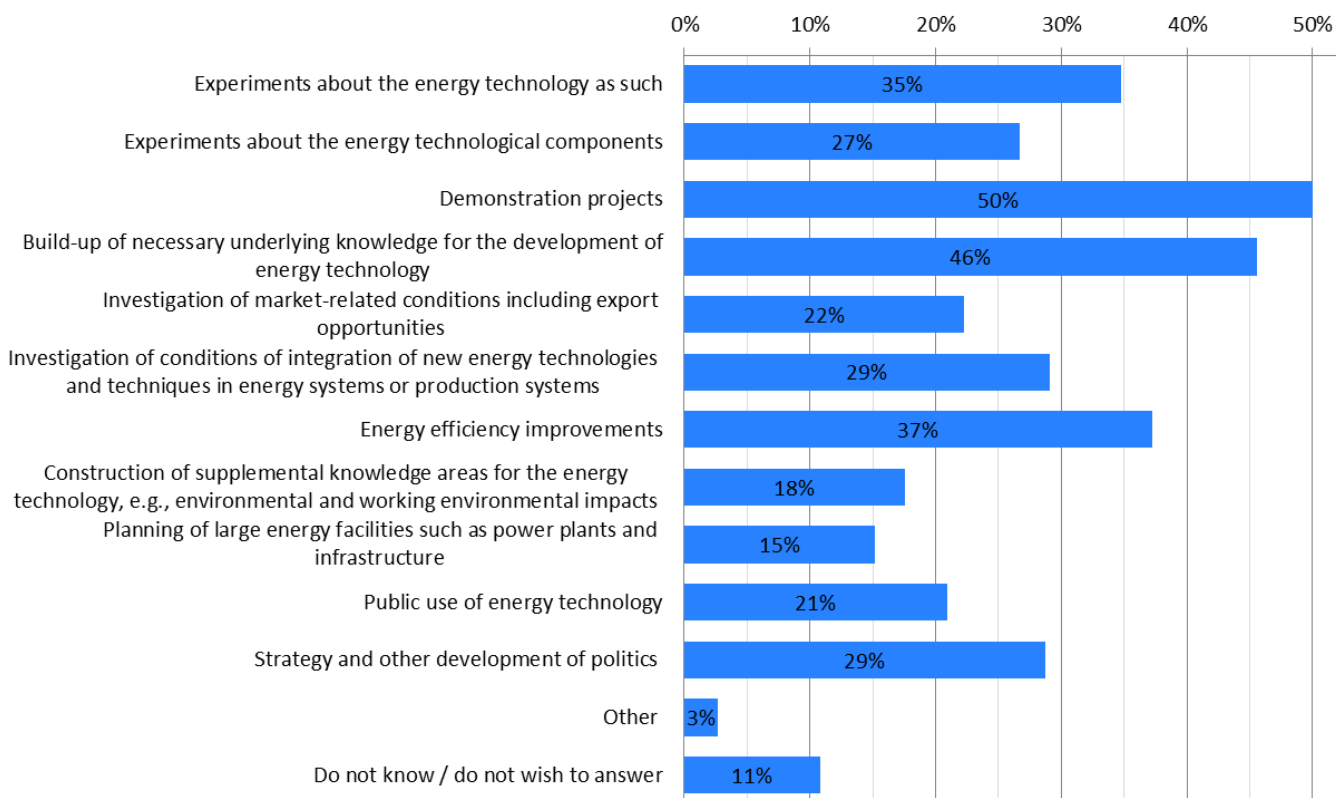
The contents of the cooperation activities are also addressed in this survey. This is done in different ways. Amongst other things the working as a process of knowledge build-up for the involved actors is measured, showing in general that access to competences and knowledge of others that complement and qualify own knowledge is often important. Actual joint-production of new knowledge in the cooperation activities is also important in many instances; however, this appears less frequently than the first mentioned reasons. The resulting outcome of cooperation in terms of energy technology is suggested measured through the parameters shown on Figure 33. It can be seen that actual new energy technology products and processes in practical use appear, however outcome in terms of new knowledge is more frequent.

Figure 33: Results of network and cooperation activities in energy innovation in Denmark (EIS Survey 2011, N=415).



