Innovation in the energy sector

Working Paper no 31

Author: Klaus Friesenbichler (WIFO)

July 2013

EUROPEAN COMMISSION
European Research Area
SEVENTH FRAMEWORK PROGRAMME
Funded under Socio-economic Sciences & Humanities

Author: Klaus Friesenbichler (WIFO)

Contributions by: Elisabeth Neppl, Kathrin Hranyai, Anna Strauss (WIFO)

Reviewed by: Thomas Bruckner (Universität Leipzig), Ina Meyer (WIFO)

Innovation in the energy sector

Work Package 302

MS50 "Research paper on innovation in the energy sector"

Working Paper no 31

WWWFOR EUROPE
WELFAREWEALTHWORK

EUROPEAN COMMISSION
European Research Area
SEVENTH FRAMEWORK PROGRAMME
Funded under Socio-economic Sciences & Humanities

THEME SSH.2011.1.2-1

Socio-economic Sciences and Humanities Europe
moving towards a new path of economic growth
and social development - Collaborative project

Innovation in the energy sector

Klaus Friesenbichler (WIFO)

Contribution to the project as a whole

This contribution discusses the policy-induced diffusion dynamics of environmental innovations. We use wind and solar power as examples of a new technology base of the electricity sector. This directly links to the renewable energy targets of “Europe 2020”; we reveal unforeseen and unintended systemic mechanisms that the interventions caused.

We discuss aspects of a socio-ecological growth path. While the ‘ecological’ component is considered by the technology field, the social element is incorporated by the two guiding questions of this research. What are the social dynamics that are relevant to the adoption of renewable energy? What are the socio-economic effects - in particular on ownership structures and the cost incidence - of selected implementation models.

Keywords: Cost incidence, diffusion, ecological innovation, economic strategy, electricity, European economic policy, industrial innovation, industrial policy, innovation, innovation policy, institutional reforms, multi-level governance, new technologies, ownership, policy options, renewable energy, security of supply, smart meter, social construction of technology, social innovation, sustainable growth, technology promotion

Jel codes: O31, O33, P48, Q48, Q58

Contents

Tables

Figures

Acknowledgements

This research has benefitted greatly from comments and expert opinions by Thomas Bruckner, Ina Meyer, Gustav Resch, Stefan Schleicher, Gerhard Zauner, Gerhard Untiedt, Andreas Reinstaller, Werner Hölzl, the participants of the workshop of Research Area III of the WWW for Europe project in Mannheim in March 2013 and the participants of the IEWT 2013 conference in Vienna in February 2013.

Disclaimer

This research does not incorporate any gender topics which were found not to be directly applicable. The usual disclaimers apply.

Abstract

This study analyses the diffusion of renewable energy (RE) technologies. It analyses the transition dynamics as the sector broadens its energy mix and changes its capital stock. This shift is found to be desirable from an environmental, geopolitical and economic perspective. Yet, it greatly increases the technical and industrial complexity, and is not Pareto-efficient. We focus on wind and solar power, and discuss their promoted deployment against the energy policy principles of the EU. Put drastically, the promotion of 'sustainability' undermined 'competitive' mechanisms. This has potentially adverse effects on the 'security of supply' due to the market design that seeks to keep prices low. RE outperforms conventional facilities. Emergency capacities, however, are also exiting, especially in Germany. If markets are seen as one, there seems to be a threshold of wind and solar power that the current back-up system can incorporate without risking the security of supply. The policy relevant crux lies in conflicting mechanisms: the top-down promotion and planning policies undermine the bottom-up market selection. Then again, without interventions the market does not provide the socially desired outcomes. If tensions aggravate further, the implementation of the new technology base is likely to stall. In addition, the generous promotion resulted in the fast deployment of RE, which may have shortened the 'formative phase' of the diffusion process. A longer formative phase would have created more learning effects and fostered more incremental innovations. In addition, costs of subsidies are allocated differently across countries. Mechanisms that allocate costs to the public budget have greater acceptance rates than budget neutral ones that assign costs to consumers. The latter affect households asymmetrically across income classes. Also ownership structures changed; a large number of actors now constitute the energy sector. Citizens increasingly appeared as producers and investors, which stimulated the social acceptance of RE, and in some cases unlocked initially unfavourable vested interests.

Executive Summary

The market selection process under-supplies socially desired renewable energy (RE) technologies. Hence policy makers intervene and promote the diffusion of existing technologies. This study analyses the market dynamics that technology policy in the energy supply sector caused. The sector is undergoing a fundamental change as it incorporates an increasing proportion of RE and changes its capital stock. This shift is desirable from an environmental, geopolitical and economic perspective. The supply structures are changing from few large-scale plants to a multitude of distributed, RE producers of various scales. The grid greatly gained complexity, and the pattern in which production followed consumption is partly being reversed.

We focus on wind and solar power as prominent examples of RE. We found that in countries where policies successfully induced their rapid diffusion, they interfered with the EU's energy policy principles. Put drastically, the promotion of 'sustainability' undermined 'competitive' mechanisms, which potentially has adverse effects on the 'security of supply'. This is due to the merit order, which ranks energy sources by their marginal costs. This market design is socially desired, since it keeps prices low. Emerging wind and solar power outperform conventional technologies whose marginal costs are greater than zero. I.e. the market selection mechanism does not provide a level playing field, and adds to the competitive pressures of the liberalisation that established suppliers face. In extreme cases, conventional power plants are forced to exit the market, which is a desired outcome in the case of 'dirty technologies. Yet, conventional power facilities such as gas or storage plants are still required to provide emergency capacities when RE is not available. This has become an issue especially in Germany.

These systemic interdependencies are pivotal to an 'energy transition'. Several remedies have been developed to avoid outages. These range from a grid expansion, additional operative management tools and emergency capacities to more flexibility in the grid access. If markets are seen as one, there seems to be a threshold of wind and solar power that the current back-up system can incorporate without risking the security of supply. Notably, there is no such threshold for the integration of RE from a technical point of view. A full provision with RE is feasible, yet would be very costly. From an economic perspective, the crux lies in the conflicting mechanisms. The top-down promotion and planning policies undermine the bottom-up market selection and put the security of supply at risk. However, without interventions the market does not seem to provide socially desired outcomes. If these tensions aggravate further, the implementation of the new technology base is likely to stall.

The choice of both technologies and instruments across the EU indicate little consideration of country characteristics. The support greatly improved the competitiveness of RE: PV and wind will achieve grid parity shortly; larger systems will not require subsidies to be cost-competitive. The fast deployment of wind and solar systems may have shortened the 'formative phase' of the diffusion, which is necessary to create learning effects and incremental innovations. In addition, the change in the energy mix comes at substantial costs. Suppliers will lose economies of scale, parts of the current capital stock will be written down, and subsidy policies need to get re-financed. Notably, the energy sector is not a perfectly ‘free’ market; subsidies already interfere strongly with the industrial dynamics.

Country case studies reveal differences in the allocation mechanisms. A mechanism that is rather neutral to the income distribution allocates costs by the general budget. In Germany, additional costs are assigned to consumers; large industrial consumers are exempt. Poorer households are asymmetrically affected. Both undermine the social acceptance of a transition in the name of a greater public good. In addition, ownership structures changed. A large number of actors now constitute the energy sector. Private households entered as pro-sumers, citizens invest into RE plants, or municipal utilities can be set up as co-operatives. The broad involvement has substantially contributed to the social acceptance of RE, in some cases unlocking initially unfavourable vested interests.

We suggest some general policy conclusions:

- The public opinion favours RE. However, the interplay between the availability of grids, backup capacity and RE is not adequately reflected by the public perception. A more comprehensive picture should be generated, perhaps through co-operative ownership models, which would pose a social innovation to many countries. This is also a precondition for the establishment of regional, self-sufficient energy systems.
- The operation of the physical grid should get optimised and where required expanded. Ubiquitous priority access of RE should be put into question against the background of security of supply.
- The energy sector is heavily subsidised. The subsidy policy should reconsider its allocation to technologies. A general reduction of subsidies with a shift in the composition of public spending towards RE is desirable.
- If the subsidy burden is allocated to consumers, budget neutrality is achieved. However, if the costs allocation varies across technology fields, the visibility to final consumers creates a false impression about the real cost structures. If energy is seen as a public good and interventions are politically desired, subsidies should be financed by the general public budget. Costs should not be allocated directly to consumers.
- The diffusion policies were successful and led to the fast deployment of RE. However, the formative phase of the technology diffusion processes needs time to generate learning effects. Efforts to further compress the diffusion timescales should be reconsidered. The policy design should be put more strongly in the sector context, including regulation, infrastructure and market mechanisms.
- Most diffusion policies do not share the respective project risk with the beneficiary (e.g., due to fixed feed-in-tariffs). A stronger consideration of risk sharing is desirable in the design of diffusion policies (e.g., through auctions or quota systems).
- The electricity market and the grids struggle to incorporate RE. More self-consumption incentivised shifts the topic away from market, and potentially alleviates arising issues (e.g., long distance transmission, missing money).

1. Introduction

Antal and Hukkinen (2010) phrase the challenge dramatically, *'major and urgent behavioural change is required to address the unprecedented environmental challenges facing civilization on Earth'.* There is an urgent call for the swift reduction in CO2 emissions to mitigate the impact of climate change. Policy documents are in line with the plethora of academic contributions that warn about the impacts of global warming (e.g., Stern, 2006; Meinshausen et al., 2009), and point out that an increase of no more than 2° Celsius cannot be reached by incremental technological changes. Both the diffusion of existing environmental technologies and innovation efforts should immediately be increased to restructure the entire energy system (e.g., Moriarty and Honnery, 2012; Köppl and Steininger; 2012).

The academic calls for 'radical reform' have found support by policy makers whose documents set more or less ambitious targets, often without committing to the implementation process. For instance, the European Union sets goals regarding the subject of climate protection, energy and the environment. The three central goals of Europe 2020 are i) Reducing greenhouse gas emissions by 20% as compared with their 1990 levels; ii) generating 20 % of energy from renewable energy (RE) resources; improving energy efficiency by 20%. These targets represent an integrated European approach to climate and energy policy that aims to combat climate change, increase the EU's energy security and strengthen its competitiveness (for the policy foundations see also European Union, 2009). It blends targets, the reduction of greenhouse gas emissions, with instruments such as the 20% RE goals.

Often the higher goals are stressed without mentioning the potential trade-offs between ecological and social policy objectives. For instance, Nobel-prize winner Joseph Stiglitz implicitly assumes that such trade-offs do not exist. He calls for investments 'in our future, in ways that help us to address simultaneously the problems of global warming, global inequality and poverty, and the necessity of structural change.'[1] This is in line with the view of many researchers that - despite technological uncertainty, switching and capital obsolescence costs - the transition to renewable energy will be as smooth as the transition from wood to coal to gas and oil (see, for instance, Moriarty and Honnery 2012 for a critical assessment).

The aim of this paper is to discuss how a broadening of the energy mix can occur, and how RE can be incorporated into existing structures. We focus on the electricity system as the backbone of a broader 'energy transition'. The electricity industry makes for considerable 21% of the total energy consumption in the European OECD countries. We use photovoltaic and wind power as showcases of highly promoted technologies that exemplify the underlying processes. Other technologies such as biomass or cogeneration are not explicitly considered.

In the following we elaborate on two guiding questions:

First, what are the social group dynamics that are relevant to the adoption of new technologies? We study the impact of RE on the use, generation and distribution of renewable energy

---

[1] See http://www.project-syndicate.org/commentary/global-warming--inequality--and-structural-change-by-joseph-e--stiglitz.

production. Thereby we sketch the main dynamics that the policy-induced diffusion of RE causes. We claim that the agents themselves socially construct the technological base.

Second, we explore some of the socio-economic effects of the adoption of RE innovations themselves. We will analyse how these general findings apply to three countries and their specific implementation models.

The remainder of this study is organised as follows:

- We depict the complexity of a shift in the energy mix. We abstractly discuss the cornerstones of the technical requirements that a far-stretching vision of energy grids incorporate, which also implies the achievement of long-run policy targets. We identify social groups that are involved in the implementation and briefly elaborate on their respective position in the technology finding process. This allows us to stylise some hampering factors, which we use to suggest some policy conclusions.
- We discuss technology diffusion instruments, the competitiveness of promoted technologies, and reflect these policies against evidence from technology diffusion processes.
- We present a three country case study to discuss two questions that are pivotal to the shift in the energy mix. First, an ‘energy transition’ causes costs: What cost incidence and ownership models exist? Second, the increase in RE in the energy mix can potentially cause major industrial discrepancies that put the security of supply at risk. How could countries overcome these?
- Eventually we summarise the results and conclude with thoughts about systemic industrial policy.

Placement in the literature

In a classification of the political economy, Walras (1888, 1954; see also Fontaine, 1993) distinguishes between i) science (e.g., pure and descriptive economics, such as general equilibrium theory), ii) arts (i.e., applied economics of industrial pursuits), and iii) ethics (i.e., a normative assessment of social systems). We accept the ethical component as given by the objectives of Europe 2020. We do not conduct a quantitative assessment in the Walrasian science sense. In this framework, we focus on ‘arts’, i.e. the socio-economic dynamics of the implementation of the given policy targets.

The present contribution rests on environmental policies that can be argued by what Aiginger (2012) labels “*systemic industrial and innovation policy*”. This describes a competition and innovation based policy mix whose instruments are derived from a series of societal and ecological goals. Such systemic policies implicitly assume that existing trade-offs can be resolved by the provision of the right incentives; conflicting goals can be harmonised with a mutual economic growth strategy. This contribution partly contrasts this perception. We take a non-normative, analytical perspective that is agnostic to potentially arising trade-offs. Similarly, we discuss the promotion instruments and accept the incentives that they provide for technology adoption, but also elaborate on the interdependencies that occur on a higher level that lead to adverse effects. We both explicitly and implicitly borrow from a wide array of both sociological and economic concepts (see Annex III).

We chose the generation of renewable energy as a specimen for systemic industrial and innovation policy that allows for a discussion of its cornerstone. The technology field exemplifies the difficulties that arise in the presence of systemic complexity, the aim to achieve higher societal challenges, and the effects of policy interventions on market mechanisms alike.

What the present study does not discuss

An ‘energy transition’ is a shift from the demand side of the provision of energy to the supply side, where the production technologies are at the core. Hence we take a supply side perspective; demand side topics are embedded in some parts, but not explicitly discussed. Similarly, the production of innovations is not being discussed.

The wider debate on energy as a whole (energy efficiency, R&D policies, e-mobility etc.) will not be incorporated in greater detail (see also European Commission, 2011a). We will not assess the adjustment of single components in the electricity system. Even minor adjustments may lead to lower re-dispatch, more efficient plants or less CO2 emissions which may make substantial welfare gains possible.

We do not conduct any quantitative estimations of a hypothetical deployment scenario, nor do we aim at a comprehensive cost-benefit analysis of the change in the energy mix. This generally holds for the implementation of the ecological goals of Europe 2020. There already are numerous estimates of the economic effects that the achievement of the Europe-wide 20% target would have.[2] Europe 2020 states that it could create over 600,000 jobs, and a further 400,000 are thought to be generated if the EU met its energy-efficiency goal. Furthermore, meeting the goals could save €60 billion on oil and gas imports by 2020. Yet, these structural shifts come at uncertain costs; e.g., existing power plants may become obsolete, or energy may become more expensive in the long run. Similarly, it states that further integration of the European energy market can increase GDP by 0.6% to 0.8%. General equilibrium models that consider obsolescence costs and refinancing a growth effect close to nil.[3]

We will not discuss technical solutions or specific projects in detail. Similarly, the chosen decentralised power generation technologies serve as mere examples of widely discussed and promoted technologies. Yet, we refrain from recommending the technologies themselves.

We concur with Europe 2020 that the current energy mix exposes the EU to severe long term risks which farseeing policy makers should strive to minimise. These involve the i) fossil fuel dependency, ii) global competition for resources, iii) climate change, and iv) competitiveness. In the following we accept these higher goals as given. We corroborate this argument in Annex II.

---

[2] On EU-wide vs. country specific targets see Resch et al., 2012.

[3] For evidence on Austria, see for instance Friedl et al. (2013).

Data

The data that we used are derived from a variety of sources including relevant academic publications, official statistics, policy documents, programme descriptions and evaluations, industry and market studies, as well as interviews with technology experts, industry representatives and public sector officials.

2. A systemic perspective of the diffusion of RE

The aim of the following is to shed light on the transition dynamics to a new capital stock in the electricity industry. The discussion has reached a substantial degree of complexity which renders an unequivocal forecast of the sector's future quasi impossible. We therefore draw on a flexible concept that helps us to analyse agent dynamics. We intentionally avoid the granular focus, which comes at the risk not to see the wood for the trees. We seek to understand the key dynamics from a macro, often conceptual perspective. This approach reduces the complexity to several key dynamics and issues.

This contribution discusses *'smart grids'* - a term that is often used to paraphrase the final stage of a self-managing, self-sustainable supply system that incorporates generation, transmission and distribution of RE, as well as demand side instruments. This definition reaches beyond the physical transmission and distribution lines, and also beyond the mere increase of RE in the energy mix. The thought translates to the creation of a new, in parts substantially altered capital stock. This implies the often cited fundamental change of the energy provision. From an economic perspective, this affects the production structures and the wholesale markets.

The remainder is organised as follows. It first introduces the thought of the technology base as a social construct that is shaped by the social groups concerned. Second, it presents various definitions of 'smart grids' that indicate that a common perception of the term is yet lacking. Next, it sketches the technical requirements that the most comprehensive definition involves, which leans on a definition used by the Joint Research Centre of the European Commission (Giordano et al., 2011). These constitute the 'technological artefact' from which the agents concerned are being derived. Their respective role and positions shape the current state of the technology implementation process. The chapter closes with a brief summary and some thoughts towards a systemic policy.

2.1 Technology as a social construct: A multi-layer, multi-agent analysis

The desired structural change of the energy industry involves substantial complexity. A single entity that owns, operates or regulates the electric grid does not exist. In addition to established players, entrants will continue to emerge; new technologies will coexist alongside old technologies, of which parts are gradually being made redundant. Both policy makers and regulators intervene with the sector's dynamics.

