2 Theoretical framework

2.1 Introduction

In this chapter, we develop our theoretical framework. The specific research question formulated in the previous chapter is: *To what extent did the learning processes in the Dutch and the Danish wind turbine innovation systems differ in the period 1973-2000 and what are the consequences of these differences?* As stated in the previous chapter, we want to take into account all the actors, organisations and institutions that influenced the development of wind turbines in the two countries. Given this starting point, the innovation system approach is a very suitable basis for our theoretical framework. We will describe this approach in section 2.3. During our research we used a number of other approaches from the field of innovation studies to help us develop some preliminary ideas on how to analyse our cases. Furthermore, later on in this chapter we will use concepts from these approaches and theories when we investigate the theoretical aspects of learning. For these two reasons, we will outline these approaches briefly in section 2.2. After discussing the innovation system approach and several other approaches used in innovation research, we go into the subject of learning. Here we answer our theoretical sub-questions. What does the innovation literature tell us about the role of learning in the development of technologies? What kinds of learning processes occur in technology development? What conditions impede or facilitate these kinds of learning? We will deal with the subject of learning processes in section 2.4.

2.2 Theoretical approaches used in innovation studies

The theoretical literature in this research field consists of a number of theoretical approaches. These stem from different traditional research disciplines, like economics, sociology, and history. To some extent they are complementary, and to some extent they overlap. The following theoretical approaches will be described: evolutionary economics (section 2.2.1), quasi-evolutionary economics (section 2.2.2), the technical system approach (section 2.2.3), the network theories (section 2.2.4), and the social construction of technology (SCOT) (section 2.2.5).

2.2.1 Evolutionary economics

Evolutionary economics was developed primarily as a reaction to mainstream neo-classical economy. In neo-classical economy, technology is regarded as an exogenous variable, not requiring a separate explanation. Production is assumed to grow as a result of growth in labour inputs and capital inputs, combined with a residual factor, called technical change. Therefore, technical change is interpreted as an upward shift in the production function (Coombs et al., 1987). It is assumed that all firms have equal access to the technology and have the knowledge needed for technical change. Firms are regarded as ‘maximisers’ that have complete knowledge of all available options.

Evolutionary economists argue, in contrast, that technical change is an endogeneous variable and therefore needs to be explained. Technical change is regarded as one of the driving forces of economic growth. The basic point in evolutionary economy is that uncertainty in technological developments cannot be ignored (Nelson and Winter, 1977). Firms do not have the ability to check all the technological options and they do not know beforehand which option will be successful. Their rationality is bounded (Simon, 1957) and their behaviour cannot be regarded as 'maximising'. The innovation process is described with the use of the evolution metaphor, borrowed from the biological evolution theory. The basic assumption is that innovation can be described by two concepts: variation and selection.

Variations are generated by innovating firms. Firms generate variations according to familiar and known paths, based on positive experiences from the past and on expectations about the future. On the basis of these experiences and expectations, firms use internal, firm-specific, search heuristics, also called 'search routines' (Nelson and Winter, 1977). In later studies, it was argued that search processes in firms are shaped not only by internal, firm-specific search heuristics, but also by cognitive frames of reference which are available at the level of a sector of firms. This cognitive frame of reference can be compared to a scientific paradigm (Kuhn, 1962). Therefore, Dosi referred to the frame of reference as a 'technological paradigm' (Dosi, 1982; 1988; Freeman and Perez, 1988).

Because of these technological paradigms, technological development is cumulative. Technologies develop according to patterns. In Nelson and Winter, 1982, these patterns are called technological trajectories. Sahal (1985) calls them innovation avenues that are marked by technological guideposts. A technological guidepost, or dominant design (Abernathy and Utterback, 1978), is a standard design that provides both evidence of the success of the technological paradigm and a direction in which to search for solutions to technical problems[5].

Because technologies develop according to fixed patterns, they are said to be path dependent. This path dependence can have negative effects, for instance, if it turns out that technological path chosen is not the most appropriate one. Because investments have been made in the development of the technology, and in the network in which the technology functions, it is often very difficult to abandon the chosen technology and shift to the 'better one' (Tushman and Anderson, 1986). This phenomenon is called lock-in (Arthur, 1988; 1989). A famous example is the qwerty-keyboard, which is now used universally, although it is not the most efficient type of keyboard (David, 1985; 1986).

Not all the variations that firms generate are successful. The variations are introduced in what is called the 'selection environment'. The most promising variations are selected in this selection environment. It is important to note that the selection environment is a broader concept than the market: it includes regulations, norms, beliefs and expectations of multiple actors, government policies, taxes and subsidies.

We will use many of the concepts developed within this theoretical approach, e.g. technological guidepost, frame of reference and technological paradigm, in section 2.4.3, where we investigate the theoretical aspects of learning by searching.

2.2.2 Quasi-evolutionary economics

This approach draws heavily on the insights developed in evolutionary economics. Because the scholars who introduced this approach, Van den Belt and Rip, have a sociological rather than an economic background, the approach is more sociological, with emphasis on institutions (like the patent system in the synthetic dye industry) (Van den Belt and Rip, 1987). Furthermore, the focus of study is different in the two approaches. In evolutionary economics attention is focused primarily on economic processes and the effects of technological change on firms or industrial sectors. In contrast, the focus in quasi-evolutionary economics is on the technology itself and on how it interacts with the selection environment.

Another important difference between evolutionary economics and quasi-evolutionary economics is that in the latter, variation and selection are considered to be dependent and closely linked, whereas in evolutionary economics they are regarded as independent and separate. In quasi-evolutionary economics, variation does not occur randomly, but is guided by heuristics and other promises of success (Van Lente,

[5] This concept is analogous to Kuhn's (1962) concept 'exemplar'.

1993). Furthermore, technology developers actively try to modify the selection environment to increase the chances of the technology they are developing. One way of doing this is to protect the innovation at the beginning by creating protective spaces or niches (Van den Belt and Rip, 1987). This method is known is 'strategic niche management' (Kemp et al., 1998; Weber et al., 1999). Niches can be R&D projects, market niches or the government-subsidised market introduction of new technologies. The locus where the linkage processes between variation and selection take place is called the technological nexus (Schot, 1992). The marketing or environmental departments of firms can serve as the technological nexus.

Concepts like variation and selection, search heuristics and technological paradigms play a large role in quasi-evolutionary economics, just as they do in evolutionary economics. Heuristics are defined as rules that promise success but cannot guarantee it (Van Lente, 1993). They are part of a shared repertoire embedded in an organisation or in a community of technical practitioners. The use of heuristics requires legitimation, like successful earlier problem solving, authority of the technical community or more general heuristics like upscaling. The concept of heuristics will be used in section 2.4.3 which deals with learning by searching.

An important point in the quasi-evolutionary theory is that technological development is assumed to be multi-layered. This assumption is very useful for analytical purposes. The layers are the following: 1. technology in general, as a symbol that is part of our culture; 2. technological communities at the meso-level, dedicated to different technological fields; 3. the niche level, focusing on one specific technology or one technological path. With regard to the multi-layered structure it is important to know is how the activities in and between the levels interact, how they interlock and how they align actors (Schaeffer, 1998).

