

# EXPLORING ENERGY TRANSITION PATHWAYS:

## insights from Denmark and Sweden

Linda M. Kamp<sup>1</sup>, Anne-Lorène Vernay<sup>1</sup>, Wim Ravesteijn<sup>1</sup>

<sup>1</sup>Department of Technology Dynamics and Sustainable Development, Delft University of Technology, Jaffalaan 5, 2628 BX Delft, The Netherlands  
E-mail: l.m.kamp@tudelft.nl; phone nr. 00-31-15-2786488

### Abstract

This paper explores energy transition pathways that are broadly considered successful in terms of technology development and implementation. From that, it aims to derive insights for better understanding transition processes and to improve management and governance methods for steering these processes. Recently, theoretical work on transition processes has evolved from static representations of uniform unilinear pathways (e.g. Rotmans, 2003; Geels, 2002) into the recognition that transition pathways are of a more diverse nature – still unilinear but not uniform (a.o. Geels and Schot, 2007, Berkhout et al., 2004). This work however, is so far strongly theoretical and hypothetical and asks for an empirical underpinning of the notions presented. This paper aims to make such an empirical contribution. It presents case study material on the successful development of wind power in Denmark and the implementation of hydropower in Sweden. The data show that these transitions are not unilinear. Instead, they change in character through time and therefore show to escape the static typologies presented in Geels and Schot (2007) and Berkhout et al. (2004). Consequently, the paper argues, appropriate and successful management methods also have to vary in time, parallel to the changes in transition characteristics.

### Key words:

*Transition pathways, dynamics, transition management*

## 1. Introduction

Transition theory has expanded enormously in the past decade, but it still faces some serious challenges. One of its shortcomings seems to be a rather static view of transitions, suggesting that socio-technical processes of change and transformation are unilinear as to their course of development. Based on theoretical reasoning, it is assumed that transitions could be distinguished and characterised in terms of their complete pathways and, consequently, that each transition involves an accompanying governance model and collection of management methods. This paper questions this assumption and shows another picture of transition processes and steering possibilities. It does so on an empirical basis. The paper presents two case-studies from the energy field. The first one concerns the development of wind power in Denmark in the period 1891-2000 (drawing upon Kamp, 2002 and Kamp, 2008). The second case is based on hydropower development in Sweden between 1882 and 2010 (drawing upon the PhD research of the second author).

The paper addresses the following research question:

*How did the transition pathways of wind power in Denmark and hydropower in Sweden evolve in time, from the viewpoint of the analytical notions of current transition theory?*

The paper is organised as follows. Section 2 presents and explains current transition theory. Section 3 puts forward the case study material. It first presents and analyses the transition pathway of wind power in Denmark and then the transition pathway of hydropower in Sweden. Section 4 draws conclusions on the nature of these transition pathways, discusses the typologies used and provides recommendations on transition management and for further research.

## 2. Transition theory

A transition is a process of change in which a system changes from one equilibrium state to another. Most of the work in transition theory builds upon work of Rotmans (e.g. Rotmans et al., 2001; Rotmans, 2003) and Geels (e.g. Geels, 2002; Geels, 2004), who were the first to construct a three level model of transitions starting in (micro-level) niches, expanding into (meso-level) socio-technical regimes and ultimately influencing the broader developments that constitute the (macro-level) socio-technical landscape. Here, niches are spaces in which technical novelties are created and protected against mainstream market selection (Schot, 1998; Kemp et al., 1998). The socio-technical landscape is an exogenous environment that cannot be influenced directly by actors in the niches and the regime (Geels, 2002). The notion of socio-technical regime has developed from the original notion of technical regime. This notion was first put forward by Nelson and Winter (1977) and refers to the beliefs and successful examples that guide innovators towards promising, marketable or feasible

options. Rip and Kemp (1998) broadened up this notion and defined it as (Rip and Kemp, 1998, p. 338): 'the rule-set or grammar embedded in a complex of engineering practices, production process technologies, product characteristics, skills and procedures, ways of handling relevant artefacts and persons, ways of defining problems – all of them embedded in institutions and infrastructures. Regimes are intermediaries between specific innovations as these are conceived, developed and introduced, and overall socio-technical landscapes.' Geels (2002) broadened up this notion still further and re-named it into socio-technical regimes, incorporating the broader community of scientists, policy makers, users and special-interest groups that also contribute to the direction of technological development.