This multi-actor setting undermines the explanatory power of common economic diffusion models. These have addressed the shape of diffusion patterns, switching costs, information cascades and characteristics of the innovator and the adaptor (e.g., Geroski, 2000). They have proven to be useful tools that describe some of the underlying industrial and organisational dynamics, and produced some stylised facts. However, they lose explanatory power with an increasing number of agents that interact in complex ways, of which many receive merely scant attention by common diffusion models (Gazheli et al., 2012).

We therefore turn to a flexible sociological concept - social construction of technology, SCOT (Bijker et al. 1987; Bijker, 2009). In a stepwise procedure we first identify technology artefacts that are relevant to the technology field. We then identify 'social groups' who attach the same meaning to the artefact, or that have vested interest in it. Agents typically have a diverging understanding of the technology, which is - among other factors - shaped by their vested interest. This 'interpretive flexibility' will diminish over time, as stakeholders increasingly turn to a joint definition. The system will eventually reach a stage where the technology finding process stabilises. When this final stage is irreversible, a 'closure' occurs.

SCOT shares its evolutionary character with Schumpeterian economics, but differs in its pivotal element, social construction. Also the evolutionary economic framework rests on markets as the main selection mechanism, where complex preferences meet the purchasing power of agents to produce somewhat exogenous outcomes. SCOT on the other hand dispenses markets and perceives the interaction process of social groups as the determinant of outcomes. It seems to implicitly argue that the market itself is a social construct (Nelson, 1997).

We feel that this very criticism supports the application of SCOT to the present setting. The technology base of the energy industry is socially chosen. It is hardly the result of a pure market process. Both policy packages that promote the diffusion of existing technologies and thematic and mission oriented R&D policies have interfered with the technology base and installed what is deemed 'socially desirable'. In addition, the sector is highly regulated - regulations that affect the installed technology base are socially set. On a similar note, we add to the work of Wolsink (2012) that reviews social acceptance of distributed generation as a first attempt to address the social construction of smart electricity grids.

SCOT allows for a multi-level analysis. The agents that we present differ in their operative level. The framework is provided by the European level, which is then implemented by national and regional entities in their respective context. Other than the neo-classical perspective SCOT does not argue that the 'best' or most efficient technical solution is the one that is implemented. Cognizant of this difference we do not fully abandon the efficiency criterion. We extend our analysis by some neo-classical efficiency considerations that are embedded in the regulatory regime; these neoclassical elements, however, stem from socially chosen objectives of the energy provision, and *inter alia* serve to at least to rule out the worst technical solution.

Limitations

We do not claim to paint an exhaustive picture. We believe that the findings can be generalised, but the extent to which they apply may differ across countries and regions. The ongoing internationalisation of the markets creates spillovers that convey technical and industrial issues from one country to another. The interlinkages render the results more applicable across borders than in a stand-alone scenario.

Notably, we focus on countries where RE is deployed on a large scale, and where all agents seem to agree with the macro-objectives of RE strategies, or at least have agreed in the period relevant to this study. The necessity to change the energy mix itself is not fundamentally questioned. This assumption does not hold for some new member states; also crisis countries that currently implement austerity programmes increasingly abandon RE programmes. In addition, in countries that politically implement endorse the broadening energy mix almost all agents concerned seem to concur to the idea of reform. Hence we merely depict their roles and positions in the bargaining process.

2.2 Interpretive flexibility of ‘smart grids’

The environmental targets of Europe 2020 are straightforward. Flagship initiatives have been set up to achieve them, which *inter alia* include smart grids (European commission, 2006b). Their aim is to implement targets that imply a linear functional chain where regulations and incentives interact to reshape the technology base (see also Aiginger, 2012). Yet, this is a challenging task when elusive concepts like ‘smart grids’ are endorsed. The various definitions differ substantially, as do the implications for existing grids and policies. The breadth of the definition suggests a substantial range into which the final implementation will fall – let alone the achievement of policy targets.

The following portrays two concepts that indicate a substantial degree of interpretive flexibility. In its most simple form, a smart grid is merely a computerised grid that provides information on power consumption. On the other extreme stands a grid in which consumers act as electricity producers in a fully automated environment with multiple nodes and self-sufficient parts. The range of interpretations has been acknowledged by some agents. For instance, the German Association of Energy and Water Industries presented ‘realistic steps to implement smart grids in Germany’ (BDEW, 2013). Since not all proposed steps deemed to be realistic, this suggests that multiple interpretations exist.

A computerised grid

The starting point was the computerisation of the grid. Its main objective is to increase the efficiency of operations. It perceives a smart grid as a computer based remote control system that supports central grid operators in their network management. For instance, the European Commission (2011b) defines smart grids *“as an upgraded electricity network to which two-way digital communication between supplier and consumer, intelligent metering and monitoring systems have been added. Intelligent metering is usually an inherent part of Smart Grids“*. A similar definition offers the Office of Electricity Delivery and Energy Utility of the United States, where a smart grid *“… includes adding two-way digital communication technology to devices associated with the grid. Each device on the network can be given sensors to gather data (power meters, voltage sensors, fault detectors, etc.), plus two-way digital communication between the device in the field and the utility’s network operations center. A key feature of the smart grid is automation technology that lets the utility adjust and control each individual device or millions of devices from a central location.”* The US view does not explicitly mention consumers as stakeholders. *“The companies making smart grid technology or offering such* *services include technology giants, established communication firms and even brand new technology firms.”*[4]

Universal grids

The technical challenges to the system that emerge if the policy aspirations are realised are considerable. A stand-alone optimisation of consumer and producer behaviour through a two-way communication system is easy to implement. This is a rather straightforward technical adjustment. Yet, it is insufficient to accommodate the emerging requirements that the policy targets bring about. More RE in the system implies a wealth of decentralised and often smaller power stations that has to be managed and integrated into the existing network. The current pattern where production follows consumption is reversed. Storage is gaining greater importance to balance increasingly erratic supply at different voltage levels that meets rather inflexible demand. Altogether, this equates to the establishment of a comprehensive energy system that fundamentally reshapes the traditional grid structure. Such a ‘universal grid’ is a holistic energy system which comprises storage facilities that compensate for deviations of electricity production and consumption (e.g., Gawlik, 2012).

This is reflected by policy definitions. For instance, the European Commission (2011b) includes consumer behaviour and states that ‘*a smart grid needs to employ advanced metering and communication technologies in order to accommodate the dynamic behaviour of end users.”*[5] More dynamic definitions incorporate the interaction between the new roles of consumers and producers. The European Smart Grid Task Force defines smart grids as *„electricity networks that can efficiently integrate the behaviour and actions of all users connected to it — generators, consumers and those that do both — in order to ensure an economically efficient, sustainable power system with low losses and high quality and security of supply and safety“.*

A similarly comprehensive definition considers the joint control of flexible consumption and production. For example, the Strategic Energy Technologies Information System of the European Commission (Smart Grids ETP, 2010; later used by the European Commission (2011f) defines a smart electricity grid as *“... an upgraded electricity network that can intelligently integrate the actions of all users connected to it (producers, consumers and the so-called prosumers (producers-consumers), in order to ensure economically efficient, sustainable power systems with low losses and high levels of quality and security of supply and safety.”*

2.3 The technological artefact: Major technical implications

This section sketches the main technical requirements that a shift in the energy mix induces. We define the grid as a collection of components which include centralised and distributed power supply, conventional and renewable production facilities, a distribution and a

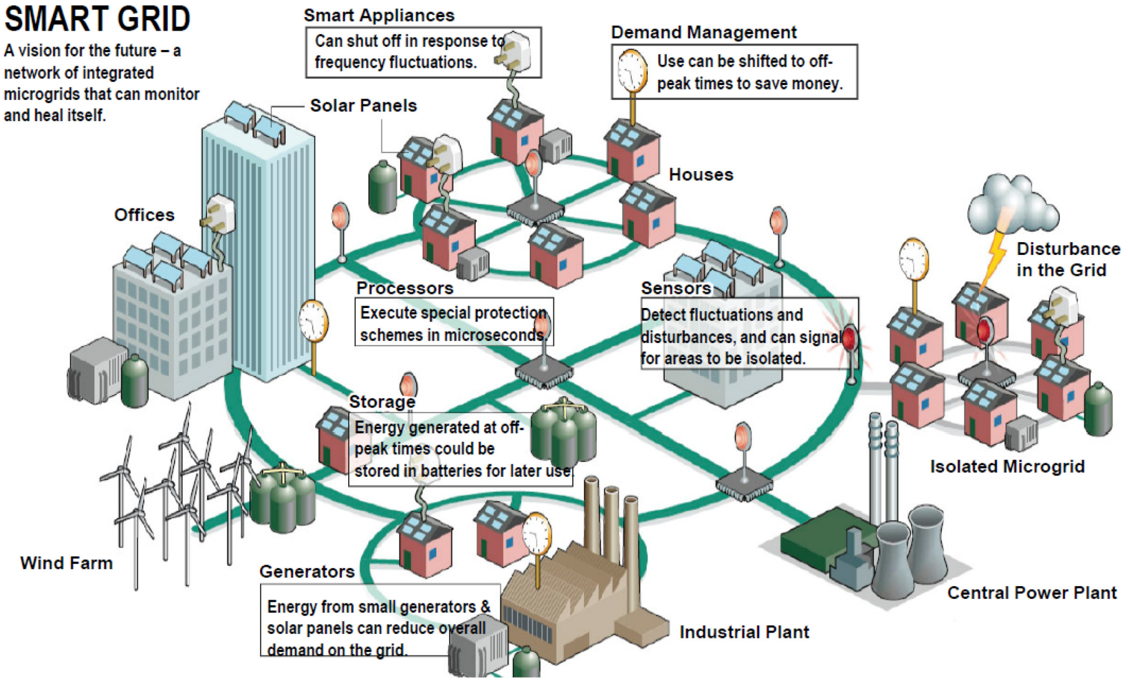
---

[4] See http://energy.gov/oe/technology-development/smart-grid.

[5] See http://setis.ec.europa.eu/newsroom-items-folder/electricity-grids.

transmission grid, consumers and ‘micro-grids’, i.e. separate sections that are partly self sufficient (see Figure 1). We thematically structure the requirements along these elements.

Figure 1 **Architecture of a smart grid**



Source: Amin, (2008).

2.3.1 Stability of existing energy production

Continuity of conventional plants. Albeit renewable energy producers will continue to enter the supply market and compete with established producers, there is still a central role for conventional power plants. Electricity cannot be stored and RE is not as constantly available as conventional power. This implies that there is a strong need for at least some existing suppliers to provide basic services. Established suppliers are required to avoid shortages by smoothing the emerging volatility in voltage. They secure the continuity of supply. In particular at peak times the system may require additional coverage, depending on the respective energy mix and physical conditions.

Storage. The unstable supply of RE, in particular of wind and solar power, requires the overall system to provide backup capacities. This is a technical challenge, because electricity needs to get transformed into another form of energy. For instance, pumped storage hydroelectricity uses excess electricity to pump water into a reservoir on a higher elevation. The storage can also be underground. It transforms electricity into potential energy. When there is strong demand for power, the water is released into turbines which produce electricity. Hence, more distributed storage technologies will be required to cover for the mismatch between supply and demand. Storage facilities incorporate existing technologies such as reservoir power plants, or prospective technologies such as electric vehicles.

Swift capacity provision. There will be shorter periods when existing plants run at full capacity. The current market prioritises the feed-in of RE, which lowers the regular demand for conventional power. However, when required due to a lack in power from the generation of RE they need to quickly increase the capacity that they provide, or go operational if they are cold reserves.

2.3.2 Renewable energy

Large scale RE suppliers. Renewable power plants have been entering the European power sector. *Inter alia*, these comprise large-scale technologies such as wind or solar parks. Most of these plants are owned and operated by investment firms that are unrelated to established utility providers. Also communities and manufacturing firms operate large-scale plants, often for their own needs. Large-scale plants, especially wind turbines, are frequently distant from the end consumer, which generates challenges to the grid to provide connectivity.

Small scale distributed power generation. Distributed energy refers to a great variety of small, modular power generating technologies, which is at or near the point of energy consumption. This is a reversal of the centralized system, where a large-scale power station at a remote location serves a multitude of customers. On the other extreme it involves complex systems that consist of electricity and thermal generation, energy storage and management systems. These highly complex systems are typically integrated with the electricity grid.[6]

Distributed generation covers parts of the energy consumption of its producers. For instance, German households that own photovoltaic systems typically consume 30% of their own production, which decreases with the system size and commercial nature of its operators (EPIA, 2012). Unused capacity is being fed back into the grid. This imposes challenges to the grid that is required to incorporate a large number of new agents that partake in the market as producers and consumers at the same time (‘prosumers’).

Notably, distributed power is not necessary renewable. Also Diesel generators are a component of distributed power production. When policy makers use the term they typically refer RE.

2.3.3 Distribution and transmission grids

The grids themselves face several technical challenges, such as incorporating strongly oscillating voltages, transmission and power conversion. This touches on all parts of a grid, which in a general sense consists of two components. A high voltage and long distance network transmits power to a low and medium voltage distribution network.

Long distance lines. With the remote power production the question arises of how to transmit electricity from the point of generation to the consumer. Due to developments in the electricity transmission technology it has become easier to install direct current (DC) lines. Direct current has significantly lower friction losses than alternating current (AC), and is therefore the preferred technology for point to point long-distance transmission. A less costly alternative to the

---

[6] For an overview see also http://www.nrel.gov/.

establishment of new lines is the optimisation of the existing high-voltage and long-distance grid.

The distribution grid and two-way transmission. The emergence of decentralised energy suppliers that feed power into the grid implies that the grid management is changing from one with few nodes to a grid which receives power from many feed-in points. As RE suppliers start to feed-in power, a two-way grid is required. The distribution grid requires smart meters (see below), and the grid management should automatically compensate for power fluctuations to avoid outages.

Power rectifiers. As the energy transmission becomes more challenging, more and more power rectifiers are required. Current networks mainly delivered high-voltage electricity from large scale power plants to low voltage users. Distributed generation reverses this model as many low voltage producers feed power into the grid.

2.3.4 Automated grid management

Information and communication technologies. RE needs to be combined with both load management and energy storage systems to render their power supply reliable. This has increased the complexity on all levels of the grid management. Information and communication technologies are implemented and combined with control instruments to secure the supply. For instance, they include power flow controls, the prevention of disturbances and operational security. This requires a data exchange platform, which is typically managed by grid operators. ICT solutions supervise the flow that is in the system, and manage the information between agents. They also serve as the basis for real-time trading, fault prevention, asset management, generation control and demand side participation (e.g., Smart Grids ETP, 2010).

2.3.5 Smart electricity meters

‘Smart electricity metering’ is a key component of a ‘smart grid’. Smart meters are the end-consumer devices that in their simplest form provide detailed information on consumption. Smart metering potentially goes farther, though (see also Annex IV). An ‘advanced meter infrastructure’ links prices to end-consumer devices that respond to price developments. This allows for electricity optimisation routines at the household level. Generally, smart metering makes usage patterns more transparent, and may help reduce the overall electricity consumption. Smart meters are a necessary technology for real time pricing, i.e. the price setting according to the present market conditions. The European Commission (2011c) provides a list of key functionalities:

Consumers. For consumers and installed devices, they provide information on power consumption in an understandable form and sufficiently often update the data to better control their energy consumption.

Energy supply. For the grid and network operators, they allow for the remote reading of meters. They establish a two-way communication between the meter and external networks such as energy suppliers and grid operators, which can be used for maintenance and control purposes. They deliver regular information on power quality to the grid operators. Hence, energy suppliers obtain access to advanced tariff systems, such as multiple tariffs, time of use registers, block tariff registers, remote tariff control, etc. They support energy supply (e.g., by pre-payment and on credit), and enable remote on and off control of the supply and/or flow or power limitation.

Decentralised generation. Smart meters are a basis for the automation of distributed power generation. They provide information on imports and exports of the local system. They operate reactive metering, which again has feedback effects on the system's internal use. Smart meters should guarantee secure data communications, which supports the prevention and detection of fraud.

2.4 Key agents and their positions

The implementation of new technologies is determined in a complex environment by many stakeholders and interest groups. The technical challenges that the political targets imply allows us to derive the main agents. Cognizant of idiosyncratic structures and interests at the region and country level we depict the main positions that emerge. Each of the players is thematically affected in different and multiple ways.

The main stances are often shaped by vested interests (e.g., the EU promotes the European market), or by industrial necessities (e.g., the reaction of transmission system operators to grid expansion plans). Nevertheless, there are conflicting positions which pose frictions the roll-out of universal (smart) grids, which policy makers can hardly resolve due to the uncertainty that the arising complexity imposes on them.

2.4.1 The European Union

The European Union provides the main policies which its agencies legally implement. Europe 2020 provides the policy targets, and the third energy package sets the framework for regulatory authorities and grid operators for topics such as grid connection, network operation, capacity allocation, congestion management and market harmonisation.

Main policies. The EU addresses goals regarding the subject of climate protection, energy and the environment. The three central goals of Europe 2020 are i) Reducing greenhouse gas emissions by 20% as compared with their 1990 levels; ii) generating 20 % of energy from renewable energy resources; improving energy efficiency by 20%. These 20-20-20 targets represent an integrated European approach to climate and energy policy that aims to combat climate change, increase the EU's energy security and strengthen its competitiveness.

The first two targets were set by EU leaders in March 2007, when they committed Europe to becoming a low carbon and highly energy-efficient economy. The agreement was enacted through the climate and energy package in 2009. The climate and energy package does not address the energy efficiency target directly. This is rather contained in the 2011 Energy Efficiency Plan and the Energy Efficiency Directive.

The second target features the sub goal of 10% renewable energy use, including green electricity in the transport sector. Recently, this target was refined in order to limit global land conversion for biofuel production, restrict indirect land-use changes, and thus to raise the climate benefit of biofuel use in the EU. For food-based biofuel supply a limit has been set at a maximum of 5% of transport energy use by 2020 (European Commission, 2012).