2.2.3 The technical system approach

Hughes is the main author to use this approach. In his historical case studies, e.g. into the development of power networks (Hughes, 1983), he convincingly argues that technologies should not be regarded as artefacts, but as parts of larger wholes of interrelated components. These components can be technical or social (Hughes, 1987). As examples Hughes mentions generators, transformers and transmission lines in the electricity system, as well as organisations, firms, banks and research organisations. The components of the system interact, thereby contributing to the common system goal. The components are so closely intertwined that it is almost impossible to distinguish between the technical and the social components. He refers to this phenomenon as the 'seamless web'. He defines a technological system as

(Hughes, 1987, p. 51): ‘containing messy, complex, problem-solving components. They are both socially constructed and society shaping’.

The system is assumed to have an inherent logic. The system goal is its expansion. The logic of the system is described by terms like ‘momentum’ and ‘reverse salient’. A reverse salient is a part of the system that inhibits or slows down its expansion and has to be removed to make the system function well. Hughes defines the boundaries of the system by way of control. The components that are under the control of the system are part of the system; the components that are not under the control of the system are not part of the system.

In the system, a crucial role is played by the system builder, who is the main actor in the system; the leader, promoter or builder of the system. Often, this actor has excellent technical and entrepreneurial capabilities. An example that Hughes uses, is Thomas Edison. We will use the concept of system builder in section 2.4.6 that deals with learning by interacting.

The main drawback of this approach is that the theoretical ideas need to be extracted from the very rich case study descriptions. There is no explicit attempt at formal theorising. Furthermore, it is not clear to what extent the conclusions drawn can be generalised.

2.2.4 Network theories

In the network approach we distinguish between two approaches: the actor-network approach and the industrial network approach. These approaches both have a sociological character. They draw heavily on the network theory in sociology, which was developed to analyse social structures at the micro level. In the network approach in the technology development literature, the focus is on the actors involved in technology development and especially on the interactions between them. The actors are embedded in networks.

Actor-network theory
The actor-network theory belongs in the first place to the social sciences. It is part of the constructivist branch of social theory. Every form of change, including technical change, is regarded as a change in actor-networks (Callon, 1986). Callon describes the actor-network as an actor world. The actors can be people, artefacts or texts. The negotiations between the actors developing a technology are taken as a starting point.

It is stressed that technological development is contingent and unpredictable and that there is no great difference between human actors and non-human actors. The focus is on the way in which an actor 'enrols' and 'translates' other actors, values and interests in such a way that the network is made strong. Here, enrolling means incorporating actors into the network, and translating implies transforming their values and interests in such a way that the actors are able to work together to achieve a common goal (Callon, 1986; 1987).

Questions about the direction in which a technology is shaped cannot be answered using this approach, because every structure is considered to be an outcome. Strong network links can be made in many different ways and the only thing that can be analysed with the help of this theory is how these links are made (Callon, 1986; 1987).

In his later work (e.g. Callon et al., 1992) Callon introduces structural aspects. He introduces the concept of techno-economic networks. The degree of irreversibility and the length and convergence of the network are measures of the strength of the network, and are therefore also measures of the success rate of the technological development. According to Callon, these measures can be measured by studying texts, artefacts, skills and money transfers. We will use these structural network aspects in section 2.4.6, when we investigate learning by interacting.

Industrial network theory

Here, the focus is on the network character of the firm and its environment. Håkansson (1990) points out that firms are embedded in their industrial networks and that changes in the network affect the behaviour of the firm. He writes that industrial technology development in most cases is the result of mutual cooperation between firms. In his network model, he distinguishes between three basic components (Håkansson (1987)):

- actors, who can be individuals, a group of persons, or even a division within a company, or a group of companies
- activities, in which resources are combined, developed, exchanged or created
- resources, which consist of physical assets, financial assets and human assets

A network has three functions:

- contributing to the development of the knowledge of actors
- co-ordinating the exchange of resources
- contributing to the mobilisation of resources

Technology development is considered to be influenced by the structure of the network, the actors involved and their inter-organisational relationships, and the specific combinations of activities and resources in the network. An innovation is thus regarded as a product of a network of actors. The main goal of the actors is to increase their control of the network. Håkansson's ideas on the structural aspects of networks will also be used in section 2.4.6.

2.2.5 The social construction of technology (SCOT) approach

This approach focuses on the way in which various actors interpret an artefact. The most important aspect of an artefact is its interpretative flexibility: different social groups attach a different meaning to an artefact (Pinch and Bijker, 1984; Bijker, 1990). Because of this interpretative flexibility, various trajectories can arise within a technology; this means that within the development of a technology, different artefacts can be developed, each embodying a different meaning of the technology. A famous example is Bijker's study on the development of the bicycle. He shows that bicycles were developed along different trajectories, e.g. a trajectory of bicycles for housewives and a trajectory of very different bicycles for sportsmen. When one interpretation becomes dominant, closure takes place, which means that only one basic design of the artefact remains (Bijker et al., 1987). Negotiation, rhetoric and enrolment all play an important role in achieving closure.

The result of closure is the formation of a technological frame, also called 'frame of meaning regarding the technology'. Such a frame is composed of a set of rules and routines used by a community to perceive and solve problems (Bijker et al., 1987). The main difference between a technological frame and a technological paradigm used in evolutionary economics and quasi-evolutionary economics is that a technological frame applies to both technologists and non-technologists, whereas a technological paradigm applies only to technologists. It is possible for more than one dominant frame to co-exist. Furthermore, not all actors need to be equally involved in the frame. Actors with a high inclusion in a technological frame will focus on solving problems perceived within the frame; this leads to incremental innovations. Actors with a low inclusion in a technological frame often use different solutions to problems or even solve different problems; this leads to the development of a competing technological frame. Karnøe and Garud (2001) elaborate on the concept of technological frame. They discern three kinds of frames: frames regarding production, frames regarding use and frames regarding regulation of a technology. Grin and Van de Graaf (1996) note that when a group of actors want to develop a technology together, they do not necessarily need to have the same frame of meaning regarding the technology. However, their frames of meaning need to be congruent; in other words they must not contradict each other. We will use these ideas in section 2.4.6 which deals with learning by interacting.

An important claim in the SCOT approach is that it is important to study not only the development of 'successful' technologies and technological paths, but also 'unsuccessful' technologies and paths (Bijker et al., 1987). Otherwise one will obtain a linear view that overlooks the 'side-tracks' of technological developments that were tried and later abandoned.

2.3 The innovation system approach

The concept 'innovation system' was developed at the end of the 1980s and the beginning of the 1990s by Freeman (1987, 1988), Lundvall (1988, 1992) and Nelson (1993, 1994). It starts from the idea that innovations are often developed within systems formed by actors and organisations. Companies, governments, universities, banks, consumers, and other organisations all contribute in a different and interactive way to innovations. These actors and organisations, the relationships between them and the institutions influencing them, together form the innovation system (Carlsson et al., 2002). Since our starting point was to take into consideration all actors, institutions and organisations that influence wind turbine development (see Chapter 1), the innovation system approach can serve as a suitable basis for our theoretical framework. Therefore, we describe this approach in some detail.

