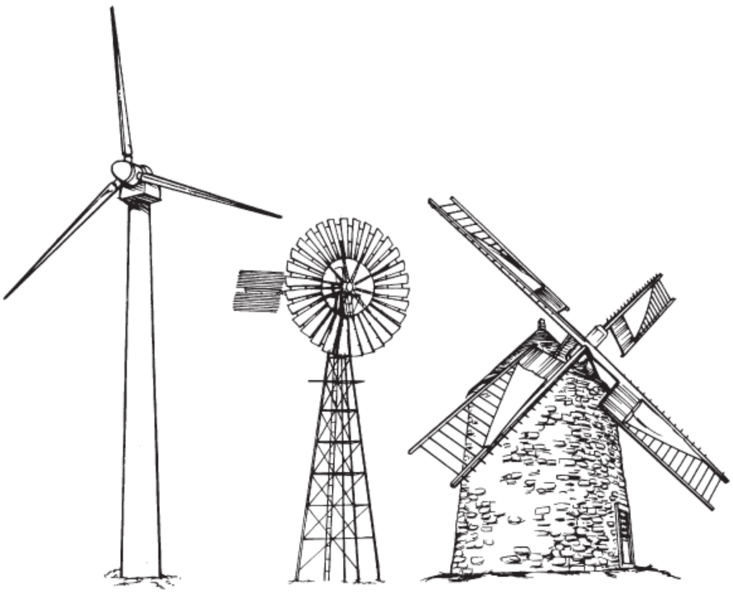
Liberalisation and **wind energy adoption** in **Europe**



Stijn van Ewijk

Liberalisation and wind energy adoption in Europe

MASTER THESIS

In partial fulfilment of the requirements for the
Master of Science in Sustainable Energy Technology and the
Master of Science in Public Administration at the
University of Twente

Author
Stijn van Ewijk

Supervisors
Dr. M. J. Arentsen
Dr. T. Hoppe
Prof. dr. ir. T. H. van der Meer

Twente Centre for Studies in Technology and Sustainable Development

Enschede, 24-05-2013

Cover image: Merriam Webster Learner's Dictionary.

Summary

The last two decades were transformative for the European electricity supply industry (ESI). Markets were liberalised and renewable energy sources took a significant share of the supply. This study relates liberalisation to the development of wind energy in the European electricity industry. It uses the multi-level perspective (MLP) to analyse the effect of liberalisation on the transition towards wind energy. The theory serves as an inspiration for a panel data analysis of electricity reform and wind energy adoption in 19 European countries.

The theoretical framework is based on the multi-level perspective on technological transitions (TT) (Geels, 2002). The MLP conceptualizes three levels that matter to TT. Technological innovation originates at the *niche level* where particular applications of the technologies enable maturation. If sufficiently mature, the technology may enter the *regime level* where technologies are applied on a large scale and on a competitive basis. The regime describes the electricity supply industry from generation to transmission, distribution and retail. Finally, at the *landscape level*, neoliberal thinking affects the regime by imposing liberalisation measures.

The hypotheses on the effect of separate liberalisation measures on the degree of wind energy adoption are tested by means of panel data analysis. Liberalisation is captured as a set of seven measures with scores according to their level of implementation. Wind energy adoption is described by shares of wind in national electricity production and shares in electric capacity. The control variables describe the relevant dimensions of the regime, niche and landscape levels that influence wind development. A fixed effects test shows correlations between liberalisation and wind energy shares.

The descriptive analysis reveals that privatisation was introduced rather independently of other measures. The explanatory analysis shows that third party access, wholesale markets and privatisation have mostly positive effects on wind energy adoption. An independent regulator negatively affects wind shares. For unbundling, the results are ambiguous. Retail markets for industry negatively affect wind energy whereas full retail markets have no significant effect. The explanatory power of the outcomes may be compromised due to a small sample size, rather crude data and mono-method bias.

Future research may focus on other renewables like solar and biomass, the nexus between liberalisation, renewable energy development and sectoral policy, or the combined application of the multi-level perspective and quantitative methods on other technological transitions. The results of this study can be an inspiration or guide for understanding technological transitions, combining qualitative and quantitative methods or designing energy policy and regulation.

Foreword

Of the great construction projects of the last century, none has been more impressive in its technical, economic and scientific aspects, none has been more influential in its social effects, and none has engaged more thoroughly our constructive instincts and capabilities than the electric power system.

(Hughes, 1993, p. 1)

As illustrated by Hughes (1993), the electric power system offers challenges that fall within both the realms of social sciences and engineering sciences. It is therefore the perfect theme for a combined thesis in Sustainable Energy Technology and Public Administration. The far reaching implications of electrification make it a subject that is not only multidisciplinary, but also highly relevant and very challenging.

The drawing on the cover explains much of the developments this thesis aims to analyse. In the early days, the Dutch harvested the power of the wind to drain marshes. Throughout Europe, wind power was used to grind, saw and bore. In Denmark firstly, wind was converted to electricity and used to electrify rural villages. Today, environmental concerns have made wind energy an important source of electricity in Europe.

The "great construction project" of the electricity supply industry led to publicly owned and vertically integrated monopolistic industries that supplied every European citizen with electric energy and provided the backbone of economic development. Liberalisation of electricity markets aims to improve the performance of this industry: higher efficiency, lower costs, better market response. And perhaps: more wind energy?

The latter question is the theme of this thesis: what is the effect of liberalisation on wind energy adoption? In answering this question I chose to adopt a well-known qualitative framework on technological change and combine it with econometric analysis of panel data. As such, my thesis is not only a study into liberalisation and wind energy adoption but also an attempt at innovating theory and methodology.

As a learning experience, this work allowed me a glimpse of what scientific research entails. I learned the pitfalls of lacking data, the unfathomability of statistics, the elusiveness of scientific discourse and the fragility of scientific rigour. I never felt as if I had to climb too steep, but firm ground to build on often lacked. With this thesis, I hope to have drained the marsh a little bit more for other researchers and policy makers.

I am grateful to many people. To Maarten Arentsen, who was a great inspiration and who helped me do research as a social scientist in spite of my engineering background. To Evren Özcan, who made sure I remained an engineer with a healthy scepticism towards social sciences. To Thomas Hoppe, Theo van der Meer, Peter Geurts and my colleagues at CSTM who made it an instructive and enjoyable experience to work on my thesis.

Stijn van Ewijk

Abbreviations

The following abbreviations are used throughout the thesis.

AC	Alternating Current
CCGT	Combined Cycle Gas Turbine
CCOT	Combined Cycle Oil-fired Turbine
CFBC	Circulating Fluidised Bed Combustion
DC	Direct Current
DSO	Distribution System Operator
ESI	Electricity Supply Industry
ETS	Emissions Trading System
EU	European Union
FE	Fixed Effects (statistics)
GDP	Gross Domestic Product
ICDE	Internal Combustion Diesel Engine
ISO	Independent System Operation
ITO	Independent Transmission Operator
kW	Kilowatt
kWh	Kilowatt hour
MW	Megawatt
M	Million
MLP	Multi-level perspective
nTPA	Negotiated TPA (see: TPA)
OCGT	Open Cycle Gas Turbine
OECD	Organization for Economic Co-operation and Development
OTC	Over The Counter (wholesale model)
PCA	Principal Component Analysis
PCC	Pulverized Coal Combustion
PV	Photovoltaic
RD&D	Research, Development and Deployment
rTPA	Regulated TPA (see: TPA)
SB	Single Buyer TPA (see: TPA)
TPA	Third Party Access
TSO	Transmission System Operator
TT	Technological Transition(s)
VI	Vertically Integrated Undertaking

Contents

1. Introduction

“ A great network of power lines which will forever order the way in which we live is now superimposed on the industrial world.

Thomas P. Hughes (1993, p. 1)

This thesis studies the relationship between liberalisation of the electricity supply industry and the adoption of wind energy technology. The empirical analysis is embedded in the multi-level perspective on technological transitions. The following sections explain the background of the research, the research question, the theoretical framework, the methodology, and the contribution of this study to the literature. Finally, the structure of the thesis is illustrated.

1.1. Background

Led by a determination to create a competitive internal energy market and bring down prices, the European electricity market has been gradually liberalised since the 1990s. Technical progress or environmental concerns were never a priority or driving force for these reforms (Verbong and Geels, 2007; Jamasb and Pollitt, 2008). In light of the growing concerns regarding climate change and environmental pollution, the effect of liberalisation on renewable energy development seems very relevant. Furthermore, quantitative research on this topic is scarce.

The reform of national European electricity markets is aimed at ultimately enabling a single European energy market. Liberalisation entails changing a vertically integrated publicly owned electricity supply industry (ESI) into a competitive and privately owned industry. The main steps for liberalisation are restructuring of the industry, the introduction of competitive markets, introduction of new regulation, and changes in ownership. The reforms of the European electricity market were initiated with the EU Directives of 1996 and 2003 (EC, 1996; EC, 2003).

Wind energy is a major source of renewable energy in the European Union. It is the second largest renewable source of electricity after hydropower. Besides, it features a much higher growth rate than hydropower; electricity production from wind has grown nearly 200 fold over the last 20 years (Eurostat). As such, wind energy seems a very relevant form of renewable energy. Moreover, it can be more easily captured than other renewables since wind energy is not used in complex hybrid forms (like bio-energy) or at widely varying scales (like solar energy).

1.2. Research question

This research aims to find the relationship between the liberalisation of the electricity supply industry and the adoption of wind energy in electricity generation. It tries to answer the following research question.

What are the effects of liberalisation of the electricity supply industry on wind energy adoption in European countries?

The specific research questions focus on the effect of the specific measures observed in the liberalisation process. They are of the following form: "What is the effect of a specific liberalisation measure in the electricity supply industry on wind energy adoption in European countries?". The measures are: introduction of an independent regulator, unbundling of existent utilities, retail market opening, wholesale market opening, introduction of third party access and privatisation of incumbents.

1.3. Theoretical framework

The theoretical framework is the multi-level perspective (MLP) developed by Geels (2002). The MLP provides a framework for analysis of technological change through interactions at three different levels. Innovation originates at the niche-level and permeates to the regime level under increasing pressure from the landscape level. MLP suits well for the empirical analysis since it explicitly distinguishes niche developments (wind energy) and landscape pressures (liberalisation). Furthermore, it takes into account many important non-technological factors that influence transitions.

The MLP has already been used for numerous case studies on the energy sector (Kemp, 1994; Geels, 2002; Geels, 2005; Verbong and Geels, 2007; Verbong and Geels, 2010; Shackley and Green, 2007; Kern and Smith, 2008; Foxon, 2011; Yuan, 2012). Following recommendations found in literature, this study aims to more rigorously and systematically apply the MLP (e.g. Genus and Coles, 2008). Since the framework has not been operationalized for panel data analysis before, this research may further develop the MLP.

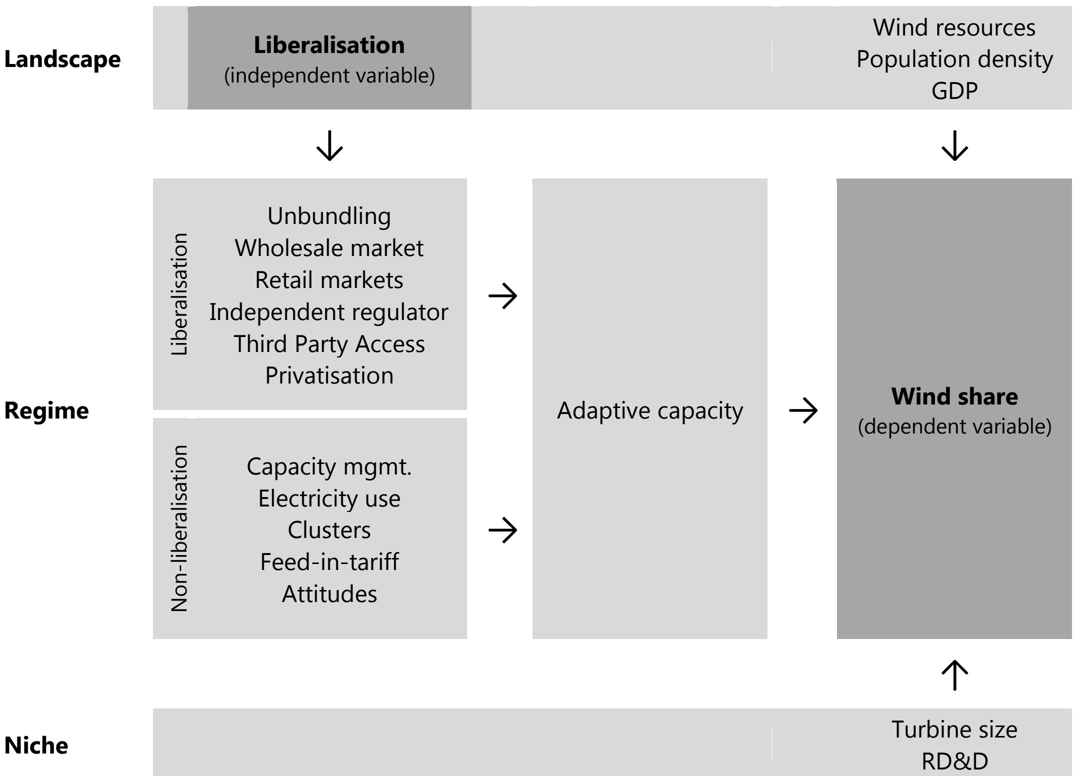


Figure 1 – Theoretical framework: causal relationships embedded in the MLP.

Figure 1 displays the theoretical framework as operationalized in this thesis. The general theory is explained section 2.1. The figure shows the causal relationships between the independent variable (liberalisation), the dependent variable (wind share), and the control variables. The variables are located at the different levels of the MLP: landscape, regime and niche. The hypotheses regard the either positive or negative effect of the separate liberalisation measures on the wind energy share. The concept of adaptive capacity explicates the causality.

The three levels have distinct properties. The landscape describes slowly changing variables and high level (European Union) politics. The regime describes the domestic electricity supply industry. The niche is a protective space for novel technologies like wind turbines. The adaptive capacity describes the susceptibility of the regime to technological innovations springing from the niche. The adaptive capacity is determined by a set of variables within the regime. These variables are partly affected by the landscape through liberalisation and partly independent of liberalisation.

1.4. Methodology

The hypotheses are tested through analysis of panel data on the electricity supply industries of 21 European countries from 1990 till 2007. The relation between wind energy adoption and liberalisation is studied by means of statistical analysis. Descriptive statistics provide insight in the dynamics of the liberalisation process and wind energy adoption. The interrelatedness of the liberalisation measures is studied by means of factor analysis. A fixed effects test discloses the average effect of each liberalisation measure on the share of wind energy in electricity generation and the electric capacity.

The sample includes 19 EU member states and Norway and Switzerland. Other EU member states were left out mainly due to lack of data. Most of the data on liberalisation is derived from an OECD survey (Conway and Nicoletti, 2006). It is supplemented by several other sources (Grote, 2008; OECD, 2003). The data on wind energy adoptions is from Eurostat and the control variables are based on a variety of sources including the International Energy Agency (IEA), Eurostat, World Economic Forum (WEF) and the European Wind Energy association (EWEA).

1.5. Contribution

Previous work on liberalisation and renewable energy development is mainly of two types. First, liberalisation has been analysed statistically with regard to performance indicators like electricity price (Steiner, 2000; Hattori and Tsutsui, 2004; Copenhagen Economics, 2005; Zhang et al., 2008; Nagayama, 2009; Schmitt and Rammerstorfer, 2010). Of these studies, none focusses specifically on both renewables and liberalisation. As an exception, Carley (2009) includes deregulation in a panel data analysis of many factors influencing renewables.

Second, the link between liberalisation and renewable energy development has been studied qualitatively. Delmas et al. (2007) analyse the effect of deregulation on renewables, but from a utility perspective. Milstein and Tishler (2011) study the effect of intermittency on fuel mix and market prices in deregulated markets. However, to the authors knowledge, liberalisation and renewable energy development have not been the core interest of a quantitative study so far. As such, this study aims to fill the literature gap on the relation between electricity market reform and renewable energy adoption.

1.6. Structure of the thesis

Figure 2 displays the structure of thesis. It illustrates the contents of the chapters 2-5 and distinguishes the sections on the three levels of the MLP with three separate columns. First, the upcoming chapter presents the theoretical framework by explaining MLP in general and subsequently discussing each level in depth. From this discussion, the hypotheses follow. The methodology chapter starts with the sample followed by the operationalization of the variables. After that, data collection for these variables is briefly described. Then, the statistical analyses are explained. Based on the analyses, the results chapter presents the descriptive and explanatory statistics and a discussion of the findings. The thesis wraps up with a conclusion.

Chapter	**Sub**	**Content**		
2. Theory	2.1	Multi-level perspective		
	2.2	Landscape		
	2.3		Regime	
	2.4			Niche
	2.5	2.5 Hypotheses		
3. Methodology	3.1	Sample		
	3.2	Operationalization		
	3.2.1	*Landscape: liberalisation*		
	3.2.2		*Regime: wind energy*	
	3.2.3	*Landscape controls*	*Regime controls*	*Niche controls*
	3.3	Data collection		
	3.4	Statistical analysis		
4. Results	4.1	Descriptive statistics		
	4.2	Explanatory statistics		
	4.3	Discussion		
5. Conclusion	5	Conclusion		

Figure 2 – Structure of the thesis.

2. Theoretical framework

> He who loves practice without theory is like the sailor who boards ship without a rudder and compass and never knows where he may cast.

Leonardo da Vinci (1970)

The empirical study of liberalisation and wind energy adoption is embedded in the multi-level perspective on technological transitions. First, the MLP is described generally and operationalized for this study. Subsequently, the operationalization is further explained by highlighting the mechanisms reigning each level of the MLP. The levels are discussed in separate sub chapters. Finally, the hypotheses on the effect of liberalisation on wind energy adoption are formulated.

2.1. Multi-level perspective

This subchapter gives an introduction to the theoretical framework. It first explains the origin and prevalence of the multi-level perspective and subsequently describes the main features of the theory. The sections that follow operationalize the MLP for liberalisation and wind energy adoption and present a causal diagram based on the MLP. The theoretical justification for the chosen operationalization is given in the sub chapters on the three levels of the MLP (sections 2.2-2.4).

2.1.1. Origin and prevalence

The MLP was first presented in its most popular form by Geels (2002). It uses elements of evolutionary economics and technology studies and draws on earlier multi-level approaches like Rip and Kemp (1998). The MLP is meant as a heuristic and analytical framework for studying technological transitions, but not as an ontological description of reality (Geels, 2002). MLP aims to avoid pitfalls of other methodologies by focussing on dynamic processes instead of end states and by inclusion of social dynamics and contexts. It deals with discontinuous change and tries to balance endogenous and exogenous dynamics (Verbong and Geels, 2010).

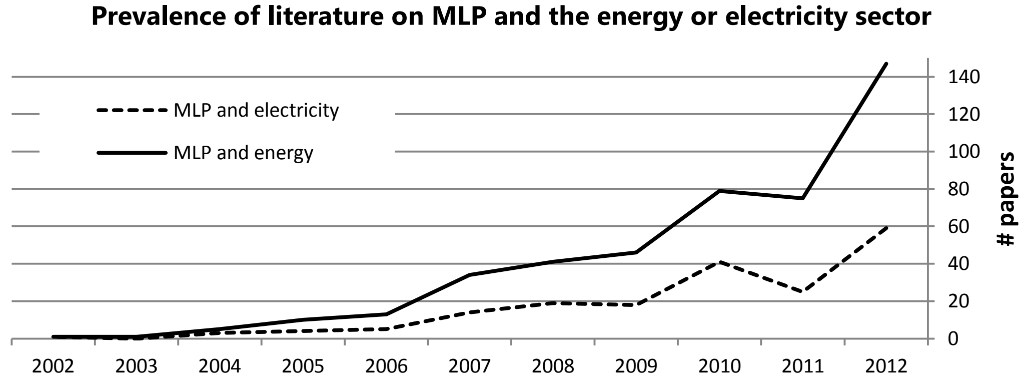


Figure 3 – Prevalence of literature on the MLP and energy or electricity (Scopus, 2013).

Several authors have used the multi-level perspective (MLP) to discuss the technological transition in the energy sector (Kemp, 1994; Geels, 2002; Geels, 2005; Verbong and Geels, 2007; Verbong and Geels, 2010; Shackley and Green, 2007; Kern and Smith, 2008; Foxon, 2011; Yuan, 2012). All these studies concern case studies of the energy sector in specific countries or general theoretical discussions. Figure 3 shows the prevalence of MLP literature on energy or electricity in the past ten years in the Scopus scientific literature database.[1] Clearly, there has been an enormous growth in the literature. Other fields of interest for MLP scholars are transport, infrastructures and sustainability (Geels, 2011).

2.1.2. Transitions in the MLP

The MLP aims to describe technological transitions in socio-technical configurations like the Electricity Supply Industry. The ESI can be categorized as a socio-technical configuration since it fulfils the societal function of powering homes, businesses and industries by means of technology. Socio-technical configurations consist of technologies, infrastructures, markets and user practices, industrial networks, sectoral policy, techno-scientific knowledge and cultural and symbolic meanings (Geels, 2002). Jacobsson and Bergek (2004) speaks of comparable "technological systems" consisting of actors and their competences, networks and institutions.

The liberalisation of the ESI and the introduction of renewable energy technology can be analysed as technological transitions. TT are "major, long-term technological changes in the way societal functions are fulfilled" and describe changes in possibly all aspects of socio-technical configurations. TT mean a change of one socio-technical configuration to another (Geels, 2002). It involves replacement or supplementing of technology, change in institutions that support the conventional technologies and the emergence of actors that trump those with vested interests in the old system (Jacobsson and Bergek, 2004).

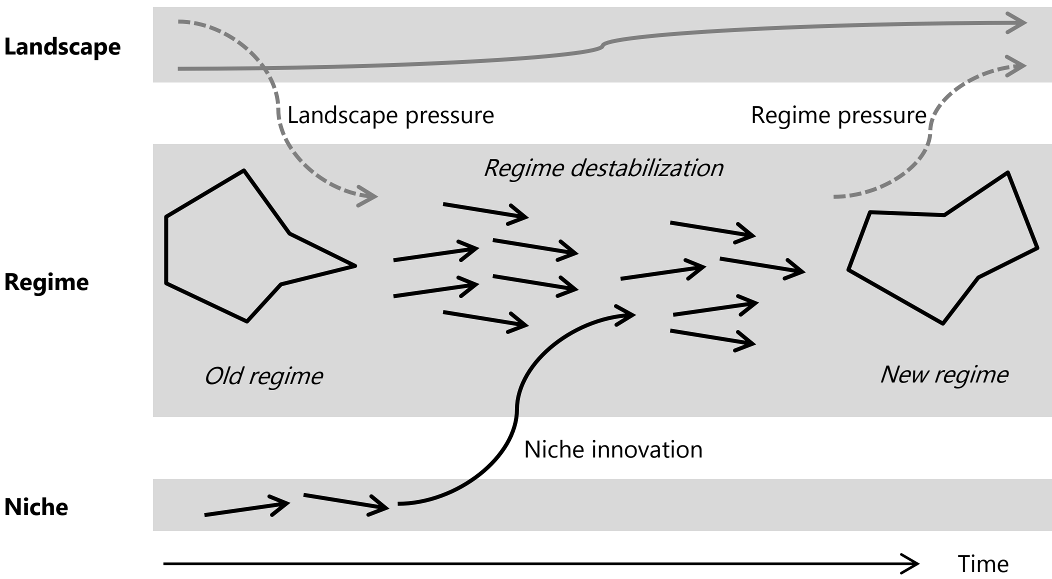


Figure 4 – Transitions in the multi-level perspective (Adapted from Geels (2004)).

[1] Based on two queries in Scopus (03-2012): ALL("Multi-level perspective" electricity) and ALL("Multi-level perspective" energy).

Figure 4 displays the essence of the MLP. The middle level of the MLP consists of the aforementioned socio-technical configuration or regime. The seven-pointed shapes indicate the regime and its dimensions. The regime is embedded in the highest level: the technological landscape. This level is described by highly inert technology-external factors such as economic growth, political trends and norms and values. Change is only incremental. On the lowest level there are so-called niches where technologies are shielded from the market selection of the regime and radical innovations can develop.

The arrows in figure 4 display technological transitions as theorized in the MLP. Technological transitions come about through interactions between processes at the three levels. First, changes at the landscape level such as economic development or political shifts create pressure on the regime. Second, niche-innovations build pressure on the regime through learning processes, improvement of technical and economic performance and support from influential actors. Third, the destabilization of the regime through landscape pressures opens the door for niche-innovations. The newly established regime may subsequently influence the landscape (Geels, 2004).

Technological transitions thus originate in technological niches where novel technologies emerge in protected markets such as aerospace applications. Novelties may "move up" in the socio-technical regimes through improvement of their performance and strategic niche management. Landscape trends regarding regime performance put pressure on the regime. Solar cells for instance entered the mainstream market through better performance, supportive regulation like feed-in tariffs and concerns over the environmental performance of the regime. Subsequently, the transition may influence landscape developments. In Germany for instance, solar cell technology is nowadays responsible for significant economic activity shaping the country's economic policies.

Regime change does not come easily since several mechanisms grant regimes stability. First, cognitive, normative and formal rules stabilize the regime through fixed search heuristics of engineers, rigid perceptions of proper behaviour, and legally binding standards and contracts. Second, interdependencies in actor networks contribute to organisational capital that leads to resistance to change. Third, material structures like power plants and the grid are inert through lumpy investments, compatibility issues and network externalities (Geels, 2004). These stabilizing effects will be addressed throughout the thesis.