The main objective of the EU policies on the energy market is the promotion of a common energy market and the facilitation of international energy trade. It promotes a harmonised European dimension to critical issues such as the development, regulation and operation of the networks. An overview of the relevant aspects is embedded in the discussion of the respective players.

The Smart Grids ETP (2010) prioritises the implementation steps for the grid development, which mainly focuses on existing structures: 1) Optimizing Grid Operation and Usage, 2) Optimizing Grid Infrastructure, 3) Integrating Large Scale Intermittent Generation, 4) Information and Communication Technology, 5) Active Distribution Networks, 6) New Market Places, Users and Energy Efficiency.

Platforms. The EU serves as a platform that bundles the interests of national players and affects the design Europe-wide policies. Platforms at the European level that are relevant to renewable energy are for instance the organisation for regulators, for system operators or the technology platform for smart grids.

- With the implementation of the third liberalisation package, the European Agency for the Cooperation of Energy Regulators (ACER) was established in 2011, which serves as a collaboration platform for the National Energy Regulators. It coordinates the regulators and participates in the creation of European rules. Under certain conditions it may also take binding individual decisions on terms and conditions for access and operational security for cross border infrastructure. In addition, it has an informational character. It monitors energy markets and gives advice to European institutions on various energy related issues.[7]
- The European Network of Transmission System Operators for Electricity (ENTSO-E) is an association of Europe's transmission system operators (TSOs) for electricity. It is the successor of ETSO, the association of European transmission system operators, which was founded in 1999 in response to the emergence of the internal electricity market within the EU. Grid operators cooperate and mutually develop commercial and technical codes and security standards and common network operation tools. In a ten year investment plan, they also coordinate technical requirements at the EU level.[8]
- To implement ‘smart grids’, the European Technology Platform for Electricity Networks of the Future (Smart Grids ETP) seeks to align policies, R&D and co-ordinate stakeholders. Its aim is the formulation and promotion of a vision for the development of European electricity networks looking towards 2020 and beyond. It is also the platform on which consultations about the technology implementation are held.[9]

---

[7] See http://www.acer.europa.eu/Pages/ACER.aspx.

[8] See https://www.entsoe.eu/.

[9] See http://www.smartgrids.eu/ETPSmartGrids.

Research, development, technology and innovation. In addition, the EU seeks to promote the sector's technological progress, and provides funding for research and development, and is a central platform for the policy dialogue through its technology initiatives. The many R&D initiatives *inter alia* include the SmartGrids Technology Platform for "Electricity Networks of the Future", research priorities in the Framework Programmes, the European Energy Research Alliance (EERA), or the relevant activities of the Joint Research Centre.[10]

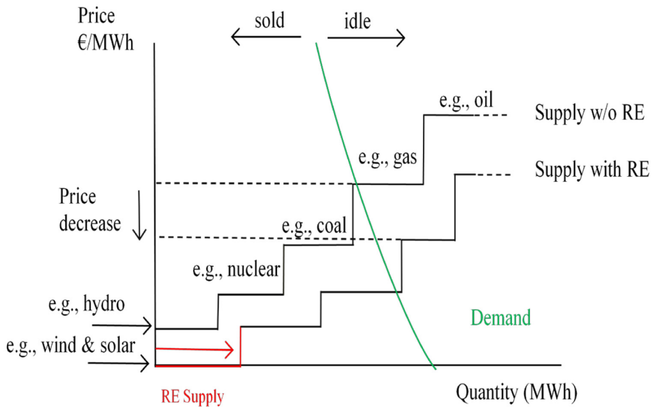
2.4.2 Regulatory authorities

The European energy policy is built on three core objectives (European Commission, 2006a): i) sustainability, ii) security of supply and iii) competitiveness. The divergence of time and location of the consumption and the supply of electricity pose a yet unresolved conflict to the wholesale market. It is unclear how to best integrate RE into the grid. At the core of the issue is the regulatory question about the economic efficiency of the *wholesale market* that underlies regulatory policies.

Static versus dynamic efficiency. Regulatory economics underlie regulatory policies. It produces two partly conflicting targets, which are both socially desired. On the one hand, there is static efficiency which seeks to keep prices low so that sellers cannot excessively benefit at the cost of buyers. On the other hand, there is the dynamic efficiency concept, which considers investment incentives and the security of supply.

The increasing share of RE intensifies this pre-existing trade-off. Static efficiency on the wholesale electricity market is guaranteed by the merit order effect. The 'energy-only' market for electricity compensates suppliers for the volumes of electricity that they make available at marginal costs. Since electricity from RE is provided at almost no marginal cost it is extremely cost competitive. Due to the merit order effect, RE displaces demand for conventional producers and lowers the price of the electricity pool (see Figure 2).

Figure 2 **The merit order effect**



Source: Adapted from Philibert (2011).

---

[10] See http://setis.ec.europa.eu/newsroom-items-folder/electricity-grids.

Due to the volatility RE requires cost intensive conventional power plants as emergency capacities. This trade-off challenges the design of the energy-only market. Regulatory authorities implement the policy objectives, including the avoidance of outages. Hence, the security of supply should be guaranteed without distorting the economic price efficiency. The question is if a market can be created in which on-call capacities are provided at an 'adequate' price level?

Capacity markets and the strategic reserve

The current regulation considers the N-1 rule. This requires electricity networks to be able to maintain supply even if one component fails (e.g., Nooij et al., 2010). Hence, overcapacities are desired and embedded in the system to avoid power shortages which would result in blackouts. In an ideal model world, the regulator has information about demand and supply that is provided by the market. Mismatches are easily avoided. Yet, due to informational asymmetries mismatches may arise, and are coped with either by a capacity market or by a strategic reserve. The fundamental difference between these two is that a capacity market seeks to cover shortages through (wholesale) market mechanisms (on the spot markets), whereas a strategic reserve is conceptually an insurance that is activated when the markets fail to deliver.

Capacity markets. Capacity markets have the objective of providing long-term cost recovery for capacity, in particular for capacity operating at low load factors, i.e. maintaining a reserve (e.g., Tomkins, 2011). A capacity market incentivises sufficient reliable capacity (both supply and demand side) to ensure a secure electricity supply even at times of peak demand. Both generation and non-generation providers of capacity, such as demand side response and storage, receive a predictable revenue stream for providing reliable capacity. They face financial penalties if they fail to do so. In this way a capacity market will ensure adequate investment to minimise the chances of blackouts (e.g., Department of Energy and Climate Change, 2012).

Hence, power plant operators gain revenues for guaranteeing output that they provide if there is a disruption of supply. Under normal conditions this 'operating reserve' is at least the capacity of the largest generator plus a fraction of the peak load. A precondition is that the operation of emergency plants is economically viable. The pre-determined capacity volume is typically assigned to suppliers which are identified through auctions; alternatively the capacity providers may receive a payment which usually is above market prices. The winners realise fixed revenues that finance the investments (Tomkins, 2011).

There are several models of how to design such a market. For instance, Elberg et al. (2012) proposes a capacity market where shortage situations capacities are provided at 'preferential prices' that are separate from the spot market whose prices remain unaffected. The preferential price is determined ex-ante by a central coordinator, which reduces the incentive to artificially reduce supply to increase the prices. The price volume is paid to all plants that are operational at the time of congestion, i.e. not only to those that provide the emergency capacity. The electricity demand on the other hand is insured against price hikes in shortage situations through options. The difference between the spot market and the preferential price is settled by a cash payment.

Strategic reserve. An alternative to capacity markets is maintaining a strategic reserve. The concept resembles an insurance option that is triggered through price mechanisms. It is comparable to an oil reserve that is consumed before scarcity restricts electricity consumption or leads to outages. For instance, relatively clean technologies such as gas turbine power plants might serve as a means to cover temporary shortages. If strategic reserves remain untouched because the market functions without congestion, the wholesale market functions as an energy-only market.

Strategic reserves are a last resort that should not be used for the day to day grid operation. This reveals an intrinsic incentive problem. Electricity prices need to reach a certain level and remain there for a pre-specified period to trigger the call for the strategic reserve. The call increases the price. The more electricity is provided by the reserve the higher the price. A higher price again increases the likelihood of a call for the reserve. Paradoxically this occurs if the dispatch functions inefficiently strategic reserves are called more often to avoid 'high prices' for consumers (see for instance Elberg et al., 2012).[11]

The target market

The EU sees more integration and a common market as the main congestion management instrument. It promotes the creation of a target market, the integration, international coordination and the related technical harmonisation of networks. The 'target model' seeks to create a European electricity market. It is thought that the poor regional integration hampers cross-border trade, reduces market liquidity, and eventually leads to a suboptimal use of resources at higher costs. The current national regulatory regimes are thought to be exposed to price manipulations by providers, because most national markets have a high market concentration (for a brief overview of market structures and the effects of liberalisation across the EU see Annex I).

The rationale for the target market is that a sufficiently integrated electricity market will facilitate the flow of capacity from areas where electricity production is cheap to areas where electricity demand is high. Hence, the highest priority on the regulatory side is assigned to the implementation of the target model, i.e. an integrated market that internationally balances any capacity issues. The target model considers international zones and capacities which use forward markets for the capacity allocation. Operationally both day-ahead and intra-day trading should be in place. The design of the Nordic power market, i.e. the Scandinavian market with its intra-day trading serves as a role model for the development of the EU target model. This system balances congestion of the electricity markets by pricing mechanisms. Policy makers put high hopes into the target market. It is supposed to allow for an accelerated grid expansion, continue the inclusion of RE, incentivise flexible production and promote demand side market participation.

---

[11] Reserve markets are Finland, Sweden, Poland and Belgium. Capacity markets are Italy, Greece, Spain, Portugal, France, Ireland and the United Kingdom. The other markets are energy only markets (Elberg et al., 2012).

2.4.3 Transmission System Operators

A Transmission System Operator (TSO) transmits electricity from the producer to the local distribution grid. It takes a central position in ensuring safety and reliability of supply because the TSO is entrusted with voltage and frequency stability. They balance excess electricity demand and supply, which is becoming an increasing issue with the advancing of the greening of the energy production mix. TSOs are among the most affected by the policy-induced trade-off between more RE in the grid and the provision of security of supply.

National and international market coupling. The new setting challenges the capacities of the existing transmission grids, which needs to match the geographical divergence of production and consumption. This is why market coupling is gaining relevance, i.e. the matching of regional systems. Another geographic dimension refers to the European market. Imbalances are to be seen in an international context.

Re-dispatch. TSOs operatively manage the security of supply and conduct grid security analyses. They combat congestion in transmission systems by modifying the generation schedules and/or demand side management tools. If there is an indication that a critical load flow will occur, the TSO prepares emergency measures. There are various instruments of a (multilateral) re-dispatch, which seek to re-balance the grid. *Preventive instruments* include the location decision of power plants or the adjustment of consumption patterns. *Curative instruments* cope with congestion when it happens; these involve either power plants or other ‘technical instruments’. Instruments that involve power plants are for instance the temporary suspension of plants or activating ‘cold reserves’, i.e. re-connecting inactive plants to the grid. Technical instruments comprise special circuits between countries, or halting construction works in a local grid to discharge alternate grids.

An increase in re-dispatch is a waste of resources, and not desirable from a welfare perspective. Static, curative as well as dynamic, preventive dispatch mechanisms have different incentives. The respective regulatory dispatch model determines the allocation of the emerging costs. It sets incentives to either expand the grid if costs are at least partially allocated to grid operators. If the costs are allocated to producers, as in preventive congestion measures, incentives to expand the grid are hampered and the expected profitability of electricity producers is lowered. This has negative feedback effects on investment decisions (Frontier Economics and Consentec, 2008).

TSOs position. Three thematic fields may describe the current positions of TSOs. The first concerns the efficiency of the grid management. Aspects such as load forecasts, information exchange, grid monitoring or the coordination of potential re-dispatch have largely been optimised. TSOs typically operate the latest and best available technology. Second, they seek to further strengthen and optimise the existing physical grid. This incorporates the thermal rating, high temperature conductors, upgrade of the capacity of the grid (e.g., from 220kV to 380kV), or the increased use of existing traces.

Grids that permanently run at full capacity hinder the efficient grid operation and increase the risk of outages. The cost of a grid expansion seems to be lower than the costs of the congestion remedy (Frontier Economics and Consentec, 2008). As a result, the biggest requirement will be the extension of the existing grid. This involves new traces and new power lines – including high voltage DC lines, or an overlay grid that connects sub-grids with power autarky. The latter contradict the needs for a grid expansion. If more local elements were self-sufficient lower investments into the transmission grid would be required.

TSOs perceive several hampering factors to the grid enlargement. First, obtaining permits and licences that are legally required is time consuming and imposes significant uncertainty on expansion schedules. Second, public space management is often not in place, and available spaces that are required for new traces are allocated otherwise. Third, the public opinion is often not supportive to the grid expansion. This is puzzling insofar that it almost everywhere it supports RE, but not the resulting infrastructural needs. Since economic and technology policies depend on the public opinion, a clear political commitment to the grid expansion is yet missing. Fourth and equally importantly, the regulation of the grids and the financing are unclear. This hinges on the ownership of the grid (Christiner, 2013).

This opinion has found support in analytical work on TSOs. Battaglini et al. (2012) find in a survey among grid stakeholders that the biggest barriers were the insufficiency or inappropriateness of regulations. In particular a common European approach for regulations and an improvement of permission procedures was seen as yet lacking. Low cost overhead cables seem to pose a barrier, and incentives for further development of new technologies were recommended to be at the core of the technology questions. Respondents identified the high costs of technologies themselves as a problem, in particular for cabling. There was a clear call to improve the public acceptance of specific projects through a clear, comprehensive and transparent project information strategy. Also Cochran et al. (2012) note that a one size fits all policy that answers the question of how to incorporate RE into the grid does not exist. This implicitly criticises standardised EU policies. The authors stylise several thematic fields that the policy mix should cover. These are lead public engagement, particularly for new transmission; coordinate and integrate planning; the development of rules for market evolution that enable system flexibility; the expansion of access to diverse resources and geographic footprint of operations; and the improvement of system operations.

2.4.4 Conventional power suppliers

The current policies have several implications for operators of conventional plants. They are required to continue investing into capacities that are capital intensive and have a long time horizon. The liberalisation increased competition from entrants that operate both existing and new technologies. In addition, there are explicit and implicit policies that pressure companies to swiftly shut down existing power plants that operate dirty technologies. These were designed to last for decades and investors planned with a low technical rate of obsolescence.

<u>Missing money.</u> The grid requires conventional power plants to continue its operation. The lack of constancy in supply of RE requires ‘back-up’ facilities to secure a steady supply. Yet, conventional power providers face the ‘missing money’ problem, which stems in the economic mechanisms of the energy only market. The market operates on the merit order, i.e. the power of the producer with the lowest marginal costs feeds in first. As a result RE displaces conventional power due to their almost non-existing marginal costs, and changes the cost

function of the overall market. This dilemma is caused by a change in the cost structure of the technology mix. In the setting without RE, producers operated technologies that had comparable marginal costs and moderate economies of scale, which allowed 'free market competition'. The emergence of RE fundamentally undermines the current feed-in mechanism.

Conventional power suppliers are profit oriented firms that operate both renewable and non-renewable power plants. Their decision whether to continue operating existing facilities or to build a new power plant is mainly driven by the profitability, i.e. by the expected feed-in tariffs in relation to the electricity demand (Frontier Economics and Consentec, 2008). They are only cost efficient if fixed costs are earned, which is increasingly difficult in the short periods they operate. Established plant operators face losses in market shares and lower scale economies, which does not allow them to operate at optimal plant efficiency levels (e.g., Christensen and Greene, 1976).

In addition to RE, the liberalisation is still ongoing and foresees more competition, and the target market adds an international element. There seems to be a combination of a proportion of RE with competitive intensity that poses a threshold where conventional power plants cannot be operated cost-efficiently any longer, regardless of how well the power plant parks are run (e.g., Schüppel and Stigler, 2013).

<u>Incoherent policy instruments.</u> More RE is politically desired and publicly promoted. At the same time it undermines the security of supply, which is also a policy goal. Notably, the current policy instruments have been designed to cope with the former market structure, whose problems were the opposite of the missing money issue. The main challenge was to combat market power (e.g., through price caps); such an instrument would now intensify the back-up provider's price dilemma (e.g., Elberg et al., 2012).

<u>Conflicting messages.</u> There are efforts to reduce the overall energy demand, which may be desirable from a societal viewpoint, but puts the business model of the conventional electricity industry at risk. The contradicting messages are reiterated by policy makers. For instance, the European Commission (2011d) lays out that, '*Massive renewable integration and energy storage technologies will have to be deployed. Energy efficiency will have to be a general driving vector, demand will become an active player within the electrical system and the increasing electrification of transport (E-mobility or Electric Vehicles) will be a challenge.*'

The industry's predicament is aggravated by its path dependency. Utility providers generally have a conservative attitude towards innovation. They operate large scale infrastructure with well established internal processes. Economies of scale and, despite the liberalisation the relative lack of competition create structures that are prone to stability (for an overview see BESSE, 2012). The technology shock is also a cultural break to the electricity industry, which traditionally has a rather low propensity to innovate. Innovations traditionally come from upstream firms, mainly machinery and equipment suppliers, and not from the industry itself.

<u>Reaction.</u> Established energy providers react strategically to maximise their profits, or rather to minimise their losses in profitability. Cognizant of the socially desired change of the energy mix, they point at their systemic relevance. In many cases they are large utility firms that also operate distribution, in some countries transmission grids. Hence, they seek to establish

alliances and identify synergies with other infrastructure providers. For instance, if power suppliers operate long distance lines, it is sometimes proposed that grids could run in parallel to motorway or railway stretches. This, however, requires an agreement with other infrastructure operators.