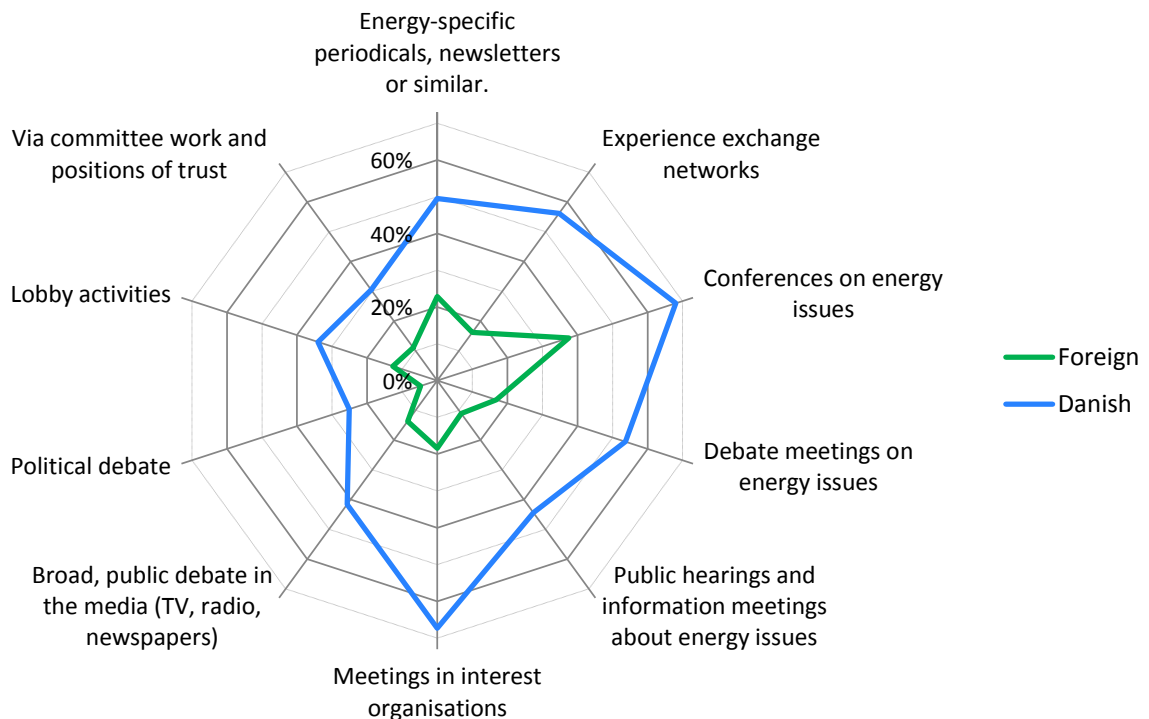
A special aspect of interaction patterns in the energy area is public-private cooperation. It can consist in many kinds of activities, also other than the often covered collaboration between public research organisations and private companies. The above mentioned survey shows that more than 60% of the actors in the energy innovation system in Denmark over a two-year period participated in formal public-private collaborations. The contents of the activities are indicated on Figure 34.

Figure 34: Contents of public-private collaboration projects in the energy innovation system in Denmark (EIS Survey 2011, N=296).



The challenges of measuring interaction in less formalized interaction activities in more or less open networks can e.g. be addressed through the parameters shown on Figure 35. The survey results here show that more than two thirds of the actors in the energy innovation system in Denmark participate in such interaction activities in connection to energy technology development, not least through conferences on energy issues, meetings in interest organisations and experience exchange networks. Most actors participate in more than one type of such networks/forums. Hence, this less formalized and open interaction and communication must be considered of significant importance for the energy innovation. Domestic interaction counts for the majority of these interactions.

Figure 35: Share of actors in the energy innovation system in Denmark that participate in debate and discussions of energy technology development in more or less open networks and forums (EIS Survey 2011, N=315).



The challenge of measuring interaction through other types of publications and media than scientific journals is touched upon in the above figure, e.g., through broad public debate in mass media. Further efforts are however needed in order to cover the issue more completely. The Eco-innovation Scoreboard referred to in Chapter 2 uses eco-innovation related media coverage as one of the indicators. Other analysts have suggested using professional magazines, trade journals, etc., as basis for analysis. One of the limitations of this is that the landscape of magazines and journals differ from one area of energy technology to another and it is difficult to establish general indicator that can be used for comparison between areas.