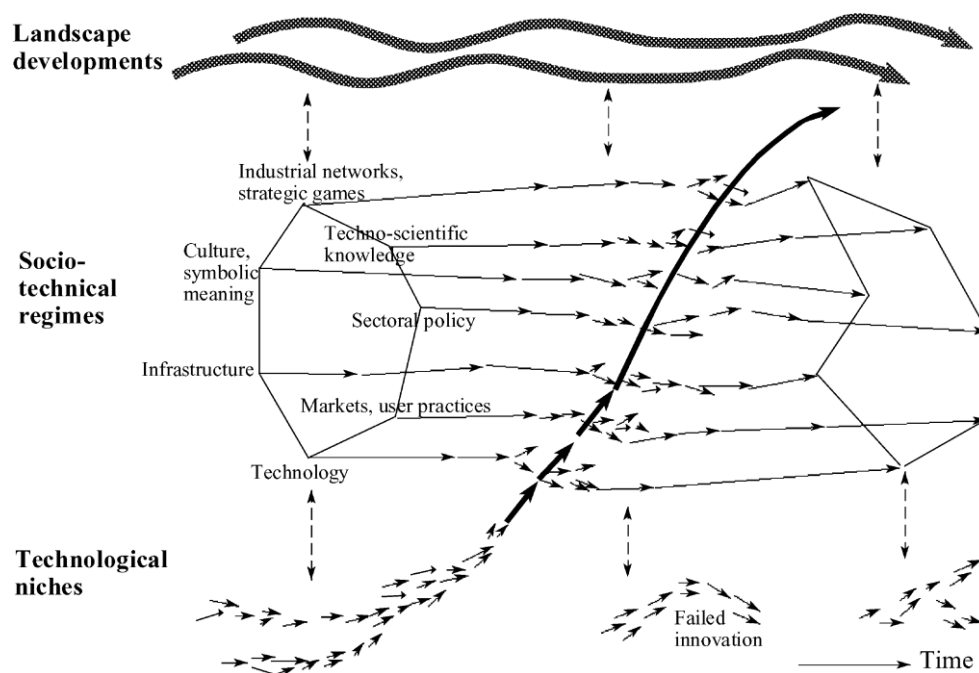


Figure 1: S-curve based socio-technical transition pathway (Source: Geels, 2002)

The multi-level perspective of transitions argues that transitions result from the interaction between processes at these three levels: (1) niche innovations that build up momentum; (2) changes at the landscape level that create pressure on the regime; and (3) a resulting destabilisation of the regime that creates windows of opportunity for niche innovations (see figure 1).

This description of socio-technical transition has been constructively criticised for being unable to encompass the full variety of transitions, e.g. by Berkhout et al. (2004) and Smith et al. (2005). In response to this criticism Geels and Schot (2007) have further developed

their ideas by proposing a typology of socio-technical transitions, which they have developed in reaction to an earlier similar effort of Berkhout et al. (2004) and Smith et al. (2005).<sup>1</sup>

Smith et al. (2005) suggest that transitions can be categorised based on the characteristics of the transition context in which they take place. In their view, regimes change as a consequence of – or in response to – selection pressures and the way these are defined or articulated by key actors. The coordination of responses diverges from high to low. The adaptive capacity of regimes determines whether the resources that are mobilised for the response come from inside or outside of the regime. Consequently, Smith et al. (2005) develop a scheme of socio-technical transformations using two axes to define the context of transitions: internal versus external resources and low versus high coordination (see figure 2). The scheme presupposes that transitions fit within a specific quadrant.

Smith et al. (2005) give some examples in order to explain their scheme. For instance, they qualify carbon capture and storage as a process of ‘endogenous renewal’: it is a highly coordinated response from the members of the electricity generation regime to the selection pressure of international attention for the reduction of CO<sub>2</sub> emissions, while internal resources are used to cope with these pressures. ‘Reorientation of trajectories’ takes place when there is a lowly coordinated response from within the regime. The wide-scale adoption of combined cycle gas turbines by the electricity sector in the UK is an example. When the response comes from outside of the regime and is highly coordinated, the transformation is a ‘purposive transition’. The push towards an energy sector dominated by nuclear power in the 1950s and 1960s in many Western countries is a case in point. The last type of transition they distinguish is the ‘emergent transformation’, which is an uncoordinated response from actors outside of the regime to selection pressures acting upon it. The transition of the energy sector from wood based to coal based to oil and gas based is put forward as an example.

Smith et al. associate the notion of transition management (see e.g. Rotmans et al., 2001), developed in view of the Geels and Schot type of transition shown in Figure 1, with their purposive transition. With regard to their other types of transition they are less explicit about governance: promoting coherence in selection pressures and developing relevant adaptive capabilities in the case of emerging transformations, enabling or interventionist measures as

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<sup>1</sup> Since Berkhout et al. (2004) and Smith et al. (2005) are written by the same three authors – Berkhout, Smith and Stirling – and present the same typology, we will in the remainder of this paper refer to only Smith et al. (2005).

to endogenous renewal and effecting broader contextual changes (like deregulation and liberalisation) when it comes to reorientation of trajectories. Smith et al. (2004) recognise that the contexts of a socio-technical regime may change and that such a change will affect the transition pattern. However, they strongly connect changing contexts with governance. In their view, governance seeks to influence the selection pressures to which regimes are exposed and their adaptive capacity.

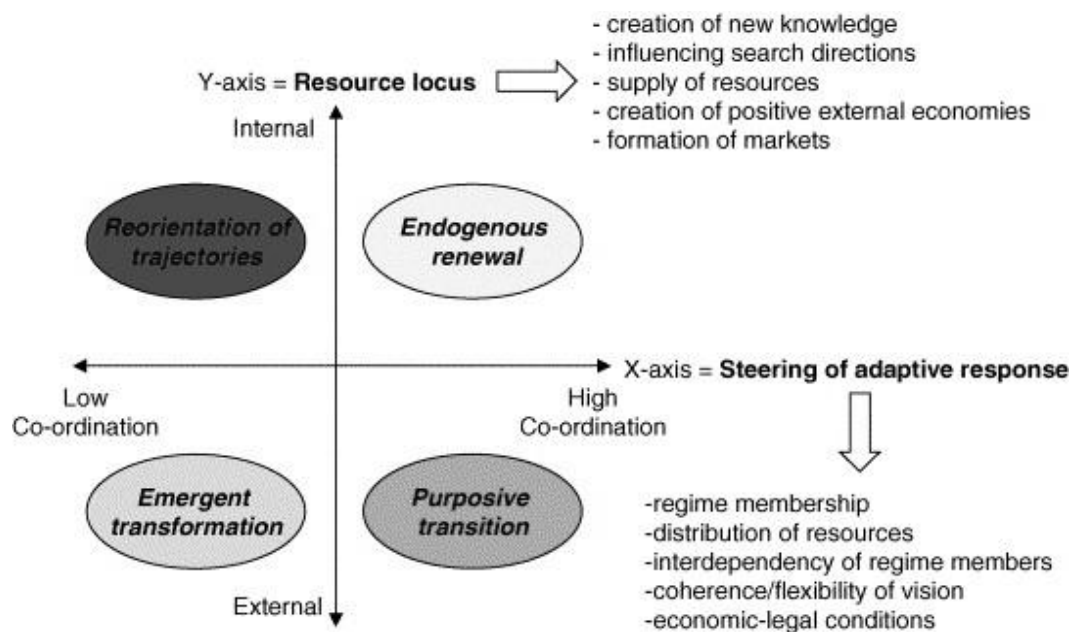


Figure 2: Transition contexts as a function of degree of coordination of responses to selection pressures and locus of adaptive resources (Source: Smith et al., 2005)