They demand a flexible legal framework that allows them to share sites, decreasing competition in the infrastructure segment. They lobby for regulatory policies that are more beneficial to them. For instance, policies incorporate a loosening of their obligation to connect any RE provider to the grid (Germany), or to show costs of the electricity generation and grids on separate invoices. They also criticise subsidy policies, and demand a halt for the promotion of RE. In some countries they demand subsidies for their own plants to maintain spare capacities.

2.4.5 Producers of wind and photovoltaic energy

The promotion of RE has spurred the appearance of various suppliers that are necessary in achieving the policy targets. In particular solar and wind power have been ascribed the highest potential of RE technologies (e.g., Moriarty and Honnery, 2012b). The following sketches the positions of the industry associations for photovoltaic (PV) and wind power.[12] These reflect the joint position of the various stakeholders. While utility providers, independent power companies and investor groups own the bulk of large systems, also private households own and operate smaller photovoltaic systems. The latter generate electricity and cover between one and three quarters of their electricity demand themselves. Hence, they shift from electricity consumers to producers at the same time, and become so called ‘pro-sumers’. This constitutes a new entrepreneurial model and might be described as a form of social entrepreneurship. Albeit the owners of RE differ their main positions are similar.

The PV industry expects to reach grid parity in the near future, i.e. long term costs will equal long term revenues (see chapter 3.2 on cost competitiveness). The time when grid parity occurs, it will differ across the market segments. In particular the utility supply and industrial segments can be expected to be cost efficient in the near future due to economies of scale. This implies that subsidy models should be designed in a fashion that allows policy makers to flexibly adjust support measure and thus react to market developments.

This affects the industries’ current competitiveness, which hinges on generous subsidy policies that are in place in almost any member country. There are various models in place where public budgets co-fund the systems, provide tax incentives such as declining balance depreciation, or guaranteed feed-in tariffs for RE. This led to a strong and socially desired increase in the EU-wide capacity of RE. The installed photovoltaic capacity soared from a mere 53 MW 2000 to 21,939 MW in 2011.[13] Wind power capacities have also been growing at an impressive rate – from 17,357 MW in 2000 to 56,535 MW in 2007 (EWEA, 2009).

EPIA (2011) and EWEA (2009) both have an interest in promoting the competitiveness of the respective technologies beyond subsidies. They expect that subsidies will be reduced as prices

---

[12] See http://www.epia.org/ and http://www.ewea.org.

[13] The bulk of capacity is installed in Germany, Spain and Italy.

reach grid parity. Their demands incorporate a continuation of tax incentives, R&D promotion, grid access, administrative harmonisation or the provision of concessional loans for RE systems. They favour cost transparency, for instance by stressing the low marginal costs through smart metering.

In addition they request a continuation of the grid expansion, whose costs should be allocated to the market as a whole. The expansion is vital for wind power that is typically generated in remote locations. Similarly, ‘grid stability’ is desired, i.e. the establishment of demand side management or storage plants. This position stems from the current energy policy, and does not consider the universal grids concept, where self-sufficient RE systems supply to local or regional consumers.

2.4.6 Politics and (sub-) national policy makers

The policy objectives are the result of a political process, be it at the regional, national or EU-wide level. These both affect and rely on the public opinion. In addition, national and regional policy makers implement the EU framework in their respective environment. Hence, they effectively shape the policy interpretation that subsequently affects the diffusion process. For instance, they adjust the regulatory policies to the characteristics of the relevant country, or they plan the necessary infrastructure, the transmission grid plans.

Promotion policies. The potential of RE depends on the respective factor endowments and path-dependency; countries with a greater share in hydro-power tend to have larger contribution of RE in the energy mix. Surprisingly, the promotion of the RE technologies shows little variance across member states, both in terms of the technologies and the promotion instrument (for an overview, see for instance Haas et al., 2011).

The promotion of RE should ideally consider timing and location of electricity generation, which is not adhered in all member states. Even more so, in some countries the integration of the growing share of RE is reaching its technical and economic limits. As a result, the question about additional subsidies arises, and whether adjustments should be made to current policies (see chapter 4 for country case studies).

Transmission grids. National policies weigh strongly in the discussion about the transmission grid. This topic is embedded in the broader debate on infrastructure provision. Also, the grid is installed under the consideration multiple objectives (cost, security of supply, distributed generation etc.) so that one and only one optimal grid does not exist. Grids are planned in a top down process, but are the indirect outcome of market and consultation processes; efficiency in transmission is distinct from the production due to the separation of grid ownership and production.

The sixth energy package of the European Commission promotes unbundled networks, i.e. the separation of the production and network operation of both electricity and gas. The implementation is country specific. The European Commission’s preferred option is complete ownership unbundling. It also tolerates grid operation by an entity that is independent from the owner of the grid, which is supposed to avoid conflict of interest. A third option is legal unbundling, i.e. energy producers retain ownership of the transmission networks, but the transmission subsidiaries would be legally independent.

2.4.7 The community level and the distribution grid

Utility companies of municipalities are the typical owners of the distribution grids. These are responsible for the roll-out of end user devices such as smart meters. In addition, they typically own conventional power plants. If universal grids are established, then electricity autarky in municipalities is achieved. Models are idiosyncratic and highly localised, with the municipality being in charge for the shape of the implementation.

Grid design. On one extreme, this may take the form of a virtual power plant. In such a plant, a common signal controls a series of small power plants. A complex system is optimised in a way that an orchestra of smaller stations works in a similar fashion to a large power plant, minimising the loss of economies of scale and automatically adjusting to the feed-in volumes of RE. On the other extreme are the mere roll-out of smart metering, and/or a minimum implementation of new technologies at the local level.

Data security. In addition, the advent of smart meters provides municipalities with information about electricity usage patterns at the household level. This evokes concerns about data security. IT experts may be able to reconstruct consumption habits of users that reflect their daily routines. Private households and corporate users are affected alike. The collected data might be abused by third parties, involving litigants, landlords and even cyber attacks with the goal to cause power outages. Hence, smart metering systems require an early awareness of their implications with data protection and privacy issues. These issues should be considered from the outset in a way that the overall policy goals are not affected. The existence of a specific and valid legal obligation is the most favourable option. It should reasonably balance the needs of the utility providers and the privacy rights of the consumers. At the same time, consumer's privacy rights may not be overridden, because their positive acceptance of and active use and involvement in the new technology are key policy concerns. (Knyrim and Trieb, 2011).

2.4.8 Small scale electricity consumers

Consumers constitute public opinion whose support is necessary to continue RE policies. This affects the support for the grid expansion, the establishment of long-distance lines, which requires land that may be scarce and might cause electromagnetic radiation whose health effects are unclear.

An intrinsic assumption of many energy policies is that consumers react to price changes, i.e. that demand is elastic. If it was, the merit order effect would induce a fall in prices when lots of RE is in the grid. Lower prices would then reduce demand, and congestion issues would not arise. The price mechanism alone would resolve arising issues. However, this view is problematic due to several reasons. Consumers such as private households or small and medium sized enterprises pay retail prices, which differ substantially from spot market wholesale prices that strongly fluctuate with the market; retail prices hardly fluctuate (most providers offer a day and a night tariff) and therefore hardly provide incentives to adjust the consumption behaviour.

Current electricity demand is inelastic. Simmons-Süer et al. (2011) establish in a survey for private households an average elasticity range between -0.2 in the short and -0.6 in the medium run. Lijesen (2007) examines real-time prices, i.e. the real-time relationship between total peak demand and spot market prices. These reactions are desired by policy models that assign consumer behaviour the potential to combat congestion. He finds a diminishing value for the real-time price elasticity ranging from -0.0014 to -0.0043. This may partly be explained by asymmetric information since not all users observe the spot market price, but rather base their decision on average costs. Yet, the coefficients remain extremely low after correcting for the unequal distribution of information. These findings are in line with survey results by Espey and Espey (2004) whose meta-study reports a range of price elasticities for residential electricity demand from -0.076 to -2.01 in the short run, and -0.07 to -2.5 in the long run. The elasticity varies over time, customer groups and across regions (e.g., Cooke, 2011).

If the limited demand response to prices is generally applicable to all users, the scope for policy makers to control the market through retail price adjustments and thereby use it as an instrument to support supply security is very limited. A stronger retail price reaction may change consumption patterns. However, this is not politically desired. Price mechanisms are currently incapable to counteract congestion – neither individual behaviour nor the willingness to pay affects the power consumption in the very short run. From this point of view, the security of supply turns into a public good (Elberg et al., 2012).

It remains unclear to which degree smart metering will change the demand reaction pattern. The first results of the roll out of smart meters are sobering, but the related automation of consumption depending on real time prices is typically not yet in place. Especially large and energy intensive consumers would have an incentive to continuously optimise their consumption (see below). Stronger price signals to end consumers may increase incentives to adjust behaviours.

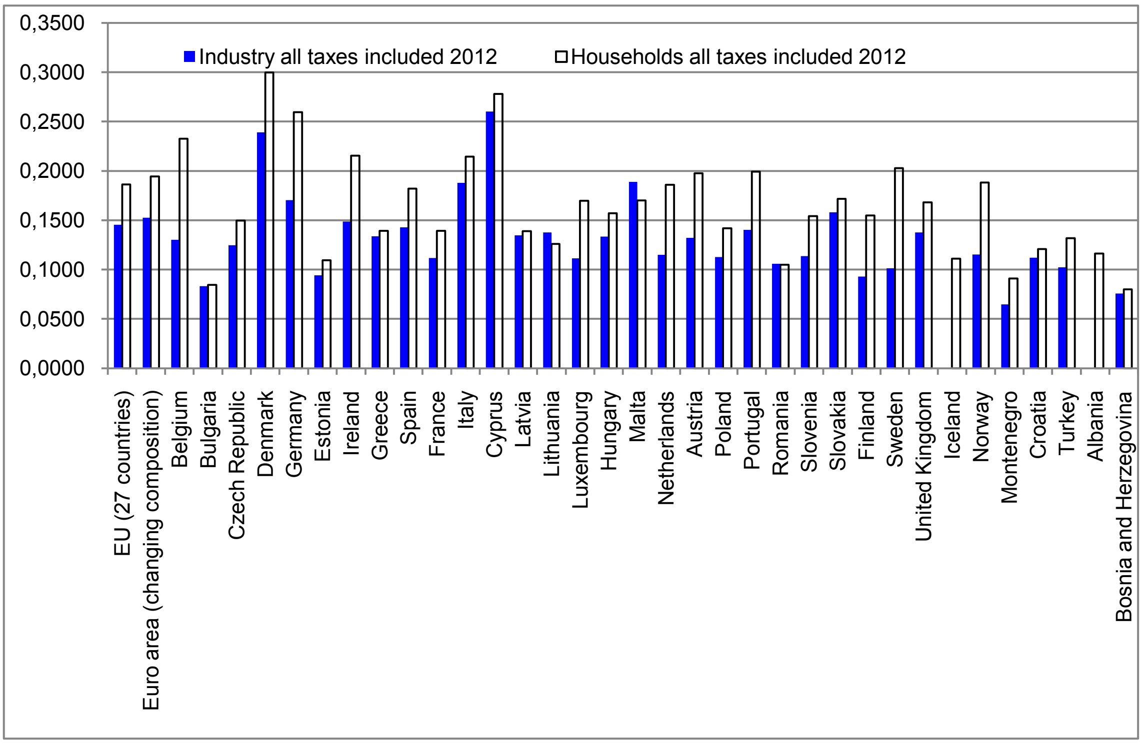
Yet, consumers have expressed reservations towards smart meters. While policy makers, analysts and utility providers support their deployment, backlashes came from the consumer side (Wolsink, 2012). Evidence from the United States shows that approval rates are low, but vary considerably across states (e.g., Karlin, 2012). Concerns refer to unclear benefits which are partly due to lacking price fluctuations so that a timely optimisation of usage patterns cannot take place, privacy issues (e.g., Knyrim and Trieb, 2011), and the yet unresolved cost allocation.

2.4.9 Large scale electricity consumers

The desired change in behaviour affects both small scale and large-scale consumers. The large scale segments comprise the industrial and commercial sector. It seems to be more elastic than the residential and SME segments. This is due to the mere differences in the volume of consumption large industrial users have more to gain from shifting load (Cooke, 2011). In addition, large consumers are more likely to have the metering infrastructure and more flexible supply arrangements required to support a more flexible response.

They have substantial bargaining power, which is also reflected by price data by Eurostat for 2010. Households pay on a European average a 28% premium for electricity in comparison to industrial consumers (see Figure 3).

Figure 3 **Household and industry electricity prices in € per KW/h across countries in Euro (2012)**



Source: Eurostat.

Also, the industrial price level is above the wholesale price level. The differences at the country level can be explained by the price setting mechanisms. These vary with the idiosyncratic market and regulatory structures; taxes and tax exemptions also complicate the price transmission mechanisms.

Nevertheless, large scale consumers do not pose a homogeneous segment. For instance, industrial processes may restrict demand flexibility when the production process cannot be interrupted or adjusted to price swings. Similarly, a user's electricity consumption may be large in an absolute sense, but make for a relatively small proportion of total operating costs. This reduces the incentive to change consumption in response to changes in price (Cooke, 2011).

2.5 Summary, discussion and conclusions

This contribution abstractly discussed the issues that currently arise from the integration of RE into the grid, which is a direct consequence of the 20% RE target of the EU. It revealed an enormous degree of complexity and multiple interdependencies of social agents. It seems that interventions in favour of the deployment of RE potentially aggravate existing trade-offs that policy makers should be aware of.

We used the social construction of technology approach (Bijker et al. 1987; Bijker, 2009) as a flexible framework to cope with the sector's inherent complexity. In a stepwise procedure we elaborated on 'smart grids' as a technological artefact. Agents typically have a diverging understanding of such a smart grid. We find that such 'interpretive flexibility' is strongly present. The most far-reaching definition comprises a fully automated, partly self-sufficient grid with multiple nodes. This grid largely reflects the policy objectives of Europe 2020, and paraphrases the final stage of a far-stretching broadening of the energy mix. On the other extreme, smart grids describe the implementation of smart meters that provide usage information to plant owners that subsequently optimise their operations. This range is important; if the policies implementation fails to achieve its final targets, a halt at an interim definition is likely.

We derived a series of technical requirements from the most comprehensive definition. These constitute the 'technological artefact' that we discuss. They comprise back up capacities that are becoming increasingly important as more volatile wind and solar power enter the grid and electricity itself cannot be stored; transmission grids will probably need to get expanded to incorporate remote RE plants (e.g., wind), distribution grids require sophistication as high and low voltages and AC and DC increasingly coexist. The multiple nodes increase complexity that challenges the operational management of the system.

The technological artefact allowed us to identify the relevant 'social groups'. For the technology finding process to stabilise, a mutual understanding of the new technology is required. Once this final stage will become irreversible, and a 'closure' will occur. This, however, is currently out of sight. The positions are too different to be accommodated by a single interpretation. Put differently, a mutual understanding of the final market mechanisms is not yet perceivable (see Table 1).

Table 1 **Stakeholder roles and their positions**

Stakeholder / Agent	Role	Key position / reaction
EU	Sets legal and policy framework (e.g., Climate and Energy Package; Europe 2020) Policy platforms R&D promotion	Europe 2020 targets (20-20-20) Target market Optimisation of the current grid
National grid policies and regulation	Implementation of EU framework Idiosyncratic policy mix: regulation, grid planning, subsidy Top-down grid planning after a consultation process under several objectives Challenge to solve the trade-offs	Grid optimisation ongoing Strong tendencies towards grid expansion despite unfavourable public opinion and hampering legal environment Ongoing debate on strategic reserve / capacity market

Stakeholder / Agent	Role	Key position / reaction
	between i) the merit order effect vs. security of supply; ii) capacity market vs. grid management; iii) capacity vs. EU target market; iv) target market vs. spatial market splitting / regional solutions	
National and regional politics	Set promotion policies Follow public opinion; may promote RE regardless of the grid structure or market mechanisms; country specific behaviour	Shape and follow public opinion
Transmission system operators	Operates and often owns the transmission grid; possible conflict of interest of a regulated monopoly; desired profitability unclear (yard stick regulation) Security of supply can come at costs; optimal allocation of dispatch costs unclear Top-down implementation of grid plans Unresolved question of how to incorporate (short-term) bottom-up flexibility needs in long term top-down plans Faces policy uncertainty (promotion, regulation, market model)	Optimisation of the grid operation Seek alliances (e.g., site sharing with other infrastructure) Improvement and expansion of the transmission grid at costs that are either socialised or incurred by the market Not favourable to incurring dispatch costs Call for a comprehensive and stable regulation
(Municipal) Distribution grid operators	Often owned by municipalities or their utility firms Implement local political decisions Often co-owner of larger scale RE plants Operates and manages the last mile, switchyards etc. Required to install smart meters	Varying positions depending on their stake in the energy mix Improved communication (e.g., enhance awareness about their role in solving the involved complexity, public awareness of technical and financial requirements Seek alliances (e.g., site sharing)

Stakeholder / Agent	Role	Key position / reaction
	Holder of data (data security concerns)	Reform promotion of RE to increase self-consumption and lower feed-in
Conventional power suppliers	Traditionally low innovation intensity Investment incentives low due to declining profitability Fierce competition (liberalisation, RE, internationalisation) Merit order effect Decrease in economies of scale, yet required for security of supply	Stress their systemic relevance Demand a (partial) halt of RE promotion; investment incentives for conventional power Demand subsidies for maintaining emergency capacities Not favourable to incurring dispatch costs
RE producers	Providers of RE: Intrinsic part of the policy objectives Rely on back-up capacities Require grid access (bottom-up) Unclear position to local energy systems	Continuation of promoting and integrating RE Market development: Market after grid (socket) parity; continuation of technology diffusion, R&D
Small scale consumers	Demand inelastic to retail prices Also producers of power (pro-sumer) Entrepreneurial pro-sumers that sell power on the market versus self-consumption Shape public acceptance	Low electricity prices Commitment to RE Reservations towards smart meters (cost-benefit)
Large scale Consumers	Demand more price elastic than for small scale consumers Sometimes also producer of electricity	Low electricity prices as a determinant of their competitiveness (varies across firms' energy intensity)

The challenges reconsidered

New capital stock and more technical complexity. The implementation of the energy objectives of Europe 2020 is fundamentally transforming the existing electricity market. It greatly increases both the industrial and technical complexity.Increasing the portion of RE that feeds into the grid pushes the market mechanisms to their boundaries, and renders parts of the existing capital stock of the electricity industry obsolete. Yet, it creates a strong need to continue investing into new facilities, on-call capacities, and transmission and distribution grids. This poses substantial challenges to a comprehensive industrial technology policy.