2.3.1 Definitions of the innovation system

A survey of the literature on innovation systems reveals that all authors use a different definition of an innovation system. Because it is such a broad concept, authors can define it differently and stress the element(s) they consider the most important. Freeman (1987) stresses the importance of institutions. He defines the innovation system as 'the network of institutions in the public and private sectors whose activities and interactions initiate, import, modify and diffuse new technologies' (Freeman, 1987, p. 1). In another book he chooses another focus: here he stresses the learning processes within the innovation system. He writes (Freeman et al., 1988) 'The national system of innovation is not just a set of laboratories, but a cumulative process of learning by producing, learning by using and learning by the interaction of producers and users'.

Lundvall (1992) uses a broader definition. He stresses the importance of institutions and learning processes. He writes that an innovation system comprises 'all parts and aspects of the economic structure and the institutional set-up affecting learning as well as searching and exploring – the production system, the marketing system and the system of finance present themselves as subsystems in which learning takes place' (Lundvall, 1992, p. 12). He also writes that 'the structure of production and the institutional set-up are the two most important dimensions, which jointly define a system of innovation' (Lundvall, 1992, p. 10). They 'form the framework for, and strongly affect, processes of interactive learning, sometimes resulting in innovations' (Lundvall 1992, p. 9).

Carlsson and his colleagues use the term 'technological system' instead of 'innovation system'. Carlsson and Stankiewicz (1991, p. 121) define a technological system as 'a network of agents interacting in a specific economic/industrial area under a particular institutional infrastructure or a set of infrastructures and involved in the generation, diffusion and utilization of technology'. Furthermore, they write 'Technological systems are defined in terms of knowledge/competence flows rather than flows of ordinary goods and services. They consist of dynamic knowledge and competence networks.' (Carlsson and Stankiewicz, 1991, p. 121).

2.3.2 Broad guidelines

It should now be clear, that there is no straightforward definition of the innovation system. Different authors use different definitions, which are often very broad. However, there is a set of characteristics upon which all researchers agree. In a study of a specific innovation system, these characteristics can be used as guidelines to build the theoretical framework. Lundvall describes them as follows (Lundvall, 1992):

- The *central focus* is on technological innovation but organisational and institutional change are considered important as well.

- Innovation systems in various countries are claimed to be *different*, and it is important to study these differences.

- The viewpoint is *holistic*, in other words, many determinants and their relationships are included in the analysis.

- A *historical perspective* is used. Innovation is seen as an evolutionary and path dependent process. Therefore, innovation can be understood best when the historical development is taken into consideration. Because innovation is path dependent and open ended, it is not possible to define an optimal innovation system. Since the system keeps changing, it is possible that at one moment one system is better suited for stimulating certain technological developments, whereas later on another system performs better.

- Innovation is regarded as an *interactive process*. Firms do not innovate in isolation, but in interaction with other actors. Innovation is influenced not only by the structures and the actors in the system, but also by the interaction between them.

- The importance of *learning*, and especially of *interactive learning*, is stressed. The accumulation of knowledge and skills is considered to be crucial. The focus is on the interactivity between the structures and the actors in the system, and on the learning processes between them.

- There are no straightforward 'rules' about how the *boundaries of the system* can be specified; in other words, how to define what belongs to the system and what does not. But, as Lundvall argues (Lundvall, 1992), it might be impossible to identify the boundaries in detail. Therefore, as Edquist argues, it might be better to try to identify the core elements in innovation systems, and focus on the relations between these (Edquist, 2001). The researcher himself needs to define the boundaries of the system he is studying. In section 2.3.3 we will discuss this issue further.

- Innovation systems consist of organisations and institutions on the one hand, and interacting actors on the other hand. Therefore, *a structural view is combined with an actor-oriented view*. But what are organisations and institutions exactly? Here again, the definitions vary. We will elaborate on this subject in section 2.3.5.

2.3.3 The boundaries of the system

As stated in section 2.3.2, there are no straightforward rules on how to define the boundaries of an innovation system. What should be included in the analysis and what should be omitted? Depending on the case studied, the boundaries can be defined by technological, sectoral or by geographical factors. If the boundaries are defined by geographical factors, they can be national, regional or local.

In studies that define the boundaries by the technology, the focus is on the specific technologies around which the system develops. In studies that define the boundaries by geographical factors, the focus is on the relationships between economic change and innovation processes in general. A good example of the last-mentioned kind of study is the book 'National innovation systems' by Nelson (1993). In this book, 15 different national innovation systems are described. These national systems differ with regard to the degree of specialisation, type of institutions and national policies. This underlines Lundvall's argument (1992) that nations are still important, even nowadays, when the economy is becoming more and more international.

Ehrnberg and Jacobsson (1997) define the boundaries of the system by the technology. They argue that, when focusing on large technological changes, one should consider four levels of analysis: the technology, the firm, the industry and the technological system.

From the above, it can be concluded that the concepts of national innovation systems and technological systems are not mutually exclusive. They can be combined, for example in a study of a specific sector in different countries. An example is Texier's research into the aerospace sector in France, Sweden and South Korea (Texier, 2000). Another example is wind turbine technology. As explained in the introduction, the development of this technology is influenced to a large extent by national policies. Therefore, in our research we will combine geographical and sectoral dimensions, as did Texier. The system we investigate consists of all actors, organisations and institutions engaged in wind turbine technology development within a nation. We will call this system the national wind turbine innovation system.

2.3.4 Organisations and institutions

As mentioned above, the core of the innovation system approach consists of three elements:

- the actors engaged in the innovation process
- the relationships between these actors
- the institutions influencing these relationships

The concept 'institution' is very important in the innovation system approach. However, it is not explained very clearly and all authors use different definitions. Furthermore, the term 'institution' is often used incorrectly and is confused with 'organisation'. Therefore, we give some attention here to the difference between 'organisation' and 'institution'. We define the terms 'organisation' and 'institution' as we use them in our research.

Organisations

The main difference between organisations and institutions is that organisations are formal structures with an explicit purpose that are consciously created, whereas institutions may develop spontaneously and often do not have a specific purpose (Johnson, 1997). North (1990) defines organisations as 'groups of individuals bound by some common purpose to achieve objectives'. Organisations include many kinds of entities:

- political bodies, such as ministries, political parties and local councils for science and technology
- bureaucratic bodies, such as public agencies and offices for implementing innovation policy

- regulatory bodies, such as agencies concerned with standards, norms and certification
- social bodies, such as academies and professional associations
- educational bodies, such as universities and schools
- knowledge-oriented bodies without economic goals, such as government laboratories
- non-profit organisations with economic goals, such as technical centres
- firms, including R&D companies, joint ventures and consortia
- bridging bodies, such as innovation centres

The organisations mentioned cover a very broad range. Galli and Teubal (1997) distinguish between hard and soft organisations, the hard ones performing hard functions of the innovation system and the soft ones performing soft functions. Hard functions are related to actual knowledge creation, while soft functions support knowledge creation by performing catalytic and interface roles. Hard functions and related organisations include:
- R&D, involving universities and public and non-profit organisations
- the supply of scientific and technical services to third parties by industrial firms, technological centres, technical service companies, universities, governmental laboratories, etc.