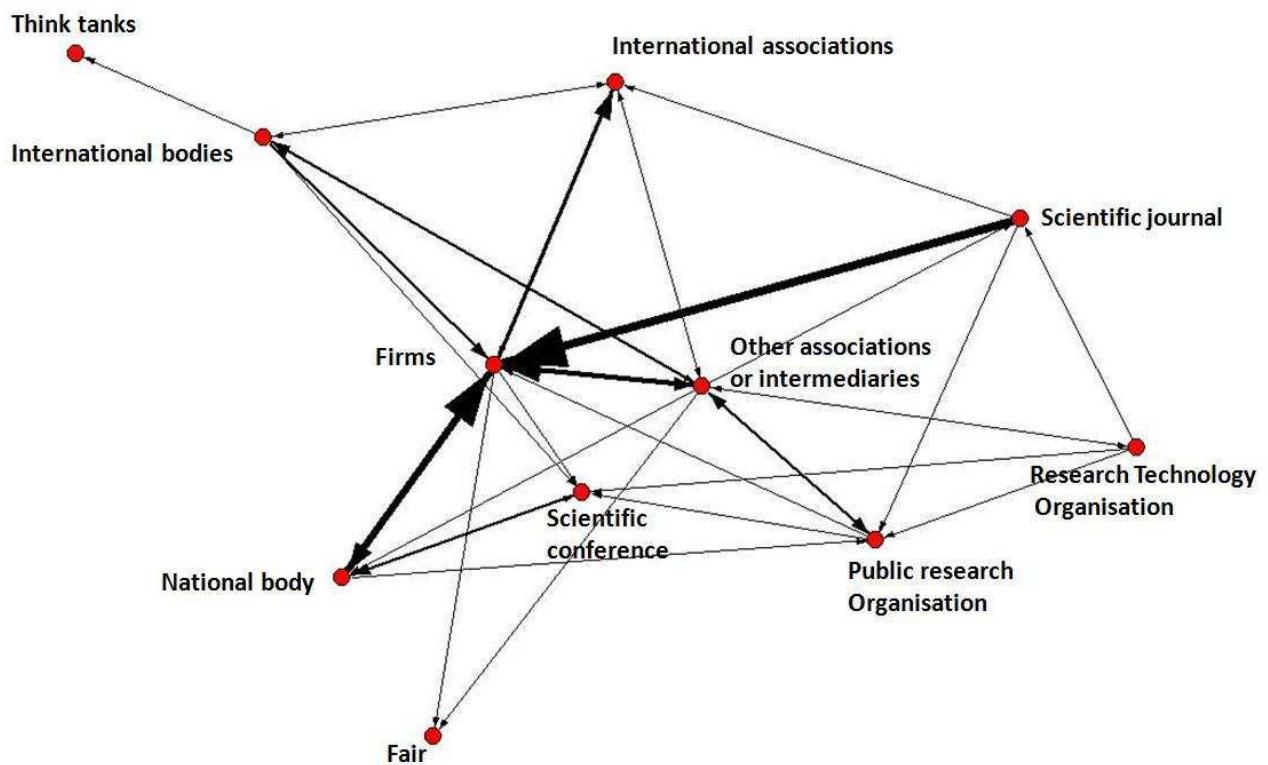
Internet based communication has changed the media landscape considerably and led to more complex media use and communication patterns. It is not always that approaches and databases that earlier were relatively well-covering, e.g., concerning contents of newspapers and professional magazines, are easily updated to the internet era. Apart from measuring interaction activities this is also a challenge in connection to statistics based on keyword and discourse analysis.

Methodologies for analysis of internet communication and internet contents (Internetometrics or webometrics) have developed considerably in recent years. It is still a young field and best-practices methodologies for producing robust indicators are not established (Katz and Cothey 2006; IDEA 2009). Concerning interaction and networks, analysis of internet links has been suggested as indicator. In an international case study of the area of 2nd generation biofuels, 57 hyperlinking webpages were identified with in total 74 hyperlinks. The results aggregated in four main sectors and the interlinking between different types of organisations are shown in Table 19 and Figure 36. The results show that firms are the most linked to type of organisations and not so frequently outwards linking (this observation is found also in other areas). With a total of 74 hyperlinks in an international study, the number of hyperlink interactions is relatively little compared to many of the other types of interaction mentioned above.

Table 19: Links between four main sectors as a percentage of total possible links in 57 sites in the area of 2nd generation biofuels (inter-sector links over 5% in bold) (IDEA et al. 2009).

From/To	Government	Industry	Public Science	Non-profit
Government	0.0%	11.3%	3.0%	6.3%
Industry	5.0%	2.9%	0.2%	1.9%
Public Science	2.0%	1.8%	1.3%	1.0%
Non-profit	9.4%	3.8%	3.0%	8.9%

Figure 36: Interlinking between different types of organisations within 2nd generation biofuels (IDEA et al. 2009).



The examples in this paragraph show that it is possible to measure much more of the innovative interaction activities that the formalized, official statistics schemes currently do. If one wants to have a thorough insight in the dynamics of energy innovation and energy technology changes, it seems obvious to employ more advanced or detailed methods. Many of the mentioned methods are however pilot approaches and need further elaboration and specification, if they are to be used in official statistics schemes.