Security of supply. There is an economic efficiency trade-off that is fundamental to the market selection process in the sector. With the promotion of RE distributed power suppliers – both large and small scale – entered the wholesale market with marginal costs that are close to zero. The merit order principle keeps prices at a minimum by feeding producers with lower marginal costs (as RE) preferentially into the grid. Hence RE displaces conventional suppliers, especially gas. The merit order adds to the competitive effects of the liberalisation, which already reduced conventional suppliers' profitability, investment incentives and economies of scale.

We argue that the current promotion of RE aggravates existing tradeoffs of the European energy-policy triangle. The promotion of i) more ecological sustainability in the form of RE partly distorts ii) the market mechanisms and its competitiveness, and eventually puts iii) the security of supply at risk. The energy triangle reflects socially desired objectives, whose mutual achievement is questionable. These trade-offs are *inter alia* reflected by the social agents' positions.

Divergence in the time of production and consumption. RE is not constantly available, which is why production occurs at a different time than consumption. When RE is not being fed into the grid, the load drop needs to get technically compensated to avoid outages. Hence, back-up capacities need to be in place, which are typically conventional capacities that secure the constancy of supply. These are more expensive than RE and harbour risks of static, price inefficiency. These additional capacities cause costs that are greater than the costs of RE, which shifts the wholesale price level upwards and are typically passed on to consumers. Hence there is a negative feedback effect on prices – while RE lowers the price, the costs of congestion management increases them.

Unresolved challenges to the grid management and its structure: An 'optimal' grid does not exist. Multiple grids are imaginable of which each meets certain criteria. From a planner's perspective, the eventual structure of the grid depends on the target function. For instance, the consideration of distributed, perhaps remote generation or the establishment of a grid with the most security of supply does not correspond with a grid that causes the least possible costs given a minimum provision.

Several unresolved questions emerge that concern the coping mechanisms in the case of congestion. These feed-back on the grid structure. Should a target market, the main regulatory response by the EU be implemented if capacities are nationally installed that render an international response futile? Should regulatory instruments be applied which the smother outcomes the merit order effect? This might for instance incorporate not connecting certain RE capacities, or fines for not providing contractually set capacities. Should capacities (or reserves) or grid management tools solve congestion issues? Is the target market to be preferred over regional solutions with self-sufficient subsystems, or over a regional market splitting, respectively?

Geographical divergence. Next to the timely divergence of production and consumption stands its geographic dispersion. In particular wind farms require new lines that connect them to the general grid. This raises the question about how to connect emerging suppliers to a grid which is planned? A power grid is not a 'web' that constantly re-emerges in a bottom-up fashion. This causes a discrepancy between centrally planned grids at the national level, the increasingly internationally interwoven markets and not systemically designed connecting lines to distributed generation capacities.

Market outcomes vs. economic planning. Both the infrastructure and the energy production are intriguing cases from an economic planning versus free market perspective. The market selection process under-supplies socially desired eco-friendly technologies. Hence public policies subsidise technologies which as a result are increasingly displacing the technologies that are currently provided by the market. These are required in order to keep the market functioning as a whole. Distributed technologies with quasi no marginal costs compete in a supposedly free market with technologies whose marginal costs are greater than zero. Hence, the market selection mechanism is not applicable, and another allocation regime is required to incorporate both classes of technologies.[14]

The integration of RE in its current form requires an expansion of the infrastructure. The transmission grids are planned by central authorities after a consultation process, and not the result of a competitive (bottom-up) selection process. Similarly, the physical grid structure changes to a plethora of distributed power producers that feed electricity into the grid at various nodes. It is unclear how a grid with sufficient flexibility to incorporate emerging producers can be set up.

In the present setting policy makers' decisions replace market outcomes. This has been, and probably still is necessary due to the planning aspects of the sector. Policies, however, face the usual uncertainty about their effective implications, what technologies are available in the long run, and what the grid requirements result (e.g., the location of the suppliers). This renders the available information imperfect, affects the efficiency the grid planning, and increases the risk of planning mistakes. Interdependencies of actions are equally unclear – which is a common outcome of complex systems (see Annex III).

Towards policy

Heterogeneous picture. An informed, comprehensive picture in the public is yet lacking. For instance, RE is widely accepted and perceived as desirable. Yet, the transmission grids that are required to implement them face a less favourable public opinion. Similarly, policy makers typically do not mention that a broadening of the energy mix will involve additional costs that some agent will have to incur.

Flexibility vs. certainty. The energy industry in general and the electricity industry in particular have a long planning horizon. On the one hand, the legal, regulatory framework should provide

---

[14] The electricity sector could be compared to telecommunications, another network industry. Other than in electricity, the telecom sector relies on marginal costs, but implements a forward looking long run incremental cost approach in infrastructural questions. However, this requires a lot of information that regulators obtain from very few companies. While this would solve the problems of the differences in the economies of scale, it is operationally not feasible in a market with multiple agents.

as much certainty as possible to investors. On the other hand, policy makers should maintain their ability to flexibly adjust policies, and share risks with beneficiaries in the case of subsidies (see chapter 3).

In particular the promotion of RE should be flexibly designed over time, and if possible distort existing market mechanisms as little as possible. A central component here is the self-consumption proportion of the generated electricity. If distributed power is being consumed locally and not fed into the grid, it is more cost-efficient (socket-parity instead of grid parity), and infrastructural challenges are substantially being alleviated. This supports the bigger picture of the entire electricity industry that seeks to broaden its production mix and is required to guarantee the security of power supply.

Grid development. The grid development should get promoted at all stakeholders, including the public opinion. To avoid excess capacities, congestion management and demand side instruments should be prioritised over capacity or reserve markets that entail unresolved questions of the cost allocation, and in addition distort the market mechanisms further. Also, a stronger bottom up aspects of grid planning should be considered. Then again, grid expansions should be pursued cautiously. Infrastructure as a policy field seems straightforward, and current shortcomings may easily tip into overcapacities that exceed the economically necessary and socially desired level of provision.

The European, the national and the local perspective. On the one hand electricity markets should benefit from natural resource endowments across the EU to optimise the resource use, e.g., sunlight in Southern Europe, Wind in Northern Europe, tidal power where the tidal differences are large. On the other hand these are country specific, and national players should maintain a European perspective and not revert to national thinking which may be detrimental to the EU as a whole (see also WEC, 2010). The ability to internationally compensate should not be sacrificed in favour of national solutions; this does not necessarily contradict localised, self-sufficient energy solutions (see also the Danish case in chapter 4).

3. Promotion instruments, cost competitiveness and diffusion lags

The aim of this chapter is to conceptually assess the appropriateness of the design of the intervention instruments. Almost all member states promote the diffusion of renewable energy production. These efforts were successful: the contribution of RE to the energy mix has been growing fast, and the growth of its penetration has been outpacing economic growth.

The technology fields that policy makers chose are mainly solar and wind power. Both have been deemed to be sufficiently mature for deployment from a technological perspective among all renewable sources (e.g., Moriarty and Honnery, 2012b; Jäger-Waldau, 2007). We use them as examples for RE technologies, and assume that other technologies such as biomass are subject to similar mechanisms, even though specific results might differ (e.g., grid parity). Also, we will not discuss technologies that still are in the developmental stage (e.g., tidal power) and technologies that are already deployed to a large extent (e.g., hydro-power).

The picture that the present chapter draws is isolated from the abstract, systemic mechanisms of the previous chapter, as well as from idiosyncratic implementation models of the country case studies that will be depicted in the next chapter. The remainder gives an i) overview of intervention instruments, and focuses on the promotion of diffusion. It then debates (ii) the effects of the policies on the cost efficiency of the operation of wind and solar power. Next it reflects the promotion against the findings about diffusion patterns lags (iii). A short summary with some thoughts on policies closes this chapter.

3.1 Policy instruments

There is a broad spectrum of intervention instruments (see Table 2). The fundamental choice is between technology push (e.g., R&D), and demand pull instruments (e.g., information platforms, adoption).

In the long run, the supply of technology is probably the most important determinant of the energy mix. The availability of competitive RE technologies may decouple the energy mix from diffusion (and perhaps industrial) policies. A lasting technology push is best fostered through a sound, well-funded research system, functioning market mechanisms, and perhaps mission-oriented R&D promotions at the firm level. However, the technology spectrum changes slowly, and the policy targets are set for the short to medium term.

Policy makers aim for quick results, and therefore intervene in market processes, despite their poor understanding of the technical peculiarities and relative inability to adequately assess the effects of their actions (Nemet, 2009). The promotion of diffusion was chosen over more general and perhaps more effective technology-push instruments such as R&D, because they are suitable for policy makers' showcasing. The alternative would have been to invest in R&D, which produces innovations in a non-linear, unpredictable fashion that enter the globally available technology pool. Innovations are then not directly attributable to single policies, let alone policy makers. Moreover, supply-push programmes involve risk and time to produce results, whereas the effects of the diffusion of existing technologies are supposedly certain (Roessner, 1984).

Table 2 **Spectrum of promotion instruments**

Addressee	Instrument
Innovation system	Government strategy, regulation, research and education system.
Producer	Direct and indirect R&D subsidies, investment promotion, guarantees, public procurement.
Demand	Financial: Direct and indirect instruments that promote generation and installation of RE systems. Non-financial: Awareness programmes and consumer information, demonstrations, deployment facilitation (e.g., assistance with safety, sitting, planning or connecting requirements)
Technology specific environment	Platform initiatives, standardisation, training, product testing facilities, consumer protection.

Source: Adapted from Roessner (1984); Haas et al. (2011).

3.1.1 Diffusion instruments

Policy makers opted for the promotion of diffusion rather than technology push support schemes. They seek to create a demand-pull situation by enlarging markets for a respective technology (Nemet, 2009).

Any promotion comes at the risk of suboptimal volumes. If subsidies are too low, delivered through the wrong instrument (see below) or not applied long enough, they do not stimulate the diffusion. If they are too high public monies are wasted, which under budgetary constraints must not happen. Therefore optimal policy instruments have a high leverage – diffusion occurs at the minimum use of financial resources. Additional policy objectives refer to the EU’s energy triangle – security of supply, competitiveness and sustainability. As a result, policy makers require lots of information about the market that is typically not available.

The promotion instruments can be direct or indirect. Direct instruments immediately stimulate the roll-out of RE, whereas indirect instruments shape the environment in which the diffusion occurs. Haas et al. (2011) distinguish instruments between investment into the production system and the operational generation of electricity through feed-in tariffs. Both interact and affect the cost competitiveness (see the section on grid parity below).

The promotion of the system

The most straightforward intervention is to subsidise *investments*. This is also simple to administer. Support is for instance provided through preferential financing products such as soft loans, or more directly through co-funding of the system through a one-off payment whose extent is set by the administration in charge. Typically criteria concerning the technical specifications are being considered.

The promotions are either allocated on a first-come, first-serve basis, or through auction. Auctions directly address the information and allocation dilemma, and are to be preferred over a first-come, first serve allocation of funds. The extent of the subsidy is the result of a bidding procedure. In a tender, investors compete for public money by providing cost estimates (system price in € per KW), and the most cost-efficient proposal receives the award. Auctions would thereby reveal the preferences of the investors and information about the systems' market.

Price instruments: Feed-in tariffs

Investment support is often coupled with the *price-based promotion of generation*, affecting the choice of the operator whether to consume the generated power or sell it to the grid. The promotion of sales can take the form of a feed-in tariff (FIT) or a production premium.

- Grid operators pay a guaranteed feed-in tariff to providers of RES-E. These partly use the produced energy themselves and feed the remaining proportion back into the grid, for which the producers obtain a fixed price. The buyers of electricity obtain a wholesale price on the electricity exchange, which is below the fixed price they had to pay. The difference between the two prices constitutes the subsidy amount, i.e. it is the additional cost of RE in the grid. These additional costs are re-financed either by tax money or by the electricity consumer. Paradoxically, RE is becoming more cost competitive due to the price increases that the pegged FIT caused.
- A production premium is a fixed payment per unit of generated energy that a government institution, the utility provider or a supplier is obliged to pay for RE.

The costs for public budgets of both schemes depend on electricity prices. Hence, both schemes are subject to substantial uncertainty. As to the FITs, the maximum cost of the subsidy is given by the level of the tariff when prices are nil. The costs of premiums are potentially higher if the price premium exceeds the level of the FIT, the alternative model. In a model world the premium option allows RE to compete with conventional sources. This considers production costs and the implementation of policies that price-in externalities. In practice, however, a fixed premium is rather a comparison of production costs of RE with the electricity price than an assessment of the environmental benefits of RE (Haas et al., 2011).

Fixed payments shift the risk of away from system operators and therefore are an effective instrument to promote the diffusion of RE. Yet, for the same reason they are exposed to substantial criticism from a public policy perspective. The risk-sharing mechanism is lopsided. Given the acquisition costs of the system and relevant start-up promotions, price pegs determine the profitability of the project's operation. They shift the risk of price fluctuations from the operator to the financing institution. Incentives to optimise pay-offs are largely lacking on behalf of the beneficiary of the subsidy. In addition, policy makers are exposed to great uncertainty about the future subsidy volume. The lower the wholesale prices due to more RE the higher the committed wedge will become. The current trend suggests a continuation of the rather low wholesale prices and therefore a high financial burden. This stems from falling prices for raw materials due to the ongoing crisis; impetus for price increases from Europe's ill-functioning CO2 market is not to be expected, either. Finally, the excess costs may undermine the public opinion, or induce budgetary constraints that tilt support measures. This would come at the risk of a halt of all support, which would harm policy makers' flexibility (see the country case study below on Spain).

In addition there are *quantity-based* mechanisms that promote the generation (e.g., tradable guarantee of origin certificates, TGC). These include public bidding processes, where bidders that win a competition receive a fixed price for a certain quantity of electricity for a set period. A similar option are tradable certificates, where market agents need to demonstrate that they have a certain portion of RE in their energy portfolio. Certificates prove that they either purchased or produced RE, or that holders purchased the certificates (Haas et al., 2010; 2011).

The highest growth in RE across member states has been triggered by FIT which was implemented in a technology-specific manner. Certificate systems tend to show a low effectiveness with respect to accelerating the deployment of less mature technologies such as solar PV (Haas et al., 2010). Yet, it has been argued that FITs are suboptimal instruments to foster the self-consumption. A critical determinant is the proportion of self-consumed energy. If the FIT is above the market price, there is no incentive to self-consume the generated power. More distributed electricity in the general grid supports the idea of entrepreneurial pro-sumers, even though it contradicts the idea of self-sustaining, localised production and consumption structures. Also, if there is no incentive for self consumption and market participation is enabled by FITs that exceed market prices, rent seekers are likely to emerge whose benefits come at social costs.

An instrument that is suitable to promote direct consumption is net-metering, i.e. the direct compensation of fed-in power with power used from the grid. This has the psychological advantage that it considers only the difference between consumption and production, promoting the very nature of decentralized energy. An exchange of cash-flows takes place in a fashion that is decoupled from the market prices (EPIA, 2012).

Indirect instruments

Indirect measures affect the diffusion process include taxes by shaping the environment. The most prominent examples are tax measures. These can be applied to competing energy sources (e.g., taxes on electricity produced with non-renewable sources, taxes/permits on CO2 emissions) or indirectly promote RE (e.g., through tax instruments such as grants, allowances, or the simplification of bureaucratic procedures). Another indirect measure is a change in the subsidies policy, e.g., a subsidy halt or reduction for non-RE. Furthermore, ancillary services often facilitate the deployment of RE (see also Table 2).

3.2 Grid parity

A key concept that allows an assessment of 'market maturity' is grid parity. It translates to cost 'effectiveness' in the sense that a technology is able to compete with established technologies on a cost basis. Different segments require different definitions of (dynamic) grid parity. For the household segment, for instance, the retail price is the comparison for grid parity. Self consumption is likely to play a bigger role. Then not the grid price that considers generation and transmission costs plus profit margins and taxes, but the generation price should be used as a benchmark ('socket parity'). For operators that do not consider self-consumption and feed all produced electricity into the grid, the wholesale price serves as the benchmark for parity (e.g., Lettner, 2013).

Grid parity is defined as the break-even point that is met when a source of energy is able to generate electricity at 'levelised costs' that equals or undercuts a given price. The levelised cost concept economically assesses the cost of the energy-generating system. It includes all costs over the project's lifetime. The lifetime is considered in order to add the dynamic component. To obtain information about static grid parity, a specific point in time is chosen. The costs that are considered involve the initial investment, the operational and maintenance investments and the cost of capital. To assess grid parity, the second major component that is required is the purchasing price of electricity – either retail or wholesale. Third, the feed-in tariff and/or the proportion of the self consumption need to be estimated. Grid parity is given if the net present value of the costs of power with a RE system is below the net present value of the power costs without a RE system. This also needs to consider self-consumption, storage and feed-in tariffs (see Lettner, 2013; Lettner and Auer, 2012a; 2012b).

Since market prices are used as benchmarks, an adverse feedback effect on the cost competitiveness of RE may occur due to the merit order effect. The more RE enters the grid, the lower electricity prices will become, and therefore it will be harder for RE to achieve grid parity. An increase in PV (or wind power) decreases its own cost competitiveness, which is sometimes labelled 'cannibalism of PV'.

3.2.1 Photovoltaics

In a global analysis of 150 countries, Breyer and Gerlach (2013) find that the 2010s will be characterized by ongoing grid-parity events for photovoltaics (PV) throughout most regions in the world. PV will be a competitive source of energy. This will cover about 75–90% of the global, addressable electricity market.