Disagreeing with the axes as defined by Smith et al (2005), Geels and Schot (2007) propose a different typology. They argue that using the level of coordination as an axis implies that coordination is assumed while it should, on the contrary, be investigated. Moreover, because pressures coming from the niche and the landscape can interact with the regime in various ways, Geels and Schot argue that these should be kept separate instead of being aggregated under the term of 'selection pressure'. Based upon this, they propose six possible transition pathways based on the strength of the landscape pressure (moderate versus large and sudden), and on whether innovations in a niche are sufficiently developed. The four transition pathways they elaborate most are 'transformation paths', 'de-alignment and re-alignment', 'technological substitution' and 'reconfiguration pathway'.

A 'transformation path' takes place when landscape pressures are moderate and niche innovations have not yet sufficiently developed. This leads regime actors to reorient their innovation activities in a way that a new regime emerges out of the old one (e.g. the transition from cesspool to sewer system in the Netherlands). 'De-alignment and re-alignment' refers to situations where divergent, sudden and large changes take place at the landscape level while none of the niche innovations are sufficiently developed yet. This leaves space for multiple innovations to emerge until one eventually dominates and forms a new core for the regime (e.g. the transition from horse-drawn carriage to automobile in the USA). Geels and Schot use the term 'technological substitution' when there are large landscape changes and when niche innovations have sufficiently developed and are ready to break through (e.g. the introduction of the steam boat as a replacement for the sailing ship in the UK). Finally, a transition may also take place when innovations developed in niches in response to local problems trigger further changes at the regime level. This situation is referred to as 'reconfiguration pathway'. In this case the landscape does not seem to play a prominent role (e.g. the transition from traditional industrial production to mass production in the USA). We have drawn figure 3 to represent the four most elaborated transition pathways in Geels and Schot's typology.

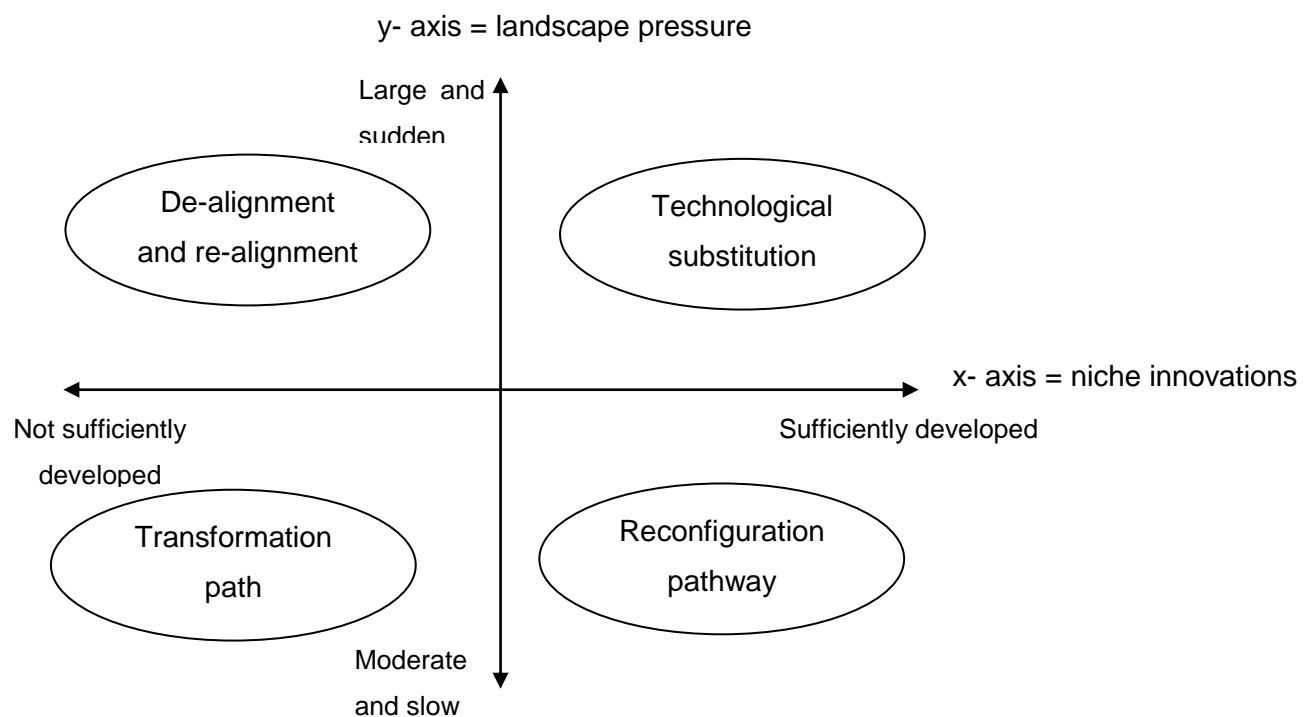


Figure 3: Typology of transitions as a function of landscape pressure and readiness of niche innovations (based on Geels and Schot (2007) and inspired by Smith et al. (2005))