2.1.3. Operationalization

In order to analyse transitions in the electricity supply industry, the three levels of the MLP need to be demarcated clearly. By definition, regimes are already defined on a functional basis: they are socio-technical configurations that fulfil societal functions (Geels, 2002). The following sections operationalize the MLP in three steps. First, liberalisation and wind energy adoption are positioned within the MLP. Second, the geographical delineation on the basis of national borders is presented. Lastly, the regime is delineated more precisely by discussing the boundaries of all seven dimensions of the regime. By delineating the regime, the boundaries of the landscape and niche are defined at the same time.

Landscape, regime, niche

The general framework for the MLP is operationalized for the case of liberalisation and wind energy adoption in Figure 5. The figure displays the technological transition towards renewables and the liberalisation of the regime. The elements of figure 4 are replaced by concrete references to the subjects of this study: wind energy technology and liberalisation measures. Liberalisation is assumed to originate at the landscape level while reshaping the regime. Wind energy technology first developed as a niche technology and is adopted by the regime. Both process are occurring more or less simultaneously.

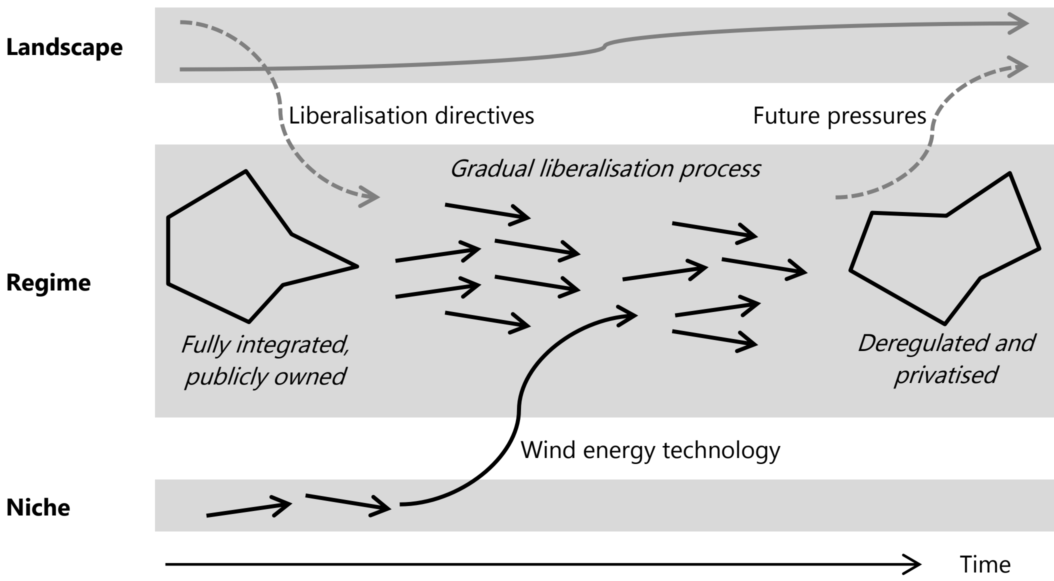


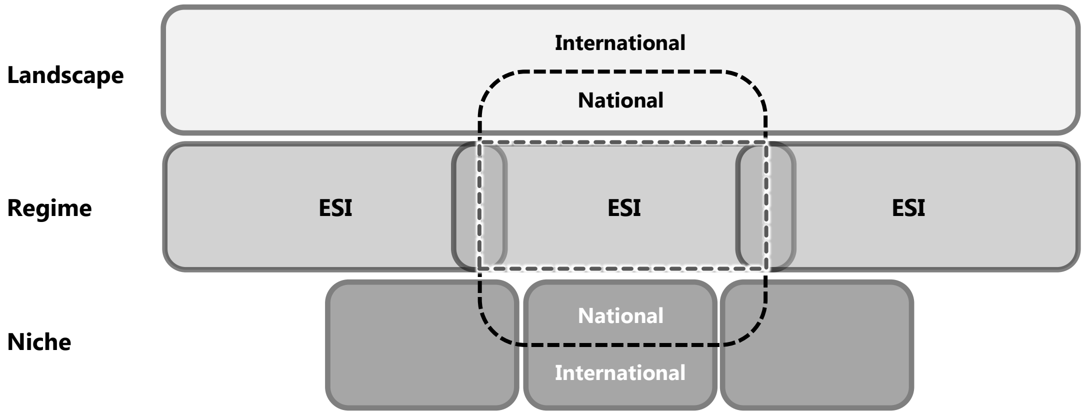
Figure 5 – Liberalisation and wind energy adoption in the MLP (Adapted from Geels (2004).

Levels and national border

Regimes must be national since historically, national governments have shaped the ESI very much. Furthermore, the necessary data for the research is mostly available on national scales only. Liberalisation measures are introduced and enforced by national governments at country-specific points in time. Also, wind energy adoption in terms of wind energy production and installed capacities are usually accounted nationally.

Figure 6 displays the delineation of the landscape, regime and niches with regard to the national borders of a country. The square with the grey-white dashed line indicates the regime. The black dashed line indicates the national border. The unit of observation of this study is the regime, i.e. the *national electricity supply industry*, the area bounded geographically by the nation frontier and conceptually by the landscape border and niche border.

The unit of observation does *not* included the parts of the landscape and niches covered by a nation. The landscape is partly national (e.g. national politics) and partly international (e.g. European commission). The same holds for niches: they are partly national and partly international. Regimes can thus be served by domestic niche developments or international niche developments. They are however expected to be served most by national niches due to geographical proximity.



White-grey dashed line: regime. Black dashed line: country border.

Figure 6 – Delineation of the MLP for the electricity supply industry.

Delineation of dimensions

The regime is contrasted more precisely from niches and the landscape on the basis of the seven dimensions that span the regime: technologies, infrastructures, markets and user practices, industrial networks, sectoral policy, techno-scientific knowledge and cultural and symbolic meanings. Based on this delineation, the dimensions are further operationalized in section 2.3 with a focus on the likelihood of adoption of niche-innovation. The delineation of the landscape and niches follows from the delineation of the regime.

Technology defines most clearly the border between niches and regimes. Technologies are simplified to generation technologies and their add-ons within the geographical (i.e. national) boundaries of a regime. All other technological features are considered under infrastructure. Landscapes refer to wider "technology-external" factors (Geels, 2002) and do thus not include technological features.

The border between regimes and niches is drawn by competition. Niches allow for development of radical novelties through protection from "normal" market selection in the regime (Geels, 2002). Niches serve as protective spaces for radical innovation that may not survive the selection environment of the regime (Rip and Kemp, 1998). So, niches are applications of new technologies that do not, or only indirectly, compete with the existent regime of the electricity supply industry. The following categories of competition can be distinguished.

1. *Direct competition* may occur when renewable electricity generation is either connected or disconnected to the grid. When connected, electricity sources compete with each other since they deliver the same product to the same market. When disconnected, users may still choose between electricity from the grid or the stand-alone generation unit. Rooftop solar panels may compete through delivering electricity to the grid or by acting as an alternative to electricity from the grid.
2. *Indirect competition* occurs when electricity is generated at locations that are not, but may potentially be, grid-connected. Since there is no alternative electricity source direct competition is absent. The production of electricity with stand-alone units may however decrease the demand for grid extensions to the concerned location, implying a weak form of competition. In Europe however, non-grid connected settlements are very rare and this category of competition can thus be neglected.

3. *Absence of competition* is likely when renewable electricity generation is applied in mobile applications or when future grid connection is unfeasible. A mobile application of wind energy that does not compete with the grid are sailing ships. Furthermore, wind turbines and solar photovoltaic systems can be set up at distant locations the grid will never reach. Such applications are niche-applications since there is no competition with the regime.

Within the regime, technologies may also be protected through additional measures (e.g. feed-in tariff). This does not count as a niche since the technology is still in competition with other regime components performing the same function. Feed-in-tariffs and other protective policies are a confirmation of the existence of competition rather than a signal that competition is absent. Such policies will be discussed further in section 2.3.4.

Infrastructure of the regime includes all the distribution and transmission nodes and links of the national electricity grid. Cross-border connections lead to overlaps in national infrastructures. Their effect is similar to the European Union directives on energy policy: they balance differences between countries. Since niche-technologies are by definition not grid connected, there is no infrastructure overlap with niches.

Markets are limited to retail and wholesale markets in this study. The retail market is always defined national, the wholesale market is either national or international. As liberalisation unfolds, wholesale markets are increasingly international. For the sake of practicality, markets are assumed national and fit within national borders. Niches are separate markets with competition conditions separate from those in the regime.

Sectoral policy consists of rules and laws regarding the electricity supply industry. Policy is imposed by the landscape on the regime. The regime does not make policy itself apart from regulations by a dedicated authority. The mandate for this authority however, originates in the landscape. Actors in the landscape are European Union officials and high level national politicians and bureaucrats.

Networks for the electricity supply industry are found to cover both the regime, landscape and niche and are therefore hard to delineate in any way. For analytical reasons, it is more interesting to look at clusters instead of networks. Clusters are network-like arrangements and by definition geographically bounded (Porter, 2000). They can therefore by analysed as phenomena that fall within national boundaries.

Culture and symbolic meaning can be described as the behavioural attitudes towards technological functions in the regime. Again, the national boundaries of the regime describes the relevant population that may hold these attitudes. This seems reasonable since public perceptions of technology may be strongly defined by national politics, national norms and values and national experiences.

Techno-scientific knowledge is found at the niche level and the regime level. Typical regime level knowledge regards optimization of incumbent technology with technological and economic knowledge. At the niche level, knowledge regards breakthrough innovation based on both fundamental sciences and applied sciences. At the landscape level, being explicitly technology-external, techno-scientific knowledge is not relevant.

2.1.4. Causal diagram

The MLP is a process-oriented theory (Geels, 2011) and does not explicitly address causality. The causality of technological transitions can be conceptualized further using the notion of adaptive capacity (Smith et al., 2005). The adaptive capacity represents the ability of the regime to adopt niche innovations and is affected by landscape pressures like liberalisation. The following sections explain the notions of adaptive capacity, landscape pressure and niche pressure.

a) Adaptive capacity

A decisive characteristic of the regime in analysing transitions is its ability to handle pressure and adapt accordingly. This dimension is expressed by Smith et al. (2005) in terms of adaptive capacity. Niche-innovations can be an important source of adaptation of regimes (e.g. Rip and Kemp, 1998; Geels, 2002). So, the adaptive capacity can be formulated as "the ability to adopt niche-innovations to increase performance". Performance criteria are for instance cost and environmental impact.

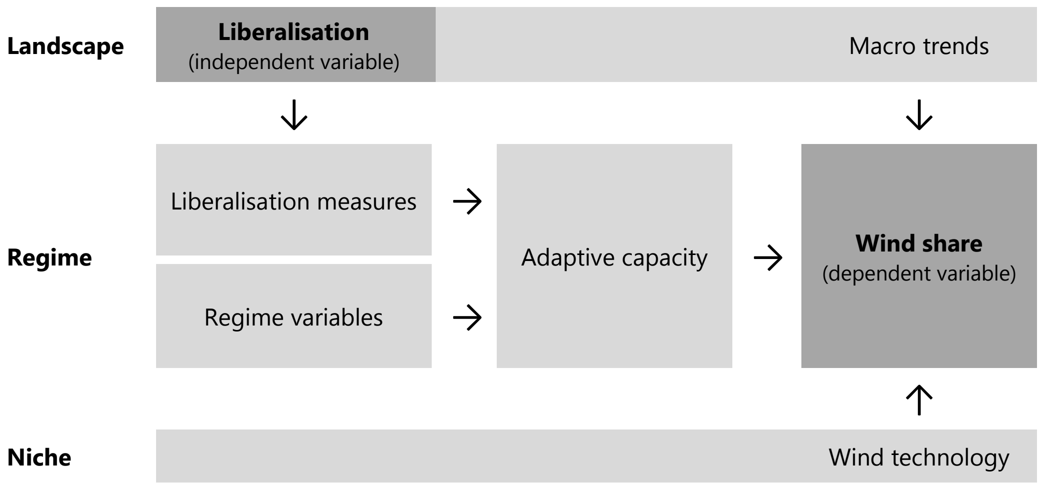


Figure 7 – Causal diagram based on the MLP.

Figure 7 presents the causal structure between liberalisation and wind energy adoption. In the illustration, liberalisation or neoliberal thinking at the landscape level results in the implementation of liberalisation measures in the regime. The measures influence the adaptive capacity. Also, several other regime level variables (relating to the regime dimensions) influence the adaptive capacity. Wind energy adoption is affected by the adaptive capacity, third variables at the landscape level and novel technologies offered by the niche level.

The following three subchapters discuss the relevant processes at each of the three levels and justify the causal structure in figure 7. First, in section 2.2, liberalisation is shown to be a landscape pressure originating in neoliberal thinking. Second, in section 2.3, the adaptive capacity of the regime is discussed with regard to liberalisation and non-liberalisation factors. Third, in section 2.4, the niche is shown to pressure the regime by offering novel technology. From these three subchapters, hypotheses are derived in section 2.5.

2.2. Landscape: electricity reform

Electricity reform originates at the landscape level in neoliberal thinking and affects the regime through concrete liberalisation measures. The following sections discuss first how reform originates in the landscape and why the envisioned effects of neoliberalism are disputable. Next, privatisation is identified as a trend separate from other reform measures. Subsequently, the European Union directives regarding the implementation of liberalisation are explained.

2.2.1. Neoliberalism

The origins of electricity reforms are found in neoliberal thinking. Neoliberalism is generally held to be "political-economic governance premised on the extension of market relationships" (Larner, 2000). As public policy, neo-liberalism is mostly defined by privatisation and liberalisation of services delivered in network industries that were previously state-owned monopolies (Belloc and Nicita, 2012). Neoliberalism is based on the proposition that "both parties to an economic transaction benefit from it, provided the transaction is bilaterally voluntary and informed" (Friedman, 1962, p. 55). Furthermore, neoliberalism presupposes that markets decide the value and thus the salary of workers and will automatically self-adjust to full employment (Palley, 2005).

The addition "neo" suggests it regards a rejuvenated form of liberalism, meaning that liberalism has been flourishing, declined and is now on rise again (Thorsen, 2009). The decline and revival of liberalism implies the existence of a competing paradigm, identified by Larner (2000) as "Keynesian welfarism". Simply put, under neo-liberalism governments abandon the welfare state and widen the space for markets. Economic liberalism first flourished in nineteenth century England with *laissez-faire* economics and free trade. After the second World War Keynesianism was the dominant paradigm with comparatively strong regulations, powerful unions, and extensive social protection. The revival of liberalism – neo-liberalism – in the last quarter of the twentieth century commenced with the economic policies of Thatcher in the UK (1979) and Ronald Reagan in the US (1980) (Palley, 2005).

Critique on neoliberalism is three-fold. First, the assumptions on the functioning of markets is thought to be wrong due to market failures like network effects. Second, liberalized markets are thought to have harmful effects like high income inequality. Third, the virtues of free market transaction are contested. Barnett (2009) holds that "proponents of free-markets think that people *should* act like utility-maximising rational egoists, despite lots of evidence that *they don't*". On the other hand, "critics of neoliberalism tend to assume that increasingly people *do* act like this, but they think that they *ought not to*".

Finger and Künneke (2011) note that liberalisation is ubiquitous in spite of "very different technological conditions of the sectors involved, different socio-political preferences and needs, and different political ideologies" (p. 1). An explanation for this high support for neoliberalism may be that neo-liberalism is more than an economic policy that derives popularity from its economic performance. Larner (2000) understands neo-liberalism both as a policy, an ideology and a discourse and notes that neo-liberalism may be more an ethical ideal than a set of established institutions. Clarke (2005) holds a similar view by claiming the neo-liberal model does not aim "so much to describe the world as it is, but the world as it should be".

Amable (2011) argues that social support for neo-liberal ideology can be based on the ethics of self-reliance. The ethics of self-reliance derives its popularity from the explicit rejection of discrimination and equal treatment of all. This frames neo-liberalism as the "American dream" were the upward social ladder is open to everybody. Amable (2011) notes that those expecting to go up the ladder will be in favour of neo-liberalism, those going down will oppose it. Logically, given the pyramid distribution of social status, neoliberalism can therefore count on majority support.

It is important to know whether or not the share of renewables is somehow a driver for liberalisation since this would complicate causal inference. According to empirical evidence by Drillisch and Riechmann (1998), liberalisation is insignificantly related to environmental commitment. The share of renewables is included in their operationalization of environmental commitment. This finding coincides with notions of other authors about environmental concerns not being on the liberalisation agenda (e.g. Verbong and Geels, 2007; Jamasb and Pollitt, 2008).

2.2.2. Privatisation

There are several reasons to isolate privatisation from neoliberalism and explore its own rationale. Contrary to other reform measures, there is solid evidence that privatisation fulfils at least the promise of higher efficiency. Furthermore, there is mixed evidence that as opposed to other liberal policies like easing market entry, privatisation has not successfully crossed the ideological cleavage and diffused to left-wing politics (Belloc, 2011; Pitlik, 2007, Potrafke, 2010). Also, factor analysis in this study shows that privatisation is executed relatively independently from all other measures in electricity reform.

Privatisation seems to have its own appeal through its promise of efficiency and utility as a "political weapon". Vickers (1991) analyses privatisation as the balance between government failure and market failure. In the case of state ownership, a government bureaucrat has both the objective of maximizing welfare and a possible personal agenda. The pursuit of a personal agenda is the cause of government failure but can be restrained by a well-functioning political system. However, political success is not always related to state-enterprise performance. Only in cases like plant closure the pressure to serve the public good may sufficiently strong to establish the feedback loop between society and bureaucratic performance.

Private ownership implies that the enterprise is driven by private profit maximization. Since social welfare is related to profit this can be advantageous for society as a whole. This effect may however be compromised in two ways. First, similar to bureaucrats, managers may feel only limited pressure to not follow their personal agenda. The performance of managers may be hard to relate to performance indicators like share prizes or product quality. Second, benefits to social welfare may be less than optimal due to market failures like distributional effects and market power.

The empirical evidence surveyed by Vickers (1991) supports the idea that privatisation can yield more efficient performance under competitive conditions. A more recent survey by Megginson and Netter (2001) shows that privatisation leads almost always to higher efficiency while lost jobs are offset by increased performance. Boycko et al. (1996) develops a model that supports the thesis that politicians are more problematic than managers. So, privatisation can be successful since it "controls political discretion". The superiority of private ownership under market power is however questionable and seems to depend very much on additional regulation.

Feigenbaum (1994) analyses privatisation through a political lens. Whereas privatisation can be a "tool box" for public officials or a "preferred mechanism" for economist, it is a "weapon" to politicians. The political perspective is not based on the premise of a ubiquitously accepted idea of public interest but on the assumption of a divide of interest and conflict. Motivations for privatisation can be 1) pragmatic, such as reducing budget drain, 2) tactical, such as attracting voters or rewarding supporters, or 3) systemic, such as lowering government expectations and transforming the stakes in the political game.

Feigenbaum (1998) shows in a cross-country case study of France, the UK and the US that privatisation motives are indeed political of nature and based, to some extent, on the ideal to change the political and societal culture. Additionally, some empirical evidence for the contention that politics matter is provided by Bortolotti et al. (2000), who show that budget constraints are drivers for privatisation. Bortolotti and Pinotti (2003) demonstrate that privatisation can be tactical game since right wing executives try to boost their re-election chances by spreading shares of public offerings among domestic voters.

2.2.3. European directives

In Europe, neoliberal thinking has materialized in the European Union directives on the single market. Most reforms of the electricity market are either directly ordered by the European electricity directives or a consequence of those directives. In some cases, like for the United Kingdom, many reform measure were already in place before the directives. Some countries became EU Member States in a later phase and where thus not directly affected by the directives in earlier years.

The Single European Act (EC, 1987) established the principle of one European internal market and paved the way for the Internal Energy Market (EC, 1988) working document. This document signalled the start of the reforms throughout the 1990s and was followed up by several directives (Bower, 2002). Liberalisation was realized through directives in 1996, 2003, and 2009 (EC, 1996; EC, 2003; EC, 2009). Table 1 displays the measures as mandated by these directives. The content of each measure and its aim are explained in the coming sections. Privatisation is not explicitly required by the directives.

Table 1 – Liberalisation steps as order by EU directives (based on EC, 1996; EC, 2003; EC, 2009).

	1996 Directive	**2003 Directive**	**2009 Directive**
Date of enforcement Implementation deadline	19-02-1997 19-02-1999	04-08-2003 01-07-2004*	03-09-2009 03-03-2011**
New capacity	Authorization Tendering	Authorization Tendering***	Authorization Tendering***
Unbundling *Transmission (T) and distribution (D) from other activities*	Accounting	Legal	D: Legal T: Ownership/ISO/ITO
Third Party Access	Regulated TPA Negotiated TPA Single Buyer	Regulated TPA	Regulated TPA
Retail market	> 40 GWh (1997) > 20 GWh (2000) > 9 GWh (2003)	Non-household (2004) All (2007)	All
Regulation	N/A	Regulatory authority	Regulatory authority

*The unbundling of distribution operators may be postponed till 01-07-2007.
**The unbundling of transmission should take effect before 03-03-2012.
***Only when authorization is not sufficient to ensure security of supply.

2.3. Regime: adaptive capacity

The adaptive capacity of the regime depends on the relationships between the niche-innovations and the many elements of the incumbent regime. This subchapter first explains the implications of the ESI being a network industry. Second, the specific political, economic, technical, and environmental features of the ESI are discussed. Third, the possible effects of different liberalisation measures are treated. Lastly, several non-liberalisation factors with possible effects on the adaptive capacity are reviewed.

2.3.1. Network effects

The electricity supply industry is a network industry with particular economic characteristics called network externalities or network effects. This subchapter explains what network effects are and how they affect the economics of the industry. The following sections first discuss the components of the industry. Next, the occurrence of network externalities is explained. Finally, the existence of monopolies and the possibilities of vertical integration of the different stages of the industry are discussed.

Network structure

Network industries provide a service through a structure of complementary components connected via links and nodes. Examples are telecom, railroad and electricity. In electricity networks, the transmission and distribution cables are the links. Nodes serve as connections between links and may transform, redirect or separate the electricity flow. The components are generators of electricity and consumers of electricity. In some cases components both generate and consume electricity.

Economides (1996) identifies one-way and two-way network. In one-way networks like broadcasting there is only one direction between components. In two-way networks like railroad and telecom the direction matters: one can ride in both directions or call and be called. The electricity network cannot be classified as either a one-way or a two-way network. It is a one-way network since many customers are provided with electricity by a central power plant. At the same time, hydropower plants, larger businesses and industry as well as households (e.g. with rooftop solar) may be both suppliers and consumers.

Figure 8 displays the main components (continuous outline), nodes (dotted outline) and links (arrows) in the ESI. Generators (G) are dedicated to producing electricity and feed it to the transmission nodes and links (T). Some generators like hydropower plants also consume for electricity storage (G7). The transmission operator guides the electricity to the distribution nodes and links (D). The distribution network is connected to the consumers (C), small producers (P) and components that both produce and consume (CP). There are mostly one-way links and some two-way links in the network.

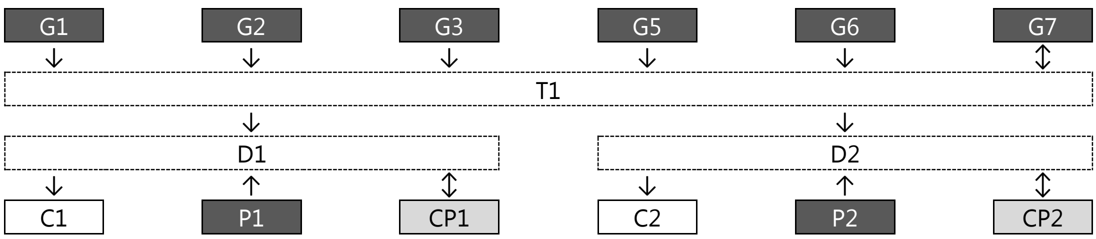


Figure 8 – Network structure of the electricity supply industry.

Network externalities

Networks feature positive externalities or network effects regarding production and consumption. Network effects are said to occur when the utility of a product increases with the number of users. Katz and Shapiro (1985) mention direct and indirect network effects. Direct positive externalities entail the increase of the possible number of interactions between network customers that can be made with each added customer (e.g. more mobile phone users increases the utility of a mobile phone). Indirect positive externalities arise when the addition of a new customer increases the variety in the offered service (e.g. a larger electricity grid implies more electric products). Typical one-way networks only feature indirect network effects (Economides, 1996).