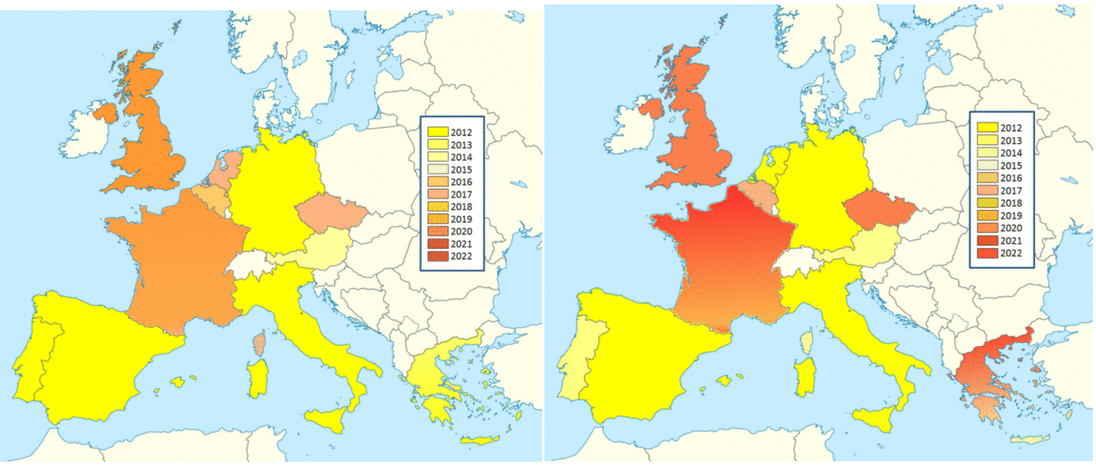
Similar results are produced in a Europe-wide project, PV-Parity. The consortium discusses the competitiveness of PV with the aim to provide advice policy makers.[15] It conducts cost - benefit analyses of the integration of photovoltaic electricity in the energy system. For each of the countries under examination, a selection, disaggregation and country-specific consideration of the key parameters and financial support schemes and their empirical scaling was conducted.

---

[15] See http://www.pvparity.eu.

The case of a hypothetical PV system was confronted with the situation without a system; the main components were the external procurement cost from the grid, its replacement by self-consumption and storage, as well as the electricity that was fed back into the grid (for the details about the calculus see Lettner and Auer, 2012a; 2012b; see Figure 4).

Figure 4 **Grid parity of PV in the commercial and residential sector**



Source: PV Parity, http://www.pvparity.eu/results/pv-competitiveness/; retrieved 15 April 2013.
Note: Commercial sector is the left and the residential sector right graph.

The cost competitiveness was strongly supported by a fall in prices for solar systems during the period from 1990 to 2010. The price reduction has particularly accelerated in the late 2000s. Between 2009 and 2011 the wholesale cost of solar modules dropped approximately 70%. The electricity price from solar energy dropped approximately 25 times (Brankera et al., 2011; Dale, and Benson, 2013). European producers of PV system have been facing increasing price competition from Chinese imports. The strong decline in prices evoked criticism about Chinese subsidy policies. The European Commission must determine by 6 June 2013 whether provisional anti-dumping duties should be applied. A final decision will not be made before the end of 2013.[16]

Promotion of PV and grid parity

Grid parity is a precondition for a technology to contend on the market place. It therefore plays a key role as a determinant of diffusion, which also affects the subsidy policies. Grid parity *per se* can be estimated with and without the consideration of promotion instruments. The country-specific mix of promotion instruments, falling system prices and increasing electricity prices led to a gain in competitiveness of PV. Put differently, operators of PV systems (which typically have received public co-funding) are likely to face lower costs over the lifetime of the PV system

---

[16] Dale and Benson (2013) provide an analysis oft the net energy flows of the global PV industry. Their results suggest that the industry was a net consumer of electricity as recently as 2010. However, there is a likelihood of more than 50% that in 2012 the PV industry will be a net electricity provider and will "pay back" the electrical energy required for its early growth before 2020.

than in the comparison scenario without the installation of a PV, where power comes from the grid alone.

For the policy maker that seeks to minimise the budgetary burden, the question is whether the operation of a RE system is cost competitive without public subsidies. If it is, the market provides an incentive to invest in RE; subsidies can be halted, or at least reduced.[17] Lettner (2013) provides such comparisons for 2012 for three countries: Austria, Germany and Italy. All countries used both FITs as well as promotions of the systems. The results for Austria show that smaller PV reached grid parity due FITs, a high self-consumption assumption (56%) and investment subsidies. Even large are cost-efficient due to FITs and the promotion of the systems. A subsidy-free world, however, does not produce grid parity for larger systems (i.e. systems over 3.5 kW). Austria does not incentivise self consumption, as the tariff is over the market price for electricity. A similar picture emerges for Germany, where large systems in the commercial already reached parity without promoted FITs. This is due to the higher benchmark. The electricity price level that serves as the comparison is higher in Germany due to the RE levy (see the country case study below). The parity situation is similar in Italy, where higher system prices are compensated by more sunlight.

Lettner (2013) concludes that, by and large, PV reached competitiveness as a decentralised generation technology, and promotion instruments should be adjusted accordingly. Generation and consumption are often overlapping. On the one hand self-consumption is desirable. On the other hand, more self-consumption may lower revenues for grid operators that require revenues to expand grids due to the greater proportion of RE.

Notably, the causality between grid parity and promotion policies goes in either way. Grid parity serves as a basis to determine the policies (promotion volumes, type of promotion etc.), and the policies themselves affect grid parity. Similarly, grid parity should not be seen as the sole policy objective. It needs joint consideration with electricity transmission issues that emerge from the timely and geographical dispersion of the production of power and electricity consumption. Cost competitiveness also relates to the substitutability; it is a precondition on which many environmental policies such as CO2 taxation or the non-delay of interventions hinge (Acemoglu et al., 2010)

3.2.2 Wind power

There is less evidence for the grid parity of wind power. Wind turbines reached grid parity in some areas of Europe and the United States in the mid 2000s. Assuming an expected decline in system prices and capital costs, and that output efficiency will continue to improve, a study by Bloomberg Energy Finance (McCrone, 2011) anticipates that the average wind farm will be fully competitive by 2016.

---

[17] Interesting lessons learnt are provided by Roessner (1984) who shows that early efforts in the 1970s to commercialise PV in the US did not lead to grid parity. As a result, the diffusion process was hampered (Roessner, 1984).

3.3 Diffusion time

The quintessential goal is not to promote cost competitiveness, but to accelerate the deployment of RE. The policy targets are set for a short time horizon, 2020. Let us assume that policies rendered RE are sufficiently mature to achieve a technology specific saturation point. How long will it take until the chosen technologies fully diffuse?

Wilson (2012) compares the historical diffusion trajectories of supply and end-use energy technologies. Growth periods are correlated with installed capacities, i.e. there is a positive network effect that reinforces the diffusion. Once a critical mass point has been reached and technologies spread spatially from their initial market, the time to reach a certain level of cumulative capacity decreases. The process is initiated by a formative phase of experimentation at the unit level. If the first phase produces competitive outcomes the unit size starts to increase, in particular when scale economies are present. The up-scaling process is distinct from the spatial diffusion process. The author explicitly warns policy makers to generously time policy targets. *'The extended length of the formative phase as a precursor to subsequent unit level growth (up-scaling) as well as industry level growth (diffusion) similarly cautions against over-exuberant efforts to compress the timescales needed to ready large-scale energy technologies for widespread deployment. Extensive diffusion takes time; so too do the knowledge generation processes that underwrite the capturing of economies of scale at the unit level'* (Wilson, 2012). These case studies are based on the stylised facts on the past diffusion of energy technologies (Wilson et al., 2011).[18] The paper uses historical relationships to assess the expected technological trajectories in future scenarios. They provide an assessment of the relationship of future low carbon technological growth in the power sector. They find that the current expectations of technology diffusion appear to be conservative relative to what has been evidenced historically.

These results should put into perspective by broadening the analysis to other technologies. For instance, Comin and Hobijn (2010) show adoption lags for 15 technologies and 166 countries over the period 1820-2003. They find that the adoption lags after the technical invention tends vary considerably and become shorter and shorter over time. Most of the variation is due to technology specific variation, which makes for more than half of the variance of adoption lags in the sample. Also, there are significant differences across countries. Case studies of country groups show variance in adoption lags across developmental episodes. The shorter the lag is the more developed a country group becomes. The differences in technology adoption account for at least a quarter of the sample's per capita income disparities.

Furthermore, the study depicts diffusion lags of certain key technologies. Some require complementary structures (e.g., cars require roads), while others are (to a greater or lesser extent) stand alone technologies (e.g., blast oxygen steel). A change that involves a shift in the consumption behaviour is more time intensive and further expands the diffusion time. For instance, the diffusion of video recorders or mobile telephones took much longer than seat belts

---

[18] Similar findings about technology formation processes have been produced for energy efficiency lamps (Menanteau and Lefebvre, 2000).

in cars or metric systems in countries that use imperial measures (e.g., Rogers 2003). This variance is also confirmed in a meta-study by Grubler and Nakicenovic (1991). They find that diffusion processes tend to last between 15 to 30 years. There is stronger evidence for the synchronization in the saturation phase rather than in their formative period. The diffusion process seems to be much more focused toward the saturation phase.

3.4 A discussion towards modified promotion policies

The diffusion of RE was heavily promoted, which led to cost-efficiency in almost all member states. In 2012, grid parity of PV has been achieved, or will be achieved shortly. In Germany and Italy, for instance, the optimisation of self-consumption allows for cost efficiency of larger systems without subsidised feed-in tariffs. Also wind turbines are expected to break even in the near future. This is agreeable with the promotion objectives, and has important implications on the design of future policies. From a systemic perspective, also the regulatory regime, the underlying market mechanisms and the requirements to the grid need to find consideration in the design of technology policy instruments.

Technology diffusion takes between 15 and 30 years; RE has hitherto been diffusing very fast, which indicates that such estimates are rather conservative when they are applied to RE. Yet, the time span is based on free market economies, and it is obvious that promotion policies accelerated the diffusion. The fast deployment may have shortened the ‘formative phase’ of the diffusion process, which is necessary to generate learning effects and allow for incremental technological improvements. Compressing the timescales further may lead to the deployment of premature technologies.

On one extreme, ‘excess momentum’ may occur where an existing technology is replaced by a newer, yet inferior one (e.g., Arthur, 1989; Farrel and Saloner, 1985; Friesenbichler, 2013). Policy attempts to prematurely roll-out RE technologies were documented by Roessner (1984). Already in the 1970s there was a mismatch between the technological maturity and commercialisation status in the USA. Appointed officials used PV as a highly visible and easy to implement technology, which had not reached the commercialisation maturity that would have been required for an effective deployment.

The current promotion system rests on pegged payments that shift all risk to the promoting agency. Beneficiaries of subsidies have no incentive to ‘optimise’ their operations. The subsidy volume is uncertain since it is the wedge between prices on the wholesale market and the fixed price. The public - or the consumer - that funds the subsidies is exposed to sever uncertainty about their financial commitment that depends on the market price. If the funding agent cannot bear the costs any more a halt of all promotion measures is imaginable as a last resort. This would restrict policy makers’ scope of action, which would come at the cost of the greening of the energy mix as a whole. Cognizant of a potential ‘swing back’, even RE industry associations such as EPIA (2011) and recommend that ‚*support schemes (including FITs) need to be adapted on a regular basis to avoid market disturbance. Profitability can be assessed on a regular basis and support schemes adapted accordingly’*.

Promotion policies should get modified so that they shift parts of the risk to operators, i.e. that a risk sharing between the co-funding agency and the beneficiary is in place. Price pegs should get alleviated in favour of auctioned promotions for newly established systems. Self-consumption should get favoured over feed-in solutions to avoid distorting effects on wholesale markets, and minimise the investment requirements to grids.

4. Transition experiences: A three country case study

In the wake of the recent crisis industrial policy is experiencing a renaissance. At the same time, policy makers are searching for solutions to societal problems and merge industrial policies with innovation policies. This led to the prominent inclusion of environmental industries, and technologies, as policy targets (e.g., OECD 2012; Soete, 2007), which prolongs the long history of governments in industrialised countries that promote the diffusion of ecological innovations (e.g., Roessner, 1984; Soete, 2007).

Recent interventions in Europe's electricity sectors draw on the Europe 2020 targets. Since the free market would not achieve the set goals, policy makers intervene to shape outcomes accordingly. These policies work through direct intervention or the legal framework; they set up constraints and incentives to affect (Kerr and Newell, 2003), even 'bias' technological change. The specific means to realise the Europe 2020 targets are implemented at the country level, so that policies are able to consider the idiosyncratic factor endowments, path dependency, market structures and the respective socio-political environment. This led to several different promotion strategies for RE across Europe, which this contribution will elaborate on.

The transformation of the energy mix does not (only) require minor adjustments, but a fundamental reform of the sector. The societal net-benefit that it promises serves as good reasoning for policy makers that maximise overall welfare. Huge investments are required. According to the IEA, the global energy sector needs to invest an estimated US$ 16 trillion in the period 2003-2030. In Europe alone, about € 500 billion worth of investment will be needed to upgrade the electricity transmission and distribution infrastructure. Albeit the net benefits from more RE are assumed positive, the shift itself is not pareto-efficient. Operators of existing machinery with a positive book value will have to write down parts of their machinery and equipment; TSOs and distribution grid operators will have to finance the grid expansion, and consumers may face higher electricity prices (Castro, 2011). Tax payers will carry the additional burden if the promotion is financed by the general budget.

This chapter discusses the experiences of three countries in their endeavour to switch to more RE. It is organised as follows:

- We justify the country selection.
- We describe the design of the main diffusion instruments.
- We depict the idiosyncratic developments along two questions:
    - What are the countries' experiences with incorporating RE in the grid while guaranteeing security of supply?
    - What cost allocation models are in place (given the ownership structures)?

4.1 Country choice

First, we identified these due to their strong increase in RE. From 1995 through 2011 the proportion of RE sources in electricity rose in Denmark from 5.1% to 40.1% and in Spain from 14.7% to 29.9%, which seems equally dynamic as in Germany where the ratios rose from 4.9% to 19.9%. Second, we sought to cover the main continental electricity European wholesale markets. Neighbouring countries are expected to integrate first and constitute regional markets before a Europe wide integration occurs. Hence, the showcases serve as specimen for their respective region. We cover the main electricity wholesale markets - Denmark is part of the Nordic, Germany of the Central European and Spain part of the Iberian, Southwest market. Third, they were selected based on their differing technological capabilities. For instance, the European Innovation Scoreboard depicts Denmark as an 'innovation leader', Germany as a 'follower' and Spain as a 'moderate innovator'. The countries also differ across variables like population size, energy dependency and use or the GDP per capita (see Table 3).

Table 3 **Country overview**

	Denmark	*Germany*	*Spain*
GDP per capita 2010 in Euro1)	30,954	29,005	24,422
Average annual GDP per capita growth 2010/19951)	3.20%	2.91%	4.08%
Population size 20122)	5,580,516	81,843,743	46,196,276
RE as a percentage of gross internal energy consumption in 20112)	21%	10%	11%
RE as a percentage of gross internal energy consumption in 19952)	6%	2%	5%
RE sources as a percentage of total electricity production in 20113)	40.1%	19.9%	29.9%
RE sources as a percentage of total electricity production in 19953)	5.1%	4.9%	14.7%
Total energy consumption in 2010; equivalent of thousand tons crude oil 2)	20,286	336,095	129,970
Total energy consumption in 1995; equivalent of thousand tons crude oil 2)	20,279	342,171	102,151
Energy dependency2)	-18.21%	59.78%	76.69%
European Innovation Scoreboard Group	Leader	Follower	Laggard

Source: 1) AMECO, 2) Eurostat, 3) IEA.

Major changes in the composition of the electricity production are typically policy induced. Hence, we included government ownership of a RE strategy in our selection criteria. In the selected countries policy makers pursue a pro-active policy. For instance, Germany implements an agenda that seems to serve as the basis for Europe 2020. The German case is best characterised by difficult starting position that is reflected by a high contribution of ‘dirty’ energy sources and a politically induced, extremely fast transition towards RE in the central European energy market. Also Spain and Denmark followed a diffusion strategy, yet, from different starting points of RE in the energy mix, factor endowments and political environments.

Non-renewable energy strategies

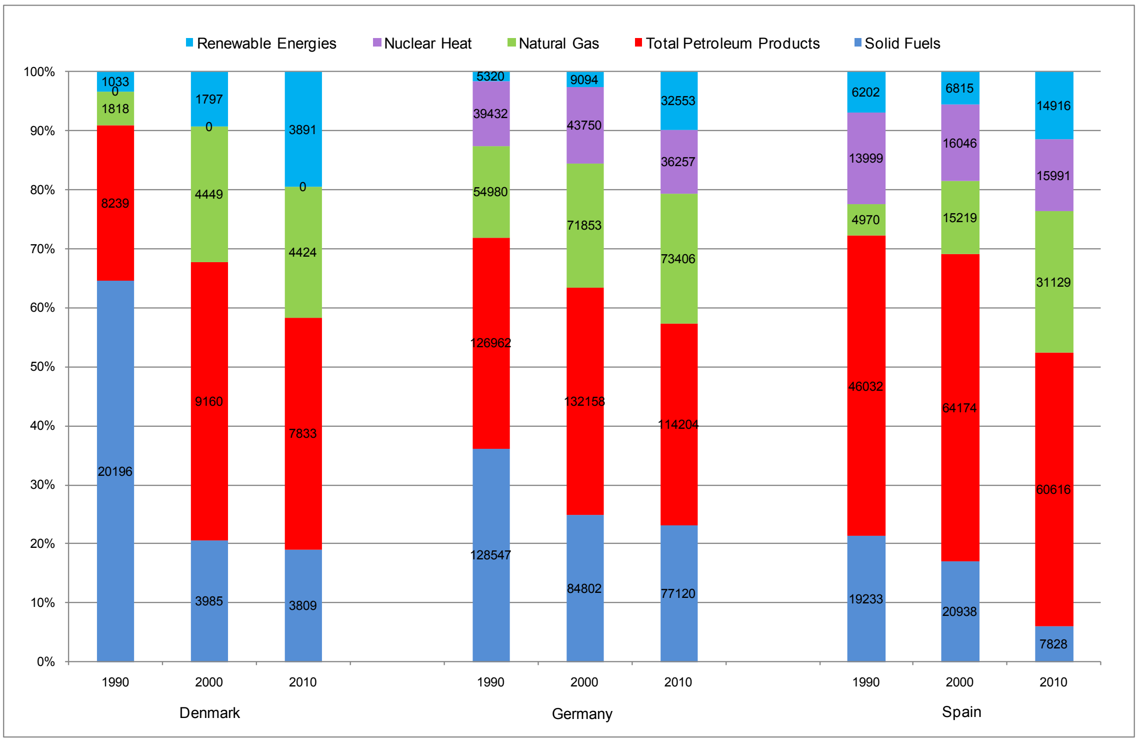
We explicitly focus on countries that seek to increase the share in RE. Not all member states effectively subscribe to the Europe 2020 targets. Cognizant of the trade off between budgetary and social targets on the one hand, and ecological targets on the other hand, in particular transition countries increasingly rely on conventional, low-cost energy. They thereby avoid the increases in production costs of the market as a whole. As a result, there is no discussion about the cost incidence; both public sector budgets and electricity consumers would struggle to absorb price shocks. Yet, this comes at the expense of environmental targets.