4E The challenge of measuring investments and identifying investors

Daniel Stefan Hain and Jesper Lindgaard Christensen

Introduction

Following the increased interest in energy innovation, the statistics in the area have improved and is now covering a wide technology field and countries. Some of the relevant statistics may be found in national accounts; however, this will usually be inadequate. As will be apparent below, there are several types of flaws and difficulties related to getting a statistical overview of investments in innovation in the energy sector; it is not just a matter of increasing the existing statistical efforts and precision, there are more generic difficulties. Obviously, activity indicators of energy innovation (cf. other chapters in this volume) are closely related to indicators of investments in energy innovation. Hence, a number of general measurement challenges, such as separating innovation and activities, apply to investment measurement as well. Furthermore, any kinds of outcome measures in the energy realm, and elsewhere, are by nature interdependent with investment activities. We will in this chapter focus on the challenges that are special to the investment activities and on the mapping of investors.

The measurement challenges may be approached from a 'receiver' perspective, i.e. the investments into a specific type of (energy) sector or activity, and it may be seen from the 'supplier' perspective, i.e. the investors. Both approaches have their limitations and challenges. We point out that in order to understand the structural features of energy innovation investments it is necessary to see these in a framework of how different types of investors specialize in certain stages of the (energy-) innovation process. We furthermore argue that there are intrinsic barriers to precise measurement, and we outline some of the most important deficiencies in the current measurements. Still, we point to some sources to draw from when conducting research on investments in energy innovation, particularly emphasizing existing firm and investor level data.

Investors, investment types and the technology life cycles

Generally, capital markets are characterized by a division of labour and specialization, which is expedient when investors need to cope with complex and asymmetric information in the market. Therefore investors can be differentiated according to the different types of investments they pursue. This accentuates that to obtain a proper analysis and understanding of investments in energy, a nuanced and disaggregated reflection of the structural composition of investors and investments is vital. Aggregated quantitative figures on for instance public funding of R&D in different sectors of energy production may very well render a first intuition regarding overall trends. Yet they are far from sufficient to properly understand and evaluate the implications of intra- and inter-industry dynamics and the systemic character of the energy investment environment, as we will argue during the course of this section.

Figure 37 illustrates the multitude of actors involved in the financing of innovation in energy, a broad landscape with various competing and complementary technologies, sectors and industries, which are partially in very different stages of development and maturity.²¹ The figure illustrates the complexity of

²¹ For the sake of simplicity, technological development here is illustrated as linear process from basic R&D to the market. This for sure does not fully acknowledge the complexity of innovation processes, including various

investment landscapes and which actors operate in this landscape. For measurement the vast complexity and the macro- meso- and micro-heterogeneity render undifferentiated quantitative figures inadequate.

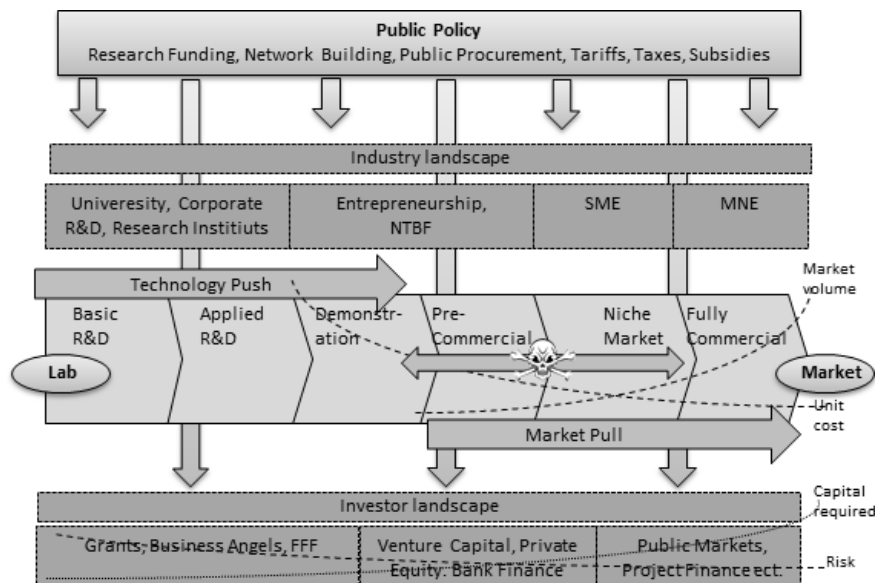


Figure 37: Segmentation of predominant firm and investor types along a stylized linear technology development process, adapted from Wüstenhagen and Menichetti (2012).