Soft functions and related organisations include (Galli and Teubal, 1997):
- diffusion of knowledge, and technology to economic and public operators acting at the interface between knowledge suppliers and users; this is done by bridging organisations, which include innovation centres and liaison units at universities and public laboratories
- policy-making by government offices, technology assessment offices, academies, universities, national committees and councils, etc.
- design and implementation institutions concerning patents, laws, standards, certification, regulations, etc.; these functions are usually performed by public or intermediate organisations
- diffusion of scientific culture via museums etc.
- professional co-ordination by way of academies, professional associations, etc.

Institutions

As mentioned above, organisations are designed to serve a specific purpose, whereas institutions appear spontaneously and do not serve a specific purpose. According to North's definition (1990, p. 3) institutions are: ‘the rules of the game in society or, more formally, the humanly devised constraints that shape human interactions’. Institutions are sets of common habits, routines, established practices, laws or rules that regulate the relations between individuals and groups, thereby reducing uncertainties. They provide humans with a means to deal with the complexity of life without engaging in global rational calculations involving a vast amount of complex information (Johnson, 1992). It is useful to distinguish between formal institutions, e.g. laws, government regulations, technical standards and norms, and informal institutions, e.g. common law, customs, traditions, norms, conventions, codes of conduct, practices, etc. (Johnson, 1997).

Institutions create patterns in human behaviour. More specifically, in the context of the innovation system, Carlsson and Stankiewicz define institutions as 'normative structures which promote stable patterns of social interactions/transactions necessary for the performance of vital social functions', but further on, they also define 'institutional arrangements (both regimes and organisations)' and 'the political system, educational system, patent legislation, and institutions regulating labour relations' as institutions (Carlsson and Stankiewicz, 1995, p. 45). Lundvall writes: 'Institutions provide agents and collectives with guide-posts for action', and 'institutions may be routines, guiding everyday actions in production, distribution, and consumption, but they may also be guide-posts for change. In this context, we may regard technological trajectories and paradigms, which focus the innovative activities of scientists, engineers, and technicians, as one special kind of institution' (Lundvall, 1992, p. 10).

Edquist and Johnson (1997) distinguish the following general functions of institutions with respect to innovation:
- reducing uncertainty, either by providing information about the behaviour of other people or by reducing the amount of information needed
- managing conflicts and cooperation between individuals and groups
- providing incentives to engage in learning and searching (e.g. status norms, perceived competitive advantage, property rights)
- providing resources (e.g. via tax rules or subsidies)

Writers using the innovation system approach and researching the overall innovative abilities of countries instead of the development of a specific technology point to the important role that institutions at the state level play in innovation. Especially important is the education and training system (Carlsson and Jacobsson, 1997). schools, universities and R&D organisations play a leading role in this system. Other important institutions are the capital system, especially the supply of venture capital and other long-term finance and the rules under which such funds are allocated, the legal system granting ownership of new inventions and new knowledge (e.g. patent legislation), the political system, and governmental policies in areas of science, technology and economics and in labour markets (Smith, 1997; Nelson, 1993; Ehrnberg and Jacobsson, 1997; Carlsson and Stankiewicz, 1991).

In general, institutions are considered to retard the dynamics of technical change, because of their inertia and rigidity (Johnson, 1992). They are regarded as inflexible. They are the result of both the functions they serve at present and the functions they served in the past. Sometimes authors who use the innovation system approach give the impression that innovators behave like puppets on the strings of institutions, having no freedom of choice at all. This impression is too extreme. First of all, insitutions not only constrain innovation, they also facilitate it (Garud and Rappa, 1994). Examples are search routines and patent legislation. Secondly, even if institutions constrain innovation, they do leave room for strategic choices. Scott (1995) distinguishes between institutions according to the room they leave to firms for strategic choices. He distinguishes:

- institutions that impose organisational behaviour; these leave no room for strategic choice; an example is direct government regulation
- institutions that authorise organisational behaviour; the organisation is not compelled to conform, but voluntarily seeks out the attentions and approval of the authorising agent; an example is ISO certification
- institutions that induce organisational behaviour; the organisation is induced to behave in a certain way, e.g. by financial incentives; examples are grants, contracts and tax benefits
- institutions that leave organisations room to choose the way they behave

Whether institutions facilitate or constrain the innovation process will depend on whether they provide what the innovation process needs. Important here is that institutions are not static, but that they can change, even in the short term. This point is recognised more and more by innovation system researchers. Johnson (1992) recognises institutional change, but remarks that this often lags behind technical change. According to McKelvey (1997), the way in which institutions are designed and their ability to co-evolve with technology will influence how well different systems perform to generate and select innovations. On the one hand, institutions provide stability in the patterns of social interaction, thereby reducing uncertainty; on the other hand, institutions are flexible and will be recreated through continuing and new social interactions.

Here we find ourselves in the middle of a very important debate in the social sciences: what determines what: does action determine structure or does structure determine action? In this case: do actions by innovating actors constitute the main source of institutional change, or is the existing institutional structure the main source of the behavioural paths of the innovators? Giddens (1984) proposed an intermediate point of view: the interactionist methodology. According to him, to explain social processes one needs to take both structural and behavioural aspects into account. As mentioned above, evidence suggests that this methodology can also be applied to technology studies: both causal links are important in technology development. Therefore, we will follow this evidence and assume that behaviour and institutional structure are both relevant in technology development and influence each other; they are intertwined. Actor behaviour is influenced by institutional structure and can to some extent change institutional structure.

2.4 Learning

Another important aspect in the innovation system approach is interactive learning. This is the transfer of knowledge between actors engaged in the innovation process. Lundvall in particular puts interactive learning at the centre of the analysis. While many other researchers concentrate on the influence of institutions on technology development (e.g. Edquist, 1997; Nelson, 1993), Lundvall and his colleagues of Aalborg University focus on the role of interactive learning between the users and producers of technology. They developed some theoretical notions on interactive learning between users and producers in innovation systems (see section 2.4.6) (Lundvall, 1992).

Like Lundvall, we put learning at the heart of our research. Therefore, we will look more closely at the concept of learning. We will investigate not only interactive learning, but also other kinds of learning that are involved in the innovation process.

Although learning is important during economic activities in general, it is especially important in innovation processes. Here, product concepts are changing or completely new products are developed. These new products often do not fit in with existing societal and technical arrangements, and require new knowledge and skills, often from a broad range of actors. The more uncertainties are attached to the new technology, the more learning is required. This is especially the case with systemic technologies, i.e. technologies consisting of several interacting parts. When these technologies need to function in varying and poorly understood environmental contexts, learning, especially learning by using, is of the utmost importance (Rosenberg, 1982). Since wind turbines are an example of systemic technologies that need to function in varying environmental contexts, learning plays a large role in their development.

What is learning? And, more specifically, what is the role of learning in technology development? Which kinds of learning, besides interactive learning, occur in technology development? And what conditions impede or facilitate these kinds of learning? We will answer these questions in this section. Our focus is on learning in innovation systems. Therefore, we will not refer to the large body of literature on learning by individuals.

2.4.1 What is learning?

In Collins' Cobuild Dictionary of the English Language, learning is defined as 'acquiring knowledge of something or skill in something through hard work or careful reflection'. From this, we can conclude that learning can mean acquiring generally new knowledge and skills and new combinations of old knowledge and skills, and it can also mean putting old knowledge and skills into new heads. Henceforth, we will use the term 'knowledge' to mean 'knowledge and skills'.