In addition, to these four pathways, Geels and Schot mention two other pathways. The first is called 'reproduction processes'. This is not really a transition pathway, but rather a 'zero proposition' about stability and reproduction where the regime remains dynamically stable and reproduces itself. The last pathway they call 'a sequence of transition pathways'. This pathway is – even more than the others - a theoretical construct. The description they provide of this sequence is rather rigid. They propose a particular sequence that requires landscape pressure to be disruptive but perceived by the actors as first moderate and then as increasing in size; the transition begins with the involvement of regime actors, and niches play a role only when regime actors loose faith (Geels and Schot, 2007, p. 413)<sup>2</sup>. The sequence they propose starts as a transformation path and moves on via reconfiguration to either technological substitution or de-alignment and re-alignment, depending on the readiness of niche innovations at the moment that landscape pressure becomes stronger.

These two approaches have two different starting points for understanding socio-technical transitions. While the view of Smith et al. based on transition context takes the regime level as the focus of analysis and leads to an analysis of how actors inside and outside the regime respond to selection pressure, the typology of Geels and Schot suggests to start with investigating the characteristics of landscape pressure and niche developments before analysing their interactions with the regime.

For the analysis of our case material we prefer Smith et al.'s typology. We do so for two reasons. The first reason is flexibility of the typology. Both typologies strongly suggest that socio-technical transitions are unilinear. Nevertheless, the categorisation of Smith et al. leaves more flexibility than that of Geels and Schot. For Geels and Schot the type of transition is determined by the state of development of niches at the moment when new landscape pressure emerge and by the strength and speed of these landscape pressures. The status quo at the moment that landscape pressure emerges thus determines the type of transition that takes place. Their typology is rather fixed. Moreover, even though they also propose a 'sequence of transition paths', they do so in theoretical and rigid terms, with a fixed order in this sequence, as described above. With Smith et al. however, even though they presuppose – or at least strongly suggest – that transitions fit within one specific quadrant, the quadrants are defined in a less fixed way. Whereas in Geels and Schot's typology the status quo at the moment that landscape pressure emerges determines the

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<sup>2</sup> We will come back to this pathway in our discussion in section 4.

type of transition, the typology of Smith et al. does not strictly refer to moment that landscape pressure emerges. This makes it possible to flexibly move from one quadrant to another during the course of a transition and as such to better encompass the full complexity of the transition.

The second reason why we prefer Smith et al.'s typology is the pointers it provides for action. Smith et al. suggest that their typology could be used to gain insights for transition management and governance, whereas Geels and Schot's sole aim is to analyse transition processes (see also Genus and Coles, 2007). Indeed, having insight in a specific transition with regard to the type of landscape pressure it is a response to and the readiness of niche innovations at the time the landscape pressure started does not provide clear pointers for action. On the other hand, having insight in a specific transition with regard to the locus of resources and the degree of coordination of steering gives more directions for action. Gaining insights for transition management is, besides better understanding transitions, our aim. For these two reasons, we will use Smith et al.'s typology in this paper to build upon. We will show that the two energy cases we discuss do not fit in one specific quadrant of the Smith et al. scheme, but the processes involved can be described and analysed in such a way that they take place in different quadrants subsequently. In doing so we show that transitions are not unilinear but 'move through the scheme' in time. Furthermore, we will critically reflect on the usability of the Smith et al. scheme in our discussion.

### **3. Case studies**

In the following subsections, we will discuss our cases, subdivided into phases in terms of the scheme presented in figure 2. They both focus on specific energy technologies, the first case concerns wind power development in Denmark and the second case focuses on hydropower development in Sweden. We are aware that we have chosen a low unit of analysis – the uptake of a one specific niche technology into a regime - and that when socio-technical transitions are considered a higher unit of analysis is usually chosen (e.g. socio-technical transition in the energy system). However, considering that Smith et al. use a similar unit of analysis – e.g. the uptake of carbon capture and storage into the energy regime - we think that it is appropriate for our purpose.



### **3.1 Case 1: Wind power development in Denmark**

#### **3.1.1 Case study description: The development of wind power, 1891-2000<sup>3</sup>**

Already in 1891, the Danish physics professor and wind pioneer Poul la Cour began experimenting with wind generated electricity. Around 1903, he developed the 'Klapsejler', a simple, robust and reliable windmill that produced direct current Electricity. During the Second World War, another type of electricity producing windmill was built: F.L. Smidth's more modern Aeromotor. In the 1940s, Smidth developed and manufactured 60 Aeromotors. In 1947, the Danish technician Johannes Juul began to develop wind turbines that produced alternating current that could be connected to the electricity grid. Juul received considerable support for his design and development work not only from SEAS utility, but also from the Association of Danish Utility Companies. The reason for this support was, that they faced an energy shortage in the 1940s. By 1962, the SEAS utility concluded, on the basis of economic calculations, that Juul's wind turbine was unable to compete with fossil fuels. Operation was stopped for economic reasons.

After the oil crisis in 1973, a development programme for wind power was set up in Denmark. The main objective was to determine under what circumstances and to what degree wind energy could make a contribution to the Danish electricity supply systems. The programme was called the Wind Power Programme. The paradigm used was science-push: the research centre Risø and the Technical University of Denmark should develop the knowledge needed to build large wind turbines. The vision used was that of large wind turbine parks built by a consortium of large Danish firms and owned and operated by utilities.