If we consider the investors in the bottom part of the figure they are specialized and ordered according to their investment capacity and willingness to consider investments in different stages of development, which is indicated by the line 'Capital required'. Because investments in innovation are increasingly expensive and because exit markets are not functioning adequately actors at the capital market increasingly syndicate but primarily within the different types of actors. One of the primary purposes of syndication is to bring the investment capacity of syndicates up to a level where they can take firms through several funding rounds. As a consequence, not only considering relationships between investors and firms, but also among investors, becomes important.

The energy innovation investment landscape

We currently have highly inadequate statistics in this field and we face a number of challenges in measuring investments in energy innovation. This is echoed in the literature, for example in a study by Gallagher et al. (2012), who point out that there is an urgent need to improve the quality of energy innovation statistics in a number of areas including measuring the R&D in private firms; Technology specific investments; Non-OECD country statistics.

What has been said up to now appears to be true uniformly across industries and sectors. However, the energy system still represents a special case due to the intense interdependencies among industries and technologies. Scholars from the technological side of research clearly point out that the future sustainable energy scenarios necessarily must include a wide set of complementary solutions to produce, store and distribute energy (Lund and Mathiesen, 2009), thus the development of a sustainable energy system is not

feedback loops between different stages. Rather it should provide a first intuition for the heterogeneity of firms and investors, and their dominant pairing in broad phases of the technology life cycle.

driven by a single factor, it is rather cutting through many industries and technologies, involving a huge variety of actors with idiosyncratic characteristics.

Another feature of the energy area is the high heterogeneity of involved industries. They differ in terms of characteristics such as capital intensity, firm population, stage in the life cycle; and from an investor perspective in the time horizon of investments and associated risk and uncertainty. Some industries, such as windmill production, have already reached a high degree of maturity and are dominated by multinational enterprises, and are characterized by enormous capital intensity in development and production. Others such as hydrogen, fuel cells, smart grid and energy storage solutions are in early phases of their development without an established dominant design, allowing for experimentation, disruptive innovation and entrepreneurial activities but also substantial technology and market risk. In addition, applied technologies differ substantially in their relevant characteristics, not only between but also within industries. One might for instance expect very different capital requirements, risk projections as well as potential investor characteristics for traditional technologies in comparison with vertical axis windmill technologies. Consequently, this macro-, meso and micro heterogeneity calls for lower levels of aggregation in quantitative analyses, thus the need for more fine-grained data.

The large variety of actors operating in the space of renewable energy, and the lack of consensus around a general definition about this space and its boundaries means that it becomes challenging to identify its population in a comparable way across studies.²² On the technological meso-level, the absence of adequate classification and data prevents differentiated studies within and between technologies. However, the co-evolutionary character of industries and technologies in the energy system make a sharper distinction between them and quantitative investment data vital to an improved understanding of the non-linearity within as well as between sub-industries.