Learning by organisations or networks of organisations

As far as learning of organisations or networks of organisations is concerned, there is not much agreement on how learning should be defined. Furthermore, little attention is paid to how it occurs (Nonaka and Takeuchi, 1995). Learning is a multi-faceted and complex concept. Dodgson (1996) defines learning by firms as: 'the way firms build, supplement and organise knowledge and routines around their competencies and within their cultures, and adapt and develop organisational efficiency through improving the use of these competencies' (Dodgson, 1996, p. 55).

The competencies of a firm are the focused combination of resources within a firm, which define its activities and position on the market. They consist of knowledge and skills and increase through learning. Teece et al. (1994) distinguish two kinds of competencies:

- organisational / economic competencies, including competencies regarding what to produce, for whom and at what cost as well as how to design the most efficient organisation
- technical competencies, which define the technological basis on which a firm builds its development and production activities

Firms can learn, although their learning is based on the learning of individuals within the firm (Nonaka and Takeuchi, 1995). An important task for firms is to organise itself in such a way that the learning of individuals within the firm results in the learning of the firm; in other words, that the knowledge and skills are distributed to the rest of the firm. Learning in firms takes place within all the departments and throughout all the activities of the firm, although at different speeds and levels (Hedberg, 1981).

Nonaka and Takeuchi (1995) add to this: (Learning firms) 'do not only simply process information (…) in order to solve existing problems and adapt to a changing environment. They actually create new knowledge (…) in order to redefine both problems and solutions and, in the process, to re-create their environment.' So, learning consists of two kinds of activity. The first kind is obtaining knowledge for solving specific problems based upon existing premises. The second kind is establishing new premises to override the existing ones. These two kinds of learning are called 'Learning I' and 'Learning II (Bateson, 1973), or 'single-loop learning' and 'double-loop learning' (Argyris, 1977; Argyris and Schön, 1978), or 'adaptive learning' and 'generative learning' (Senge, 1990).

Learning by forgetting

Most authors claim that learning is cumulative. What is learnt depends on what was learnt before. By learning, a knowledge base is gradually built up. However, Hedberg points to the fact that learning is not always cumulative. As circumstances change, the knowledge and skills that are needed may change as well. Then the firm needs to unlearn, discarding obsolete knowledge and skills (Hedberg, 1981). Johnson (1992) refers to this phenomenon as 'learning by forgetting'. He points out that learning by forgetting can both occur consciously, or deliberately, which he calls 'creative forgetting' and unconsciously, which he calls 'forgetting'. Creative forgetting involves removing old habits of thought, routines and patterns of co-operation, both within and between firms, making way for new habits of thought, routines and patterns of co-operation and new learning processes. It takes time and resources, and is typically problem-triggered (Hedberg, 1981). Changes in techno-economic paradigms in particular involve a great deal of creative forgetting (Freeman and Perez, 1988). Unconscious forgetting may occur when knowledge and skills are not managed well in a firm or network. An example of unconscious forgetting resulting in organisational forgetting can come about when employees with specific, relevant knowledge leave a firm or network.

Learning has an internal and an external component (Teece et al., 1994; Malerba, 1992). Internally, firms learn mainly through their R&D activities. Furthermore, they learn via other firm activities, like marketing and manufacturing and, especially, via interactions between these activities. Externally, firms learn in interaction with other actors like customers, suppliers and science-based knowledge providers like R&D laboratories and universities. We will elaborate on these kinds of learning in the following sections.

Learning processes in a firm are influenced by both internal and external factors. Internal factors are for example quality control, job training, job rotation, communication between different departments, norms and habits of workers, trust and legitimacy, and supervision (Orozco Barrantes, 2001). The learning capacity of a firm is also influenced by the environment of the firm (Hedberg, 1981). Learning requires neither too much change nor too much stability. Too much change can prohibit learning and experimenting. On the other hand, if established and successful behaviours never grow obsolete, there is little inducement to learn. Furthermore, an environment which is (perceived as) very hostile may impede learning as well. Learning in changing environments may occur defensively or offensively. Defensive learning means adjusting yourself to reality, while offensive learning involves using knowledge to improve the fits between the organisation and the environment, either by changing the organisation or by trying to change the environment (Hedberg, 1981).

2.4.2 Kinds of knowledge and learning

Having discussed the role of learning in the context of technology development, we now need to investigate which kinds of learning can be distinguished in this context. First of all, we will describe different kinds of knowledge that are distinguished in the literature. Then, we will link these kinds of knowledge with kinds of learning.

Kinds of knowledge
Dannemand Andersen (1993) presents a taxonomy of knowledge in the form of dichotomies. The dichotomies are the following:

1. embodied knowledge and disembodied knowledge

Embodied knowledge is knowledge that is present inside a technological artefact or inside persons. An organisation can use knowledge embodied in a technological artefact without understanding the technology. For example, a wind turbine builder may use a gearbox that he has not built himself but which he has bought from a supplier. He can use the gearbox for building wind turbines without needing to know how to produce a gearbox himself. Disembodied knowledge is knowledge that is freely available, for instance, knowledge that is written down in scientific reports.

2. tacit knowledge and formalised knowledge

Formalised knowledge is knowledge that is written down, e.g. in books and reports. Others can acquire this knowledge simply by reading the texts. Tacit knowledge is not written down, but remains in the heads of people[6]. This form of knowledge is far more difficult to transfer from one person to another. Dosi et al. (1988, p. 1126) write that 'tacitness refers to those elements of knowledge, insight and so on, that individuals have which are ill-defined, uncodified and unpublished, which they themselves cannot fully express and which differ from person to person, but which may to some

[6] A good example from everyday life is riding a bicycle. You can do it, but it is difficult to explain to someone how to do it. You can only demonstrate and let the other person imitate.

significant degree be shared by collaborators and colleagues who have a common experience'. Polanyi (1958, 1966) is the first to emphasise the importance of tacit knowledge. He writes that when knowledge has a high tacit component, it is extremely difficult to transfer without intimate personal contact, demonstration, and involvement. Whereas most other early literature on learning is concerned mainly with formalised knowledge, recent studies (Teece, 1981; Davis, 1986; Dosi et al., 1988; Von Hippel, 1994) have started to give more attention to the tacitness, or 'stickiness' of knowledge.

3. R&D-based knowledge and experience-based knowledge

As the terms imply, R&D-based knowledge is based on research and development, and experience-based knowledge is based on experience.

Malerba (1992) adds two more kinds of knowledge: internal and external knowledge.
Internal knowledge is generated within the company in areas such as production, R&D and marketing and in the interactions between these areas. External knowledge is obtained from outside the firm, e.g. from other firms within the same industry, from suppliers or users, or from research institutes.

Garud (1997) presents another taxonomy of knowledge. He identifies the following three kinds:

1. know-why

This kind of knowledge is the knowledge about why something works the way it does; it concerns the scientific background. The laws of motion in nature are examples of this kind of knowledge. Such knowledge is generally produced in universities and other specialised organisations.

2. know-how

Know-how is the knowledge about how to produce something, and about how to do it in an efficient way. It often refers to skills. Know-how is often tacit knowledge and is therefore difficult to transfer. It can be a basis for sustainable competitive advantage.

3. know-what

This kind of knowledge means knowing how to use something. It involves knowledge of facts.