In 1977, it was decided to build two 630 kW turbines, the Nibe turbines, which were partly based upon Juul's design. No Danish company was found to be interested in manufacturing these turbines. Therefore, they were procured on a multi-contract basis. Other actors involved were the Risø research centre, the Technical University of Denmark and the SEAS utility, which partly financed the wind turbines. The Nibe turbines suffered many technical problems. In the early 1980s, eight more large wind turbines were built. Here also, the utilities were involved from the beginning, attracted by the R&D subsidies that had been made available. All but one of these eight turbines were built by the company Danish Wind

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<sup>3</sup> The case study material presented in this section is based upon Kamp, 2002; Kamp et al., 2004 and Kamp, 2008.

Technology, which was established in 1981 by the Danish Ministry of Energy and SEAS. All wind turbines suffered from technical problems with the blades and the gearboxes. Building wind turbines proved to be more expensive and risky than foreseen. In the early 1990s, the Danish state sold its shares in Danish Wind Technology.

At the same time, in the 1970s a bottom-up wind turbine development path developed, relatively independently from the R&D programme set up by the Danish state. The first bottom-up wind turbine producers were adherents of the grassroots movement and small entrepreneurs. The grassroots activists were attracted to the idea of small locally-owned and locally-governed power production units, instead of large power production units that were centrally-owned and centrally-governed by the utilities. In 1978, about ten small wind turbine manufacturing companies were active on the Danish market. The majority of these companies had a background in agricultural equipment manufacturing. Slowly, by way of trial-and-error and interactive learning with turbine owners and researchers, they improved their wind turbines. Their design philosophy was to build wind turbines that worked reliably and safely. Also these turbines were partly based upon Juul's design. The turbine manufacturers encountered all kinds of technical problems. Gradually, practical and hands-on knowledge about the poorly understood wind turbine technology accumulated. On the basis of this knowledge, the design rules were gradually improved.

In 1978, a wind energy department was created at the Risø research centre. The research centre only received governmental financing for three years. Therefore, their strategy was to be of immediate service to the wind turbine manufacturers. If the manufacturers could be convinced of the usefulness of the research centre, it could in the future get its financing through orders from the manufacturers. Therefore, the goal of the members of the research centre was to develop a viable wind turbine industry in order to insure their future orders. In this way, a tight network between wind turbine producers, owners and the Risø research centre was formed. Another favourable circumstance was the size of the Danish home market. Already in 1979, investment subsidies were introduced. The relatively large home market gave the Danish turbine manufacturers the opportunity to produce a relatively large number of wind turbines and to learn by doing during the process. The relatively large user group had organised itself in the Windmill Owners Association. This association was able to act as a strong party during negotiations on buy-back tariffs with the utilities.

In the early 1980s, the size of the Danish home market decreased. Coincidentally, at the same time a very large market was formed in California, because large investment subsidies for wind turbine buyers were introduced there. Because the Danes produced relatively high

quality wind turbines and were able to prove this with statistics, they were able to capture a large part of the Californian market.

In 1986, the Californian investment subsidies expired. Exports declined and came to a halt in 1988. However, this decline in Californian wind turbine demand was offset by a rise in Danish wind turbine demand. The Danish market had started to grow after 1985. In that year, the utilities had signed a 100-MW agreement, which meant that they had to install 100 MW of wind turbines within the next five years. This enabled the Danish turbine manufacturers to make a new start.

After 1985, turbine development gradually changed from a trial-and-error process to a more R&D based and formalised process. In 1986, the Wind Turbine Guarantee Company was set up, to guarantee the long-term financing of large export projects. One of the conditions that the manufacturers had to meet in order to qualify for the guarantees was that their turbines had to be approved according to a new, harsher approval system. The manufacturers were required to lay down their knowledge in a more formalised way. Furthermore, they had to scale up and improve their turbines further, because the utilities' demand was for relatively large and cost-effective wind turbines. With the help of Risø, the Danish manufacturers succeeded in meeting the utilities' demand and building up a strong position on the world market.

After 1986, wind turbines became larger and larger and more and more complex machines. Therefore, the input of regulations and science became more and more important. A harsher approval system and more formalised design rules were put into place. This made the wind turbines easier to implement into large utility-owned wind parks.

### **3.1.2 Case study analysis: The wind power transition pathway**

An analysis in terms of system innovation, regime shifts and their determining, conditioning and/or accompanying circumstances, including selection pressures, locus of resources and trajectories permits a breakdown of the wind power transition into separate time periods. Here, the locus of the resources refers to the dominant actors involved, the ones that define the problems, take the initiatives to solve them and bring in or mobilise the resources needed. Generally, at first the dominant actors found themselves outside the Danish energy regime, while later energy regime actors took over the dominant positions. In terms of Smith et al. we can chronologically distinguish the following trajectories (see also table 1):

*1. Emergent transformation (low co-ordination, external resource locus): 1891-1947 – Dispersed activities based on external resources*

In this period, Danish professor La Cour and technician F.L. Smidth developed and sold the first electricity producing windmills in the Danish countryside, outside the energy regime.

*II. Reorientation of trajectories (low co-ordination, internal resource locus): 1947-1962 - Utilities become actively involved in dispersed activities*

Juul's activities took place outside the regime but were based upon financial resources from utilities.

*III. Purposive transition (high co-ordination, external resource locus): 1973-1977 - Wind Power Programme instigated by the State*

In this period, the Danish state as an actor outside the regime set up a programme to introduce renewable energy technologies into the Danish energy regime. This effort was highly coordinated, mainly by policy bodies. The resources that were made available were mainly R&D subsidies, a resource locus external to the regime.