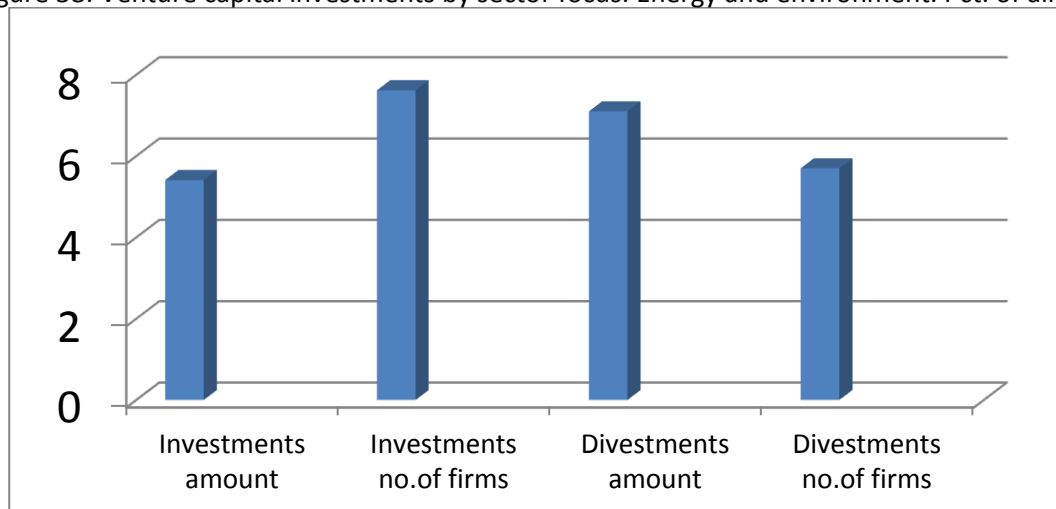
Mapping investments

Sources for energy innovation span a wide array of different compilations of statistics of varying quality, when it comes to measuring investments and innovation. The World Energy Outlook from International Energy Agency²³ is an example of statistics that cover part of the field, however, only partially as it is based on information from its 28 member (OECD) countries leaving a range of countries who are not member of OECD out of the statistics. The bias in that is illustrated by the fact that public spending on energy R&D in Brazil, Russia, China, India, Mexico, and South Africa totaled 13.6 billion USD, which corresponds to the amount of all the IEA members combined (ibid.). Moreover, much of the statistics in the field is based upon R&D-statistics, which is an often-used input indicator for innovation. Nevertheless, it is far from capturing all innovation outputs. An example of statistics where we do have some knowledge of investor and investment type (debt/equity) and rationale are statistics from the investor organizations. The providers of statistics on venture capital, such as EVCA, now report investment activities in the clean tech industry, which is now the third largest investment target for venture capital investments. Figure 38 illustrates the share of venture capital investments going to clean tech firms.

²² For instance, the study of Hain (2013) on publicly funded Danish renewable energy R&DD projects illustrated how an undifferentiated utilization of data can lead to highly questionable results. Even though data clearly distinguishes between the technological fields of the funded projects, the involved actors are immensely heterogeneous and span from universities and manufacturing firms over business services such as accountants and IT consultants to craftsmen such as carpenters.

²³ <http://www.iea.org/stats/index.asp>

Figure 38: Venture capital investments by sector focus: Energy and environment. Pct. of all inv., 2011, EVCA.



Although this provides us with some information, especially when we have information over several years, it is far from being a perfect indicator for trends in energy innovation investments. Thus, clean tech is more than the energy area and although venture capital firms often invest in innovation the numbers may include other investment purposes.

This leads to a further issue. A pre-requisite for mapping investments into energy innovation is obviously that the object for investment, energy innovation, can be identified. Therefore, the statistics on investments into energy innovation is closely related to the general statistics for energy innovation. A generic challenge is that we are unable to separate activities and industries; in other words to make a clear delineation of the energy sector. Many firms are involved in energy innovations even if belonging to another main industry in the official classifications, thus making it difficult to analyze the total activities (see the section on classification systems by Klitou elsewhere in this volume).

As a starting point for empirical analysis of firms operating in the renewable energy and green technology space, Statistics Denmark recently provided an indicator for 'green firms', which can be utilized for descriptions of this segment. However, for empirical research it still represents a very crude classification, not taking industry and technology boundaries into account. Besides, the applied identification methodology, including a non-negligible usage of multiple imputation techniques to deal with missing data, leads to more fundamental considerations regarding the overall validity of this classification.

For more detailed analyses of firm-internal R&D investments and their source of finance, one might also consider additional R&D survey results provided by Statistics Denmark.²⁴ This data provides information of firms' investments in basic as well as applied research and development by sectors, which include environmental and energy related research. More interestingly, it also provides information about the sources of capital for these investments. However, when utilizing this data, one still faces the problem of lacking definitions and blurry boundaries of these energy related sectors. This data is not available for the whole population of Danish firms, but only for a subset of between 5.000 – 7.000 annual survey recipients, so the possibility to combine it with other data sources is limited.

²⁴ Consider «<http://www.dst.dk/en/Statistik/dokumentation/Declarations/statistics-on-research-and-development---r-d-statistics---business-sector.aspx>» for a detailed description of firm level R&D data provided by Statistics Denmark.

Mapping investors

While the question of how and where investments are allocated across energy industries and technologies has received growing attention in recent years, the question who ultimately invests and why has received much less attention. Nevertheless, answers to these questions are of crucial importance for generating a more comprehensive understanding of energy finance.

Indeed, the investors' landscape in energy is scattered. Figure 37 some pages earlier depicts typical investors, and where in the investment landscape they specialize. However, it remains a rough, stylized picture that cannot capture all details and dynamics. Large MNEs internally allocate resources to innovation projects, but are also actively acquiring equity stocks via mergers, acquisition or corporate venture capital. For industry finance, also non-profit organizations, large institutional investors, private and public project developers et cetera are heavily involved in determining the amplitude and trajectory of future innovation projects. In early stages direct public R&D funding often is integral for new technological possibilities to emerge. And in between these stages specialized financial intermediaries operate such as venture capitalists.

Intuitively, the rationales of for instance public funding agencies (long run technological development), venture capitalists (high returns in the short – medium run) or private banks (low risk in medium – long run) are likely to result in quite distinct capital allocation patterns with respect to target firm and technology preferences. The question remains to what extent these investment activities are documented with data? Generally, aside of well documented funding activities by public agencies (especially RD&D), data on other types of (mostly private) investments is scarcer. As a result, we know very little about which types of investors finance which types of industries, technologies and firms, and which financial vehicle they use. In the same vein, research is sparse when it comes to mapping intra- and inter-firm flows of finance of energy innovation activities, including private investments in R&D and FDI and M&A investments between firms. To sum up, the heterogeneity of investors and investment targets calls for micro-level data able to clearly identify them and isolate their particular rationales. Too aggregated statistics are likely to 'average out' possible problems and opportunities alike.