Supply and demand curves for regular products and network products

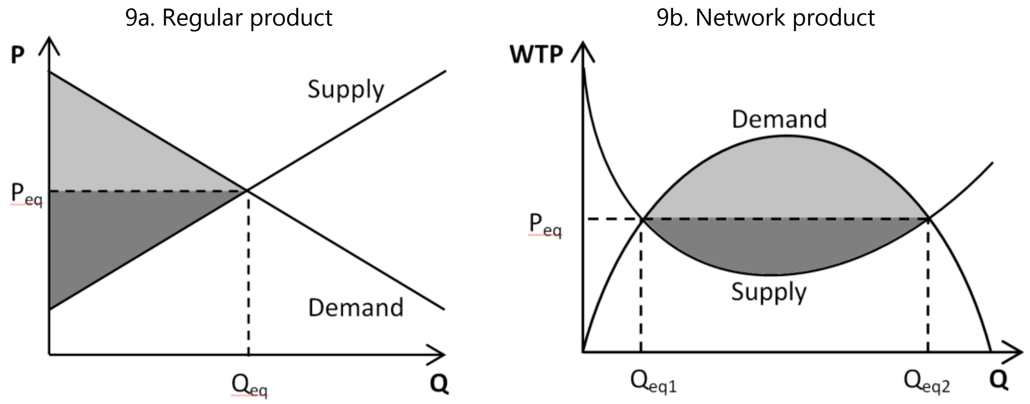


Figure 9 – Supply and demand curves for regular products and for network products.

Figure 9 displays the effect of network externalities on the supply and demand curves of network products. Graph 9a shows the supply and demand curve for normal products under perfect competition. For a higher unit price P, more suppliers are willing to produce. For a lower unit price P, more consumers are willing to buy the product. The curves meet at the equilibrium price P_{eq} for the equilibrium quantity Q_{eq}. The upper marked area illustrates gains for consumers if the price is lower than the price they are willing to pay. Similarly, the lower marked area shows gains for suppliers in case the price is higher than the price at which they are willing to produce.

Graph b shows that in network industries, supply and demand curves are radically different. The quantity expresses the network size (expected number of connections) and the price is expressed as willingness to pay.[2] The demand curve start at zero since a network with zero connections has no value. For more than zero connections, the product value rapidly increases. At some point, the curve declines since some customers find the service less valuable. Clearly, the lower equilibrium needs to be reached in order to make the network industry profitable. For a monopolist without price discrimination, maximum profits are found in between Q_{eq1} and Q_{eq2}. As such, a monopolist would not provide the highest social benefit. Competition can push prices down (and expectations up) to P_{eq} at Q_{eq2}.

[2] For regular products, a lower price leads to a higher demand. For network products, a higher demand leads to a higher willingness to pay. As such, the causality between price and demand is reversed. In other words, the price increases with the expected number of units sold.

Monopolies and vertical integration

The transmission and distribution networks are natural monopolies because competition would entail a duplication of the infrastructure (Steiner, 2000). Without price discrimination, a monopolist utility would find the highest profits between $Q_{eq,1}$ and the $Q_{eq,2}$ in figure 9.[3] As such, a monopolist would most likely not serve all customers that are in fact willing to pay for the service. A competitive market could drive the number of connections closer to $Q_{eq,2}$. In the presence of network externalities, an oligopolistic market (with few suppliers) thus leads to a larger network and lower prices than a monopoly (Economides and Himmelberg, 1995).[4]

Vertical integration is the bundling of several network activities (generation, transmission, distribution) under single ownership. Vertical integration allows actors to increase their economic control and offers monopolistic profits (Künneke, 1999). Vertical integration can be a necessity when the complementary nature of network services obstructs separate pricing of services: when metering and accounting of each stage in the network is impossible, only a total price can be paid for the network service and thus only one company can be rewarded.

Vertical integration of generation and transmission is attractive for transmission operators since generators depend fully on transmission operators. Integration could lead to better planning of infrastructure and generation investment and operation. However, vertical integration under the assumption of non-overlapping transmission infrastructure implies that generation effectively becomes a monopoly and thus the benefits of competition will be lost (Steiner, 2000).[5] The same is true for the integration of production with distribution. From a societal perspective, unbundling may therefore be attractive.

2.3.2. Electricity features

The theory so far analysed the electricity supply industry in a very generic way by focussing solely on network effects. The industry has however unique technical, economic, political and environmental features that are decisive for its lay-out and make it distinct from other network industries. These features complicate the industrial organisation of the ESI and may matter in the adoption of novel technologies. The following sections discuss technological, economic, political and environmental features.

Technology

A major technical challenge posed by the electricity system is load balance. In most parts of the electricity grid, there are no storage options and electricity is delivered via a network that needs instantaneous balance of supply and demand (Jamasb and Pollitt, 2005). Supply and demand can be matched by influencing generation (supply side management) and consumption (demand side management) or, sometimes, by storing electricity. In the case of renewable electricity production, the means of generation vary in adaptability of power supply or dependency on weather conditions. The balancing of supply and demand is therefore becoming increasingly complex.

---

[3] Monopolist profits are calculated as the product of the difference between the supply and demand curve and the number of connections.

[4] An oligopoly here means a small number of local monopolists instead of a single national monopolist. An oligopoly does not entail duplication of infrastructure.

[5] A competitive effect is only possible if there is more than 1 transmission operator and customers can choose different generation/transmission companies that are all connected to their distribution grid.

Supply side management consists of adapting the electric power production of generators in order to meet demand. In liberalised markets, demand is met by assigning production slots through a merit-order or auction system to power plants. Power plants that produce at the lowest costs get the first slots, followed by those with slightly higher prices. Renewable electricity comes first in the merit order through low operational and fuel costs (Klessmann et al., 2008).

Demand side management entails steering demand directly or indirectly in order to flatten the demand curves. This may increase the efficiency of the supply-side by allowing power plants to keep running at their optimal production level. Additionally, for systems with a large share of nuclear energy, demand side management may guarantee consumption of base load production since nuclear plants cannot be shut off due to safety and technical reasons. Drawing on Strbac (2008), the following categories of demand side management can be distinguished.

- *Price-discrimination* entails higher pricing of peak hours to incentivize consumers to spread their consumption. Real-time info on electricity prices with use of smart meters allows users to adapt to prices on a smaller time scale. Consumers may also agree on consumption reduction in advance in exchange for financial benefits.
- *Direct load control* allows utilities to steer the power consumption of appliances directly through for instance radio control. Customers taking part in direct control programs are compensated via their electricity bill.
- *Indirect load control* consists of steering power consumption by enabling appliances to react on frequency changes. Because of simple physics, the frequency of the current drops when supply cannot keep up with demand. Smart appliances note this drop and may adapt their consumption.
- *Load limiting* entails capping the energy use of customers. Load limiting schemes allow customers to plan their energy use within certain boundaries but shave the peaks through limiting the maximum consumption.

Storage of electricity is possible in a variety of ways. Storage systems can be mechanical (pumped hydro, compressed air, flywheel), electrochemical (batteries), chemical (hydrogen), electric (capacitor, magnetic field) or thermal (heat storage). Currently, global storage capacity covers about 3 per cent of generation capacity. Pumped hydro storage is applied at the largest scale and covers about 99 per cent of all electric storage capacity in the world. Compressed air energy storage and batteries are most popular after hydro. Several types of batteries as well as pumped hydro storage are considered most mature technologies (IEC, 2011).

Economics

Economically, electricity is a commodity that poses unique challenges regarding pricing, investment and positive externalities. First, like mentioned in section 2.3.1., separate vertical stages require measurement and accounting of electricity flows between the stages. However, the lack of possibilities to store electricity make it difficult to trade and set prices in a manner similar to other commodities (Jamasb and Pollitt, 2005). As such, advanced systems are needed to allow for competition. The introduction of competition in certain segments of the electricity production chain is only possible with modern metering and information technology.

Second, electricity does not have distinct characteristics per generation technology, i.e. the possibilities for transforming and marketing the product are limited (Defeuilly, 2009). Competition is therefore strongly focused on price. This characteristic is important since the political and environmental issues discussed in the following sections are partly caused and strengthened by it. Since other characteristics such as reliability, security of supply and environmental impact are not felt when using the product, market demand for them may be poorly articulated.

Third, the conventional generation technologies and transport systems have large scales and last for decades (Jaag and Trinkner, 2011). Time horizon and scale of investment in innovation are thus high and therefore risky. Investments are sunk and asset-specificity is high. In other words: incurred costs are irreversible and are not taken into account in further decision making. Rational asset owners exploit their assets as long as there is return on operational costs. This makes asset owners vulnerable to abusive price-setting (i.e. price setting that only allow return on operational costs, not on total investment).

Politics

Electricity is regarded a “basic good” to which all people should have access. The high consumer utility of electricity and the lack of alternatives result in a very low price elasticity. Monopolists may easily exploit their market power and raise prices to undesirable levels. Additionally, utilities may be inclined to deny access to customers if the marginal costs outrun marginal profits. Public intervention is felt legitimate when it warrants secure, safe and affordable supply of electricity to all and refrains utilities from abusing a monopoly position (Arentsen and Künneke, 1996).

Politics may however be incentivized “too strongly” to intervene. Widespread domestic consumption makes consumers roughly the same group as voters and infrastructure performance thus highly political. The political importance of energy supply incentivizes government to behave opportunistically towards the producing company, i.e. to keep the prices at marginal cost. Producers will react with underinvestment in technologies with low market return, high payback periods, and high asset specificity. Moreover, maintenance will be kept to a minimum. As such, politics may jeopardize the long term performance of the industry (Spiller, 2011).

Environment

The size of the ESI makes its environmental performance of no small importance. Conventional modes of electricity supply feature neglected costs including negative impacts from discovery, extraction, production, distribution and consumption of resources and electricity. The ESI typically fails to internalize environmental impacts of its services. Social costs like pollution and global warming are not included in the costs, resulting in higher than optimal consumption levels (Brown, 2001).

In Europe, electricity generation is one of the major sources of carbon dioxide. The emission trading system (ETS) was launched in 2005 and aims to reduce carbon dioxide emission by “cap and trade”. The system allows energy-intensive industrial plants and electric utilities to trade rights or permits to emit carbon dioxide. The trading scheme internalises the environmental implications of carbon dioxide to some degree. The EU ETS is the largest emission trading scheme in the world (Convery, 2007).

2.3.3. Liberalisation measures

This subchapter discusses the different liberalisation measures and their possible effects on the adaptive capacity of the regime with regard to the earlier explained network effects and specific economic, political, environmental and technical features of the industry. The measures are unbundling of the vertical stages, introduction of wholesale markets, introduction of retail markets, establishing an independent regulator, introduction of third party access and privatisation of incumbent utilities. After a brief overview, the separate measures are discussed.

a. Overview

Liberalisation entails the restructuring and deregulation of the ESI. Figure 10 summarizes the main steps of liberalisation based on Jamasb and Pollitt (2005) and Künneke and Fens (2005). The figure compares the ESI before and after liberalisation. The shaded parts of the value chain indicate monopolies. The blank parts indicate competitive market structures. Before liberalisation started in the late 80s in the United Kingdom, the ESI was a fully integrated publicly owned monopoly. Liberalisation took place during the 90s and 00s and introduced competition in the value chain. Only the grid remains a monopoly.

Under liberalisation, the value chain is unbundled by legally forcing incumbent utilities to split their activities into separate entities that focus solely on a single part or several parts of the value chain (e.g. generation or distribution). An independent regulator is installed to handle regulatory issues. Parts of the value chain are (partly) privatized with the aim of increasing efficiency. Generation, trade and retail are made accessible for newcomers (open entry). Transmission and distribution remain monopolies but incentive regulation aims to increase performance. Third Party Access (TPA) allows all retailers and generators to use the infrastructure. The literature evidence for the effects of the different measures is summarized in Appendix A.

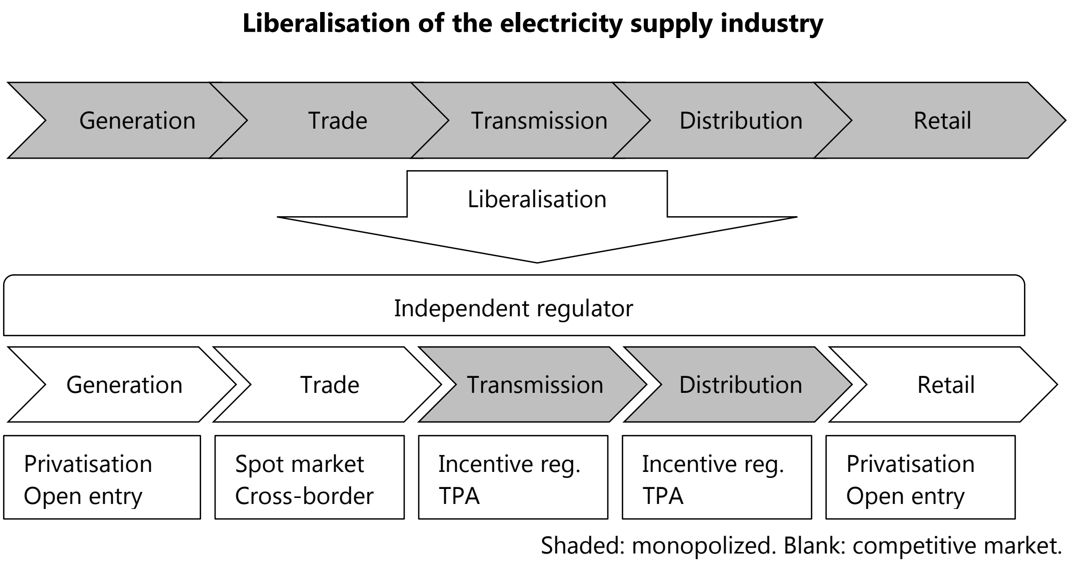


Figure 10 – Liberalisation. Based on Jamasb and Pollitt (2005) and Künneke and Fens (2005).

b. Unbundling

Unbundling is the separation of potentially competitive activities (Künneke, 2007) and aims to improve performance through competition. Separating formerly vertically integrated companies may increase competition by preventing anti-competitive behaviour of incumbents and easing access to newcomers (Jamasb and Pollitt, 2005). Unbundling entails separation of Distribution System Operators (DSO) and Transmission System Operators (TSO) from other activities in formerly vertically integrated undertakings (VI) (EC, 2003). Relevant other activities within VI are generation and retail (also called supply).

The European Union distinguishes ownership unbundling, legal unbundling, functional unbundling and accounting unbundling (EU, 2005). Using slightly different terms, Künneke (2007) states that ownership unbundling presents the greatest magnitude of economic and legal unbundling, followed by legal, management (functional) unbundling and administrative (accounting) unbundling. The 1996 directive mandated at least accounting separation, the 2003 directive set legal unbundling as the minimum norm (EC, 1996; EC, 2003). However, legal unbundling of TSOs has not led to effective unbundling (EC, 2009). Therefore, the 2009 directive requires more stringent forms of unbundling.

The 2009 directive gives three options (EC, 2010). Ownership unbundling requires full ownership unbundling of transmission from other activities in the ESI. It may be chosen if the network company is vertically integrated or already (legally) unbundled. The independent transmission operator (ITO) may only be chosen when the network company is vertically integrated. It requires independence of the transmission operator, but not ownership unbundling. Independence can be seen as a form of unbundling in between legal and ownership unbundling. An alternative to the ITO is the independent system operator (ISO). In this case, the transmission assets remain with the vertical integrated company but other tasks concerning transmission are outsourced to an independent operator.

Empirical evidence is far from conclusive on the benefits of unbundling. Steiner (2000) finds the effect of unbundling of transmission and generation on price negative but insignificant in a study on 19 OECD countries. Using an extended dataset and a fixed effects analysis, Hattori and Tsutsui (2004) find price to be positively and significantly related. Schmitt and Rammerstorfer (2010) finds no significant relationships. Copenhagen Economics (2005), studying the EU-15 member states, conclude price to be negatively significantly related to TSO unbundling.

The effect on the utilization rate was found positive and significant by Copenhagen Economics (2005). The reserve margin deviation is found negatively significantly related by Steiner (2000). Investment is positively significantly related to unbundling of TSO, but negatively significantly related to unbundling of the whole chain (Schmitt and Rammerstorfer, 2010). The latter contradiction is problematic since it does not allow for general explanations of the merits of unbundling, especially since the independent variables partly overlap (unbundled TSOs lead to at least partly unbundled chains).

Vertically integrated companies are incentivized to obstruct entry of renewable electricity generation as this may take a share of their conventional production (Alderfer, 2000). Separation of generation and transmission (or distribution) is thus crucial for avoiding anti-competitive behaviour by incumbents and ensuring access to new entrants (Jamasb and Pollitt, 2005). The liberalisation in the UK provides evidence of the importance of cross subsidizing when separation led companies to leave the retail market altogether (Jamasb and Pollitt, 2005). In summary, unbundling may advantage renewables.

c. Wholesale markets

Wholesale markets are expected to increase competition between generators through competitive allocation of production time slots. Wholesale markets can be seen as a result of unbundling of transport and production (Boisseleau, 2004). Because of this, electricity became a commodity that could be traded through either a bilateral market or an organized market. There are three theoretical models for generation dispatch: vertically integrated monopoly, bilateral markets and power pools. In the vertically integrated monopoly, generation dispatch is decided by the monopolist based on cost and technical constraints and there is no competition.

The bilateral model or "Over The Counter" (OTC) model entails tailor-made contracts between buyers and sellers. It is not considered a full wholesale market in this study due to numerous market failures (it is operationalized as absence of a wholesale market). Boisseleau (2004) highlights four market failures in bilateral markets. First, price transparency is low due to a lack of a common market place with published prices. Second, this lack of transparency allows for price discrimination since buyers and sellers have an interest not to tell anyone their contract terms. Third, market liquidity is low since tailor-made contracts are hard to substitute (partly) with contracts with new partners. Fourth, transaction costs are high since buyers and sellers have to seek each other. These seeking costs may be prohibitively high for the short-term contracts that are essential to competition.

The power pool model allows generators and consumers to exchange electricity through a single-price clearing auction for certain time slots. This type of market gathers the bids of buyers and sellers and uses them to construct a supply and demand curve. The price at which supply and demand meet is called the single clearing price and is paid by the buyers to the sellers. If the results of the auction do not fit with the transmission capacities, generators at different locations may be forced to increase or decrease their production. The costs of this are shared by all producers. The resulting price system is however highly complex and susceptible to manipulation (Boisseleau, 2004).

Power pools may use a locational pricing model to compensate for varying transmission and congestion costs. As such, the price for electricity and transmission are bundled instead of separated. The transmission system operator collects all bids and calculates the price taking into account the technical capabilities of the network. The approach is especially useful for weak networks and may incentive generators to invest in new plants at more suitable spots concerning transmission capacity. A disadvantage of the system is the complex and not fully transparent price-setting, although traders are served by having to deal with only one product instead of two (Boisseleau, 2004).

Empirical evidence on the functioning of wholesale markets regards price, utilization rate and investments. There are two significant relationships: wholesale markets are found to affect prices negatively significantly according to Steiner (2000) but positively significantly according to Hattori and Tsutsui (2004). Hattori and Tsutsui (2004) explain their outcomes with reference to possible exercise of market power as noticed by authors such as Green and Newbery (1992), Brennan and Melanie (1998), Ocaña and Romero (1998) and Borenstein and Bushnell (1999). Schmitt and Rammerstorfer (2010) and Copenhagen Economics (2005) do however not find significant relationships for price.

The competitive wholesale market poses challenges for renewable electricity generation. Wholesale electricity markets are largely based on a day-ahead markets but weather predictions are not accurate enough to approximate production as well as for conventional sources. By the time predictions are sufficiently accurate, the electricity generation rights have already been allocated and market liquidity is low. Conventional generators can profit from this in two ways. First, in case of high renewable energy production, conventional generators may buy back electricity under cost price. Second, in case of low renewable energy production, they can sell their electricity above cost (Neuhoff, 2005). Altogether, wholesale markets may hamper the adoption of renewables.

d. Retail markets

Retail markets introduce competition by allowing consumers to select their supplier of preference. Removal of price controls and other regulation should enable price setting under free market conditions. The European Union demands market opening since 1997 for large consumers (EC, 1996). Since 2007, all consumers including households should be able to choose their supplier freely (EC, 2003).

For consumers, free market choice is not completely free. Defeuilly (2009) summarizes three components of the costs of switching of supplier. First, search costs entail identifying alternatives and comparing their offers. Second, learning costs entail building the relationship with the new supplier which includes for instance understanding bills and service structures. Third, transaction costs occur because of negotiating (most relevant for larger users) and formalising the contract. These switching costs may bar consumers from choosing new suppliers even if their offer is better than the incumbents'.

Retail markets have several possible effects on the electricity supply industry. Through competition, geographical niches (e.g. remote areas) and other niches (e.g. green power) that were neglected by the incumbent may be served better. Price levels may go down and service levels may increase. Also, the pressure on the whole supply chain to decrease prices through higher efficiency can rise through competition (Defeuilly, 2009).

There is no evidence that the promises of lower prices through retail markets have been fulfilled. Retail market opening has been found to significantly influence prices negatively by Hattori and Tsutsui (2004). Copenhagen Economics (2005) finds a negative but insignificant relationship between retail market opening and price. The utilization rate is not affected at all by consumer choice (Copenhagen Economics, 2005).

In retail markets, new products that match better with individual consumer interests may be developed (Defeuilly, 2009). More specifically, consumers may spur renewable electricity generation through green power demand. A study by Bird et al. (2002) shows that green power marketing becomes more popular under competition. Both new entrants and incumbents are encouraged to offer green power to obtain or retain clients. However, the construction of new capacity lags far behind green power programs. As such, retail markets may boost renewables, albeit slowly.

e. Independent regulator

Independent regulators are considered a precondition to successful liberalisation. They have three possible activities. First, they regulate monopolies through tariff setting, providing access rules, and licensing operators. Second, they oversee competition in wholesale and retail markets. Third, they protect customers by handling their complaints. In some case, regulators commit to wider policy obligations such as promotion of renewables (Larsen et al., 2006).

Three features of independent regulators stand out. First, they are at arm's length of the government through for instance earmarked funding and exception from civil service salary rules. Second, they are at arm's length of stakeholders in the ESI through arrangements that avoid personal interests of regulators in the ESI . Third, they have independent decision-making competencies concerning rule making, rule application and litigation (Larsen et al., 2006).

Independent regulators have two important possible effects on electricity markets. First, they may avoid market failures like excess competition (leading to loss of capacity) and opportunism by monopolists. Second, they could limit political opportunism vis-à-vis investors in the ESI by creating a stable regulatory framework (Zhang et al., 2008) (Larsen et al., 2006). There is little empirical evidence on the effect of independent regulators.

With regard to renewables, independent regulators may be advantageous mostly because of a possible reduction of investment risk. Since wind energy poses high investment risks as compared to other sources of energy, introduction of an independent regulator may disproportionally stimulate investment in wind energy. Also, supportive policies for renewables may be embedded in a stronger regulatory framework due to an independent regulator.

f. Third Party Access

Third Party Access forces network operators to provide access to generators and retailers. It is complementary to the opening of trade and retail markets. There are three forms of TPA. Negotiated Third party Access (nTPA) allows suppliers and consumers to freely negotiate a contract. Single Buyer Third Party Access (SB) gives states the right to designate single buyers within the area covered by the network to handle trade. Regulated Third Party Access (rTPA) grants access to networks on the basis of fixed pre-published tariffs (Bier, 1999).

There is debate on the virtues of each system, without any outcomes. Jamasb (2006) notes that regulated TPA is more likely to guarantee easy access as negotiated TPA has caused disputes and uncertainty in "some" countries. Bier (1999) considers neither of the systems "clearly superior". Empirical evidence on the merits of TPA is contradictory. Hattori (2004) finds a negative significant relationship between a dummy variable for both TPA and retail access and price and price ratio. However, Copenhagen Economics (2005) finds TPA for transmission to be significantly positively related to price. Steiner (2000) and Schmitt and Rammerstorfer (2010) find TPA of no significant influence on price.

Regarding wind energy, TPA seems crucial in allowing new, innovative actors to enter the regime. Local energy initiatives that proved successful in Denmark (Meyer, 2007) may more easily enter the regime under TPA. Wind energy producers may more easily gain access to the grid under fair and transparent entrance rules. Since innovative technologies need high investment in research and development, strong regulation may be needed to protect the financially vulnerable actors in this field (Ramesohl et al., 2002). Furthermore, local initiatives, that can only function with TPA, have been suggested to have success rates superior to those of projects typically undertaken by large incumbent utilities (Meyer, 2007; McLaren Loring, 2007).

g. Privatisation

Privatisation entails the partial or complete sale of public enterprises to private actors. Privatisation is expected to lead to cost saving and efficiency improvement in the affected firms, provides proceeds for the government, and reduce future liabilities (Jamasb and Pollitt, 2005). Zhang (2008) summarizes four effects of privatisation of the ESI: different managerial incentives through a change in property rights, access to private capital market instead of tax revenues for investment, more precise and measurable objectives, and removal of political and interest group influence.

Empirical evidence for the effects of privatisation in the ESI is contradictory. Steiner (2000) and Schmitt and Rammerstorfer (2010) find a positive significant relationship with (industry) price but Hattori and Tsutsui (2004) find price to be negatively significantly related (Schmitt reverses the indicator so the sign changes). However, Copenhagen Economics (2005) does not find significant relationships. Zhang et al. (2008) conclude privatisation to be positively significantly related with capacity per capita and labour productivity.

The effect of privatisation on wind energy adoption is hard to predict. Privatisation may direct R&D activities towards themes that more directly benefit the private shareholders (Munari, 2002). Moreover, adopting wind energy implies the development of a new business model. Private companies can be expected to focus on (short-term) profitability. Since wind energy may not be as profitable as other sources of energy and needs more risky investments, it is unlikely that privatisation will spur wind energy adoption.