Lundvall (1997) introduces another kind of knowledge: 'know-who'. This refers to social skills, involving information about who knows what or who knows how to do things.

Kinds of learning
Garud links the three kinds of knowledge he distinguishes (see above) with three kinds of learning. Know-why is acquired by learning by searching, know-how by learning by doing and know-what by learning by using. He is not the first researcher to identify these kinds of learning. In the following sections, we will describe the literature in which these kinds of learning were developed. Furthermore, we add a fourth kind of learning: learning by interacting. This kind, also called ‘interactive learning’, is widely used in the innovation system approach, especially by Lundvall and his colleagues. Whereas in processes of learning by doing, learning by using and learning by searching, knowledge creation takes place, learning by interacting is connected with knowledge diffusion.

In the remainder of this section we will go into these kinds of learning in more detail. We will use concepts from the theoretical approaches in innovation studies, which we presented in section 2.2. We are particularly interested in how to operationalise these kinds of learning. What do we look for in our case studies to identify learning by searching? In the literature, no methodology has yet been developed for operationalising learning in innovation research. We therefore develop our own methodology. On the basis of the innovation literature, we identify conditions that facilitate the kinds of learning we have identified. In the following sections, we will begin by describing the kinds of learning in some detail, and then we will list the conditions that facilitate them. In the case study chapters, we will use these 'facilitating conditions' as a guide to identify the different kinds of learning.

2.4.3 Learning by searching

We will start by describing the form of learning that first comes to mind when thinking about technology development: learning by searching. During learning by searching, 'know-why' is acquired. Learning by searching is related to the systematic and organised search for new knowledge. It is a broad concept that includes a whole spectrum of activities ranging from basic research to discovering the optimal design characteristics of a product and discovering the design characteristics desired by the market. Synonyms for learning by searching are R&D (research and development) and ‘learning by studying’ (Garud, 1997). Johnson (1992) separates ‘learning by searching’ from ‘learning by exploring’. He argues that ‘learning by searching’ occurs mainly in firms and is closely linked with production, whereas ‘learning by exploring’ occurs in universities and is less profit oriented. However, the two are strongly interdependent and the borderlines between them are becoming increasingly blurred. Therefore, we will not make this distinction. In the following, we will only use the terms ‘learning by searching’ and ‘R&D’, which we will use interchangeably. R&D consists of searching for new technological options, testing them and learning about their viability. Testing usually occurs on a small scale, e.g. in a laboratory or by building a prototype.

According to Andersen and Lundvall, it is fruitful to analyse R&D mainly as search strategies which are themselves following routines (Andersen et al., 1988). This idea was put forward first by Nelson and Winter (1977, 1982). They argued that, because of their bounded rationality, designers cannot predict in advance which R&D choice will turn out to be the best. Instead, they apply search routines, or, in other words, heuristics when looking for improvement in the performance or cost-efficiency of a product. This method is cheaper and faster than trying out every possibility, although the solution found is not necessarily the best one possible (Frenken et al., 1999). Nelson and Winter (1977) define heuristics as 'beliefs in what is feasible or is at least worth attempting'. In connection with technological heuristics, Dosi in 1982 introduced the concept of the 'technological paradigm'. He defined this as: 'a 'model' and a 'pattern' of solution of selected technological problems, based on selected principles and on selected material technologies'.

Another concept used by Dosi to analyse guiding rules in R&D is the concept of exemplar. An exemplar is an early example which has proved to work and which serves as a guide in subsequent R&D processes. It provides both evidence of the success of the paradigm and solutions to technical problems (Frenken, 2001). While analysing the same phenomenon, Sahal introduces the concept 'technological guidepost' (Sahal, 1981). Such a guidepost is an early design that stands out above all others. It 'becomes the foundation of a great many innovations via a process of gradual evolution' (Sahal 1981, p. 33).

The actors involved in R&D are generally universities, research organisations or research departments of firms. R&D results are mainly written down in research reports or articles, which means that a great part of the R&D results is in the form of formalised knowledge. R&D results are often protected by patents. However, the knowledge often leaks out, even when protected by a patent (although at a slower pace) (Garud, 1997).

Now we know what learning by searching is, we need to know how to operationalise it. What interests us most is which (institutional) conditions in the innovation system facilitate learning by searching. On the basis of the above, we can list the following:

1. the presence of a technological guidepost, guiding the direction for search
2. the availability of an appropriate scientific theory on the subject, guiding the direction of search
3. the presence of a technological paradigm, guiding the direction of search
4. the presence of standards and regulations, guiding the direction of search

These conditions are particularly important for learning by searching at the network level. When notions about technological guideposts and technological paradigms are shared, actors can work together in their search, accumulating knowledge in the network. Of course, there are other prerequisites for learning at the network level. We will go into these in section 2.4.6.

The innovation literature also mentions other institutional factors in the innovation system which facilitate learning by searching:

5. changing circumstances

When circumstances change, firms feel the need to start searching. If nothing ever changes, firms are tempted to keep on performing in the same way as before. However, when changes occur too quickly, firms may become paralysed and stop learning by searching (Hedberg, 1981). The anticipation of changes may also cause learning by searching (McKelvey, 1997).

6. an environment that is not (too) hostile

Just like quick changes, a hostile environment may cause paralysis (Hedberg, 1981; see also Carlsson and Jacobsson, 1997).

7. the availability of capital

Searching costs money and involves risks. Because the outcomes are uncertain, it is possible that no good, readily applicable results are obtained. Although it is often thought in scientific and policy circles that innovation is a good thing, firms are often less enthusiastic, because of these risks. However, the possibility of an increase in competitive advantage as a result of the innovation is a strong pull towards investing money in searching. Governments can provide venture capital or R&D subsidies in order to lower the threshold for investment.

8. some level of knowledge and experience in the field of study

Especially in the case of entirely new technologies or innovation in new technological directions, firms have an advantage if they do not have to start from zero. Here, in addition to on-the-job training, the educational system plays a role. Another way to acquire the level of knowledge that is needed, is to obtain it in an embodied form, i.e. hire people that have the knowledge.

9. the possibility of making mistakes and learning from them

This is connected with time. Time has to be available for testing and experimenting. Money is also needed for testing and experimenting (see above).

10. the way the ownership of novelties and new knowledge is organised
The possibility of receiving property rights on research results is often an incentive for searching. Why should a firm invest money in R&D when the results can easily leak to others? However, there is another side of the ownership coin. When property rights are granted, there is a danger that the road will be closed to other firms eager to search in the same direction. An example is the present R&D in biotechnology, where the ownership of patents by some parties provides a disincentive for other parties to invest money in R&D in the same field.

2.4.4. Learning by doing

As mentioned above, besides R&D, other kinds of learning, namely learning by doing, learning by using, and learning by interacting, are also important in technology development. Although in innovation research in general, a great deal of attention has always been given to R&D, increasing attention has also been given to these other kinds of learning. The difference between R&D and these kinds of learning is that R&D is aimed primarily at the generation of knowledge, whereas the other kinds of learning are not. They are more or less by-products of (economic) activities that are performed for other purposes.