*IV. Emergent transformation (low co-ordination, external resource locus): 1977-1985 - Both top-down and bottom up wind turbine development outside the energy regime*

This period is the key period for the development of wind power in Denmark. In various places, effort was put into the development of wind power. Top-down coordinated R&D programmes resulted in the Nibe turbines and eight other R&D-based wind turbines. Here, utilities did play a role, but not as the dominant actors. Resources were mainly R&D subsidies and the problems and directions were mainly defined by policy makers and R&D institutes. Also, many bottom-up developments took place in networks of wind turbine manufacturers, owners and the Risø research centre. Wind turbine owners were not utilities, but co-operatives and private persons (mainly farmers). These developments took place completely outside the energy regime. The degree of coordination is not immediately straightforward in this period. Resources came from various parties, but subsidies played a large role. This would point at high coordination. However, visions were not coherent and actor networks were dispersed. Therefore, we choose to mark this period as characterised by 'low coordination'<sup>4</sup>. By way of trial and error and interactive learning, these actor networks slowly built up a successful wind turbine sector in Denmark that were able to outcompete most other manufacturers on the large Californian market of the early 1980s.

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<sup>4</sup> We will pick up on this point in the discussion in section 4.

Table 1: Development of wind power in Denmark: phases in the transition. The roman numbers indicate the sequence of phases.

	Low co-ordination	High co-ordination
Internal resource locus	<i>Re-orientation of Trajectories</i>  <b>II.</b> 1947-1962: Utilities finance dispersed activities  <b>V.</b> 1985-1986: Utilities become more actively involved in dispersed activities	<i>Endogenous Renewal</i>  <b>VI.</b> 1986-2000: More co-ordinated involvement of energy regime
External resource locus	<b>I.</b> 1891-1947: Dispersed activities based on external resources  <b>IV.</b> 1977-1985: Both top-down and bottom-up wind turbine development outside energy regime  <i>Emergent Transformation</i>	<b>III.</b> 1973-1977: Wind Power Programme instigated by the State   <i>Purposive Transition</i>

*V. Reorientation of trajectories (low co-ordination, internal resource locus): 1985-1986 - Utilities become actively involved in dispersed activities*

In 1985, the utilities became actively involved in these dispersed activities when they signed the 100-MW Agreement, in which they agreed to install 100 MW of wind power in the next five years. This helped the Danish wind turbine manufacturers after the Californian market subsidies had been abolished. Differently from the previous periods, the Danish utilities played a dominant role in this period.

*VI. Endogenous renewal (high co-ordination, internal resource locus)): 1986-2000 - More coordinated involvement of energy regime*

After 1986, the development and implementation of wind turbines became more and more coordinated, e.g. by way of the Wind Turbine Guarantee Company that was set up in 1986 and by the implementation of a harsher approval system and more formalised design rules.

### **3.2 Case 2: Hydropower development in Sweden**

#### **3.2.1 Case study description: Emergence, growth and maturity of a socio-technical system, 1882-2000**

The first electric networks in Sweden were implemented in the 1880s in factories and towns. Electricity was generated on the basis of hydropower or imported coal, since Sweden has very little domestic fossil fuels (Kaijser, 1992). The first Swedish hydropower plant was built in 1882 (Perers et al., 2007). At that time the context was not very favourable to hydropower. For 500 years a rule regarding water streams had prevailed in Sweden. It was called the Kings Veil and stated that in the larger rivers at least a third of the water should be able to flow freely (Jakobsson, 2002). This rule had been implemented to protect the interests of the agrarian society. This agrarian society which was very powerful at the time was displeased with hydropower. Indeed, over time agrarian production had become increasingly dependent on the proper outflow of water to cultivated land. The agrarians were thus against the idea of retaining water for power production which they saw as a threat to their activity.

When in the 1890s alternating current emerged, this enabled the transport of electricity over higher distances. Regional instead of local electricity networks could be built. In 1899, under pressure of pro-industrial members, Parliament agreed with a change in the water law. Dams could be built in spite of the aforementioned King's Veil if given governmental permission. However, the water flow could not be altered. For the hydropower industry, it was only a small victory: by law they could only guarantee an electricity delivery equal to the minimum river discharge. Dissatisfaction grew among the engineers. While they had the know-how required to efficiently harness power from water, they were helping to develop hydropower plants that would be operated far below their full capacity (Jakobsson, 2002). Overall, between 1882 and 1900 about 40 MW of hydropower capacity were installed.

The situation changed in the early 20th century. Black coal used in steam engines was gaining importance as an energy source, putting countries like Sweden with no domestic access to black coal at a disadvantage. The government started to look for an alternative energy source with low price in order to ensure the competitiveness of domestic companies

(Perers et al., 2007). As a result, political interest in support of hydropower, also referred to as “white coal”, emerged and in 1901, it was decided to promote it. It is with that purpose in mind that the Swedish State Power board, later on called ‘Vattenfall’, was created in 1909 (Perers et al., 2007). Moreover, five other companies interested in developing hydropower had emerged. These companies made large investments in the development of hydropower and high-voltage transmission lines (Kaijser, 1992). This is the starting point for large-scale regional hydropower generation in Sweden.

Over time, it became crucial both for public and private hydropower companies to change the water legislation so that they could fully exploit the infrastructure they had invested in. Supported by the engineering community, hydropower companies started a campaign asking on the one hand for a new water law and on the other hand for limiting political influence on hydropower developments. A battle begun between the agrarian community and the industrial community. During the First World War, Sweden faced major difficulties in energy supply. This finally gave a decisive advantage to the hydropower industry (Jakobsson, 2002).

In 1918, a new water law was thus passed facilitating the building of hydropower stations (Kaijser, 1992). Moreover, water courts composed of lawyers and technicians and upon which politicians would have limited influence were created and were given authority to decide about water-related civil engineering projects (Jakobsson, 2002).