Despite the problems discussed above, it is possible to point to some sources to draw from. For publicly funded R&D, fairly comprehensive data on projects funded by Denmark's major energy technology research and development programs is provided by a joint database managed by Denmark's Technical University (DTU).²⁵ Regarding other sources of finance, one might use data provided by 'Navne og Numre Erhverv' (NNE),²⁶ which provides detailed information on firm level balance sheet facts, ownership structures and the like. Conditional on solving the generic issue of the ill-defined industry boundaries and the resulting problems to identify energy related firms, equity investments of various kinds, such as venture capital or M&A's could also be analyzed using traditional commercial databases Equity investment databases. For instance the M&A information platform 'Zephyr',²⁷ provided by the 'Bureau van Dijk', offers very rich information on current and past equity deals, and the involved investors and forms of finance.

²⁵ <http://energiforskning.dk>

²⁶ <http://erhverv.nnmarkeddata.dk/>

²⁷ <https://zephyr2.bvdep.com>

Outlooks and challenges

Just as there are difficulties in separating investments in firms and activities we face a similar difficulty when we look at the investor side of it. The majority of investors invest in multiple industries, in fact, even if e.g. the venture capital investors have gained interest in the clean tech industry generally, and energy in particular, then the number of dedicated venture capital funds is a small minority. Moreover, after a period with increasing interest from investors in this area there are now indications of less attention from funds to clean tech investments. For example, the Danish fund Vækstfonden has had an inexpedient development of their clean tech portfolio companies and announced in May 2013 that they would currently no longer invest in the clean tech segment. Whether this will have implications for future efforts to collect data in this area remains to be seen.

The object of study – innovation – itself poses also problems. Innovation statistics are relatively new and are not fine grained to an extent that makes it perfect for comprehensive studies of energy innovation. A number of ad-hoc surveys try to advance the statistical picture of investments into energy innovation, but they are inherently difficult to compare due to differences in methodologies, sampling, and definitions. Turning to national accounts it is clear that what is measured are primarily factors like production volumes, energy sources, and energy prices. Obviously, these measurement efforts are important, but largely inadequate for energy *innovation*. For investments and especially outputs for innovation the statistics are reliant on inadequate indicators, especially when it comes to investments beyond the RD&D phase. Organizations such as The OECD have compiled information in special studies²⁸ that do compare e.g. patents for member countries as well as discuss other measurement issues. Even if this at a first glance seems beyond the investment perspective, it is nevertheless important in investments as well due to the fact that patents have now become an important parameter in both the decision to invest and in the subsequent possibilities to exit from the investment.

Generally, such studies are valuable to advance our understanding and statistical picture of the industry, but again, they are not as developed as in many other industries/investment areas. To summarize, major shortcoming of data sources available and obstacles for quantitative research on the finance of innovation in energy include (i.) the absence of consensus regarding the definition and boundaries of the renewable energy space and its sub-industries, (ii.) the lack of categorization and documentation of applied technologies, (iii.) the non-consideration of demand side factors, (iv.), the missing understanding and data regarding the external supply of finance (investor types and rationales) as well as firms' internal allocation of resources towards innovation activities, and (v.) non-comparability of data across countries.

It is an ambitious requirement to future standards of data to solve all of these problems. But steps towards a better statistical understanding of the (financial) dynamics of the industry require that some of these issues are addressed.

²⁸ For example, OECD, 2008. Environmental Policy, technological innovation and patents. OECD studies on environmental innovation, Paris, and OECD, 2011. Fostering innovation for Green Growth, OECD Green Growth studies. OECD Publishing, Paris.

5. Conclusion

The review study behind this report has shown that a row of different sets of indicators of innovation systems have been proposed in the latest decades – by researchers as well as by practitioners of statistics and indicator analysis. There is not established a common consensus of which set of indicators is optimal, neither in principle nor in practice. Hence there is no international best practice established. Departing from an originally relatively on-sided science-push and technology-push oriented perspective, e.g., in OECD, two new branches of indicator schemes have appeared: A firm-focused branch that addresses attention to innovation on the level of firms, including a smaller or larger part of the firms' contexts. This perspective is primarily an economics perspective. And a change-focused branch that addresses innovation as a matter of change on societal or sectoral level, often integrating socio-economic and technical-material aspects. The issue of energy change towards sustainability has most explicitly been addressed by the latter branch, however, overlaps and mixes of the two perspectives exist. At the same time the research-focused perspective also still thrives in some contexts.