The kind of learning that economists first looked into was learning by doing. This concept was introduced by Arrow in 1962. During learning by doing, know-how is acquired. Know-how resides in individuals, organisational routines and manufacturing practices (Garud, 1997). According to Arrow, learning by doing takes place at the manufacturing stage after the product has been designed. Learning at this stage consists of increasing production skills. These skills accumulate with experience in time (Garud, 1997). Through productive processes many problems, faults and bottle-necks are demonstrated and solved. Furthermore, through trial-and-error practical experience is gained on how to produce the technology. This increases the efficiency of production operations (Rosenberg, 1982).

An important aspect of learning by doing is the development of 'rules of thumb' (Sahal, 1981). Learning by doing generates mainly tacit knowledge. As Sahal argues (Sahal, 1981), technological progress is largely a matter of practical experience; it depends much less on 'knowledge imported from without' than on 'experience from within'. The down-side is that, if a long time has passed since last the technology was last produced, the experience can be forgotten and lost (Neij, 1997).

In 1988, Freeman reformulates the 'learning by doing' concept into the more specific concept 'learning by producing' (Freeman et al., 1988). According to Freeman, the actors involved in learning by doing are generally production departments in firms.

However, other researchers point to the fact that learning by doing also takes place in other parts of firms, e.g. in marketing and sales departments. Because these departments are not directly engaged in production, we will not use the term ‘learning by producing’, but instead we will use the more general and more widely used concept of ‘learning by doing’.

Which (institutional) conditions in the innovation system facilitate learning by doing? Since this kind of learning originates as a by-product of economic activity in general, we claim that learning by doing always exists. Producing is sufficient to trigger it. This claim is supported by numerous articles about learning curves (see for instance Yelle, 1979; Neij, 1997; 1999; IEA, 2000b). This literature demonstrates that as a result of learning by doing, the price of a product decreases when more products are made.

Therefore, the only facilitating condition for learning by doing is the number of products produced. We split this condition into two conditions:

1. time
   Know-how is built up slowly. Therefore, firms need time to build up this knowledge stock. When changes occur quickly, there may be too little time to profit from learning by doing.
2. a high production rate
   The higher the production, i.e. the more products there are to practice on, the more will be learned by doing (Neij, 1999). One of the factors influencing the production rate is market demand. Therefore, demand-oriented technology policy can play a role to increase learning by doing.

2.4.5 Learning by using

In his book published in 1981, Sahal mentions that ‘it is plausible, however, that at least some of the useful know-how is acquired in the *utilisation* of technology’. He uses the phrase ‘learning via diffusion’, meaning that the increased adoption of a technology leads to improvement in its characteristics. Rosenberg elaborates on this subject and introduces the concept of ‘learning by using’ (Rosenberg, 1982). He writes that learning by using is especially important in connection with products that consist of complex, interdependent components. When these products are used, especially when they are subject to prolonged stress, the outcome of the interaction of the components cannot be precisely predicted by scientific knowledge or techniques. This interaction can only be assessed after intensive or prolonged use. One of the main purposes of learning by using is to determine the optimal performance characteristics of a durable product since these affect the useful life of the product (Rosenberg, 1982).

The actors involved in learning by using are the users of the technology. Often, these users are firms, like the technology developers. But the users can also be other actors. In the case of wind turbines, the users are the owners of the wind turbines.

Conditions in the innovation system that facilitate learning by using are as follows:

1. the presence of users. This may seem obvious, but it does not have to be. Sometimes, technologies are developed entirely by R&D departments without the involvement of users.
2. the existence of a user group of a minimum size and degree of sophistication. The characteristics of the product under consideration determine the minimum size of the demand and its minimum degree of sophistication (Andersen et al., 1988).
3. There have to be contacts between the user and the producer to enable the producer to learn from using. We will investigate this in the following section.

2.4.6 Learning by interacting

As mentioned above, Lundvall places learning in innovation systems at the centre of the analysis. He points specifically to the importance of learning between users and producers. Realising that contacts between users and producers are necessary for successful innovation Andersen and Lundvall introduced the concept of interactive learning, or, in other words, learning by interacting (Andersen et al., 1988). Their main point is that successful innovation is to a large degree dependent on close and persistent user-producer contacts. The reason is that, particularly in complex innovation processes, firms are hardly ever able to have or develop all the required knowledge and skills in-house. Especially if the required information is tacit and difficult to formalise and communicate more broadly, learning has to occur during direct face-to-face contacts. The more complex the technology, the more one needs to rely on the expertise of others (Lundvall, 1988; Carlsson and Stankiewicz, 1991). Another motive for learning by interacting is the need to reduce technological and market uncertainty by improving the predictability of the technology development (Dodgson, 1996).

Andersen and Lundvall state that learning by interacting is the basis for many incremental innovations, and that the experiences of learning and minor innovations are important prerequisites for many radical innovations (Andersen et al., 1988). In his book ‘National systems of innovation – towards a theory of innovation and interactive learning’, Lundvall (1992) presents some theoretical notions on learning by interacting in user-producer interactions. These interactions enable users and producers to learn and innovate in the following way. During the interaction process, the user can communicate potential needs. This results in 'demand-pull' innovations.

In the meantime, during the interaction process, the producer can communicate potential technical opportunities. These result in 'technology-push' innovations. Here, Lundvall emphasises the communication of qualitative and tacit knowledge. Furthermore, he stresses that, because of the existence of learning by interacting, innovation cannot be regarded as a process that takes place only in R&D departments (Lundvall, 1992). Instead, innovations occur as a result of on-going interactive learning processes.

When the concept of learning by interacting was developed, the idea was that the only actors involved in this kind of learning were users and producers (e.g. Andersen et al., 1988). According to Garud (1997) this kind of learning takes place in the nexus of the relationship between the user and the producers. But, if one is considering technological development from the perspective of the innovation system, one realises that other relationships are important as well, e.g. the relationship between the producer and the scientist or the relationship between the producer and the policy-maker. Learning by interacting also takes place in these relationships. Therefore, in the following we will not concentrate solely on user-producer relations but we will also take into account other relations in the innovation system.

Conditions for learning by interacting

Learning by interacting takes place where it is in the interest of the actors to collaborate and exchange knowledge. It involves linking actors with different backgrounds, e.g. from different industrial cultures, or from user and supplier communities. The actors involved need to make investments and commitments. Interactions continue if the parties are motivated to take part and remain involved, because they expect some benefit. These benefits can include co-production and sharing of knowledge, and a reduction of costs and risks, e.g. through alignments of views and closure of technological controversies, or co-operation in building up new markets (Williams et al., 2000).

Knowledge often cannot simply be transported from one actor to another. It is often tacit, specific and commercially sensitive (Dodgson, 1996). Before he can use the new knowledge, the receiving actor needs to translate it, combine it with other knowledge, and transform it. Therefore, the main prerequisite for learning by interacting is proximity. In this context, proximity involves not only physical distance, but also organisational, economic and cultural proximity (Andersen et al., 1988). The central idea is that learning by interacting will be restricted if these distances become too great (Lundvall, 1992). Geographical and cultural closeness, Lundvall argues (1988), facilitate effective interaction and therefore national borders tend to enclose networks of technological interaction. Common government and heritage (language, culture, education, national standardisation) facilitate communication within nations. He points out that information transfer can only take place if there are channels of information through which the message can pass and if there is a code of information. Other requirements for learning by interacting include common codes of conduct, a certain lack of competition, mutual interest in the learning process and trust between the actors (Lundvall, 1988; Nooteboom, 2001).