At that time most of the developments were taking place in the southern part of Sweden, close to the urban areas. At the end of the 1930s, most of the potential in southern Sweden was exploited and interest grew to build dams in the northern part of the country. In 1936, a 200 kV high voltage grid was built which encouraged harnessing of northern rivers (Perers et al., 2007). Until the 1950s the hydropower production capacity drastically increased going from about 1GW in 1930 to little more than 3GW in 1950.

In the 1950s, nuclear power gained interest within the Swedish energy regime and among policy makers. The Swedish government saw nuclear energy as a vital energy source for the future and supported R&D into nuclear power (Kaijser, 1992).

Also, in the early 1950s, the environmental impact of hydropower started to be criticised. In 1951, the Swedish Tourist Association demanded an inquiry in order to decide which rivers should be left untouched by the hydropower industry. However, this demand was rejected by the government. A year later an organisation called the River Saver organised a public meeting to discuss the issue. This resulted in a new law passed in 1953 stating that

hydropower companies had to inform the local government of their plans before any dams were to be built (Kaijser, 1992). This made it easier for environmental groups to protest against new projects. However, in 1952, an upgraded electricity line of 400 kV was built which further facilitated the expansion of hydropower in the northern part of the country (Perers et al., 2007). As a result, in 30 years hydropower installation more than tripled to reach almost 11GW in 1970.

The environmental lobby against hydropower continued. In the 1950s and 1960s, environmental groups even lobbied for a faster introduction of nuclear power to save the Swedish wild rivers (Kaijser, 1992). Finally, in 1993 the four most important unharnessed rivers were protected against hydropower development (Jakobsson, 2002). This also marked the end of hydropower expansion. Nowadays, no new dams are being built and most of the efforts are concentrated on refurbishing and upgrading existing plants. Still, hydropower, with 16.2 GW of installed capacity, represents about half of the electricity that is produced in Sweden (Perers et al., 2007).

### **3.2.2 Case study analysis: The hydropower transition pathway**

Hydropower development in Sweden has a long history and when analysing this history we can identify a number of phases. We can see the emergence, the growth and the increasing maturity of a socio-technical system. Moreover, different actors played a role in different phases of the development. Initially, engineers and the industrial community supported and pushed forward the development of hydropower in Sweden. Later on, politicians played a leading role in the expansion of the system by coordinating large scale developments. Finally, with increasing environmental concern political coordination switched from fostering to restricting and then completely stopping further developments. An analysis in transition terms, taking a closer look into resources, actors involved in gathering them and level of coordination can help us better understand the transition that has taken place (see also table 2).

#### *1. Emergent transformation (low coordination; external resource locus): 1882-1909 - Pioneering activities*

During this phase, the first hydropower plants were built by engineers and industrial players. No supporting network of actors existed and developments were the results of local interest rather than coordinated actions. Moreover, no socio-technical system, or regime, existed yet and as such resources had an external locus. Initial developments were limited by the existing water law which was strongly supported by the dominating agrarian community. Pro-industrial members of Parliament lobbied for changes with limited results.



*II. Purposive transition (high coordination; external resource locus): 1909-1918 - Political interest and support*

In the late nineteenth century, the need for a competitive domestic alternative to coal-based steam engine grew stronger. The potential of hydropower started to be recognised and politicians decided to take a leading role in promoting large scale hydropower development. For that purpose Vattenfall, the Swedish power board, was created. Hydropower development became highly coordinated even though it was still limited by the water law.

*III. Endogenous renewal (high coordination; internal resource locus): 1918-2000 - Large scale developments and environmental protest*

The difficult energy supply experienced during the war gave a decisive advantage to hydropower. In 1918, a new water law was amended which facilitated hydropower developments. Moreover, hydropower developers which had been lobbying for limiting political influence on hydropower development were successful. Special water courts with little political control were created and had the authority to decide about water-related civil engineering projects. Hydropower developments were still highly coordinated but by industrial actors from within the regime rather than political actors. In 1953, a law was established which stated that hydropower companies had to present their full development plan to the local government when new hydropower plants were to be built. This was the result from increasing environmental protest against hydropower developments by NGOs such as River Savers. This law also made it easier for environmental groups to protest against further hydropower development. Hydropower development remained highly coordinated but with regained political influence especially from local authorities. Environmental groups that actively protested against hydropower development gained their final battle in 1993. In that year, a law was passed protecting the last four most important unharnessed rivers. From then on no new hydropower plant was built.

Table 2: Development of hydropower in Sweden: phases in the transition<sup>5</sup>. The roman numbers indicate the sequence of phases.

	Low co-ordination	High co-ordination
Internal resource locus	<i>Re-orientation  of Trajectories</i>	<i>Endogenous  Renewal  III. 1918-2000: Large scale developments and environmental protest</i>
External resource locus	<b>I.</b> 1882-1909: Pioneering activities  <i>Emergent  Transformation</i>	<b>II.</b> 1909-1918: Political interest and support  <i>Purposive  Transition</i>

## 4. Discussion and conclusions

### 4.1 Transition pathways

Both transition cases in this paper show how transitions change characteristics in the course of time. In time, both the implementation of hydropower in Sweden and the development of wind power in Denmark went through various subsequent phases which correspond to the quadrants of Smith et al.'s scheme. Each phase could be characterised in terms of a dominant actor (or group of actors) and/or a specific technological regime, which reflects both internal system mechanisms (see also Hughes, 1983) and external socio-economic and socio-historical processes. In table 2, the hydropower case shows a pathway from quadrant 3 to 4 to 2. In table 1, the wind power case shows a more complex transition pathway with the following order of quadrants: 3 - 1 - 4 - 3 - 1 - 2. We might conclude from this that there is