2.3.4. Non-liberalisation factors

The adaptive capacity of the electricity supply regime can be expressed more elaborately using the elements of regime proposed by Geels (2002). The following sections discuss each element. The main constructs of interest in this study – liberalisation and wind energy – cover already partly the regime dimensions of technology and markets. Since there is still much more to technology and markets, they are discussed in the same way as the other dimensions.

a. Technology

For adoption to be successful, wind energy needs to be an attractive alternative to incumbent technologies regarding its performance. As will be shown in section 2.4.2., the competitive advantage of wind energy depends on the characteristics of incumbent technologies regarding siting, risk, cost and pollution. Thus, the relative performance of niche technologies with regard to regime technologies is of great influence on the adoption of novelties. In other words, the technology dimension describes the difference in performance between regime and niche technology.

Assuming that regime performance is comparatively stable, the technology dimension can be operationalized solely at the niche level. This makes sense, since especially the cost element of wind has changed dramatically: total costs per unit of electricity from wind in Denmark nearly halved from 1990 to 2006 (Krohn, 2009). Furthermore, siting issues have become of much smaller importance since the capacity per installed turbine in Europe has risen from approximately 0.1 MW in 1990 to 1.7 MW in 2007 (Krohn, 2009). Such radical performance changes cannot be noted for conventional technologies. The technology dimension is further discussed as a niche trait in section 2.4.2.

b. Infrastructure

Grid-connected distributed generation faces two challenges: installation of new lines and management of intermittent production. Regarding new lines, the relatively small scale of renewable electricity generation demands small and numerous grid connections. Renewable electricity projects may be inhibited by lumpy investments for connections. This can be solved by either coordination or socialization of costs. In the first case, project developers concentrate their investments on certain areas to share the costs. In the second case, the project developers only pay the connection charge of the cable from the last distribution point. The additional costs are shared among the other network users (Neuhoff, 2005).

The grids ability to management intermittent production depends on the total electricity generation fuel mix, the transport capacities, the storage capacities, and the cross-border capacities. Large shares of adaptive sources like hydropower and gas allow for large shares of wind energy whereas large shares of base load power like nuclear energy complicate capacity management. As such, the fuel mix, as a characteristic of the infrastructure to which new wind capacity is connected, can be of great importance for its adaptive capacity.

c. Markets

Geels (2002) calls markets the "application domain" of technologies. Of all dimensions of the regime, markets may be influenced most by liberalisation. In other words, a liberalised regime is distinct from a non-liberalised regime mostly because of its market structure. Apart from all the measures of liberalisation such as retail market opening or unbundling, there are some more characteristics of markets that may matter in the adaptive capacity of the regime.

Electricity markets feature many distortions and market failures that may influence the transition. Prices may not reflect cost and benefits through unpriced pollution and indirect or direct subsidies. Furthermore, a lack of capital and improper discounting deters investors in renewable energy (Sovacool, 2008; Neuhoff, 2005). Also, Carley (2009) shows that the adoption of renewables is correlated with average electricity retail price and the electricity use per capita.

d. Networks

Actors and networks with their mutual interdependencies grant the regime stability in the form of "organizational capital" (Geels, 2002). At the same time, networks allow for the exchange of tacit and explicit knowledge and may induce problem identification and visions of the future and thereby the development of novel solutions. Networks provide actors with a resource base in terms of knowledge, information and ideas for the future (Jacobsson and Johson, 2000; Jacobsson and Bergek, 2004).

The importance of networks may be best illustrated by so-called clusters. Clusters are "geographic concentrations of interconnected companies, specialized suppliers, service providers, firms in related industries, and associated institutions" with both a competitive and a cooperative relationship within a particular field (Porter, 2000). Clusters are believed to increase productivity of members, increase innovation capacity and stimulate the formation of new businesses that support innovation. For innovation in the electricity supply industry, clusters may therefore be of great relevance.

Verbong (2007) shows how networks evolved in the Dutch electricity supply industry as displayed in figure 11. First, the number of actors and links increase through unbundling, regulation and cross-border trade. Second, households are drawn into the regime through retail market opening. Third, the national government loses ties and is less involved in the regime through introduction of an independent regulator. Finally, provinces and large municipalities are excluded from the network through privatisation. However, in order to study the effects on innovation, other actors like research institutes should be included in the analysis.

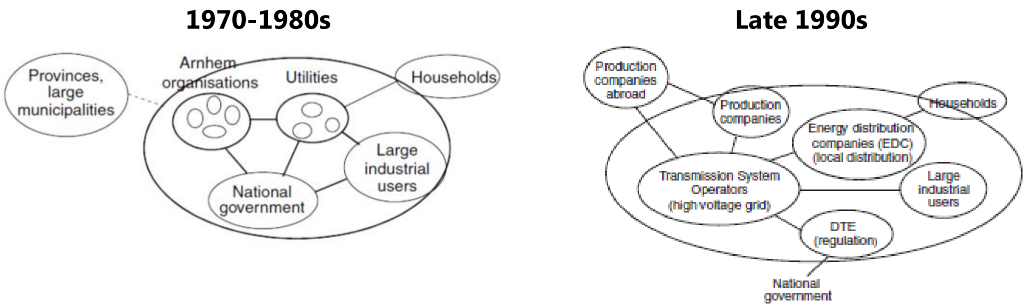


Figure 11 – Actors and networks in the Dutch electricity regime (Verbong and Geels, 2007).

e. Sectoral policy

Regulative and formal rules cement habits and routines within a regime through legally binding contracts, standards or subsidies (Geels, 2004). Jacobsson and Bergek (2004) speak more broadly of institutions that influence connectivity, incentive structures or demand structures. The adoption of renewables may depend on political and regulatory support, tax and subsidy incentives, and spatial planning policies. Administrative procedures and grid connection procedures may lengthen lead times or lead to termination of projects.

Taxes and subsidies are important success factors for wind energy. Munksgaard (2008) for instance holds that the success of wind power in the Danish electricity market is mainly due to high feed-in tariffs in the 1990s. However, intermittent support for renewables may have done renewables more harm than good: in the United States, intermittent support : "soured the country's intellectual consciousness against alternative energy systems" (Sovacool, 2008). Carley (2009) shows that tax incentives in the United States unexpectedly decrease renewables whereas subsidies have a positive influence on the adoption of renewable technologies.

Administrative frameworks regarding for instance spatial planning may hamper renewable energy development since they are often tailored towards existing technology (Neuhoff, 2005). Spatial planning can thus hamper on-shore wind energy adoption significantly (McLaren Loring, 2007). The WindBarriers project (EWEA, 2010) finds that for administrative procedures, the environmental impact assessment and compliance with spatial planning are major barriers in European countries. For grid connection, a lack of information on available capacity and a lack of planning regarding grid extension poses barriers. Also, land ownership policies and the environmental impact assessment delay wind energy projects (EWEA, 2010).

f. Culture/symbolic

Normative rules stabilize norms and values regarding for instance the performance of products and may block new criteria that ultimately improve the regime's output (Geels, 2004). Geels and Verhees (2011) operationalize cultural dynamics for the case of nuclear energy using a mix of approaches to cultural legitimacy. More simplified, Sovacool (2008) summarizes four normative views on energy. The economic view regards electricity as a commodity. The ecological view emphasizes aspects like resource scarcity and environmental pollution. The social welfare view sees electricity services as a social necessity. The energy security view, finally, emphasizes the geopolitical side of electricity supply. Each view leads to different problem diagnoses and proposed solutions.

Both the supply and the demand side of the regime may influence the adaptive capacity through normative rules. Sovacool (2008) finds that companies tend to focus on their core business and disregard energy issues. For consumers, the physical removal of harms (pollution) from the location of benefits (in-house electricity) lowers popular attention for these issues. Similarly, Neuhoff (2005) sees that the lack of distinctive properties for differently generated electricity leads to price-focused competition. At the same time, Americans feel "entitled to abundant energy sources" (Sovacool, 2008). In summary, the regime may be shaped by certain public perceptions of energy sources.

Many studies in wind energy adoption have focussed on the fact that renewable energy generally benefits the larger population while disadvantaging the local population. Of all renewables, especially wind energy may be constrained by socio-political, market and community acceptance (Wüstenhagen et al., 2007). Jobert et al. (2007) and many others show that visual impact, ownership, information and participation are of importance for social acceptance. In Denmark for instance, private ownership based neighbourhood cooperatives may be an important reason for local acceptance (Meyer, 2007) (Ornetzeder and Rohracher, 2013). In the UK, local, cooperative ownership may similarly be a success factor in wind energy adoption (McLaren Loring, 2007).

g. Techno-scientific

Cognitive rules "blind" engineers by directing them in routine search patterns within the regime, thus blocking companies from breakthroughs (Geels, 2004). Technological routines emphasize the optimization of scale and scope of existent production facilities (Künneke, 2008). Finger et al. (2005) mention human specificity as a form of asset specificity: investments in technological knowledge cannot be directed to novel products and thus strengthen the existent regime. So, research and development in for instance coal technology may solidify its position in the energy mix disproportionately.

Public investment in techno-scientific knowledge may prevent lock-in. Public investment is important since firms may not reap the benefits of private innovation and therefore abstain from it, for two reasons. First, there is the risk of losing potential profits through spill-over. Patents in energy technology can more easily be circumvented than in for instance pharmaceutical industries (Neuhoff, 2005). Second, only large scale application of novelties leads to significant learning and thus cost-reduction. Firms alone may not be able to realize such learning and reap the benefits.

As such, government investment in energy innovation can be key in the adaptive capacity of the regime. However, such investments mostly facilitate techno-scientific learning in niches instead of regimes. Government funding for breakthrough innovation may rather be directed to newcomers or research institutes than to incumbents. Therefore, the niche level seems more apt for operationalizing changes in techno-scientific knowledge that support the adoption of wind energy technology. This is discussed further when the techno-scientific knowledge is quantified in section 3.2.3.

2.4. Niche: wind energy innovation

Niches act as "incubation rooms" for radical innovations (Schot, 1998). For wind energy, stand-alone units for rural electrification seem to be the main niche applications in recent decades. To fully understand the development of wind turbines, the following sections take a long-term perspective starting in the 12th century. Subsequently, the maturity of wind energy technology is discussed and expressed in terms of performance in comparison with conventional technology. Also, the development of wind turbine performance over time is discussed.

2.4.1. Niche applications

The first grid connected wind turbines for regular electricity production marked the entrance of wind energy in the regime. On a long-term time-scale, two niche-developments preceded this: the application of wind mills for production processes that peaked in the 18th century and stand-alone turbines for rural electrification that were introduced at the start of the 20th century. Since the 1950s, wind power has made its way into the European electricity supply industry regime.

The earliest records of windmills are of the 12th century in England and France. By the 14th century, the Dutch were leading in the development of windmills and used them for draining marshes in the Rhine delta. In the centuries that followed, many more applications of windmills were introduced, mainly by the Dutch. Table 2 lists applications of windmills and their first occurrence for the period 1500-1800. Windmills were at their heights in the 18th century. After that, the numbers "rapidly declined" (Fleming and Probert, 1984). A large windmill in the Netherlands in 1720 had a capacity of approximately 5 kW (Smil, 2007).

The introduction of steam engines phased out wind powered production processes. Wind energy only became popular again with the introduction of electricity. The first electricity producing wind turbines were designed and installed around 1900 in Denmark for rural electrification. By 1910, there were hundreds of turbines supplying villages with electricity. Batteries guaranteed electrical power during windless days. The turbines had capacities of 5 to 25 kW and rotor diameters of up to 23 meters (Fleming and Probert, 1984).

Wind energy started entering the regime after World War II. The interest in wind energy grew because of fuel shortages, rising electricity costs, energy independence concerns and the recognition that fossil fuels are finite. Also, there was an increasing knowledge of aerodynamics. Research into wind energy for electricity generation intensified in the 1950s and turbines were connected to grid. In spite of technical successes, the commercialization of wind energy was slowed down by relatively cheap fossil fuels and the promise of abundant and cheap electricity from nuclear fission. The oil crisis in the 70's however motivated developed countries to invest in research and development (Fleming and Probert, 1984). Ever since, shares of wind energy in the electricity sector have been increasing.

Table 2 – Applications of windmills and their first occurrence (Davids, 2007, p. 62-63).

16th century		17th century		18th century	
Application	**1st time**	**Application**	**1st time**	**Application**	**1st time**
Oil	< 1550	Gunpowder	1600-1625	Cacao	1700-1800
Mine-pumping	c. 1550	Hulling	1600-1625	Pumping seawater in salt pans	1772
Paper	1586	Tanning	1600-1625		
Hemp	1589	Brasilwood	1601		
Washleater	1592	Fulling	c. 1620		
Saw	1592	Mortar	c. 1628		
		White lead	c. 1630		
		Trass	c. 1630-1660		
		Mustard	1630-1675		
		Stone sawing	c. 1658		
		Tobacco/snuff	c. 1660		
		Iron grinding	c. 1677		
		Canon boring	c. 1689		

2.4.2. Maturity

Geels and Schot (2007) speak of sufficiently or not sufficiently developed niche-innovations. This notion may be operationalized quantitatively to assess the potential of innovations. The adoption of novelties depends on the regime criteria for technology and the performance of novelties with regard to these criteria and barriers. The following sections first derive indicators to assess the relative performance of wind turbine technology. Subsequently, the historical development of wind turbine performance is discussed.

Comparative performance

To qualitatively assess the maturity of wind energy turbines in comparison to conventional technologies, four basic indicators can be constructed. They concern cost, pollution, risk and siting. Siting may be the least obvious choice but can be regarded an important socio-political characteristic of technologies. Wüstenhagen (2007) notes that small plant sizes lead to a larger number of siting decisions. Second, low energy densities (i.e. capacity factor) lead to a high visual impact per generated unit of output. These features are mutually reinforcing since visual impacts play a major role in siting procedures.

Table 3 gives an overview of common generation technologies. The choice of technologies is based on EC (2008). Included are Open Cycle Gas Turbine (OCGT), Combined Cycle Gas Turbine (CCGT), Internal Combustion Diesel Engine (ICDE), Combined Cycle Oil-fired Turbine (CCOT), Pulverized Coal Combustion (PCC), Circulating Fluidised Bed Combustion (CFBC), Nuclear power, hydropower, wind power and solar photovoltaic.

Appendix B gives an abstract overview of the conversion steps and conversion products for these technologies. The conversion chains start with hydrogen since this is the common source for energy carriers used in electricity production. It is found in the sun (where it is turned into radiation) and in other stars that are the original source of uranium for nuclear power plants. The final product is alternating current (AC). The aim of the figure is to give an overview of the fundamentals of each technology and show the main differences and similarities. The part of the conversion chain covered by the actual power plant is indicated with dotted lines.

Table 3 – Key figures for generation technologies (EC, 2008; Eurelectric, 2009; own analysis).

Technology	Production cost [€/MWh]	Investment cost [€/kW]	O&M cost [€/kW]	Fuel cost [€/MWhe]	Plant size (MW)	Capacity factor* [-]	Intermittent /adaptable? [Yes or No]	Emissions [kg CO2 eq./MWh]
Gas - OCGT	70	310	10	56,6	250	0,48	No/Yes	640
Gas - CCGT	55	635	25	37,1	650		No/Yes	420
Oil - ICDE	113	800	40	84,1	50	0,18	No/Yes	690
Oil - CCOT	100	1.000	50	71,4	175		No/Yes	585
Coal - PCC	45	1.265	60	16,5	800	0,59	No/No	820
Coal - CFBC	50	1.400	70	19,3	300		No/No	960
Nuclear	68	2.680	90	8,1	1.600	0,76	No/No	15
Hydro *large*	90	1.350 1.800 2.510	40 55 75	-	20 75 250	0,27	No**/Yes	6
Hydro *small*	123	2.900 4.500	85 130		2 10		No**/Yes	
Wind *onshore*	93	1.140	35	-	2	0,21	Yes/No	11
Wind *offshore*	113	2.000	80	-	3,6	0,34	Yes/No	14
Solar PV	700	4.700	80	-	1	0,09	Yes/No	45

* Based on total capacities and outputs in EU-27.
**Hydropower is dependent on the seasons, but storage capacities in (artificial) lakes make it incomparable to intermittent sources like wind and solar.

Based on table 3, the indicators can be constructed for each technology. The indicators serve as proxies for the relative attractiveness of the technologies under certain economic, environmental and socio-political conditions. In a competitive market for instance, total cost may matter. Under great environmental awareness, pollution may matter. The indicators are calculated as follows.

- *Cost* is represented by the total production costs per unit of electricity. Cost indicates the attractiveness of generation technologies for public or private decision-makers. The indicator omits subsidies and taxes that may be decisive in the actual production costs and related profits.
- *Pollution* is represented by carbon dioxide equivalent emissions during the whole lifetime per produced unit of electricity. Pollution may serve as a proxy of social and political resistance to generation technologies. The indicator neglects pollution like particulate matter and toxic substances and the score is therefore relatively low for coal and solar photovoltaic.
- *Risk* is the ratio between investment per unit of electricity and operational, maintenance and fuel costs per unit of electricity. Risk is a proxy for the financial uncertainties of generation technologies. The indicator does not compensate for fuel price sensitivity. The risk for gas and oil specifically may therefore be higher.

- *Siting* is represented by the inverse of the product of typical size and capacity factor. It serves as a proxy of difficulties in siting new capacity due to the amount of siting procedures and the visibility of installations. The indicator suffers from the wide range and plant sizes for both wind (one turbine or a whole wind farm) and solar photovoltaic (few panels to fields full of them).

Figure 12 presents the scores of all indicators. All scores are normalized for better inter-indicator comparison and the square root is taken to compensate for outliers and to visualize low scores better. It can be observed that fossil technologies generally come with high pollution but at low cost, low to intermediate risk and few siting problems. Nuclear fission and most renewables are non-polluting, have low costs but pose an intermediate financial risk. Only solar photovoltaic performs very differently from the other renewables: it has high costs, poses high risks and has highly problematic siting. In Appendix C, the scores of wind energy are directly compared to those of other technologies.

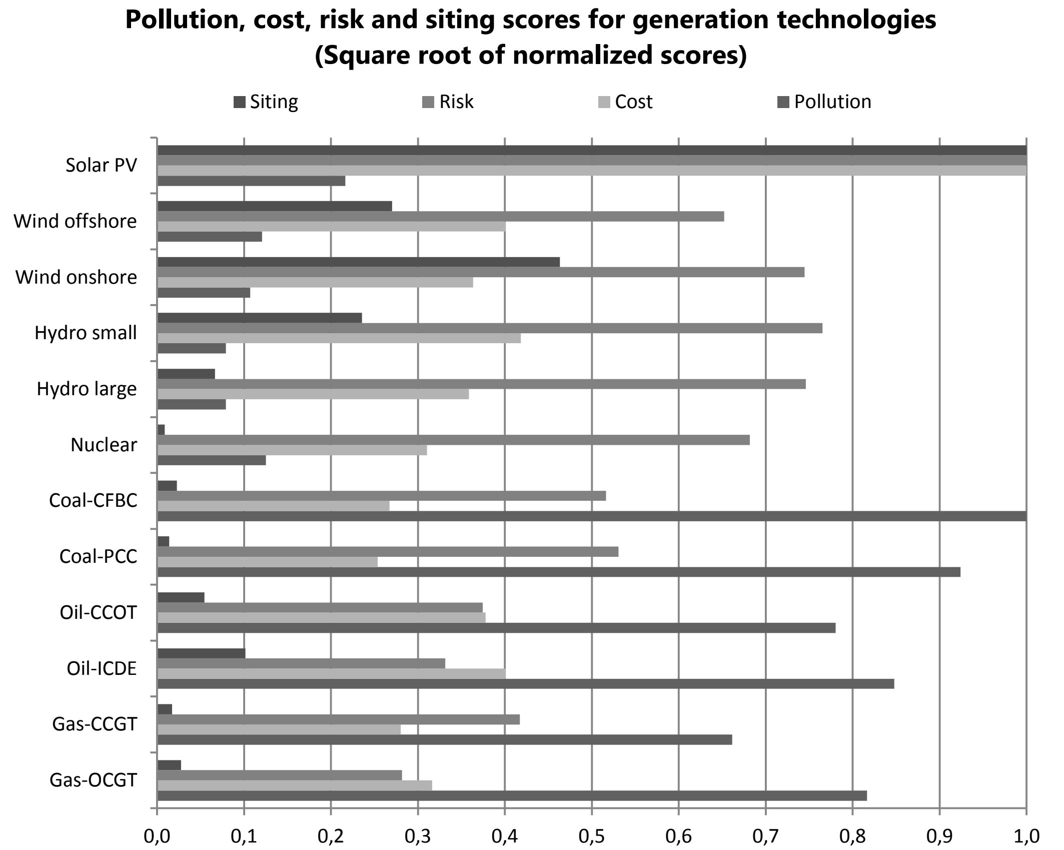


Figure 12 – Performance of generation technologies (input values from table 3).

Dynamic performance

The dynamic performance of wind energy entails the increase in performance over time through learning. Learning is mostly expressed in economic or technological terms. Learning regarding economic performance in wind energy typically focus on the price of capacity or the price of produced electricity as a function of cumulative capacity, cumulative energy or cumulative units installed or produced (Junginger et al., 2005). Learning rates in multiple European countries have been calculated by Neij (1999) and IEA (2000).

Regarding technological learning, there is a clear trend in increasing wind turbine sizes as illustrated in figure 13. This trend is driven by economic concerns and the desire to fit more capacity within the space dedicated to a wind farm (Hansen, 2007). Turbine size seems of importance for both economic and siting barriers to wind energy. As larger turbines tend to be more cost-effective, increased turbines size may help to overcome economic barriers. Also, the larger the turbine, the less siting issues can be expected since wind farms can be smaller and less numerous.

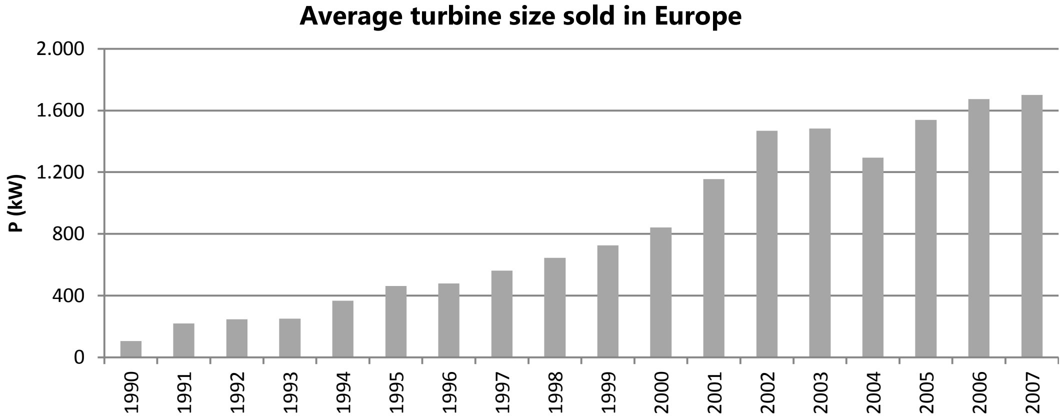


Figure 13 – Average turbine size sold in Europe and capacity factor (Krohn, 2009).

2.5. Hypotheses

The hypotheses can be derived from the analysis of the measures of liberalisation (in section 2.3.3), the descriptions of the elements of regime with regard to adaptive capacity (in section 2.3.4), and the analysis of the niche (section 2.4) . Table 4 summarizes what main effects the liberalisation measures are expected to have on different criterion for each element of the electricity supply industry regime. The fourth column briefly explains the mechanism through which wind energy adoption is affected. Several measures are mentioned more than once since they have an effect on different elements of the regime. The sign of the correlation is however similar for each occurrence of the same measure.

Table 4 – Hypotheses for the effects of liberalisation measures on wind energy shares.

Regime element	Barrier	Reform measure	Mechanisms	Expected correlation
Technology	Risk	Independent regulator	More stable long-term frame-work for investment.	+
	Cost	Privatisation	Shorter ROI periods of private investors favour conventional sources.	–
Infrastructure	Capacity mgmt.	Wholesale market	Issues with predicting power production for allocation.	–
	Connectivity	Total unbundling	Distributed generation not blocked by distributors.	+
Markets	Supply	Third Party Access	Enabling new actors with in-novative technologies.	+
		Unbundling	Prevention of cross-subsidies and blocking newcomers.	+
	Demand	Retail market	Demand for green energy clearly formulated in retail.	+
		Wholesale market	Market power conventional power obstructs wind energy.	–
Networks	Stability	Liberalisation*	Increased diversity, accessibil-ity and international reach.	+
Sectoral policy	Stable support	Independent regulator	Constant market conditions through less political med-dling.	+
Culture/ symbolic	Acceptance	Third Party Access	Initiatives like co-operations distribute costs and benefits	+
Techno-scientific	Incumbents	Privatisation	Private investors focus R&D to short-term profit.	–
	Newcomers	Third Party Access	Newcomers create innovative wind energy concepts.	+

*This hypothesis cannot be related to a specific measure, rather to the whole set.

3. Methodology

> It is impossible not to envy the man who can dismiss reason, although we know how it must turn out at last.
>
> Charles Sanders Peirce (1877)

The research questions can be answered by choosing a sample, operationalizing the theoretical framework, collecting the data and choosing the means for data analysis. The hypotheses are tested with a fixed effects test of liberalisation measures and wind energy shares in 17 European Union countries and Norway and Switzerland. This chapter first discusses the choice of the sample. Then, the operationalization of all variables is explained and the data collection is discussed. Finally, the statistical methods for data exploration and hypothesis testing are considered.