Van Est, Grin and Van de Graaf note that learning by interacting, which they call 'joint innovation learning', is facilitated when the actors involved share the same frame of meaning about the technology. Frames of meaning consist of problem definitions and preferred solutions, appreciative systems (or value systems) and overarching theories that help to explain the situation. However, sharing the same frame of meaning is not a necessary condition for learning by interacting. For successful learning by interacting, the frames of meaning of the actors involved in the learning process need to be congruent, which means that they do not contradict each other (Van Est, 1997; Grin and Van de Graaf, 1996).

Although proximity is important to if effective learning by interacting is to occur, actors also need to be diverse to a certain degree; they need to have slightly different knowledge bases. Obviously, there would be nothing to learn from interacting if the knowledge bases of the actors were exactly the same. Different knowledge bases lead to the emergence of new ideas, which in turn might lead to the development of new technologies or even new technological paradigms (Cohendet and Llerena, 1997). Therefore, to facilitate learning by interacting the distance between the interacting actors should be neither too small nor too large (Nooteboom, 1992).

Cohendet and Llerena (1997) point out that norms of openness and disclosure are important for learning by interacting. When there are strong intellectual property rights, on the other hand, information is not disclosed and shared. In that situation, the learning trajectories are narrow and the scope of research is small. However, this is at odds with our statement in section 2.4.3, namely that strong intellectual property rights stimulate learning by searching. We assume that finding some kind of middle course will be the best solution. An example is a policy in which pre-competitive research is only subsidised if the results are made public, whereas competitive research does not need to be made public.

Lundvall (1988) makes another interesting claim. On studying the relationship between the character of technological change and spatial interactions, he suggests that the nature of interactions varies among technologies. When the technology is standardised and relatively stable, the information that is exchanged may be translated into standard codes, and long-distance transmission of information at low cost is possible. Then, user-producer relationships over a long distance can be effective.

However, when the technology is complex and keeps changing, a short distance can be important. The information codes can be flexible and complex, and a common cultural background can be important for establishing tacit codes of conduct and for facilitating the decoding of complex knowledge. When the technology and user needs are complex and changing, a short distance is even more important. From the above, the hypothesis can be derived that in the later, more orderly stages of the innovation process long-distance links work well, whereas in the early chaotic stages local networks are required.

Learning in networks

This brings us to the subject of networks and their importance for learning. As mentioned in section 2.2.4, Håkansson provides a framework that illustrates the relation between learning, innovation and networks. He points out that (Håkansson, 1987) one of the three functions of a network is to contribute to the knowledge of the actors, which involves the transfer of information. Some of the information exchanged in networks may be marketed information in the form of staff training programmes, market analyses or technical advice. However, much of the information is transferred via the informal exchange of ideas (Carlsson and Stankiewicz, 1991). Relations within a network are investment intensive and often very durable, building on gradually developed trust. Therefore, a firm has to limit these relations and be selective with regard to with whom relations should be developed (Håkansson, 1987).

The flow of information within a network may well result in a blending of visions or of frames of meaning regarding the technology (see also section 2.2.5). Sharing the same frames of meaning may then lead to a reduction of perceived risk and a coordination of search efforts and investments between formally independent actors; this may turn learning by searching into a collective activity (Carlsson and Jacobsson, 1997). Therefore, the type of actors in the network may co-determine the search direction of the individual firm. Therefore, it is to be expected that a firm with strong network links with academia and weak network links with users will most probably search in directions that differ from those of firms that have strong network links with users and weak network links with academia.

Because of the structural aspects of networks, they can be regarded as a kind of institution. Like institutions, they may both facilitate and impede learning. Strong and stable networks are likely to contain a lot of inertia and path dependency. This can mean that new technologies or new technological ideas that are not shared by the members of the network may be exploited slowly or not at all (Carlsson and Jacobsson, 1997). Therefore, the emergence of a new technology may require the creation of new networks.

What else is known about relationships between the character of the network and learning? Callon (1992) introduces structural aspects of networks, like stability, irreversibility, length and convergence (see section 2.2.4). Carlsson and Stankiewicz (1991) state that the role of the entrepreneur, or network builder, is important in that it is to provide the vision that will increase the learning rate in the network.

Williams et al. (2000) point to the importance of intermediaries for learning by interacting in networks. Their role is to facilitate the transfer and diffusion of knowledge. When knowledge is difficult to communicate, e.g. because it is tacit or because it is too complex, intermediaries transfer this knowledge in a 'person embodied' form, in other words: in person. They cross the boundaries between organisations, departments or knowledge communities. Sometimes their role is to include other actors who do not experience sufficient incentives, but whose involvement may be crucial. Often, intermediation is shared among several actors. Critical for good intermediation is the ability to mobilise knowledge and resources and to cross different spaces (especially between users and producers) (Williams et al., 2000).

To conclude

Summarising, (institutional) conditions that facilitate learning by interacting are:

1. mutual interest in the learning process
2. proximity in the broad sense, including geographical closeness, cognitive closeness, a common language and culture, national standardisation, common codes of conduct, a certain lack of competition and mutual trust between the actors, and congruent frames of meaning regarding the technology
3. norms of openness and disclosure
4. the presence of an intermediary if information is not transferred easily or if not all relevant actors cooperate spontaneously
5. the presence of a network builder
6. the capacity to build new networks and to destroy obsolete ones

2.5 Conclusion

In this chapter, we have constructed our theoretical framework. As a starting point, we used the innovation system approach with its emphasis on the importance of actors, institutions and the interactions between actors. We will use this approach as a guideline for our case study descriptions in chapters 3 and 4. Within these descriptions we focus particularly on the learning processes within the Dutch and Danish wind turbine innovation systems, investigating the learning processes as defined in this chapter: learning by searching, learning by doing, learning by using and learning by interacting. In order to determine to what extent these learning processes were present within the innovation systems, we use the 'facilitating conditions' that we obtained from our literature research in this chapter. We analyse whether these facilitating conditions were present within each innovation system and if so, to what extent. The facilitating conditions are as follows:

1. Learning by searching

Facilitating conditions:
- the presence of a technological guidepost, guiding the direction of search
- the availability of an appropriate scientific theory on the subject, guiding the direction of search
- the presence of a technological paradigm, guiding the direction of search
- the presence of standards and regulations, guiding the direction of search
- changing circumstances
- an environment that is not (too) hostile
- the availability of capital
- some level of knowledge and expertise in the field of study
- the possibility of making mistakes and learn from them
- the way the ownership of novelties and new knowledge is organised

2. Learning by doing

Facilitating conditions:
- time
- a high production rate

3. Learning by using

Facilitating conditions:
- the presence of users during technology development
- a user group of minimum size and degree of sophistication
- contacts between the user and the producer

4. Learning by interacting

Facilitating conditions:
- mutual interest in the learning process
- proximity in the broad sense, including geographical closeness, cognitive closeness, a common language and culture, national standardisation, common codes of conduct, a certain lack of competition, mutual trust between the actors, and congruent frames of meaning regarding the technology
- norms of openness and disclosure
- the presence of an intermediary
- the presence of a network builder
- the capacity to build new networks and destroy obsolete ones