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<sup>5</sup> Our case study findings regarding hydropower development in Sweden are based on an analysis that is not as deep as that for wind power development in Denmark. In the hydropower case, some stages are very long and the movement through the scheme not as dynamic as in the wind power case. We do not exclude the possibility that more data would reveal more dynamics. This shows the importance of empirical data in our approach.

no theoretically prescribed sequence; such a sequence should be empirically established. Note that the pathways that are shown by both cases are also different from the sequential pathway that Geels and Schot (2007, p. 413) describe – but for which they do not give any empirical evidence. In the sequential pathway they propose, the regime actors are the initial actors to react on landscape pressures, and niches only play a role when regime actors loose faith. The sequence they propose starts as a transformation path and moves on via reconfiguration to either technological substitution or de-alignment and re-alignment, depending on the readiness of niche innovations at the moment that landscape pressure becomes stronger. Our data, however, show that other sequences are also possible. The case studies show that real socio-technical processes escape the static typologies implied in current transition theory. Instead, from our cases a dynamic model for transitions emerges.

When using Smith et al.'s scheme in our analysis we encountered – besides the impossibility of assigning our case study material to one quadrant - three additional problems. These problems are: (1) the vagueness of the quadrant definitions; (2) the vagueness of the quadrant borders, and (3) the lack of a systematic view of the dynamics involved in relation to Smith et al.'s suggestion that the context determines the pattern of transitions.

The first problem – the vagueness of quadrant definitions - has to do with the indicators for the quadrants that do not necessarily go together. For instance, 'high coordination' as defined by Smith et al. implies concentrated resources, a coherent vision, and interdependent regime members. But it is possible that resources are concentrated while a number of strong networks exist that each have a different but coherent vision. In this situation, which we saw in the wind power in Denmark case, the concentration of resources points at 'high coordination' while the number of networks and visions point at 'low coordination'.

The second problem - the vagueness of the quadrant borders - comes from the fact that low versus high coordination and external versus internal resource locus are not real dichotomies, but can better be represented by scales from low to high (see also Geels and Schot, 2007, p. 402, where they mention that coordination slowly increases and should not be assumed in terms of a typology). Both the first and the second problem are especially clear in the wind power in Denmark case, where it appears to be hard to assign either the term 'high coordination' or 'low coordination' to the period of both top-down and bottom-up developments outside the energy regime.

The third problem - the lack of a systematic view of the dynamics involved in relation to Smith et al.'s suggestion that the context determines the pattern of transitions - is addressed by our case studies. Our specified descriptions and analyses reveal how, in the course of time, the analysed transitions change in character and move from one quadrant to another. Besides that, our cases also give us some interesting first insights for going beyond typologies and understanding how the context determines the pattern of transitions, or, in other words what triggers the transitions investigated to go from one quadrant to another. Aspects like an increasing sense of urgency among regime members and niche actors appear to play a role here. In the Danish wind power case, the energy crisis and the need for a harsher approval system were clearly triggers for moving the transition from low coordination to high coordination. Moving from external to internal resource locus took place when the large Californian market for wind power collapsed and the Danish home market for wind power needed to be increased. In the Swedish hydropower case, the difficult energy supply during the First World War triggered the transition to move from external to internal resource locus.

## **4.2 Transition management**

The lessons of these insights for sustainability transitions are evident. Transition processes are difficult to steer, not only because they are multifaceted and have their own dynamics, but also because they change character in the course of time. Consequently, the methods of controlling and adjusting these processes –governance modes as well as management tools - have to be reconsidered and adapted continuously. This calls for a flexible approach in which transitions and their management are constantly monitored and assessed.

Transition processes involve diverging contexts and intervention tools should fit in with the specific contextual characteristics. High coordination presupposes central actors that have the opportunity to intervene directly, including the use of traditional management methods. Low coordination, however, involves a large variety of actors and limits the steering possibilities from the part of one them. The resource base of transitions is also essential in choosing intervention tools. Changes within the range of a regime are relatively localised and could be directed or influenced partly through known instruments. Broader transformations require more complex management processes involving a variety of strategies, including new and innovative ones.

### **4.3 Recommendations for further research**

Let us wrap up this paper with some recommendations for further research. Firstly, the work of Smith et al. provides a good point of departure for transition research, though their viewpoints require sharpening and elaboration. Quadrant borders need further specification and clarification so that the distinction between the quadrants becomes more straightforward. Such an improved typology can form the starting point for more case study research into transition dynamics.

Secondly, it would be interesting to combine Smith et al.'s typology by that formulated by Geels et al. in a new integrative analytical framework, which might not only increase our understanding of transitions, but also give us deeper insight in the possibilities and limitations of steering transitions. It would enable us to make a connection between what happens at the niche and landscape level with the response of the regime in terms of coordination and locus of resources. First insights based on the case studies in this paper suggest that high coordination and/or internal resource locus takes place when the landscape pressure is considered to be high and low coordination and/or external resource locus when the landscape pressure is considered to be low.

Thirdly, it would also be interesting to go beyond typologies and understand more in general which processes and interactions trigger transitions to go from one quadrant to another. For our case studies we presented some first ideas and insights, but more in depth analysis is needed to scrutinize the processes and interactions involved; and also generalisation based on more case study research and theoretical reflection is needed.

Generally, besides theoretical reflections also continued case study research into historical and current transition processes remains necessary in order to increase our understanding of transitions and our capabilities to steer them into directions that are both desired and necessary in view of present world problems.

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