The points and conclusions made in the chapters above about the different current challenges of indicators and measurement of energy innovation systems stand for themselves and will not be repeated in details here. No one would probably deny that the many examples of indicators and figures presented in Chapter 3 and 4 offer much interesting information and insight into a number of important issues. The question here is however also: How well do the available indicators altogether cover the field? Do they ensure sufficient overview and insight in the energy innovation systems, adequate for the challenges facing the energy area? On a general level, it can be concluded that there is some indicator information available both concerning the resulting performance and output of the energy innovation system (output indicators), concerning the activities in the innovation systems (throughput indicators), and concerning the support and investments in the innovation systems (input indicators). It is however also clear that the coverage on many points could be considerably better. While there are bits and pieces available for an indicator scheme of energy innovation systems, there are still many missing elements and gaps that need to be filled before a comprehensive indicator scheme can be established. Amongst other things, the definition and delimitation of product categories and technology categories to be addressed need to be developed further. Moreover, the time track must be improved for many indicators in order to monitor developments over time. Among the advanced challenges is also a better coverage of the role of demand-pull factors, including market formations, policy efforts, and interplay between market formations and other activities, e.g., technological experimentation, investments and developments of new niches. The build-up of network relations and collaboration between actors of different kind is part of this.

In addition to development of indicators and statistics on national level, further international harmonization and consensus is needed. This is a prerequisite for being able to compare between countries and between different areas of energy technology, energy consumption fields, etc. The attempts in some countries to establish national energy technology scoreboards can be developed and improved.

The challenges of climate deterioration and the quest for greening of economy including more sustainable energy systems are currently among the major driving factors for policy development. It would be useful if the efforts for developing indicator schemes and statistics that can cover and reflect these issues are sped up and reinforced. This also includes further research on the topic. Some initial steps have been taken, but there is need of several more.

Appendixes

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List of acronyms

€	Euro
BERD	Business Expenditures on R&D
CCS	Carbon dioxide Capture and Storage
CIS	Community Innovation Survey, EU
CN	Combined Nomenclature
ComExt	Intra- and extra-EU trade data
CPA	European Classification of Products by Activity
CPC	1. Central Product Classification 2. Cooperative Patent Classification
DENP	Danish Energy R&D projects
ECLA	European Classification System
EIS	1. European Innovation Scoreboard 2. Strategic research alliance on Energy Innovation System and their dynamics
ENS	Energistyrelsen, Danish Energy Agency
EPO	European Patent Office
ERMINE	Electricity Research Road Map in Europe
ERTD	Energy Research, Technology and Development
EST	Environment Sound Technologies
EU or EU-27	European Union
EW	ERAWATCH
GBAORD	Government Budget Appropriations or Outlays on R&D
GDP	Gross Domestic Product
GHG	Greenhouse gases
GICS	Global Industry Classification Standard
HRST	Human resources in Science and Technology
HS	Harmonised Commodity Description and Coding System
ICB	Industry Classification Benchmark
ICTSD	International Centre on Trade and Sustainable Development
IEA	International Energy Agency
IEADCC	IEA Climate Change Database
IPC	International Patent Classification
IPTS	Institute for Prospective Technological Studies (of the JRC)
ISI WoS	ISI Web of Science
ISIC	International Standard Industrial Classification
JRC	Joint Research Centre (of the European Commission)
MEI	Measuring eco innovations
MS	Member State of the European Union
MSCI	Morgan Stanley Capital International
NACE	Statistical Classification of Economic Activities in the European Community
NAICS	North American Industry Classification System
OECD	Organisation for Economic Co-operation and Development
PCT	Patent Cooperation Treaty
PPP	Purchasing Power Parities
PRODCOM	Classification of goods used for statistics on industrial production in the EU
PV	Photovoltaic
R&D	Research and Development
RD&D	Research, Development and Demonstration
RCTA	Revealed Comparative Technology Advantage
RON (95)	Research Octane Number ("EuroSuper" or "EuroPremium")
RTD	Research Technology Development
SET-Plan	(European) Strategic Energy Technology Plan
SIC	Standard Industrial Classification
SIEC	Standard International Energy Product Classification
S&P	Standard & Poor's
S&T	Science and Technology
UN	United Nations
UNEP	United Nations Environment Programme
UNSPSC	United Nations Standard Products and Services Code
USD	US Dollar
USPC	United States Patent Classification
USPTO	United States Patent and Trademark Office
WEC	World Energy Council
WIOD	World Input Output Database
WIPO	World Intellectual Property Organization