4.2 Country case studies

The following explains the country specific factors that drove the developments of the overall energy mix. Both their economy wide energy consumption and the composition of energy sources vary significantly. The total energy consumption in the equivalent of thousand tons crude oil was almost stagnant in Germany: +6% between 1990 and 2010. Denmark’s energy consumption fell by -36%, and Spain’s demand increased by 44% in the same period. All countries increased their contribution of RE. The strongest increase was in Germany. Only one percent stemmed from RE in 1990; this number is dwarfed by 10% of RE in 2010. Also Denmark increased its proportion of RE significantly, from 3% in 1990 to 19% in 2010. In Spain the share grew by approximately 66% - from 7% in 1990 to 11% in 2010. In all selected countries the lower consumption of solid fuels enabled the shift in the composition (see Figure 5).

The three countries differ in their strategy. Germany is pursuing a strategy that rapidly shifts the energy mix towards RE. The systemic change generates friction costs that push the existing system to its boundaries. Denmark is an example of a country where the change occurred more slowly, and more co-operative, democratic supply structures emerged. Eventually, Spain is an example for a member state that halted its promotions for renewable energy due to budgetary reasons. We do not provide a detailed discussion about the country’s political bargaining processes.

Figure 5 **Gross inland energy consumption by sources in Denmark, Germany and Spain over time**



Source: Eurostat.

Note: Figures in 1,000 tons of crude oil. Gross inland consumption is calculated as follows: primary production + recovered products + total imports + variations of stocks - total exports - bunkers. It corresponds to the addition of final consumption, distribution losses, transformation losses and statistical differences

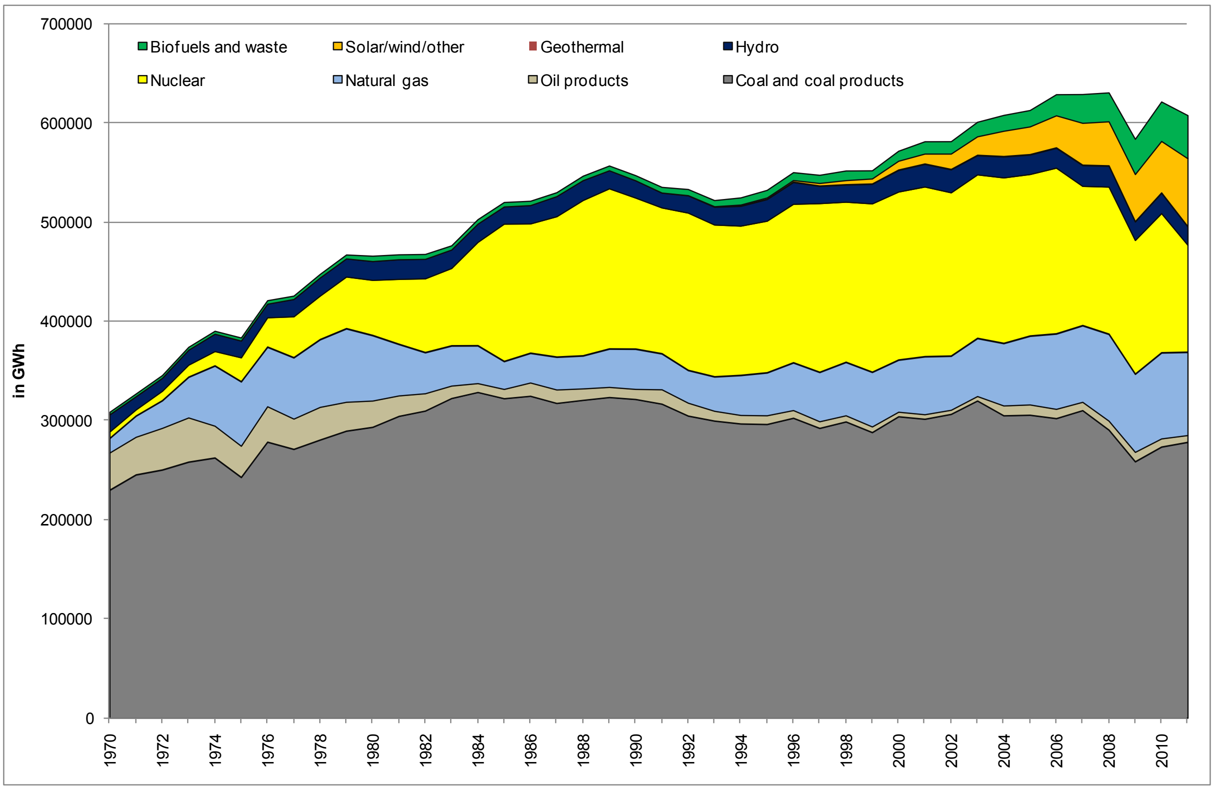
4.2.1 Germany

Germany is a front runner in renewable energy policy. Its policies can be generally seen to have successfully initiated a 'greening' process in not only electricity production, but also in the heating and transportation sector. The discussion about a change in the energy mix already began in the 1980s amidst of anti-nuclear protests. It was the aftermath of the oil crisis of the 1970s, the acid rain controversy was ongoing and there was an emerging awareness about climate change. It topic was triggered by the book 'Energiewende', energy transition, by the Öko-Institut Freiburg (Krause et al., 1980) that scientifically discussed opting out of nuclear power and oil. The general discussion was moulded into effective policies in December 1990, when the electricity feed-in act obliged grid operators to grant access to distributed producers. This marked the starting point for a series of regulatory and promotion measures that facilitated the deployment of RE in Germany.

In 2000, this act was replaced by the "Renewable Energy Act", which was accompanied by the goal to increase the portion of RE to 12.5% by 2010, which the policy bundle only marginally missed. Renewable energy systems receive a 20 year guaranteed payment for their electricity supply. The regulatory act uncoupled the FIT from the electricity retail price. It set prices according to effective generation costs. Hence, FITs were customised, which led to a differentiated pricing between and within generation technologies, depending on plant type and size, and external factors such as wind speed, sun hours, or fuel type in biomass. Tariff digression was embedded in the design to encourage technology learning. In 2004 the act was amended, and subsidy volumes were adjusted to the benefit of PV, biomass and geothermal power. FITs for wind power were reduced (Haas et al. 2011).

RE as part of the total electricity production increased from 3.5% in 1990 to 6.2% in 2000 to 19.9% in 2010. Solar and wind power was virtually non-existent as an electricity source in 1990, increased to 1.6% in the total electricity production by 2000, and peaked at 11.3% in 2011. The remaining renewable sources were mainly bio-fuels and bio-gas as well as hydro-power. In 2011, the bulk of electricity came from coal and coal products (46%), nuclear plants (18%) and natural gas - 14% (IEA data; see Figure 6).

Figure 6 **Germany's electricity output by sources**



Source: IEA data, own illustration.

The rapid deployment of RE has evoked criticism which this section will elaborate on. In particular it has been argued that i) the cost incidence model asymmetrically favours the wealthy and that the burden for households is disproportionally high, that ii) security of supply is being put at risk.

Albeit these issues are widely acknowledged in Germany, there still is universal support for the 'energy transition', the 'Energiewende'. In a public consultation about the grid development plan, the biggest counter-forces expressed an interest to slow down the process, not to halt it. Hence, the policies will continue to implement the current agenda – a nuclear phase-out by 2022, massive expansion of RE and the fulfilment of Germany's ambitious climate targets (Schleicher-Tappeser and Piria, 2012).

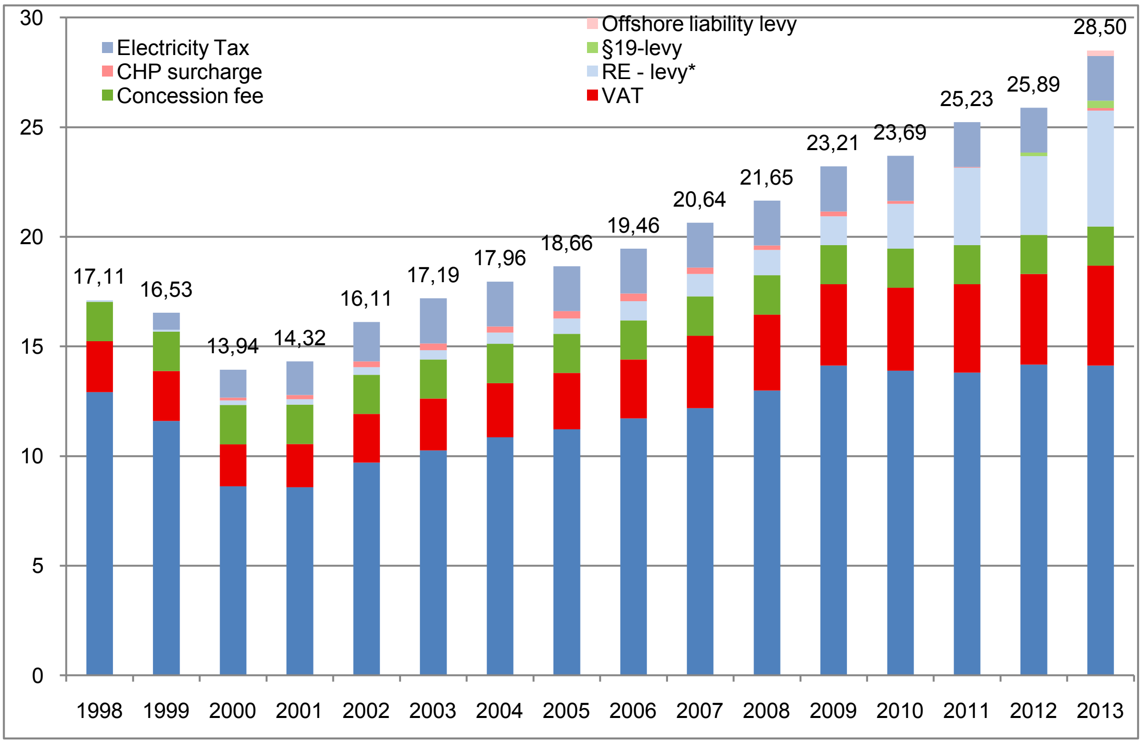
Energy subsidies and cost incidence

The deployment of RE has been criticised for its high costs. This, however, eclipses the subsidy structure of the electricity industry as a whole. All energy sources, including fossil-nuclear generation, are heavily subsidised. Both direct and indirect promotion instruments are in use. The accumulated subsidies between 1970 and 2012 across energy source in real figures amount to € 187bn for atomic energy, € 177bn for black coal, € 65bn for brown coal and to € 55bn for renewable energy. The subsidy volume for renewable energy has increased significantly in recent years. It will continue to rise due to the 20 year time horizon of pegged FITs. In 2012, € 13bn was paid to promote RE. This figure is still dwarfed by € 40bn for conventional power (Küchler and Meyer, 2012). In the medium term, public monies for RE are expected to pass beyond the promotion levels for conventional power generation.

A fundamental difference lies in the choice of promotion instruments. The renewable energy act considers the 'energy transition' to be budget neutral. It bills additional costs to electricity consumers through various levies and surcharges. The allocation scheme makes subsidies for RE visible to the electricity consumer and to the public, respectively. Conventional energy is subsidised through public budgets and therefore largely invisible to the general public. This generates the picture that only RE has cost that exceeds the amounts shown on end consumers' electricity bills (Küchler and Meyer, 2012).

Electricity prices have more than doubled since 2000. The RE levy increased from circa 1.5% in 2000 to approximately 19% of the total price, and makes for about 35% of the overall price increase (see Figure 7). Let us assume the volume of subsidies for conventional energy sources were allocated in the same way as RE subsidies. The mark-up would then amount to 10.2 ct per KW/h in 2012 (Küchler and Meyer, 2012), which is substantially higher than the 5.277 cent of the RE levy in 2013 (2012: 3.592 cents).

Figure 7 **Electricity price development in Germany**



Source: BDEW data (2013).

Private households and SMEs pay the additional costs; big energy consumers such as heavy industry are quasi exempt (e.g., BMU 2011). Manufacturing firms whose electricity cost amounts to at least 14% of the company's gross value added are eligible for a reduction. The scheme is staggered according to firms' electricity consumption. In 2013, firms under 1 GWh/a pay the full mark-up (i.e. 100% of the levy), eligible firms with a consumption between 1-10 GWh/a pay 10%, 10-100 GWh/a pay 1% of the mark-up. Firms above 100 GWh/a merely pay 0.05 ct/kWh, which is a negligible amount. This exemption scheme is subject to a current state aid trial.

In 2013 the total cost of the RE levy will amount to € 20.4 billion, of which private households will pay 35%. 30% will be allocated to the industrial sector; 20% to the crafts, trade and services; the public sector will cover 12% and agriculture and transport the remaining 3%. Approximately 2,000, or 4% of all industrial firms, are at least partially exempt from the RE levy; fully exempt firms consume 16% of the industrial power consumption; 47% of all power is consumed by firms without any exemption.[19]

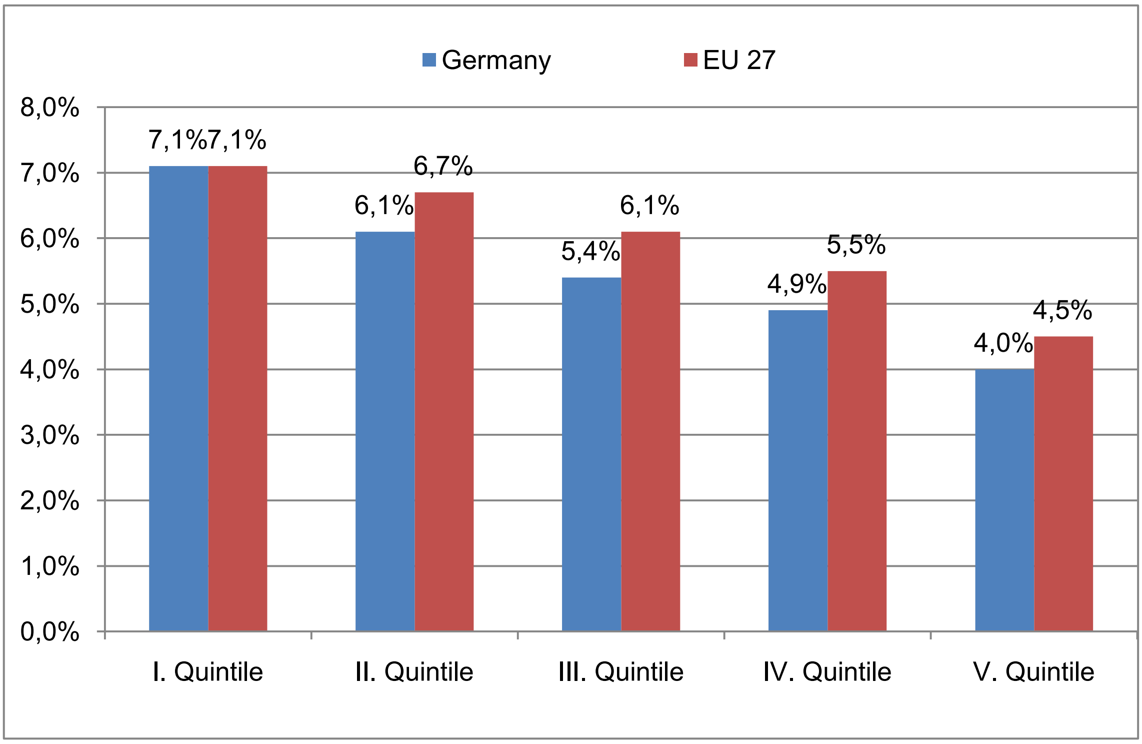
Another concern refers to the impact of the increases of electricity prices across the distribution of household incomes. The less wealthy spend relatively more on electricity of their household income than the wealthy. Hence, the additional costs for more RE are disproportionally distributed. The poor pay relatively more for electricity, and therefore pay a relatively larger burden of the change of the energy mix than the wealthy. The basket of goods and services for

---

[19] See http://www.bdew.de/internet.nsf/id/17DF3FA36BF264EBC1257B0A003EE8B8/$file/Foliensatz_Energie-Info-EE-und-das-EEG2013_31.01.2013.pdf.

Germany shows that in 2005 (most recent figures) the bottom quintile spent 7.1% on power, far more than the wealthiest quintile that spent only 4% (see Figure 8). Unfortunately savings ratios are not available, and the substitution elasticity of power prices increase is also unclear (ceteris paribus).

Figure 8 **Electricity expenditures in households across income quintiles (2005)**



Source: Eurostat.