3.1. Sample

The unit of observation is the electricity supply industry regime. As discussed in section 2.1.3, the regime is defined by national borders. So, for the statistical analysis, the units of observation are effectively countries. The sample consists of 17 countries within the European Union (as of 2010) as well as Norway and Switzerland. Of the EU member states, Malta, Cyprus, Slovakia, Slovenia, Bulgaria, Romania, the Baltic States and Luxembourg are left out. The sample is comprised because of data availability issues, late accession dates and unexploited wind energy markets. With yearly observations in a time span ranging from 1990 to 2007 and 19 countries, there are 342 observations per variable.

The markets of Malta, Cyprus, Slovakia and Slovenia are left out since they are "unexploited" as compared to other national European markets who are either emerging, growing or developed (EWEA, 2010). As such, these markets feature many zero's and unstable growth with relatively high jumps in production levels. The shares of wind energy are probably too low to serve for a meaning statistical analysis. Moreover, data for many variables is lacking. The Baltic States are removed from the sample mainly because they are not included in the main source of data on liberalisation (Conway and Nicoletti, 2006). The data could not be derived from other sources since for several indicators (like privatisation) there is no information on how the survey questions were interpreted.

Norway and Switzerland are included in the sample since they feature very European conditions regarding climate, institutions and wealth. Moreover, cooperation is very close between Norway, Switzerland and the European Union when it comes to energy. As such, policies are very alike. Norway, has a leading position in introducing reforms whereas Switzerland is relatively slow. This enriches the sample. A disadvantage of including Norway and Switzerland is that they lack incentives for renewables and emission targets given by the European Union. The sample is therefore tested both with and without Switzerland and Norway.

The availability of data seems to be biased towards larger and more developed countries. At the same time, larger and more developed countries also feature earlier accession dates to the European Union. These biases should be taken into account when interpreting the results. It basically means that outcomes are only representative of developed states within the European Union or with similar energy sectors due to intensive cooperation (Norway and Switzerland).

3.2. Operationalization

This section describes the indicators and operationalization of liberalisation and the transition towards renewable energies. There are seven indicators on liberalisation and three regarding the transition towards renewable electricity generation. Two liberalisation indicators are partially overlapping and cannot be used simultaneously in statistical tests. First, the liberalisation indicators are treated and subsequently the wind energy adoption variables are presented. Furthermore, the control variables are discussed. The operationalization is summarized in table 5.

3.2.1. Independent variable: liberalisation

Liberalisation is captured by the variables unbundling, introduction of a wholesale market, introduction of a retail market, establishing an independent regulator, third party access and change of ownership. The indicators have been chosen based on Jamasb and Pollitt (2005) and with an eye on existent empirical studies (Hattori and Tsutsui, 2004; Nagayama, 2009; Steiner, 2000; Zhang et al., 2008; Copenhagen Economics, 2005). Like for some aforementioned studies, data is derived from Conway and Nicoletti (2006). Much of the operationalization is predefined by this database.

Regarding the choice of measures, there is not much flexibility since the OECD database (Conway and Nicoletti, 2006) is by far the best and most complete source. In comparison with studies like Steiner (2000), this research aims to be more complete by not only using the OECD database (Conway and Nicoletti, 2006) but also information on the introduction of independent regulators (from other sources). Furthermore, by using dummies for variables with more than two scores, the statistical analysis can reveal more information. The following sections describe the operationalization and data sources per indicator.

a. Unbundling

Unbundling is represented by two indicators: one for unbundling of generation and transmission and one for unbundling of the total industry. Unbundling of generation and transmission is represented as either integrated, accounting separated or fully unbundled (Conway and Nicoletti, 2006). Similar to Hattori and Tsutsui (2004), the accounting separation is ignored since it is much closer to full integration than to separation and therefore distorts the indicator representativeness. Unbundling of the total chain is expressed as integrated, mixed or unbundled. It serves as a crude indicator for unbundling effects throughout the chain. There is a dummy for each case. Data is provided by Conway and Nicoletti (2006).

Table 5 – Operationalization of liberalisation, wind energy shares and control variables.

Category		Indicator	Operationalization
Liberalisation		Unbundling transmission	Unbundling of transmission and generation 0/1 = integrated/separate companies
		Unbundling total chain	Degree of unbundling in total chain 0/1 = not integrated/integrated 0/1 = not mixed/mixed 0/1 = not unbundled/unbundled
		Wholesale market	Presence of wholesale trade market 0/1 = no market/market
		Retail market	Presence of retail market 0/1 = not partly opened/partly opened 0/1 = not fully opened/fully opened
		Independent regulator	Presence of independent regulator 0/1 = no regulator/regulator
		Third Party Access	Presence of TPA for transmission 0/1 = no TPA/TPA
		Ownership	Ownership structure of the ESI 0/1 = not public/public 0/1 = not mostly public/mostly public 0/1 = not mixed/mixed 0/1 = not mostly private/private 0/1 = not fully private/fully private
Wind energy		Share in production	Lagged share wind energy in electricity production [%]
		Share in capacity	Lagged share wind energy in electric capacity [%]
Controls	*Landscape*	Wealth	Gross domestic product (GDP) per capita [Current US$/capita]
		Wind resources	Ratio of wind potential and average sector size [-]
		Population density	Amount of people per unit of area [Capita/km^2]
	Regime	Grid access	Grid access lead time [months]
		Electricity use/capita	Electricity consumption per capita [kWh/capita]
		Clusters	Survey score on well-developed, deep clusters [-]
		Administrative barriers	Administrative lead time [months]
		Attitudes	Share population willing to pay more for renewables [%]
	Niche	Turbine size	Avg. turbine size sold in Europe [kW]
		RD&D	Total RD&D over five preceding years [M Euro]
	-	Existence wind	Dummy for wind energy or not 0/1 = no wind energy/wind energy

b. Wholesale market

The existence of a wholesale market is represented by a dummy variable (0 or 1) similar to Steiner (2000) and Hattori and Tsutsui (2004). Unfortunately, it is hard to find and operationalize the actual sizes of the power exchanges. Not all electricity is traded via power exchanges and power exchanges have become increasingly international. This all may have an influence on the degree of competition and the possibly resulting price decreases. It must be assumed that deviations in the actual size of the wholesale market are approximately randomly distributed. Data is provided by Conway and Nicoletti (2006).

c. Retail market

Retail market opening is operationalized as not existent, open to some or all non-household consumers, or fully opened. This is different from Steiner (2000) who uses the consumer threshold and Hattori and Tsutsui (2004) who combine TPA and retail access in one indicator. The opened market share in per cent may be the best indicator of competition (and consumer thresholds a distorted reflection of this). The sources on opened market share are however contradictory and incomplete. Moreover, such values do not explicitly account for the (in this study) essential difference between households and non-households since households as compared to businesses may have a totally different approach to choosing renewable or non-renewable electricity. So, the indicator is split into three dummies indicating the absence of retail access, access of non-households and access for all. Data is provided by Conway and Nicoletti (2006).

d. Independent regulator

Independent regulators are operationalized as either absent (0) or present (1). This offers sufficient distinction to analyse the effect of the credibility and regulatory stability they grant to the industry. The operationalization is similar to Steiner (2000). Zhang et al. (2008) include a binary indicator for regulatory independence in their regulatory indicator but also address the source of income of the regulator. This seems more applicable to their data set (developing and transitional countries) than to the data set of this study since European governments can be assumed to not abuse their power through cutting financing. Data is provided by Grote (2008), OECD (2003) and regulator websites.

e. Third Party Access

Third Party Access is operationalized as either absent (0) or present (1). Steiner (2000) distinguishes different models of TPA. However, the hypotheses in this study do not discriminate between the different forms of TPA. Even if there were clear ideas on differences in virtues of the systems, the data still provides very limited possibilities to draw statistically significant conclusions. This is because initially nearly all the states choose for rTPA and in 2003 the EU even made rTPA the sole option (EC, 2003). Data is provided by Conway and Nicoletti (2006).

f. Ownership

Ownership structure is operationalized as either public, mostly public, mixed, mostly private, or fully private. This quite elaborate distinction is drawn from the Conway and Nicoletti (2006) database. It would be presumptuous to think that privatisation has just an either negative or positive effect. Possibly, there is an optimum between fully public and fully privatized. Therefore, the variable is separated into dummies in order to find out the optimal balance between public and private ownership.

3.2.2. Dependent variable: wind shares

Wind energy adoption is captured by two variables: the share of wind energy in the total electricity production and the share of wind energy in the total installed electric capacity. The variables cover both the aspects of constructing new capacity and using it efficiently for electricity generation. As commonly done, the third variable total production or total capacity is controlled for by calculating shares instead of absolute amounts. There is a one-year lag between the wind energy variables and the liberalisation variables. Data is from Eurostat and the US Energy Information Administration (EIA) (the latter source for total capacities only).

The two dependent variables have complementary strength and weaknesses. The production variable suffers from fluctuating total production levels whereas the capacity variable neglects the effect of varying capacity factors. Total production levels may vary much because of third variables like international trade or economic growth. Capacity factors vary per country and per year mainly due to differences in weather and climate. At the same time, the production variable incorporates the consequences of capacity factors rather well, while the capacity variable suffers much less from fluctuation in total capacities. Together, the variables draw a fairly representative picture of wind energy adoption.

Wind energy adoption is not expected to react immediately to liberalisation. Zhang et al. (2008), focussing on liberalisation and new capacity, do however not use lagged variables. The same holds for Carley (2009) who studies among others deregulation and renewable energy in the ESI. Only Copenhagen Economics (2005) uses one-year lagged variables when comparing liberalisation and price. It may even be possible that only the announcement of certain measures already has an effect; i.e. the chosen operationalization allows effects to precede causes. Steiner (2000) aims to capture this by introducing a variable "time to liberalization". However, Hattori and Tsutsui (2004) find this variable to be representative of time only since it mostly depicts a linear trend.

For capacities however, a lag seems even more urgent than for prices. The use of capacity may increase swiftly under changing policies but installing new capacity generally takes years. Production may therefore change on both the short and long run. As a result, the amount of lag is rather arbitrary and it is uncertain whether all measures really have their most important impact with a delay of one year. Each measure for liberalisation possibly has its own distribution of impacts over the years following its introduction. As a compromise, this study uses a one-year lag. In other words, the liberalisation measures in year t are compared with wind energy shares in year t+1.

3.2.3. Control variables

The control variables are derived from the MLP and related to the three levels. On the landscape level, the control variables are GDP/capita, population density and wind resource potential. For the regime, the control variables concern grid access, electricity use per capita, cluster development, administrative lead times and willingness to pay for renewables. Niche processes are captured by turbine size developments and RD&D spending. Much of the theory behind the control variables has already been presented in section 2.3.4.

Outside the theory of MLP, there is one more control variable: existence of wind energy. This variable is introduced merely because of a statistical technicality. As will be shown in the statistical analysis in section 3.4.1., there are many zeros in the data for wind energy shares. These values may give a false idea of stagnated growth while they actually only illustrate that wind energy adoptions have yet to start. Therefore, a control variable that is 1 for the existence of wind energy and 0 for the absence of wind energy is included.

Landscape

On the macro-level, three control variables are used: GPD/capita, population density and wind resource potential. Carley (2009) shows that wealth in terms of GDP/capita and wind resource potential are of significant influence on renewable energy success in the US. Population density is expected to be relevant with regard to siting issues. The data for the GDP/capita is from Eurostat. For population density, both the Eurostat and World Bank database are incomplete, but for different years and countries. As a solution, population density is the average of the figures of Eurostat and the World Bank. Wind resource potential in terms of possible annual electricity generation by wind energy has been estimated for 2030 by the European Environment Agency (2009).

For wind resource potential, detailed analysis on economically feasible potential is carried out for onshore wind energy only. Therefore, the control variable is limited to the "unrestricted technical potential" of both onshore and offshore wind energy. In other words, the control variable captures the theoretical maximum amount of electricity that can be generated per country using wind energy. The estimates use approximated turbine performances in 2030 but the resulting figures are valid for any year since it is the comparative sizes of country potentials that matter. Since offshore data is only presented as a graph, the used figures are rounded estimations. For onshore data more precise values are used. The total unrestricted technical potential is divided by the sector size of the country. Sector size is calculated as the average amount of electricity produced over the time span 1990-2007. It is average to avoid confusion with sector growth as an explanatory factor in wind energy shares.

Regime

At the regime level, the control variables are grid access lead times, electricity use per capita, cluster development, administrative lead times and willingness to pay for renewables. The control variables are related to the seven dimensions of the regime (Geels, 2002). The control variables for the dimensions of technology (turbine size) and techno-scientific knowledge (RD&D spending) seem more appropriate for the niche level and can thus be found there.

Grid access

Regarding infrastructure, capacity management and connectivity have been mentioned as important factors. Capacity management is not an issue in most sample countries since they feature relatively low shares of wind energy. Connectivity can be expressed as lead times for grid access. The WindBarriers project (EWEA, 2010) published lead times for grid access in most European countries. For some countries, the data is compromised since it is based on an average of a cluster of similar nations. Moreover, the data is from wind energy projects in 2007 and 2008 only. It can however be expected that lead times have not changed radically over time since they are related to slowly changing regulations and procedures.

Electricity use per capita

For markets, it has been mentioned that electricity price and electricity use per capita are of importance. The electricity price is doubtful as a variable since the relationship is two-way: high electricity price may make wind energy competitive, but wind energy may also lead to higher electricity prices. Even with a one-year lag, the variable may only capture the country-specific effect (e.g. high shares lead to both high prices in the same year and high shares in years to come). The causality of high electricity use does make sense: it can be expected that high electricity consumption is relatively hard to cover with renewables since it takes relatively more space, effort and financial resources as compared to country or population size. This variable can therefore be a good predictor of the share of wind energy. Data is from the World Bank.

Cluster development

The World Economic Forum publishes an annual account of global competitiveness including the results of a survey on cluster development and deepness among business leaders from many countries (Schwab and Porter, 2005). There are two issues with the available data that are threats to the validity of causal inferences. First, the data is too recent and thus the variable scores do not precede wind energy innovation. The oldest data is from 2005 which means the data is representative of the last years of the time series only. Second, the data is only available for whole nations without discriminating for sectors. No sector is treated explicitly.

However, it is reasonable to assume that relative cluster spread and deepness has not changed much between countries. Furthermore, since the data is for the whole country, the time-precedence issue seems to matter less: it is far more likely that deep and widespread clusters in a whole country lead to wind energy innovation than that wind energy innovation only can boost clusters in the whole country. Further, it is assumed that countries with good networks in general also feature good networks in the wind energy sector since any technology-specific factor stretches many fields of expertise and sectors (e.g. mechatronics, aerodynamics, mechanics, meteorology).

Sectoral policy

Given the breadth and complexity of sectoral policy, it may be best captured by looking at its direct consequences rather than the policies itself. The delay of wind energy projects in terms of administrative lead times is a clear direct consequence of the barriers posed by sectoral policy. It can be assumed that sectoral policy that leads to large delays, also prevents wind power project from succeeding at all. High administrative barriers and associated long administrative lead times deter wind energy developers or make projects fail in an early phase.

The WindBarriers project (EWEA, 2010) studied administrative lead times of wind energy projects in Europe and provides average administrative lead times per country. The data has limited value since some countries were bundled in the research on the basis of their number of wind parks. Also, wind offshore data is not split per country. It can however be expected that countries with high administrative barriers for onshore wind energy also feature high barriers for offshore wind energy since the involved actors are partly the same.

Willingness to pay

It has been stated before that social acceptance is key in wind energy projects. Attitudes to wind energy are hard to capture, especially as times series for all countries in the sample. The European Union regularly captures public opinion in the Eurobarometer surveys. The most suitable survey was performed in 2005 and surveys among others the willingness to pay more for energy produced from renewable resources (EC, 2006). Time-series data is unfortunately not available.

The data is of limited use for two reasons. First, Norway and Switzerland are not included in the sample. Second, the public opinions may have been influenced by earlier renewable energy developments and current energy prices. Germans for instance, may not be willing to pay much more since they already have high shares of renewable electricity. Furthermore, countries with high energy prices may be less willing to pay even more for renewables. The survey may still be fairly representative however given the large differences in respondent answers between countries.

Niche

The control variables at the niche level are turbine size and RD&D spending. These controls partly refer to two dimensions of the regime: technology and techno-scientific knowledge. However, as already argued in section 2.3.4, they seem most appropriate at the niche-level, since turbine size actually describes the maturity of the niche innovation, while techno-scientific knowledge on wind energy captures the effort within the niche to increase the maturity of the technology.

Turbine size

For technology, the competitive advantage regarding cost, risk, pollution and siting has been mentioned. This advantage is the result of the performance of conventional technologies and wind energy. The competitive advantages of wind energy may be captured by looking at shares of other fuels in the energy mix. This is however problematic since shares add up to 1 and may correlate for that reason only. Also, certain forms of energy have contradictory effects: coal for instance may boost wind energy since it is polluting but also hamper its development since it makes wind energy relatively expensive.

As an alternative, the control variable for technology may focus on technological development or increase of competitiveness of wind energy. Over time, technological development has made wind energy ever more competitive. It can be assumed that conventional technologies have not undergone similar performance increases since they have been existent for a long time. As such, the competitiveness of wind energy could be captured by creating a variables on technological development in wind turbines.

Turbine size accounts for increasing economic performance through scale advantages of larger turbines. Additionally, turbine size may explain non-linear growth of wind energy production.[6] The control variable gives the average turbine size sold in the year the related electricity from wind was produced. Data for typical wind turbine size is based on the average turbine size installed in Europe per year (Krohn, 2009). Due to a lack of data, the value for 2008 is calculated by averaging the turbine sizes installed in Denmark and Germany (DEI, 2012; Molly, 2012).

[6] Wind energy output often grows non-linearly. This may be due to increased technological performance only. When the installed number of turbines is equal every year, output may grow non-linearly because of increased turbine size.

RD&D

A straightforward indicator of techno-scientific knowledge is the country budget for research, development and deployment (RD&D) in wind energy. The International Energy Agency (IEA) has data on this. The effect of RD&D may have a time lag longer than the default lag of 1 year, depending on whether it entails more fundamental or more applied research. Furthermore, only the cumulative effects of several subsequent years of investment may be really felt. Therefore, this variable aggregates the RD&D budget of the last five years. The time lag thus ranges from 6 till 1 years. For some countries, data for some years is lacking. This is generally only the case for lower RD&D budgets of either early years or countries with low (close to zero) investment in general. Therefore, this is not considered a problem.

3.3. Data collection

The dataset for the indicators of liberalisation is mostly derived from the OECD regulations database (Conway and Nicoletti, 2006). Additional data for the establishment of independent regulators is found in literature (Grote, 2008; OECD, 2003) and on regulator websites. Wind energy production and capacity shares are calculated on the basis of data from Eurostat and US the Energy Information Administration (EIA). Control variables are based on various sources including the European Commission (EC), World Bank, Eurostat, World Economic Forum (WEF), European Environmental Agency (EEA), European Wind Energy Association (EWEA), International Energy Agency (IEA), Danish Energy Agency (DEI) and the German Wind Energy Institute (DEWI) (Molly, 2012). Section 3.2.3 on the control variables explains which source pertains to which control variable.

The OECD database (Conway and Nicoletti, 2006) is from the OECD international regulation database. It is based on a survey across 26 OECD countries from 1975 to 2008. The survey questions and answer options are presented in Appendix D. Since most of the data for liberalisation is derived from a single survey, there might be a mono-operation bias. In other words, since the operationalization of the construct uses a single method, this method is part of the construct actually studied (Shadish et al., 2001). This is illustrated by the fact that some indicator scores do not coincide with values reported by other sources. Adjustment for these discrepancies is impossible since the OECD database does not explicitly tell what definitions were used in answering the questions. The main issue that underlies this problem may be that some policy measures are introduced gradually whereas most studies assume a sudden change in their operationalization.

3.4. Statistical analysis

The hypotheses on liberalisation and wind energy adoption are tested by conducting statistical analysis. First, exploratory analysis can reveal *what* has happened regarding liberalisation and wind energy during the concerned time period. Second, the explanatory data analysis can reveal *why* things have happened. The following sections first treat the explanatory analysis and then discusses choosing the best approach for testing the hypotheses. Subsequently, the chosen fixed effects linear model is discussed in detail.

3.4.1. Exploratory analysis

The exploratory analysis of the data set aims to discover the particular characteristics of the data. First, descriptive statistics can clarify the distribution of the data and highlight how wind energy shares and liberalisation have developed over time. Second, principal component analysis aims to discover the relationship between the independent variables, i.e. it aims to discover whether or not certain liberalisation measures followed roughly the same introduction pattern. This may enhance the theoretical understanding of the liberalisation process.

Descriptive statistics

Descriptive statistics can be used to get acquainted with the characteristics of the dataset. They present quantitative descriptions in a manageable form (Babbie, 2007). The characteristics or so-called distribution of the data is appropriately described by the mean, minimum, maximum and standard deviation. The standard deviation is a measure for the spread of values in the dataset. The standard deviation S_N is calculated as in the equation 1 with N being the total number of observations, x_i an observation and $\bar{x}$ the mean (Weisstein, 2012c).

$$S_N = \sqrt{\frac{1}{N} \sum_{i=1}^{N} (x_i - \bar{x})^2} \qquad (1)$$

Skewness provides a measure of the degree of asymmetry of a distribution (Weisstein, 2012b). Skewness gives additional information about the distribution in terms of prevalence of extreme values on either the left side or the right side of the distribution. In a positively skewed distribution, extreme values are found on the right side. In a negatively skewed distribution, extreme values are found on the left side of the distribution. SPSS calculates skewness as the adjusted Fisher-Pearson standardized moment coefficient which includes an adjustment for smaller sample sizes (Doane, 2011). The maths is given by equation 2.

$$G = \frac{N}{(N-1)(N-2)} \sum_{i=1}^{N} \left(\frac{x_i - \bar{x}}{S_N}\right)^3 \qquad (2)$$

Additionally, the number of observations is in itself of interest since it is highly decisive in the significance of later statistical outcomes. A box plot allows visualization of distribution of the data as well as comparison of distributions over time. All these exploratory techniques are mainly interesting for the data on wind energy adoption but not so much for the variables on liberalisation. The following section describes an exploratory technique that grants insight in the liberalisation indicators.

Factor analysis

Factor analysis reveals the interrelatedness of a set of variables by giving a number of factors and their relatedness to the concerned variables. The factors represent a number of liberalisation variables that form a cluster through similar patterns. Such clusters mean in practice that the variables describe phenomenon that occurred in roughly the same way, e.g. two liberalisation measures were introduced at the same time or with the same speed in most countries. When the variables are somehow related, the number of relevant factors will be lower than the number of variables, i.e. if variables are related they are correlated most with a few factors only.

Following Steiner (2000), principal component analysis (PCA) is chosen over other methods. The input for the PCA is all the data for the different measures of liberalisation. The analysis returns a number of factors and a weight for each combination of factor and variable. The weights indicate to what degree a variable coincides with a factor. From these results it can be observed whether certain measures were introduced as packages or if they were introduced more separately. The variables that have their highest weight with the same factor, are closely related.

Component extraction in SPSS. Analyse – Dimension reduction – Factor.

3.4.2. Choosing the right test

Descriptive statistics and factor analysis provide some insight in what is happening with liberalisation and wind energy. To understand *why* this happens the variables need to be related using statistical tests. Since the data features time series of individual countries, the observations may be auto-correlated. In other words, the wind energy shares of separate countries may be structurally different. A multi-level analysis with the independent variables modelled as fixed effects accounts for this. The following sections first discuss country-specific effects and subsequently address random and fixed effects.

Country-specific effects

A simple F-test can be used to test for country-specific effects (Steiner, 2000). Country-specific effects are structural differences between the wind shares of different countries. The problem of country-specific effects is illustrated in figure 14 by means of example data. The thin regression lines are for five different units of observation, the thick regression line is for the combined data. Due to the structural differences in wind shares of countries, the single regression misrepresents the actual relationship between the variables per country.

Differences in the means of country data are indicative for structural differences between countries. The F-test compares the means of different of wind energy scores per country. In other words, the mean wind energy share of one country is compared with the mean wind energy share of another country. The null-hypothesis of equal means of country wind shares is rejected. As such, the simple linear model should be rejected. The following section discusses the possible causes of country-specific effect and

Example of bias through unit-specific effect in linear regression

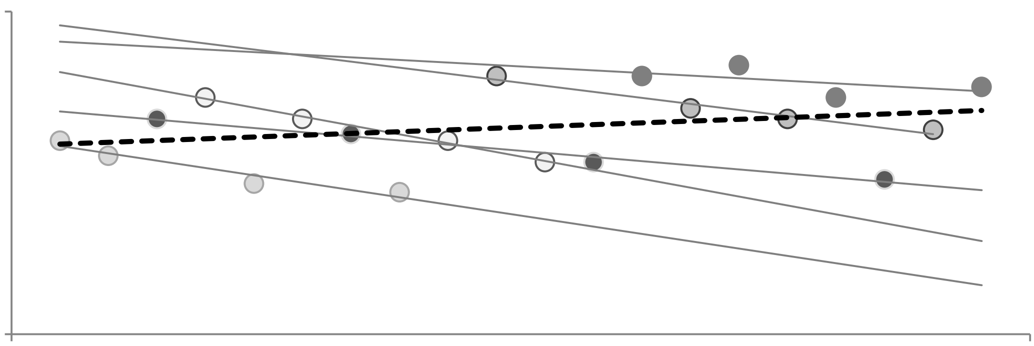


Figure 14 – The possible role of unit-specific effects in linear regression (no real data).

Country-specific effects in SPSS. Compare means – One-way ANOVA.

Random or fixed effects

A second consideration regarding the choice of statistical test is the possible relationship between the specific effects and the independent variables. Figure 15 shows how a relationship between those groups of variables can complicate causality. If there is a correlation, parameter sizes will be biased. There are two possible models. A random effects model assumes that country-specific effects are not correlated with the independent variables. The fixed effects model assumes that country-specific effects are correlated with the independent variables.

For samples that are non-randomly drawn from a population, the fixed effects model can be assumed to be more appropriate (Dougherty, 2007; Steiner, 2000). In similar studies, fixed and random effects tests are very common (e.g. Steiner, 2000; Hattori and Tsutsui, 2004; Copenhagen Economics, 2005; Carly, 2009). In a non-ideal random sample, the unobserved variables could be random characteristics of countries. In the sample of this study however, unobserved variables like nature protection may very well be related to either liberalisation itself or data availability regarding liberalisation. This would lead to confounding variables, which can be avoided by using fixed effects.

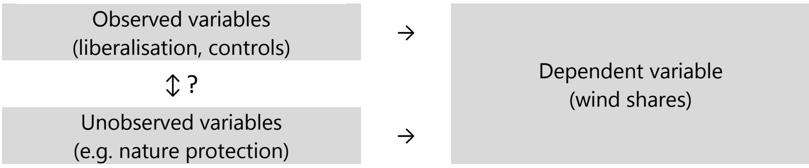


Figure 15 – Unobserved variables may correlate with independent variables.

3.4.3. Fixed effects model

The fixed effects (FE) model is appropriate for testing the hypotheses. The mixed model option in SPSS allows models with fixed and random effects to be tested. The following sections explain the math drawing on Albright and Marinova (2011) and Escobar (2011). Equation 1 is a simple model that captures wind energy shares y_{it} of countries i in year t based on their country mean levels A_i and the normally distributed error term e_{it}. The term A_i can be split into the average outcome α_m and the country-specific outcome α_i. The resulting equation 3 consists of a fixed effect α_m and a random effects $\alpha_i + e_{it}$.

$$\left.\begin{aligned} y_{it} &= A_i + e_{it} && (1) \\ A_i &= \alpha_m + \alpha_i && (2) \end{aligned}\right\} \quad y_{it} = [\alpha_m] + [\alpha_i + e_{it}] \qquad (3)$$

$$r_{ij} \sim N(0, \sigma^2)$$
$$\alpha_i \sim N(0, \tau_{00})$$

Equation 3 does not yet include any variables and parameters yet. First of all, if the country-specific effect can be (partly) described by country-level variables like domestic wind resources, such variables may be included. In equation 4, the country-effect of wind resources RES_i is added in the equation for the intercept A_i and substituted in equation 1. Variables like RES_i are group-level predictors: they have predictive power only for countries as a whole. The single parameter X quantifies the effect of RES_i on y_{it}.

$$y_{it} = [\alpha_m + X(RES_i)] + [\alpha_i + e_{it}] \qquad (4)$$

The fixed effect parameter X will explain some of the variance in y_{it} and therefore decreases the value of the random effect α_i in equation 4 as compared to its value in equation 3. So, instead of assuming that country-specific effects are randomly distributed over the cases, they are explicitly related to independent variables like domestic wind resources. This distinguishes the fixed effects model specification from the random effects model. In the random effects model, the variation of the intercept A_i (the specific effect) would be assumed random instead of correlated with RES_i.

Besides the country-level effects, also within-country effects may be included. The within-country variance can be assigned to time-variant variables like Gross Domestic Product (GDP). Such variables are individual level predictors, i.e. they predict on the level of individual observations for a single country at a single point in time. The effect of GDP within a certain country i is measured by parameter Y_i. The parameters Y_i can be split into β_m and β_i to allow for a distinction between the average effect and the country-specific effect. Equation 7 combines country-level and within-country effects.

$$y_{it} = [\alpha_m + X(RES_i) + Y_i(GDP_{ij})] + [\alpha_i + e_{it}] \quad (5)$$

$$Y_i = \beta_m + \beta_i \quad (6)$$

$$y_{it} = [\alpha_m + X(RES_i) + (\beta_m + \beta_i)(GDP_{ij})] + [\alpha_i + e_{it}] \quad (7)$$

Again, just like for the intercept A_i, it is not assumed that the estimates for Z_i are randomly distributed across countries. Therefore, the term Z_i must not only be explained by the average effect β_m and the random effect β_i, but also by variables like RES_i. In equation 8, the variable RES_i is added to equation 7. Subsequently, equation 9 is the rewritten version of equation 8 by ordering the fixed and random effects. The error term is now a three-fold term that correlates with the independent variable.

$$y_{it} = [\alpha_m + X(RES_i) + (\beta_m + Z(RES_i) + \beta_i)(GDP_{ij})] + [\alpha_i + e_{it}] \quad (8)$$

$$y_{it} = [\alpha_m + X(RES_i) + \beta_m(GDP_{ij}) + Z(RES_i)(GDP_{ij})] + [\alpha_i + \beta_i(GDP_{ij}) + e_{it}] \quad (9)$$

Equation 9 shows what kind of model is used by SPSS. Naturally, the other variables are included in the same way as RES_i (when time-invariant) or GDP_{ij} (when time-variant). The parameter estimates for X and β_m are of core interest. Furthermore, the grand mean α_m is given by SPSS. The random effects terms describe the unexplained variance. However, due to the multi-level nature of mixed models, there is no standard approach for finding the explained variance (e.g. Edwards et al., 2008).

The mixed model function of SPSS allows the user to first distinguish the grouping (or subject) variable. In this study, the countries are the subject variables. Subsequently, the explanatory variables can be added as fixed effects to the model. All ordinal variables are split into dummies. Only main effects are considered, since the data set is too small to feature sufficient observations with combined effects. At t-test shows the significance of the parameters estimates.

Fixed effects in SPSS. Analyse – Mixed Model – Linear.

4. Results

> Now I know why there are so many people who love chopping wood. In this activity one immediately sees the results.
>
> Albert Einstein
> (Seelig, 1956)

This chapter presents the results of the data-analyses and reflects on them. First, there are exploratory statistics that provide a general understanding of liberalisation and wind energy adoption. Subsequently, the explanatory statistics explicate the effects of single liberalisation measures on wind energy shares. Finally, the discussion of the results includes the evaluation of the hypotheses, reflection on the use of the MLP and recommendations for future research.

4.1. Descriptive statistics

Descriptive statistics provide first insight in the dataset on liberalisation and wind energy shares. First, key descriptive indicators are given. They are frequency, mean, standard deviation and skewness. Second, the progress in electricity reform is visualized through time. Third, principal component analysis is used to find cluster of liberalisation measures. The current state of implementation for the clusters is plotted. For wind energy, a plot of capacity and production shares as well as a box plot for production offer understanding of the data.

4.1.1. Key descriptive indicators

Table 6 gives the key descriptive indicators. The frequency column shows that the different scores for all indicators of liberalisation but privatisation are moderately well spread. This provides sufficient opportunities to find statistically significant relationships. The skewness of the indicators shows that most indicators, except for the independent regulator and third party access, are right-tailed, i.e. there are relatively few high values. This means that the sample features more instances of weak liberalisation than of strong liberalisation.

As a result of the moderately even spread of indicator scores, the means of binary indicators vary around 0,5. For shares of wind energy, the mean is 1,16, i.e. the average share of wind energy in the sample for the years 1990-2007 is 1,16 per cent. The standard deviations do not give much additional information for the indicators of liberalisation since the limited number of scores lead to easy to understand distributions. For wind energy, the relatively low standard deviation shows that values are concentrated around the mean.

For wind shares, roughly 16 per cent of the values are exactly zero. This may have an undesirable effect on estimator sizes in further analyses; zeros can give a false ideas of stagnated growth whereas they in fact represent the absence of an wind energy industry. Therefore, a variable controlling for the existence of wind energy is introduced (see also section 3.2.3). Skewness testing shows that wind shares are relatively often low. This coincides with the high number of zero's and may point to exponential growth.

Table 6 – Descriptive statistics: frequency, mean, standard deviation and skewness.

Indicator	Frequency	Mean	St. dev.	Skewness
Wind share	378	1,16	2,77	3,92
0 %	59			
0 – 18,92 %	318			
18,92 %	1			
Wholesale market	378	0,37	0,48	0,55
No market	*239*			
Market	*139*			
Unbundling Total	378	0,70	0,71	0,52
Integrated	*170*			
Mixed	*153*			
Unbundled	*55*			
Unbundling TSO	378	0,45	0,50	0,20
Integrated	*208*			
Unbundled	*170*			
Retail market	378	0,81	0,84	0,38
No market	*176*			
Business only	*99*			
All	*103*			
Independent regulator	378	0,53	0,50	-0,13
No regulator	*177*			
Regulator	*201*			
Third Party Access	378	0,56	0,50	-0,25
No TPA	*166*			
TPA	*212*			
Privatisation	378	1,12	1,20	0,94
Public	*146*			
Mostly public	*119*			
Mixed	*56*			
Mostly private	*34*			
Private	*23*			

4.1.2. Electricity reform

Electricity reform can be analysed statically or dynamically. This section starts with the dynamic analysis by visualizing the historical implementation of the liberalisation measures. Figure 16 displays the number of sample countries that have taken certain measures during the period 1990 – 2007. The interval between the first directive (1996) and the second directive (2003) shows a "wave" of reforms. The relationship between the measures is confirmed by the graph. For instance retail markets can only function if other measures like unbundling and TPA have been introduced. Therefore, the introduction of retail markets lags behind whereas TPA is a "frontrunner" from the later nineties onwards. Similarly, most measures are preceded by an independent regulator since the regulator is needed to actually execute the measure and oversee the implementation.

The current state of electricity reform can be retrieved from the data in two steps. First, the current state comprises of the levels of reform and the experience of countries with those levels of reform. Great Britain, for instance, has 20 years of experience with a completely privatized industry whereas Hungary has 12 years of experience with mixed ownership in the industry. The UK thus features a highly reformed industry in terms of levels and experience. Second, since reform measures may be highly correlated they may need to be represented by aggregate indicators to grasp the real state of affairs. Third party access and retail market opening for instance often go together for instance since they are complementary and may thus be represented by a single indicator.

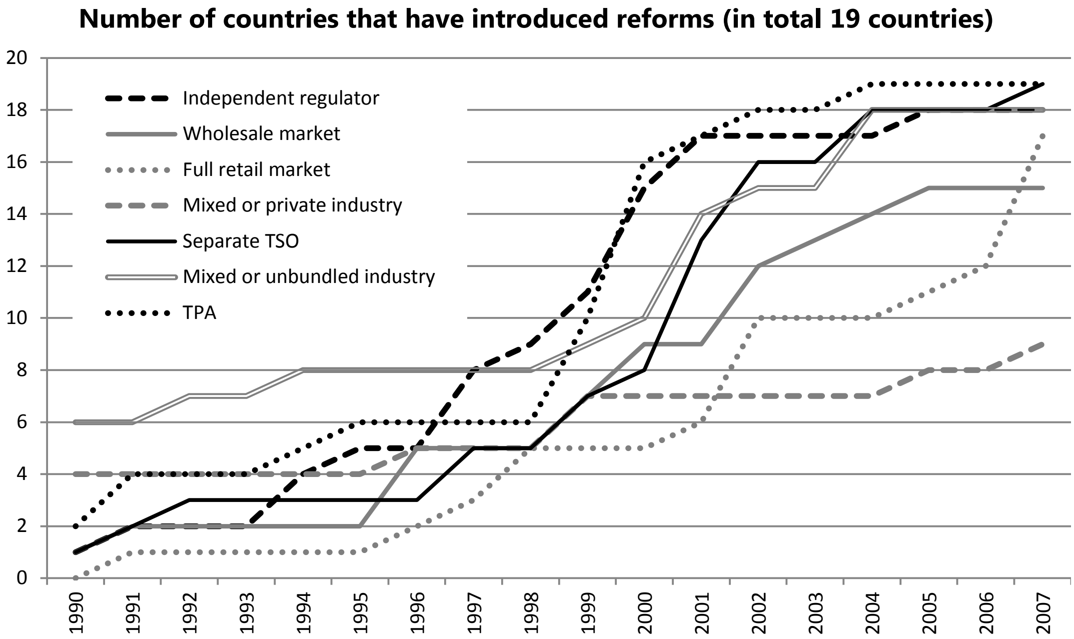


Figure 16 – Measures introduced in sample countries (sources mentioned in section 3.3).

Factor analysis reveals the statistical relationships between the independent variables. Table 7 shows the factor loadings. A factor loading close to 1 indicates that a variables is closely related with that factor. Three factors can be distinguished. The first factor seems to represent mostly elements of competition, the second has to do mostly with access for newcomers (though an element of competition, so the distinction is not perfect) and the third represents the single variable privatisation. The first and second factor can also be summarized as "deregulation" (again, wording is not perfect, merely pragmatic) as opposed to "privatisation" since the values indicate that the first two factors are highly correlated with each other.

Table 7 - Rotated component matrix for the indicators for liberalisation.[7]

Indicator	Competition	Access	Privatisation
Wholesale market	0,870	0,295	0,101
Unbundling Total	0,758	0,340	0,303
Unbundling TSO	0,688	0,613	0,088
Retail market	0,670	0,553	0,244
Independent regulator	0,298	0,895	0,102
Third Party Access	0,463	0,759	0,216
Privatisation	0,182	0,140	0,968

[7] Extraction Method: Principal Component Analysis. Rotation Method: Varimax with Kaiser Normalization. Rotation converged in 5 iterations.

The factor analysis shows that privatisation – as theorized – is very distinct from other liberalisation measures. This justifies graphing the deregulation measures as a function of the degree of privatisation since these labels represent two distinct groups of variables. The most recent state of liberalisation (2007) can thus be represented graphically as in figure 17. The deregulation measures are averages of the years of experience with a certain measure. For measures with different scores, the years of experience with that score have been corrected.[8] Figure 17 shows that most countries fall in the lower left quadrant since they are moderately deregulated and moderately privatized. The UK stands out as having both a very much deregulated and privatized electricity supply industry. Norway is nearly as deregulated as the UK and Germany and Belgium are close to the UK when it comes to privatisation.

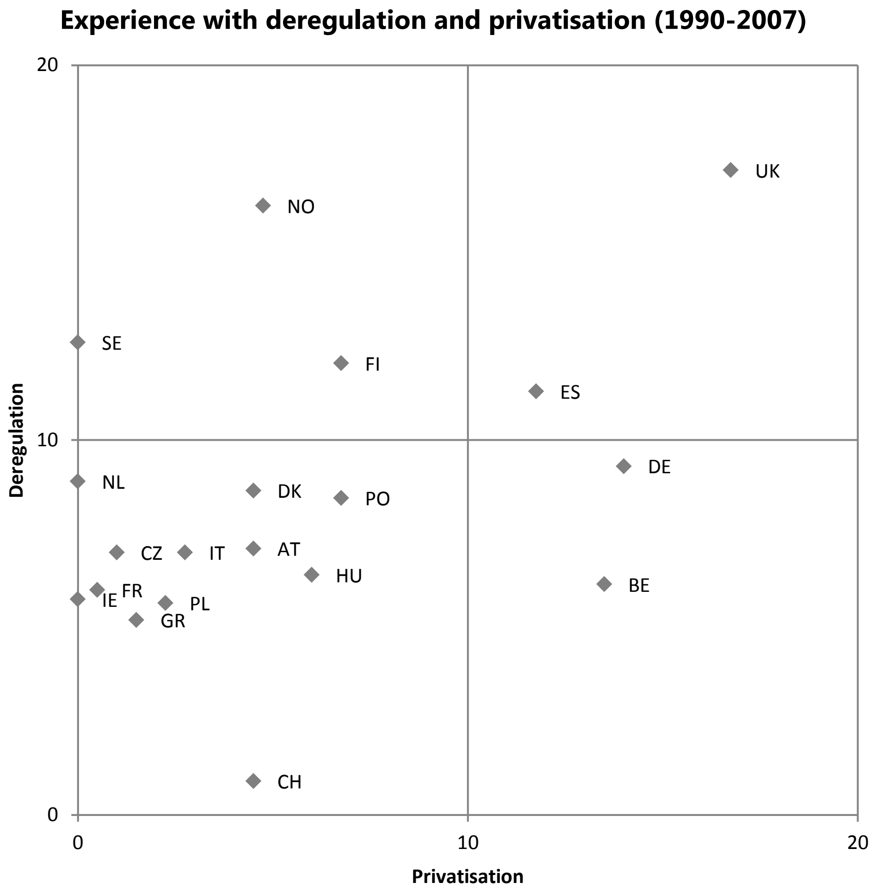


Figure 17 – Deregulation and privatisation in effective years of experience.[9]

[8] The axes represent the average number of years the liberalisation measures or privatisation have been effective from 1990 till 2007. For measures with non-binary scores lower than maximum values are compensated for by multiplying the number of years of experience with the ratio between the concerned score and the maximum score. For instance: maximum privatisation gives score 4 therefore 6 years of mostly private industry (score 3) counts as 6 * (3/4) = 4,5 effective years of experience. The method fails to take into account experience with privatisation or deregulation before 1990. The effect of this is however minimal since only the UK was significantly liberalised by 1990.

[9] AT = Austria, BE = Belgium, CH = Switzerland, CZ = Czech Republic, DE = Germany, DK = Denmark, ES = Spain, FI = Finland, FR = France, GR = Greece, HU = Hungary, IE = Ireland, IT = Italy, NL = Netherlands, NO = Norway, PL = Poland, PO = Portugal, SE = Sweden, UK = United Kingdom.

4.1.3. Wind energy transition

The wind energy transition is captured in terms of wind shares in electricity production and electric capacity. Figure 18 show the wind energy shares in production and capacity, as well as the capacity factor. The capacity factor is calculated by dividing the actual production with the theoretical maximum production.[10] From the graph, it can be seen that the capacity factor is both stabilizing and growing. Also, the fluctuations in the capacity factor show the importance of including both production and capacity as dependent variables in the statistical analysis. Figure 19 shows the boxplot for wind energy production shares over the period 1990-2008. From the plot, it can be observed that shares have risen much over time. Furthermore, a small number of countries seems to be leading.

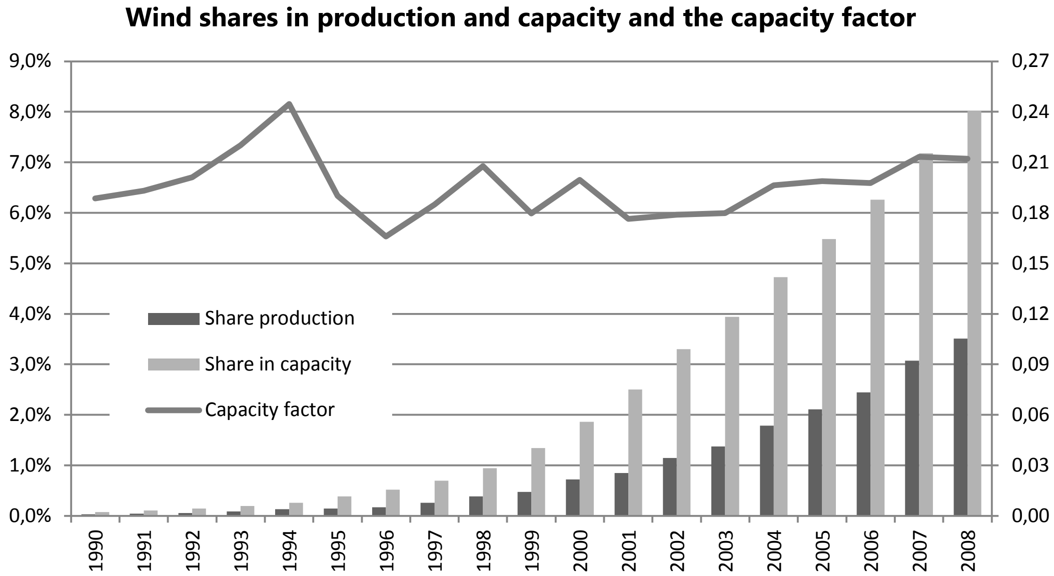


Figure 18 – Wind shares in production and capacity and the capacity factor (Eurostat, EIA).

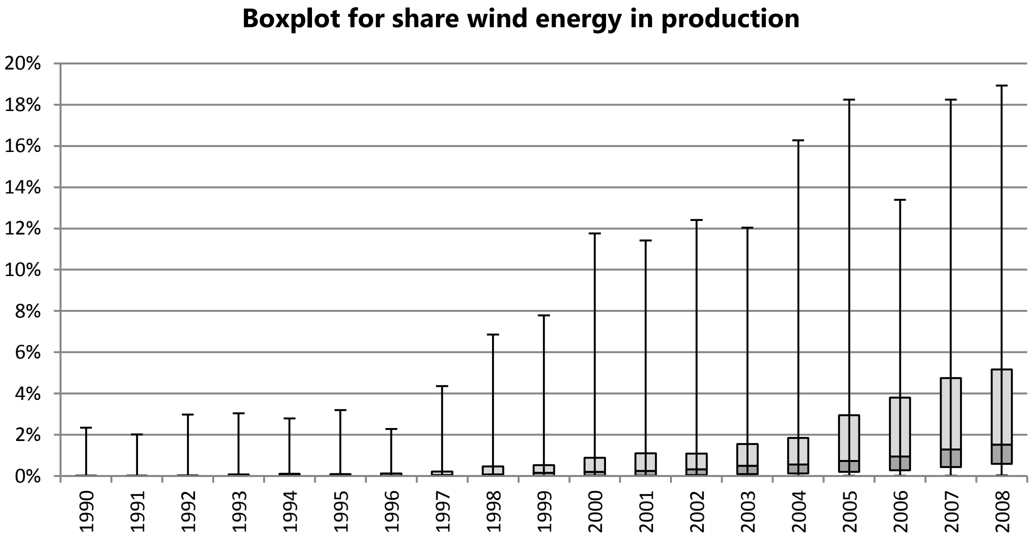


Figure 19 – Boxplot share wind energy in production (Eurostat).

[10] The theoretical maximum production is the capacity multiplied by the number of hours in a year.

4.2. Explanatory statistics

Table 8 gives the results of the fixed effects model test. Each column represents the results of a different test. There is variety regarding the dependent variable, the type of unbundling and the sample countries. The estimator sizes represent the average increase in the share of wind energy under the implementation of this measure. For some variables, like privatisation, the scores are ambivalent: more privatisation is not positively correlated in general, but a privatisation score of 3 is associated with the highest shares of wind energy. Similarly, for the retail market, opening up only seems to boost wind energy if households are included and not only businesses.

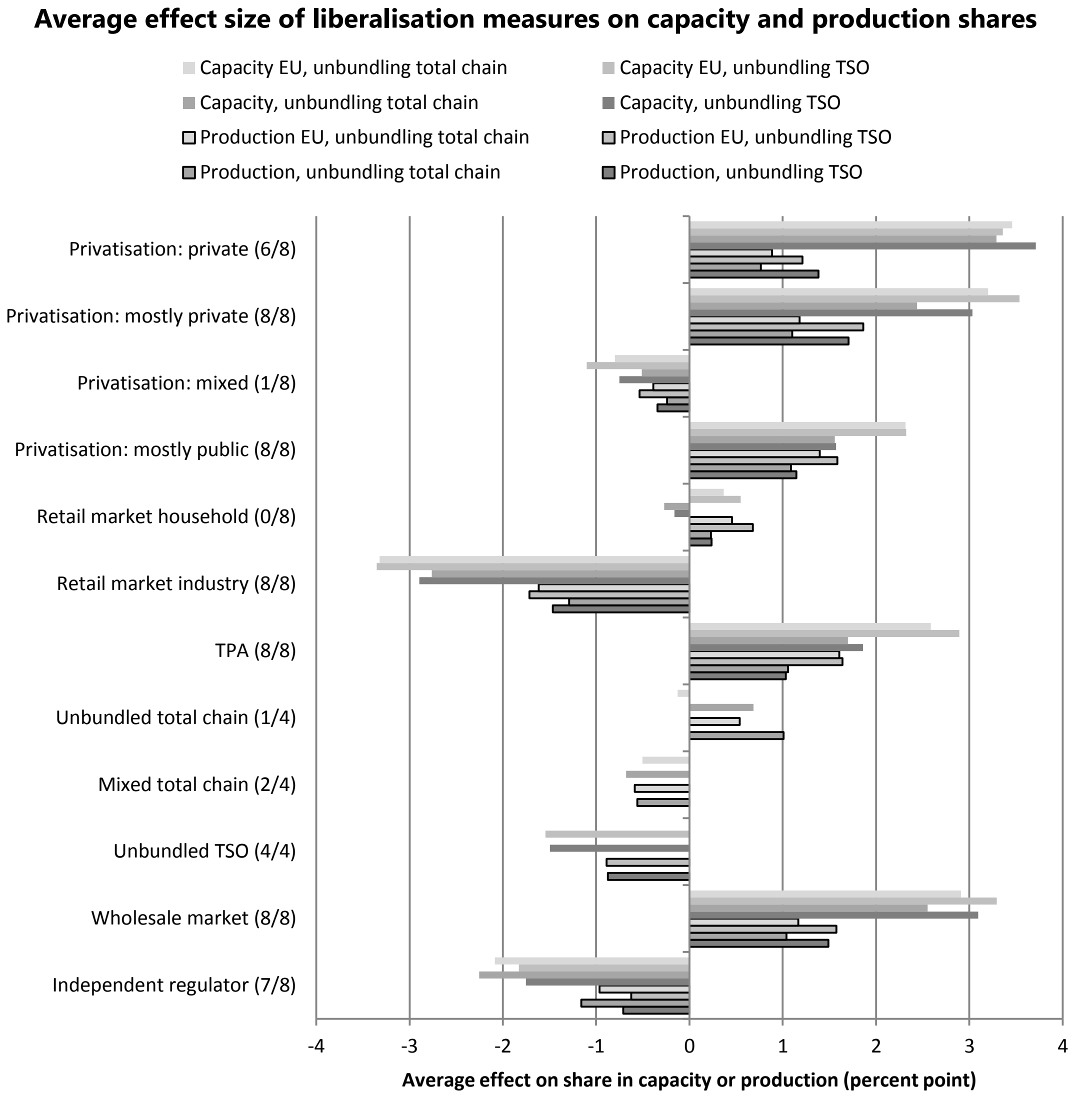
Table 8 – Results of fixed effects test of liberalisation measures and wind energy shares.

	Wind energy production share				**Wind energy electric capacity share**			
	Unbundling TSO	**Unbundling total chain**	**EU, unbundling TSO**	**EU, unbundling total chain**	**Unbundling TSO**	**Unbundling total chain**	**EU, unbundling TSO**	**EU, unbundling total chain**
Independent regulator	-0,709	-1,161	-0,624	-0,965	-1,751	-2,255	-1,830	-2,086
	-1,540*	-2,555***	-1,255	-1,926**	-2,369***	-3,039***	-2,310**	-2,583***
Wholesale market	1,489	1,040	1,576	1,168	3,094	2,553	3,295	2,910
	3,243***	2,336***	3,402***	2,551***	4,192***	3,514***	4,464***	3,944***
Unbundled TSO	-0,876		-0,890		-1,497		-1,543	
	-1,733**		-1,678**		-1,843**		-1,827**	
Mixed total chain		-0,560		-0,588		-0,680		-0,503
		-1,442*		-1,348*		-1,073		-0,716
Unbundled total chain		1,009		0,538		0,685		-0,126
		1,805**		0,885		0,751		-0,129
Third party access	1,033	1,058	1,642	1,607	1,859	1,698	2,894	2,586
	2,008**	2,116**	2,928***	2,906***	2,247**	2,080**	3,238***	2,902***
Retail market industry	-1,463	-1,291	-1,715	-1,615	-2,894	-2,760	-3,352	-3,320
	-2,683***	-2,394***	-3,062***	-2,897***	-3,301***	-3,136***	-3,756***	-3,694***
Retail market household	0,236	0,231	0,680	0,455	-0,160	-0,271	0,549	0,366
	0,371	0,369	0,977	0,657	-0,156	-0,265	0,495	0,328
Privatisation: mostly public	1,146	1,087	1,587	1,396	1,570	1,558	2,322	2,318
	3,698***	3,531***	4,313***	3,656***	3,153***	3,101***	3,961***	3,765***
Privatisation: mixed	-0,342	-0,239	-0,536	-0,386	-0,751	-0,510	-1,100	-0,799
	-0,779	-0,549	-1,176	-0,840	-1,064	-0,719	-1,514*	-1,079
Privatisation: mostly private	1,707	1,100	1,864	1,182	3,034	2,438	3,538	3,202
	3,090***	1,971**	2,952***	1,758**	3,418***	2,675***	3,515***	2,956***
Privatisation: fully private	1,382	0,765	1,212	0,885	3,712	3,292	3,358	3,460
	1,920**	1,042	1,655**	1,179	3,209***	2,747***	2,878***	2,861***
GDP/capita	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000
	1,415*	0,627	1,630*	1,207	0,673	0,216	0,681	0,558
Population density	-0,002	-0,002	-0,002	-0,003	-0,002	-0,002	-0,002	-0,003
	-0,882	-0,979	-1,059	-1,439*	-0,659	-0,795	-0,683	-0,890
Wind resources	0,003	0,000	0,002	0,000	-0,007	-0,009	-0,006	-0,006
	0,387	0,050	0,364	0,000	-0,681	-0,828	-0,550	-0,529
Grid access	-0,026	-0,032	-0,034	-0,042	-0,058	-0,063	-0,069	-0,073
	-2,791***	-3,425***	-2,507***	-3,041***	-3,789***	-4,112***	-3,157***	-3,250***
Electricity use	0,000	0,000	0,000	0,000	0,000	0,000	0,000	0,000
	-1,039	-1,071	-0,287	-0,616	-1,155	-1,258	-0,316	-0,509
Cluster development	-1,535	-1,328	-1,494	-1,394	-1,826	-1,632	-1,683	-1,623
	-4,891***	-4,246***	-4,568***	-4,274***	-3,621***	-3,195***	-3,229***	-3,087***
Administrative barriers	0,022	0,020	0,034	0,029	0,049	0,047	0,068	0,068
	2,184**	2,031**	2,908***	2,506***	2,981***	2,875***	3,692***	3,607***
Willingness to pay			-0,345	0,635			-1,837	-1,594
			-0,240	0,418			-0,800	-0,651
Turbine size	0,001	0,001	0,001	0,001	0,003	0,003	0,002	0,002
	2,770***	2,720***	1,017	1,189	4,194***	4,061***	2,385***	2,163**
RD&D	0,002	-0,002	0,002	-0,002	-0,010	-0,014	-0,010	-0,011
	0,325	-0,325	0,248	-0,303	-0,878	-1,182	-0,822	-0,866
Wind or not	1,133	1,150	1,716	1,645	1,756	1,762	2,848	2,813
	2,255**	2,327***	3,065***	2,934***	2,173**	2,183**	3,193***	3,112***

T-statistic in italics. *p < 0.1, **p < 0.05, ***p < 0.01

Figure 20 visualizes the results of table 8 by graphing the estimator sizes as bars. All eight experiments are plotted. The absence or presence of an outline for the bars represent the distinction between the dependent variables (capacity share or production share). Per type of dependent variable, the four scenarios are indicated by different shades. The effect size for capacities are larger in general since capacity shares are larger than production shares. This is due to the below average capacity factor of wind energy. The names of the liberalisation measures at the vertical axis also mention the number of statistically significant results among the total number of measured effects sizes for that measure. The number of measured effect sizes differs per measure since not all measures were included in all experiments. If the findings are significant across all tests ($p \leq 0.1$) they can be assumed to be solid. Based on this, the following can be concluded.

- Mostly private and mostly public industries have a positive effect on both shares of production and share of capacities. Fully private industries have a positive effect that is significant in most experiments. Mixed industries have a small negative effect that is significant in only one instance.
- Retail market opening for industry has significantly negatively affected wind energy adoption. Full market opening has a positive effect in most tests but none of the tests yields significant outcomes.
- Third party access has a positive and significant effect on wind energy adoption in all eight tests.
- Full unbundling of the total chain yields positively affects wind energy whereas mixed unbundling of the total chain has negative effects. For unbundling of the TSO, only significant negative effects are found.
- Wholesale markets are found to have positive significant effects on wind energy adoption in all tests.
- The independent regulator has a negative effect on wind energy development that is significant in 7 out of 8 tests.
- Of the control variables, grid access, cluster development, administrative barriers, and turbine size have significant effects in all eight tests. The control variable for the existence of wind is also significant. Unexpectedly, cluster development has a negative effect and administrative barriers have a positive effect.



The numbers behind the measures at the vertical axis indicate the occurrence of significant effects among all effects for this measure. For some variables, there are less than 8 effects since they were not included in all tests.

Figure 20 – Average estimated effect of liberalisation measures.

4.3. Discussion

Empirical evidence suggests that liberalisation has a mixed effect on wind energy adoption in the electricity supply industry. In this subchapter, the analyses and the assumptions are reflected upon. The following sections discuss the results of hypothesis testing, possible methodological flaws, the merits of the multi-level perspective, the significance of the results and possible directions for further research.

4.3.1. Evaluation of hypotheses

Generally, liberalisation has a mixed effect on wind energy adoption. There are both measures that have a positive significant effect and measure that have a negative significant effect. Since interactions have not been analysed, the cumulative result of liberalisation cannot be assessed. The following section discusses the hypotheses regarding each measure.

Privatisation

Privatisation was expected to negatively influence wind energy adoption but the statistical outcomes mostly suggest that privatisation has a positive effect. Industries with mixed ownership do however not feature a positive influence on wind energy. The results may not be fully consistent since the number of observations is rather low per category of ownership. Furthermore, the dataset speaks of public or private *industries* whereas in reality *companies* are either more privatized or not. This heterogeneity is lost in the operationalization. Also, privatisation may be restricted to certain stages of the value chain, e.g. only production companies may be privatized in one country whereas only distribution is privatized in other countries.

Independent regulators

Regulators are unexpectedly shown to have a negative effect that is significant in most tests. There are two explanations. First, Johanssen et al. (2004) notes that 8 out of 15 European regulators have the objective of an environmentally friendly electricity supply whereas 11 out of 15 have the objective of economic efficiency and 14 out of 15 strive for more competition. If this means that environmental concerns are ranked much lower than economic efficiency, regulators may disadvantage relatively costly options like wind energy. Second, the positive effect of regulators may already be captured by the other measures. Regulators may play an important role in the proper execution of other liberalisation measures. As such, their net effect may still be positive. Additional insight could be gained by studying the combined effects of regulators and measures like unbundling. The dataset may however be too small to justify such analyses.

Unbundling

Unbundling does not have the clear positive effect that was expected. The unbundling of transmission and generation has significant negative influences. Since wind capacity is not connected to the transmission grid but to the distribution grid, the meaning of this is rather limited. A fully unbundled industry, i.e. including unbundling of distribution and smaller production units, does have a mostly positive effect however. A mixed industry has a negative effect. This may point to the conclusion that unbundling of distribution has a positive effect. Since there is no separate variable for unbundling of distribution, this hypothesis cannot be tested however.

Wholesale markets

Wholesale markets were expected to negatively influence wind power but in fact have a significantly positive influence. This may have to do with cross-border transport since wholesale markets are often international and thus allow excess wind energy to be traded to other countries. Germany is a good example of this. In literature, this finding is confirmed by Bird et al. (2005) who argue that in the United States, sufficiently flexible and fluid markets that do not penalize intermittent production can help to facility wind energy adoption. The European wholesale markets perhaps meet these criteria.

Retail markets

Retail market opening was expected to have a positive effect on wind energy shares. Supplier choice for industry has a negative effect whereas full retail market opening has mostly a modest positive effect. This suggests that in a fully opened market, household supplier choice compensates for the negative effect of industry supplier choice. It could thus be true that consumers boost wind energy but that this effect is offset by industry choosing for less costly conventional sources of electricity. However, since the results on full retail market opening are not significant, it is not possible to draw clear conclusions on this measure.

Third party access

Third party access is found to have the expected positive effect. The results are significant for all the tests. TPA may thus indeed positively influence wind energy shares through access for new and innovative actors. It supports the claims by Meyer (2007) and McLaren Loring (2007) who argue that local initiatives are generally more successful than projects undertaken by incumbent utilities.

Control variables

Many of the control variables yield the expected effects on wind energy adoption. Contrary to the expectations, cluster development has a negative effect and administrative barriers a positive effect. Both variables are time-invariant and therefore of limited reliability. The assumption that countries with well-developed clusters also feature well developed clusters for wind energy was perhaps unjust. For administrative barriers, the assumption that large administrative lead times deter developers or correlate with failed projects could also be incorrect.

4.3.2. Multi-level perspective

The multi-level perspective has, overall, been proven useful as an inspiration for setting up empirical experiments and establishing hypotheses. Moreover, the use of the MLP for quantitative analysis of liberalisation and wind energy adoption may provide lessons further analyses of technological transitions. The following section first relates some choices in the use of the MLP in this study to critiques on the MLP found in literature. Subsequently, the tension between the complexity of the MLP as a narrative tool and the simplicity of statistical analysis is discussed.

Agency, operationalization and niche emphasis

The MLP has been criticized as focussing too much on structure and not enough on agency (Smith, 2005; Genus, 2008). Geels (2011) points out that agency *is* given a role but may indeed lack in certain forms. It is among others proposed to incorporate findings from business studies and strategic management to further develop the role of agency. As an answer to that, this study integrates the theory of clusters in the dimension of networks. In general however, the demand for more agency is hard to meet in statistical empirical work. Since aggregation and averaging is an integral part of data collection, agency is by definition filtered out. This is legitimate since the larger sample size (as compared to a case study) allows neglecting certain specific events. As such, MLP is in its basic form perhaps more suited for studies with a larger N than single cases.

Among others Genus (2008) calls for better operationalization and delineation of the regime. Geels (2011) responds that MLP is an analytical tool that may be operationalized for different scopes such as a primary fuel or the complete electricity system. The operationalization and delineation used in this study may however be applied more generally. Especially for network industries, general guidelines on how to operationalize the levels seem possible. The use of the notion of competition to draw the line between niche and regime may be a useful addition to the MLP. It is applicable in network industries since the presence of a connection with an infrastructure is the main criterion for the presence of competition. More generally, this study has shown that the MLP can operationalized such that existent data can be used to quantitatively describe the transition.

Berkhout et al. (2004) note that niche processes as drivers for regime change are overemphasised in comparison to drivers at the landscape level. Geels (2007) proposes transition pathways that combine both landscape and niche pressures to avoid the bottom-up bias. Dahle (2007) identifies similar pathways. However, in this study, both types of pressures are explicitly dealt with using the concept of "adaptive capacity" (Smith et al., 2005): the landscape changes the susceptibility of the regime to change whereas niches changes the regime through offers innovative products. This approach may be more flexible and attractive than the highly stylized and therefore restrictive transition pathways. Archetype pathways are hard to match with reality and may lead to the creation of many hybrid pathways. Therefore, the notion of adaptive capacity seems more suitable as an analytical tool that incorporates landscape pressures and niche developments. Moreover, it can be easily related to other theory on for instance markets as shown in this study.

Ontology versus methodology

Geels (2011) identifies a tension in social sciences between ontology and methodology based on the work by Hall (2003) and Abell (2004). Geels (2011) characterizes the MLP as a process-oriented theory with an ontology that outstrips the simplicity of variance theory (statistical analysis of variables) and violates the assumptions of regression techniques. He claims that the MLP "should not be reduced to a mechanical procedure by forcing it into a variance theory straightjacket" and that "research of complex phenomena such as transitions cannot be reduced to the application of methodological procedures".

This study combines elements of the MLP with variance theory. It captures a technological transition through the lens of the MLP and by means of statistical analysis. In other words, this research studies the relationship between two variables by correlational analysis *and* explication of the mechanism between those variables with the use of the MLP. There are several reasons to do so. First, the approach is actually supported by other statements of Geels (2002; 2011) claiming that the MLP is mainly a heuristic and not an ontological tool. As such, it can be a search method for setting up a panel data analysis.

Furthermore, the contention that the MLP outstrips statistical analysis in complexity, seems exaggerated. There is not so much a problem of analytical tools but rather a data availability problem. Whereas the MLP case studies do not require standardized data, statistical analysis requires large standardized data sets. Besides, even without large numbers of variables, random assignment or appropriate statistical tests that control for instance specific effects can yield valuable results. Instead of simplifying or violating the theory of the MLP, such experiments can validate and strengthen the outcomes of case studies.

4.3.3. Future research

Future research may focus on three aspects. First, this study focuses on wind energy whereas many other renewables like solar and biomass may be just as important in relating environmental performance of the ESI with liberalisation. Wind energy was chosen since it features exemplary characteristics (it covers most issues that are typical to renewables), relative straightforward applications and good data availability. For solar and biomass, off grid applications and combined heat and power complicate research. As such, the operationalization of the MLP would need to be different and data collection will be a challenge of its own. Second, this study is too abstract to result in concrete policy suggestions regarding liberalisation and wind energy. It would be interesting to deepen the understanding of the nexus between liberalisation, renewable energy development and sectoral policy and thus provide outcomes that are more useful to policy makers. Lastly, the MLP has been operationalized and used for statistical analysis for a rather specific case. Further research could apply the same approach to a wealth of technological transitions in for instance transport, energy and communication.

5. Conclusion

> “...no matter how many instances of white swans we may have observed, this does not justify the conclusion that all swans are white.

Sir Karl R. Popper (1959)

This study relates liberalisation to wind energy adoption by means of statistical analysis of 19 European countries based on the multi-level perspective (MLP) for technological transitions. Liberalisation was conceptualized as a landscape pressure altering the ability of the electricity supply industry regime to adopt wind energy technology offered by the niche level. This process was stylized into a causal diagram that served as the basis for a fixed effects panel data analysis.

In comparison to similar panel data analyses, this study uses a more elaborate operationalization of liberalisation and focuses on the yet unexplored topic of renewable energy development. Furthermore, it innovatively uses the MLP for setting up a statistical analysis instead of performing cases studies. As such, this work can be a step forwards in the development of the theoretical understanding of technological transitions.

Liberalisation was analysed as two separate processes: privatisation and regulation. The exploratory analysis confirmed this distinction. Not all hypotheses were confirmed. Privatisation had a mostly positive effect on wind energy shares, just like third party access and wholesale markets. Independent regulators, retail markets for industry and unbundling have mostly negative effects. For retail markets including households, results were not significant.

The explanatory power may be compromised since the sample was rather small and features very diverse countries. Furthermore, most data on liberalisation is somewhat crude and suffers from mono-method bias. The MLP proved to be an inspiration and a guiding concept for understanding the causality of technology adoption and setting up the statistical analysis. Also, the MLP theory provided insight for formulating the hypotheses and choosing control variables.

This study may provide some references points for designing renewable energy policy in liberalised electricity markets. Future research may focus on other renewables like solar and biomass, the nexus between liberalisation, renewable energy development and sectoral policy, or the application of MLP and statistical analysis to other technological transitions. Either for public policy or for scientific research, this study can hopefully be a guideline and inspiration.

Bibliography

1. Abell, P. (2004). Narrative explanation: an alternative to variable-centered explanation?. *Annual Review of Sociology*, 287-310.
2. Albright, J., & Marinova, D. M. (2010). Estimating multilevel models using SPSS, Stata, SAS, and R. Information Technology Services, Indiana University (http://www. indiana. edu/~ statmath/stat/all/hlm/).
3. Amable, B. (2011). Morals and politics in the ideology of neo-liberalism. *Socio-Economic Review*, *9*(1), 3-30.
4. Arentsen, M. J., & Künneke, R. W. (1996). Economic organization and liberalization of the electricity industry: in search of conceptualization. *Energy Policy*, *24*(6), 541-552.
5. Babbie, E. R. (2007). *The practice of social research*. Wadsworth Publishing Company.
6. Barnett, C. (2009). Publics and markets: what's wrong with neoliberalism?. *Smith, S. Pain, R., Marston, S., Jones Iii, JP (Eds.). The Sage Handbook of Social Geography. London, Uk: Sage*, 269-296.
7. Belloc, F., & Nicita, A. (2011). The political determinants of liberalization: do ideological cleavages still matter?. *International Review of Economics*, *58*(2), 121-145.
8. Belloc, F., & Nicita, A. (2012). Neo-liberalism, Partisanship, and Public Policies. *Society*, 1-7.
9. Berkhout, F., Smith, A., & Stirling, A. (2004). Socio-technological regimes and transition contexts. *System innovation and the transition to sustainability: theory, evidence and policy. Edward Elgar, Cheltenham*, 48-75.
10. Bier, C. (1999). Network access in the deregulated European electricity market: negotiated third-party access vs. single buyer. CSLE Discussion Paper.
11. Bird, L., Wüstenhagen, R., & Aabakken, J. (2002). A review of international green power markets: recent experience, trends, and market drivers. *Renewable and Sustainable Energy Reviews*, *6*(6), 513-536.
12. Bird, L., Bolinger, M., Gagliano, T., Wiser, R., Brown, M., & Parsons, B. (2005). Policies and market factors driving wind power development in the United States. *Energy Policy*, *33*(11), 1397-1407.
13. Boisseleau, F. (2004, January 26). *The role of power exchanges for the creation of a single European electricity market: market design and market regulation* (p. 416). Delft, South Holland, The Netherlands: Delft University Press.
14. Borenstein, S., & Bushnell, J. (1999). An empirical analysis of the potential for market power in California's electricity industry. *The Journal of Industrial Economics*, *47*(3), 285-323.
15. Bortolotti, B., Siniscalco, D., & Fantini, M. (2000). Privatisation and institutions: a cross country analysis. (375).
16. Bortolotti, B., & Pinotti, P. (2003). The political economy of privatization. (45.2003).
17. Bower, J. (2002). Seeking the Single European Electricity Market. *Oxford Institute for Energy Studies, Oxford.-VIII*.
18. Boycko, M., Shleifer, A., & Vishny, R. W. (1996). A theory of privatisation. *The Economic Journal*, 309-319.
19. Brennan, D., & Melanie, J. (1998). Market power in the Australian power market. *Energy Economics*, *20*(2), 121-133.
20. Brown, M. A. (2001). Market failures and barriers as a basis for clean energy policies. *Energy policy*, *29*(14), 1197-1207.
21. Carley, S. (2009). State renewable energy electricity policies: An empirical evaluation of effectiveness. *Energy Policy*, *37*(8), 3071-3081.
22. Gómez-Acebo & Pombo Abogados, S.L., Charles Russell LLP (2005). Unbundling of electricity and gas transmission and distribution system operators.
23. Clarke, S. (2005). The neoliberal theory of society. *Neoliberalism: A critical reader*, 50-59.
24. Convery, F. J., & Redmond, L. (2007). Market and price developments in the European Union emissions trading scheme. *Review of Environmental Economics and Policy*, *1*(1), 88-111.
25. Conway, P. and G. Nicoletti (2006), "Product Market Regulation in non-manufacturing sectors in OECD countries: measurement and highlights", OECD Economics Department Working Paper No.530. [Database available from: http://www.oecd.org/eco/reform/indicatorsofregulationinenergytransportandcommunications etcr.htm]

26. Copenhagen Economics. (2005). Market opening in network industries: Part II sectoral analyses. *Copenhagen Economics for DG Internal Market*.
27. Dahle, K. (2007). When do transformative initiatives really transform? A typology of different paths for transition to a sustainable society. *Futures*, *39*(5), 487-504.
28. Davids, C. A. (2007). Innovations in Windmill Technology in Europe, c. 1500–1800; The State of Research and Future. In: Directions of Inquiry,' NEHA-Jaarboek voor Economische, Bedrijfs- en Techniekgeschiedenis 66 (2003): 43–57.
29. Defeuilley, C. (2009). Retail competition in electricity markets. *Energy Policy*, *37*(2), 377-386.
30. Da Vinci, L. (1970). *The notebooks of Leonardo da Vinci* (Vol. 1). Edited by Jean-Pual Richter). Courier Dover Publications.
31. Delmas, M., Russo, M. V., & Montes-Sancho, M. J. (2007). Deregulation and environmental differentiation in the electric utility industry. *Strategic Management Journal*, *28*(2), 189-209.
32. DEI (2012). Master data for wind turbines as at end of December. URL: http://www.ens.dk/en-US/Info/FactsAndFigures/Energy_statistics_and_indicators/OverviewOfTheEnergySector/RegisterOfWindTurbines/Sider/Forside.aspx
33. Dougherty, C. (2007). *An Introduction to Econometrics*. Oxford University Press, USA.
34. Drillisch, J., & Riechmann, C. (1998, December). *Liberalisation of the Electricity Supply Industry-Evaluation of Reform Policies*. Energiewirtschaftliches Inst.
35. Economides, N., & Himmelberg, C. (1995). Critical mass and network evolution in telecommunications. *Toward a competitive telecommunications industry: Selected papers from the 1994 Telecommunications Policy Research Conference*. University of Maryland, College Park, MD.
36. Economides, N. (1996). The economics of networks. *International journal of industrial organization*, *14*(6), 673-699.
37. Edwards, L. J., Muller, K. E., Wolfinger, R. D., Qaqish, B. F., & Schabenberger, O. (2008). An R2 statistic for fixed effects in the linear mixed model. Statistics in medicine, 27(29), 6137-6157.
38. EEA (2009). Europe's onshore and offshore wind energy potential - An assessment of environmental and economic constraints.
39. Escobar, M. R. (2011). Mixed effects modelling using SPSS. http://mixedreviews.files.wordpress.com/2011/08/mixed-effects-modeling-using-spss.doc.
40. Eurelectric (2009). Statistics and prospects for the European electricity sector 37th edition eurprog 2009.
41. European Commission (1987). Single European Act. *Official Journal of the European Communities,* L 169 of 29.6.1987.
42. European Commission (1988) The internal energy market. Commission working document. COM (88) 238 final, 2 May 1988. [EU Commission - COM Document]
43. European Commission (1996). Directive 96/92/EC of the European Parliament and of the Council of 19 December 1996 concerning common rules for the internal market in electricity. *Official Journal of the European Union, L*, *27*, 20-29.
44. European Commission (2003). Directive 2003/54/EC of the European Parliament and of the Council of 26 June 2003 concerning common rules for the internal market in electricity and repealing Directive 96/92/EC. *Official Journal of the European Union*, *46*.
45. European Commission (2006). Attitudes towards energy. Special Eurobarometer 247 / Wave 64.2 - TNS Opinion & Social.
46. European Commission (2008). Energy sources, production costs and performance of technologies for power generation, heating and transport. *Commission Staff Working Document accompanying the Second Strategic Energy Review, An EU Energy Security and Solidarity Action Plan. SEC (2008)*, *2872*.
47. European Commission (2009). Directive 2009/72/EC of the European Parliament and of the Council of 13 July 2009-concerning common rules for the internal market in electricity and repealing Directive 2003/54/EC. *Official Journal of the European Union*, *14*.
48. EWEA. (2010). WindBarriers. Administrative and grid access barriers to wind power. July 2010.
49. Feigenbaum, H. B., & Henig, J. R. (1994). The political underpinnings of privatization. *World Politics*, *46*(2), 185-208.Feigenbaum, H., Henig, J. R., & Hamnett, C. (1998, November 13). *Shrinking the state: The political underpinnings of privatization*. CAMBRIDGE-PRINT ON.
50. Finger, M., Groenwegen, J., & Künneke, R. (2005). Quest for Coherence between Institutions and Technologies in Infrastructures, The. *J. Network Ind.*, *6*, 227.
51. Finger, M., & Künneke, R. W. (2011, November 1). *International handbook of network industries: The liberalization of infrastructure* (M. Finger & R. W. Künneke). Edward Elgar Publishing.

52. Fleming, P., & Probert, S. (1984). The evolution of wind-turbines: An historical review. *Applied energy*, *18*(3), 163-177.
53. Foxon, T. J. (2011). A coevolutionary framework for analysing a transition to a sustainable low carbon economy. *Ecological Economics*, *70*(12), 2258-2267.
54. Friedman, M. with the assistance of Rose Friedman. 1962. *Capitalism and freedom*.
55. Geels, F. W. (2002). Technological transitions as evolutionary reconfiguration processes: a multi-level perspective and a case-study. *Research policy*, *31*(8), 1257-1274.
56. Geels, F. W. (2004). From sectoral systems of innovation to socio-technical systems: Insights about dynamics and change from sociology and institutional theory. *Research policy*, *33*(6), 897-920.
57. Geels, F. W. (2005). *Technological transitions and system innovations: a co-evolutionary and socio-technical analysis*. Edward Elgar Publishing.
58. Geels, F. W., & Schot, J. (2007). Typology of sociotechnical transition pathways. *Research policy*, *36*(3), 399-417.
59. Genus, A., & Coles, A. (2008). Rethinking the multi-level perspective of technological transitions. *Research Policy*, *37*(9), 1436-1445.
60. Geels, F. W. (2011). The multi-level perspective on sustainability transitions: Responses to seven criticisms. *Environmental innovation and societal transitions*, *1*(1), 24-40.
61. Geels, F., & Verhees, B. (2011). Cultural legitimacy and framing struggles in innovation journeys: a cultural-performative perspective and a case study of Dutch nuclear energy (1945–1986). *Technological Forecasting and Social Change*, *78*(6), 910-930.
62. Green, R. J., & Newbery, D. M. (1992). Competition in the British electricity spot market. *Journal of political economy*, 929-953.
63. Grote, D. (2008). Can an 'independent' regulator be effective in a hostile environment? Presentation for the ESRC Centre for Competition Policy (CCP). 11-06-2008. URL: www.uea.ac.uk/polopoly_fs/1.106475!grote.ppt .
64. Hall, P. A. (2003). Aligning ontology and methodology in comparative research. *Comparative historical analysis in the social sciences*, *374*.
65. Hansen, A. D., & Hansen, L. H. (2007). Wind turbine concept market penetration over 10 years (1995–2004). *Wind energy*, *10*(1), 81-97.
66. Hattori, T., & Tsutsui, M. (2004). Economic impact of regulatory reforms in the electricity supply industry: a panel data analysis for OECD countries. *Energy Policy*, *32*(6), 823-832.
67. Hughes, T. P. (1993, March 1). *Networks of power: electrification in Western society, 1880-1930*. Johns Hopkins University Press.
68. IEA (2000). Experience Curves for Energy Technology Policy. International Energy Agency, Paris, France.
69. IEC (2011). Electrical Energy Storage White Paper.
70. Jaag, C., & Trinkner, U. (2011). A General Framework for Regulation and Liberalization in Network Industries. In: International Handbook of Network Industries. Finger, M. and Künneke, R. (eds), 2011, pp. 26-53.
71. Jacobsson, S., & Johnson, A. (2000). The diffusion of renewable energy technology: an analytical framework and key issues for research. *Energy policy*, *28*(9), 625-640.
72. Jacobsson, S., & Bergek, A. (2004). Transforming the energy sector: the evolution of technological systems in renewable energy technology. *Industrial and corporate change*, *13*(5), 815-849.
73. Jamasb, T., & Pollitt, M. G. (2005). Electricity market reform in the European Union: review of progress towards liberalisation and integration.
74. Jamasb, T. (2006). Between the state and market: Electricity sector reform in developing countries. *Utilities Policy*, *14*(1), 14-30.
75. Jamasb, T., & Pollitt, M. (2008). Liberalisation and R&D in network industries: The case of the electricity industry. *Research Policy*, *37*(6), 995-1008.
76. Jobert, A., Laborgne, P., & Mimler, S. (2007). Local acceptance of wind energy: Factors of success identified in French and German case studies. *Energy policy*, *35*(5), 2751-2760.
77. Sander Johansen, K., Holm Pedersen, L., & Moll Sørensen, E. (2004). Independent regulatory authorities-a comparative study of European energy regulators.
78. Junginger, M., Faaij, A., & Turkenburg, W. C. (2005). Global experience curves for wind farms. *Energy policy*, *33*(2), 133-150.

79. Katz, M. L., & Shapiro, C. (1985). Network externalities, competition, and compatibility. *The American economic review*, *75*(3), 424-440.
80. Kemp, R. (1994). Technology and the transition to environmental sustainability: the problem of technological regime shifts. *Futures*, *26*(10), 1023-1046.
81. Kern, F., & Smith, A. (2008). Restructuring energy systems for sustainability? Energy transition policy in the Netherlands. *Energy Policy*, *36*(11), 4093-4103.
82. Klessmann, C., Nabe, C., & Burges, K. (2008). Pros and cons of exposing renewables to electricity market risks—A comparison of the market integration approaches in Germany, Spain, and the UK. *Energy Policy*, *36*(10), 3646-3661.
83. Krohn, S., Morthorst, P. E., & Awerbuch, S. (2009, March). *The economics of wind energy*. European Wind Energy Association.
84. Künneke, R. W. (1999). Electricity networks: how 'natural'is the monopoly?. *Utilities Policy*, *8*(2), 99-108.
85. Künneke, R., & Fens, T. (2007). Ownership unbundling in electricity distribution: The case of The Netherlands. *Energy Policy*, *35*(3), 1920-1930.
86. Künneke, R. W. (2008). Institutional reform and technological practice: the case of electricity. *Industrial and corporate change*, *17*(2), 233-265.
87. Larner, W. (2000). Neo-liberalism: Policy, ideology, governmentality. *Studies in political economy*, *63*.
88. Larsen, A., Pedersen, L. H., Sørensen, E. M., & Olsen, O. J. (2006). Independent regulatory authorities in European electricity markets. *Energy policy*, *34*(17), 2858-2870.
89. McLaren Loring, J. (2007). Wind energy planning in England, Wales and Denmark: Factors influencing project success. *Energy policy*, *35*(4), 2648-2660.
90. Megginson, W. L., & Netter, J. M. (2001). From state to market: A survey of empirical studies on privatization. *Journal of economic literature*, *39*(2), 321-389.
91. Meyer, N. I. (2007). Learning from wind energy policy in the EU: lessons from Denmark, Sweden and Spain. *European Environment*, *17*(5), 347-362.
92. Milstein, I., & Tishler, A. (2011). Intermittently renewable energy, optimal capacity mix and prices in a deregulated electricity market. *Energy Policy*, *39*(7), 3922-3927.
93. Molly, J. P. (2012). Status der Windenergienutzung in Deutschland - Stand 31.12.2011. DEWI GmbH. Presentation.
94. Munari, F. (2002). The effects of privatization on corporate R&D units: evidence from Italy and France. *R&D Management*, *32*(3), 223-232.
95. Munksgaard, J., & Morthorst, P. E. (2008). Wind power in the Danish liberalised power market—Policy measures, price impact and investor incentives. *Energy Policy*, *36*(10), 3940-3947.
96. Nagayama, H. (2007). Effects of regulatory reforms in the electricity supply industry on electricity prices in developing countries. *Energy Policy*, *35*(6), 3440-3462.
97. Neij, L. (1999). Cost dynamics of wind power. *Energy*, *24*(5), 375-389.
98. Neuhoff, K. (2005). Large-scale deployment of renewables for electricity generation. *Oxford Review of Economic Policy*, *21*(1), 88-110.
99. Ocaña, C., & Romero, A. (1998). A simulation of the Spanish electricity pool. *CNSE, Madrid, juin*.
100. OECD (2003). Stability pact - South East Europe compact for reform, investment, integrity and growth. Independent regulators in the South-East European countries.
101. Ornetzeder, M., & Rohracher, H. (2013). Of solar collectors, wind power, and car sharing: Comparing and understanding successful cases of grassroots innovations. *Global Environmental Change*.
102. Palley, T. I. (2005). *From Keynesianism to neoliberalism: Shifting paradigms in economics*. Pluto Press.
103. Peirce, C. S. (1877). The fixation of belief. Popular Science Monthly 12 (November 1877), 1-15. From: http://bocc.ubi.pt/pag/peirce-charles-fixation-belief.html
104. Pitlik, H. (2007). A race to liberalization? Diffusion of economic policy reform among OECD-economies. *Public Choice*, *132*(1-2), 159-178.
105. Popper, K. R. (1959). The logic of scientific discovery. London: Hutchinson, 1.
106. Porter, M. E. (2000). Location, competition, and economic development: Local clusters in a global economy. *Economic development quarterly*, *14*(1), 15-34.
107. Potrafke, N. (2010). The growth of public health expenditures in OECD countries: do government ideology and electoral motives matter?. *Journal of Health Economics*, *29*(6), 797-810.

108. Ramesohl, S., Kristof, K., Fischedick, M., Thomas, S., & Irrek, W. (2002). Die technische Entwicklung auf den Strom-und Gasmärkten. Eine Kurzanalyse der Rolle und Entwicklungsperspektiven neuer dezentraler Energietechnologien und der Wechselwirkungen zwischen technischem Fortschritt und den Akteursstrukturen in den Strom-und Gasmärkten. Brief expert opinion for the Monopolkommission. *Wuppertal Institute for Climate, Environment and Energy*.
109. Rip, A., & Kemp, R. (1998). *Technological Change. In: Rayner S., Malone EL (editors).* (pp. 327-399). Battelle Press.
110. Schmitt, S., & Rammerstorfer, M. (2010). Ownership unbundling, investments and consumer prices–A panel data analysis.
111. Schot, J. (1998). The usefulness of evolutionary models for explaining innovation. The case of the Netherlands in the nineteenth century. *History and Technology, an International Journal*, *14*(3), 173-200.
112. Schwab, K., & Porter, M. E. (2005). Global Competitiveness Report: 2004–2005. *Growth*.
113. Seelig, C. (1956). Albert Einstein: A documentary biography. Staples Press.
114. Shackley, S., & Green, K. (2007). A conceptual framework for exploring transitions to decarbonised energy systems in the United Kingdom. *Energy*, *32*(3), 221-236.
115. Shadish, W. R., Cook, T. D., & Campbell, D. T. (2002). Experimental and quasi-experimental designs for generalized causal inference. *2*.
116. Smil, V. (2007). Energy. In: Berkshire Encyclopedia of World History, 646-654.
117. Smith, A., Stirling, A., & Berkhout, F. (2005). The governance of sustainable socio-technical transitions. *Research policy*, *34*(10), 1491-1510.
118. Sovacool, B. K. (2009). The intermittency of wind, solar, and renewable electricity generators: Technical barrier or rhetorical excuse?. *Utilities Policy*, *17*(3), 288-296.
119. Spiller, P. T. (2011). Basic economic principles of infrastructure liberalization: a transaction cost perspective. In: International Handbook of Network Industries. Finger, M. and Künneke, R. (eds), 2011, pp. 11-25.
120. Steiner, F. (2000). Regulation, industry structure, and performance in the electricity supply industry. *Available at SSRN 223648*.
121. Strbac, G. (2008). Demand side management: Benefits and challenges. *Energy Policy*, *36*(12), 4419-4426.
122. Thorsen, D. E. (2009). The Neoliberal Challenge. *Oslo University*.
123. Verbong, G., & Geels, F. (2007). The ongoing energy transition: lessons from a socio-technical, multi-level analysis of the Dutch electricity system (1960–2004). *Energy Policy*, *35*(2), 1025-1037.
124. Verbong, G. P., & Geels, F. W. (2010). Exploring sustainability transitions in the electricity sector with socio-technical pathways. *Technological Forecasting and Social Change*, *77*(8), 1214-1221.
125. Vickers, J., & Yarrow, G. (1991). Economic perspectives on privatization. *The Journal of Economic Perspectives*, *5*(2), 111-132.
126. Weisstein, Eric W. (2012a). "Parametric Test." From *MathWorld*--A Wolfram Web Resource. http://mathworld.wolfram.com/ParametricTest.html
127. Weisstein, Eric W. (2012b) "Skewness." From *MathWorld*--A Wolfram Web Resource. http://mathworld.wolfram.com/Skewness.html
128. Weisstein, Eric W. (2012c). "Standard Deviation." From *MathWorld*--A Wolfram Web Resource. http://mathworld.wolfram.com/StandardDeviation.html
129. Wüstenhagen, R., Wolsink, M., & Bürer, M. J. (2007). Social acceptance of renewable energy innovation: An introduction to the concept. *Energy policy*, *35*(5), 2683-2691.
130. Yuan, J., Xu, Y., & Hu, Z. (2012). Delivering power system transition in China. *Energy Policy*.
131. Zhang, Y., Parker, D., & Kirkpatrick, C. (2008). Electricity sector reform in developing countries: an econometric assessment of the effects of privatization, competition and regulation. *Journal of Regulatory Economics*, *33*(2), 159-178.

Appendices

Appendix A – Empirical evidence in several studies on liberalisation

Study	Scope	Independent variable	Dependent variable	Effect/significance (p = 0.05)
Steiner (2000)	Electricity sector in 19 OECD countries from 1986 till 1996.	Unbundling G/T	Utilization rate Industry price RMD	+ (sign.) – – (sign.)
		Privatisation	Utilization rate Industry price RMD	+ + (sign.) –
		TPA	Utilization rate Industry price RMD	– – +
		Wholesale	Industry price	– (sign.)
		Time to Lib.	Industry price	+ (sign.)
		Time to Priv.	Industry price	+
Hattori and Tsutsui (2004)*	Electricity sector in 19 OECD countries from 1987 till 1999.	Unbundling TSO	Price Price ratio	+ (sign.) –
		Privatisation	Price Price ratio	– (sign.) –
		TPA/Retail	Price Price ratio	– (sign.) – (sign.)
		Wholesale	Price Price ratio	+ (sign.) –
Copenhagen Economics (2005)	Electricity sector in EU-15 Members from 1993 till 2003.	Free choice	Price Utilization rate	– 0
		Unbundling TSO	Price Utilization rate	– (sign.) +
		TPA-transmission	Price Utilization rate	+ (sign.) –
		Ownership	Price Utilization rate	– +
		Wholesale	Price Utilization rate	+ +
		Congestion mgmt.	Price Utilization rate	+ +
Zhang et al. (2008)**	Electricity sector in 36 developing and transition countries from 1985 till 2003.	Regulation	Generation/cap Capacity/cap Labour productivity Utilization rate	– – – +
		Competition	Generation/cap Capacity/cap Labour productivity Utilization rate	– – – +
		Privatisation	Generation/cap Capacity/cap Labour productivity Utilization rate	– + (sign.) + (sign.) +
Schmitt and Rammerstorfer (2010)***	Electricity sector in 16 European OECD countries from 1995 till 2007.	Unbundling TSO	Investment Price	+ (sign.) / NA –
		Overall unbundling	Investment Price	NA / – (sign.) +
		TPA	Investment Price	+ / + +
		Wholesale	Investment Price	+ / – +
		Threshold	Investment Price	– / – –
		Public ownership	Investment Price	+ / + – (sign.)

*Based on a fixed effects test excluding time to privatisation and time to liberalisation.
**Based on a simple model without combined effects.
***Basic model. Fixed effect with TSO unbundling/fixed effects with total unbundling.

Appendix B – Conversion routes for common electricity generation technologies

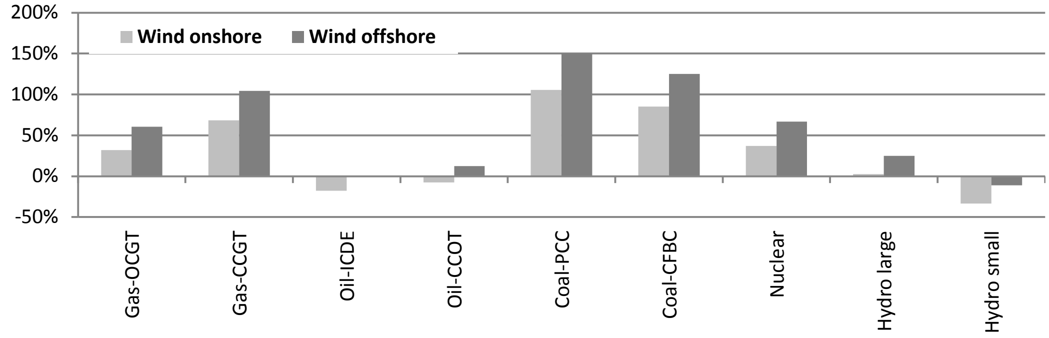
Summary of electricity production technologies starting with common energy source hydrogen (own analysis based on multiple non-scientific sources).

Technology	*Product*	*Conversion*	*Product*	*Conversion*	*Product*	*Conversion*	*Product*	*Conversion*	*Product*	*Conversion*	*Product*	*Conversion*	*Product*	*Conversion*	*Product*	*Conversion*	*Product*	*Conversion*	*Product*
Gas - OCGT	Hydrogen	Fusion	Solar radiation	Photo-synthesis	Organic	Anaerobic digestion	Gas	→	→	→	→	Burning	Exhaust flow	Turbine	Rotation	Generator	→	→	AC
Gas - CCGT	Hydrogen	Fusion	Solar radiation	Photo-synthesis	Organic	Anaerobic digestion	Gas	→	→	→	→	Burning	Exhaust flow	Turbine	Rotation	Generator	→	→	AC
											↙ ↓	←	←	↓ ↙					
											Exhaust flow	Heating	Steam flow	Turbine	Rotation	Generator	→	→	AC
Oil - ICDE	Hydrogen	Fusion	Solar radiation	Photo-synthesis	Organic	Anaerobic digestion	Oil	→	→	→	→	Burning	Exhaust flow	Piston en-gine	Rotation	Generator	→	→	AC
Oil - CCOT	Hydrogen	Fusion	Solar radiation	Photo-synthesis	Organic	Anaerobic digestion	Oil	→	→	Burning	Exhaust flow	Heating	Exhaust flow	Turbine	Rotation	Generator	→	→	AC
Coal - PCC	Hydrogen	Fusion	Solar radiation	Photo-synthesis	Organic	Anaerobic digestion	Coal	Pulverize	Pulver	Burning	Exhaust flow	Heating	Exhaust flow	Turbine	Rotation	Generator	→	→	AC
Coal - CFBC	Hydrogen	Fusion	Solar radiation	Photo-synthesis	Organic	Anaerobic digestion	Coal	Fluidize**	Mixture	Burning	Exhaust flow	Heating	Exhaust flow	Turbine	Rotation	Generator	→	→	AC
Nuclear	Hydrogen	Explosion*	→	→	→	→	U-238/235	Enrich	U-238/235	Fission	Radiation	Heating	Steam flow	Turbine	Rotation	Generator	→	→	AC
Hydro	Hydrogen	Fusion	Solar radiation	→	→	→	→	→	→	→	→	Heating	Water flow	Turbine	Rotation	Generator	→	→	AC
Wind	Hydrogen	Fusion	Solar radiation	→	→	→	→	→	→	→	→	Heating	Air flow	Turbine	Rotation	Generator	→	→	AC
Solar PV	Hydrogen	Fusion	Solar radiation	→	→	→	→	→	→	→	→	→	→	→	→	Photo-voltaic	DC	Converter	AC

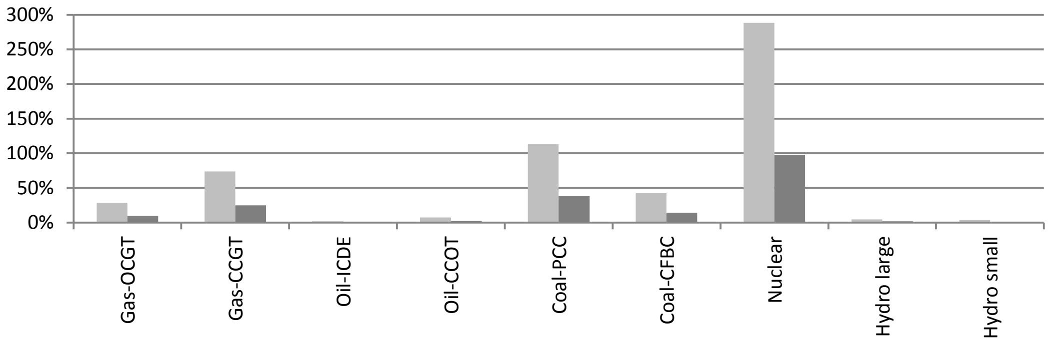
*In supernova's. **The CFBC uses air flow to circulate a suspension of coal and bed material through the furnace for higher efficiency.
Note: dotted lines indicate borders of electricity generation plants.

Appendix C – Comparative performance of wind energy

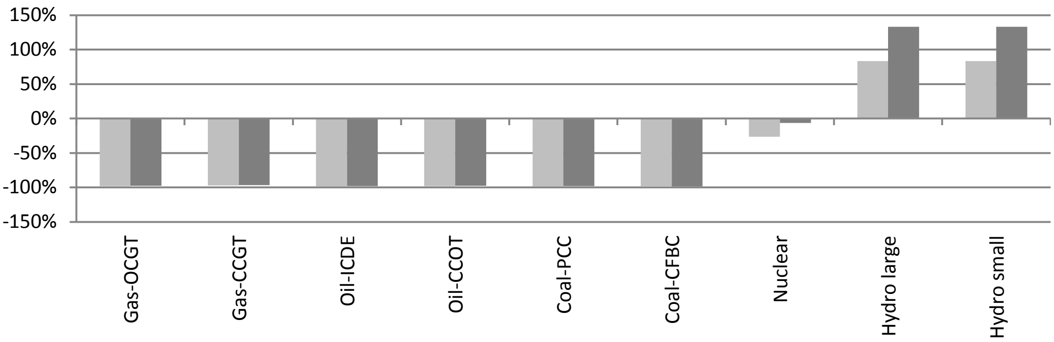
Economic competitiveness: wind versus conventional
Additional production cost per unit of electricity (%)



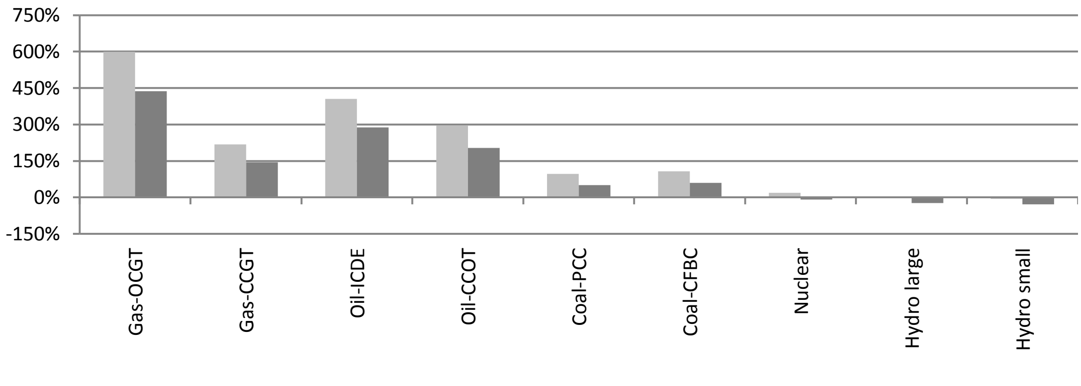
Siting problems: wind versus conventional
Additional problems per unit of electricity (thousands %)



Environmental pollution: wind versus conventional
Additional CO2 eq. per unit of electricity (%)



Investment risk: wind versus conventional
Additional risk (%)



Appendix D – Survey questions and answer options

Questions of the OECD survey on electricity regulation (Conway and Nicoletti, 2006).

Question	Answer options					
How are the terms and conditions of third party access (TPA) to the electricity transmission grid determined?	Regulated TPA		Negotiated TPA		No TPA	
Is there a liberalised wholesale market for electricity (a wholesale pool)?	Yes			No		
What is the minimum consumption threshold that consumers must exceed in order to be able to choose their electricity supplier ?	No threshold	<250 gigawatts	250-500 gigawatts	500-1.000 gigawatts	> 1.000 gigawatts	No consumer choice
What is the ownership structure of the largest companies in the generation, transmission, distribution, and supply segments of the electricity industry?	Private	Mostly Private	Mixed	Mostly Public	Public	
What is the degree of vertical separation between the transmission and generation segments of the electricity industry?	Separate Companies		Accounting separation		Integrated	
What is the overall degree of vertical integration in the electricity industry?	Unbundled		Mixed		Integrated	