‘Democratisation’ of energy

In the former industrial structures large scale, centralised power plants dominated the market in an oligopoly. Relatively few shareholders benefitted from the producers’ rents. This pattern changed. In particular the Danish model (see below) can be seen as a democratisation of energy supply. Also in Germany ownership structures often have strong community participation, let alone stand alone systems in private households that are directly owned. Similarly, municipal utility firms are publicly held, yet subject to indirect civil group participation. New forms of citizen participation in RE parks evolved. In the ‘citizen power plants’ (‘Bürgerkraftwerke’) people can purchase shares and directly participate in the new supply structures. In addition to the direct involvement of consumers, the decentralised energy production induces investments in regions, which is why the regional political elites typically favour RE.

Altogether, this reflects a ‘democratisation’ of energy. The German ownership distribution of RE plants is as follows: 39.7% private persons, 14.4% project developers, 11% funds and banks, 10.8% farmers and 9.3% industry. Only 6.5% are owned by the four big utility providers. 8.3%

are in other hands such as national or international electric utility providers, regional generators or contracting firms.

Moreover, the new ownership structures are *inter alia* reflected by competition policy. The profit maximising behaviour in a concentrated market rendered the industry prone to interventions by competition policy makers and regulators. Distributed renewable energy production splits up the market among many players, alleviating concerns about the abuse market power.

Undermined market mechanisms

Along with liberalisation policies the rising proportion of RE intensified the competition on the German electricity market. Mainly established players were affected, who lost both market power and the scope for price manipulations. This induced a desired fall in wholesale peak electricity prices by approximately 45% in the period 2007 to 2012, which was completely absorbed by the profit margins of utility providers. In addition, RE policies have been accelerating this development. The merit order system generated a price-quantity curve that is extremely flat in the lower load range, which is covered by hydro-electric, nuclear and brown and anthracite coal plants. Plants in the upper load range have high marginal costs – old gas, coal and oil plants. In 2011 these were on average merely 1,000 hours operational, which equates to their break-even point. Currently anthracite coal plants are being built, which will aggravate the competitive intensity. By 2014 capacities of approximately 8 GW will go operational to cover mainly Southern Germany. This makes for approximately a seventh of the market's overall capacity. Bringing these plants into service will add to the economic pressure on existing plants. In particular other stone coal plants will suffer. The operational potential for typical peak load plants (e.g., gas turbines) is below 170 hours, far below the required 1,000 hours (LBD, 2012).

The decrease in wholesale prices reached a level where coal and gas plants hardly earn their fixed operational costs. Power plants that cover peak demand in excess of 45 GW lost approximately 70% of their operating hours since 2007. As a consequence, these plants are likely to exit. However, they have been providing the flexibility that the market requires. At the end of 2012 circa 15-18 GW of Germany's power plant park is not profitable any longer and close to shutting down. About a third of these capacities are required plant reserves that are activated in emergencies such as plant outages or when there is extreme weather. Another third are oil and gas plants that are activated at peak times. The remainder mainly consists of old anthracite coal plants that are likely to shut down. By 2022 forecasts expect that the operation of a capacity of 26-31 GW will not be economically feasible. This means that all anthracite plants that were operation in 2012 are out of business. These processes come at the risk of the energy only market's failure to guarantee the security of supply (LBD, 2012).

The German system reached its own boundaries several times. For instance, on 8 and 9 December 2012 the neighbouring Austria had to deliver power to Germany to stabilise the power supply. The situation was grotesque insofar that German power was exported to Austria and Italy. Non-performance of the delivery contracts would have induced substantial surcharges, which is why a re-direction of the capacities was not feasible. Also, this came despite strong winds on those days in Northern Germany, where wind turbines produced approximately 20,000 MW. The transmission grid was not sufficiently equipped to transmit this power to the more strongly industrialised and densely populated South where the energy demand was high.

Two months after this incidence, on 8 February 2012, a cold spell increased the electricity demand in Germany. The supply side was restricted. Nuclear plants were off-line, the weather did not allow for the generation of RE, and the Russian supplier Gazprom reduced its delivery to serve its home market. Again Austrian back-up capacities were used to provide the security of supply.

The emerging picture shows an energy-only wholesale market and an infrastructure that repeatedly failed to guarantee the security of supply. The volatility of RE, the infrastructural challenges and the undermined market mechanisms have fundamentally changed the sector. The situation seems paradoxical against a policy design background that considers competitive market selection. The merit order effect, the subsidy policy and the liberalisation led to the exit of non-RE plants. A partial reversal of the original policy objectives is perceivable, which considers emergency capacities from undesired, relatively dirty technologies.

Reactions to arising issues

While a flexible policy design is desirable and adjustments to existing policies are required, the means are arguable. In particular, instruments that are currently applied in Germany promote conflicting policy objectives, since there have been calls for subsidies for maintaining back-up capacities. Hence, the phase-in promotion of RE would be combined with the promotion of undesired technologies that policy makers sought to phase-out. Quintessentially, all energy producers would receive subsidies, the state would be the old and new central player, and the market selection process would be undermined. This is not desirable in an industry in which many decentralised players compete, and central planning is neither feasible nor desired.

Policy makers need to guarantee the security of supply, which resulted in a discussion about the grid, and spare capacities or maintaining a strategic reserve. The strategic reserve does not partake in the wholesale market. It is triggered by a shortage and a price increase, which induces a volume of approximately € 12bn. This is then paid to the entity of all plants, and not only to the providers of emergency capacities who would otherwise exit the market due to their lacking profitability. Approximately 40% of the volume, € 4.8bn, is paid to nuclear facilities (12,000 MW) and brown coal plants (18,000 MW).

Albeit it is widely acknowledged that certain issues exist, there still is universal support for the ‘energy transition’, the ‘Energiewende’. In a public consultation about the grid development plan, the biggest counter-forces expressed an interest to slow down the process, not to halt it. Hence, the policies will continue to implement the current agenda – a nuclear phase-out by 2022, massive expansion of RE and the fulfilment of Germany’s ambitious climate targets (Schleicher-Tappeser and Piria, 2012).

The transmission grid

Next to the shortage of back-up capacities stands the grid management and its structure. The German transmission grid is operated by four regulated, private companies. The TSO market is split geographically among four private companies: TenneT TSO GmbH, Amprion, TransnetBW GmbH, Amprion GmbH and 50Hertz Transmission GmbH. This geographical split touches on the question about what the optimal price zone is, i.e. a zone without any bottlenecks. There are requests that there should be a single German price zone, which holds against the background of ongoing discussions at the EU level. The current split requires justification – alternatives should be compared, such as several price zones or nodal prices (Schleicher-Tappeser and Piria, 2012).

The current grid structure seems suboptimal; and an expansion is discussed to preclude congestion. Four parallel North-South high-voltage direct current (HVDC) lines are supposed to connect the wind power plants of the North with large consumers in the South. They can be considered as a part of a future European HVDC overlay grid. However, they pose a considerable investment. Initial cost estimates have already been increased by the consortium in charge, and the time schedules have already slipped considerably.[20] In addition, the new lines may render the system inflexible, increase vulnerability and stability risks. Long distance lines might also "*solidify the structure of a centrally organised power supply from large units for decades*". A relatively minor grid adjustment would be needed if the regulatory system accepted missing a few hours per year of wind peaks. This would only marginally reduce the yearly wind output and contribute substantially to the system's security. Yet, this would contradict the legally guaranteed access to the grid. As to fossil energy and CO2 emissions, some research institutes and NGOs have argued that some of the proposed lines partly function as "lignite HVDC lines", because they allow carbon intensive coal plants to run more often than today. A weaker grid would favour more flexible gas plants located close to the bottlenecks (Schleicher-Tappeser and Piria, 2012).

4.2.2 Denmark

Denmark used to be a net importer of energy, and considerably oil dependent. 90% of its energy came from oil when the oil crisis hit in 1973. As a consequence, the country sought to diversify its energy mix to reduce its exposure to supply shocks. The original considerations of the government to establish nuclear power plants were heavily criticised by anti-nuclear movements. As a result the government abandoned its atomic energy plans. Denmark then started to support RE, mainly wind power due to its natural factor endowments - strong and steady winds, and its decentralised settlement structure.

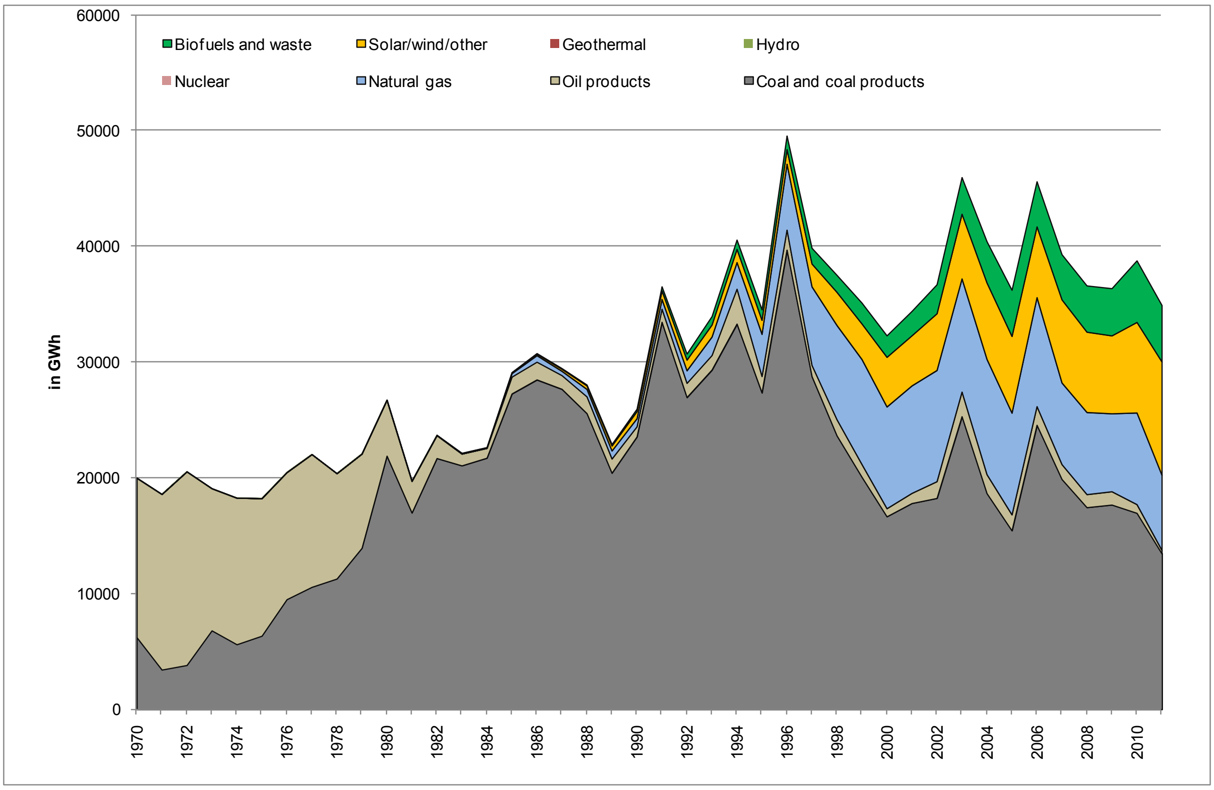
Already in 1974 an expert commission declared that covering 10% of the electricity demand with wind power was feasible in the grid structure at the time. In 1986, approximately 1,200 wind power systems provided one percent of the total electricity demand. In the early 1990s, wind

---

[20] See http://www.economist.com/news/business/21580484-huge-offshore-energy-project-may-prove-expensive-disaster-white-elephants-seen-north-sea.

power was prominently placed in the Danish energy plans. Policies set a wind energy target of 10% in 2005, which was by far exceeded; almost 20% of Denmark's electricity was produced with wind in 2005. In the more windy west of the country almost a quarter came from wind. In 2011 RE covered approximately 41% of the electricity output, of which 28 percentage points stemmed from wind power (Haas et al., 2011). In 2011, coal and coal products accounted for approximately 39% of the total electricity, and natural gas for 19% (IEA data; see Figure 9).

Figure 9 **Denmark's electricity output by sources**



Source: IEA data, own illustration.

The rapid deployment of wind power in Denmark in the last two decades of the 20th century can be explained by several factors. The key drivers have been a stable legal environment that promoted the generation of RE; the energy policies included other relevant topics such as energy efficiency or the public provision of wind atlases to best use the local potential. The Danish promotion strategy relies on feed in tariffs, whose levels have been designed flexibly. Policy makers have continuously adjusted the level of the FITs – after they had been decreased substantially to low levels, they increased in recent years (Haas et al., 2011; Meyer, 2007). In addition to FITs, a series of other policies supported the deployment of wind, including particular ownership models, spatial planning issues, regulations of the grid-connection, or tax issues (Olesen et al., 2004).

Denmark's policy makers continue to set ambitious and holistic goals.[21] The Energy Agreement 2012 considers a 12% reduction of gross energy consumption by 2020 (base year: 2006); a share of 35% renewable energy in 2020; and 50% wind energy in Danish electricity consumption in 2020. Most notably, it foresees that Denmark's entire energy supply (i.e. electricity, heating, industry and transport) is operating on RE by 2050.[22] In 2013, the government banned the installation of oil or gas heating in new buildings, which will also be phased out in existing building from 2016 onwards. This is accompanied by a programme that promotes the switch of heating systems.

The Danish success story has several characteristics, including i) a citizen led RE movement that transformed the energy sector, and ii) the promoted development of an eco-technology industry.

From grassroots movements to systemic change

The ownership of Denmark's RE policies rests on a broad base. Denmark has a long tradition in decentralised power generation. Already in the late 19th century early wind turbines were owned by farmers, co-operatives and municipalities. Denmark's shift away from oil dependency was led by its citizens and numerous bottom-up initiatives of which many sought alternatives for nuclear power. Rendering RE more competitive, the small scale turbines that were already installed at the time underwent a series of incremental innovations, which received public support (Schreuer and Weismeier-Sammer, 2010; Jorgensen and Karnoe, 1995; Maegaard, 2009).

The majority of RE systems were owned by co-operatives until the early 1990s. Shareholders received beneficial treatment through tax exemptions, low electricity prices and preferential treatments of local neighbourhoods. These were mainly owned by local initiatives and cooperative, whose ownership type was also supported by public policies (Bowyer et al, 2009; Haas et al., 2011).

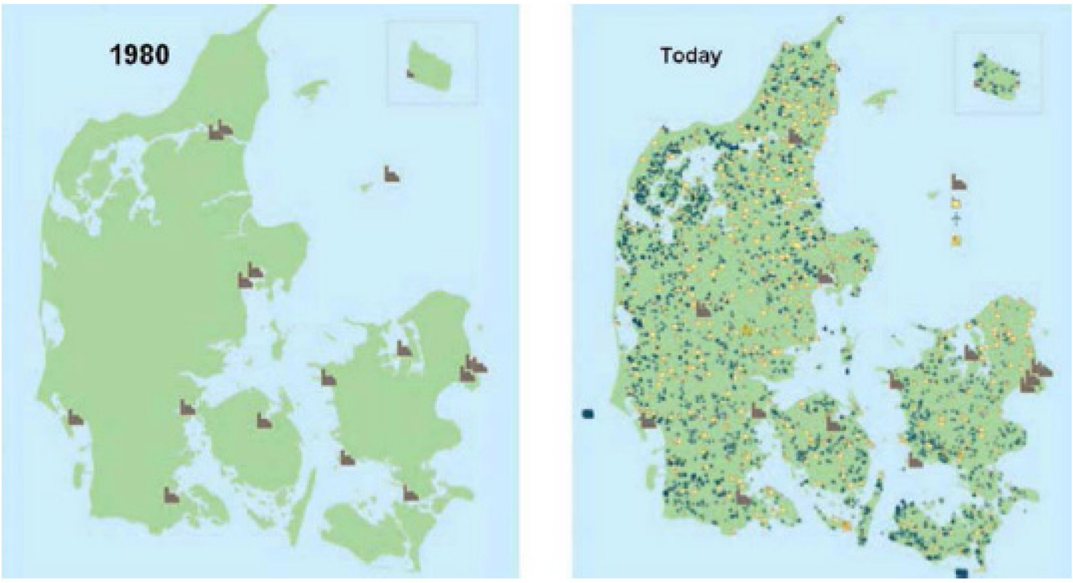
The municipalities' role was pivotal in Denmark's transition towards distributed RE and its reduction of CO2 emissions (see Figure 10). The combined production of heat and power (CHP) may have been the single most important initiative. The change CHP to supplying 60% of the electricity and 80% of the demand for heat has created local infrastructures that gradually and entirely transitioned towards RE. The local consumer-owned and municipality-owned CHPs have delivered a large portion of the national power production, and substantially contributed to today's distributed power generation pattern.

---

[21] See http://www.energie-experten.org/uploads/media/DK_Energy_Agreement_March_22_2012.pdf.

[22] See http://www.stateofgreen.com/Cache/StateOfGreen/de/de820d42-73df-4d5f-9b10-f28cac7ee68f.pdf.

Figure 10 **Distributed power generation in Denmark (1980 and 2010)**



Source: Energinet (2009) in Cochran et al. (2012)

The initial boom slowed due saturation tendencies at the time of the Danish electricity reform in 1999, which was embedded in the sector’s liberalisation. Technological developments outpaced the market absorptive capacity, which led to several changes in feed-in tariffs and price support mechanisms. In addition, municipalities were required to indicate how suitable sites were. Government regulations, however, ruled out most locations from onshore wind development. As a result, new onshore wind turbines declined after 2001, halting in 2004 (e.g., Haas et al., 2011).

The decline in new systems also altered the ownership structure. Few cooperatives were meeting the regulations and were as a consequence taken over by larger energy companies. This trend was criticised in the public, as the “beloved windmills are now seen as money machines for someone else” (e.g., Kruse, 2006). Also more and more professional developers and farmers entered the market. Most owners then saw turbines as financial investments, optimising cost structures and increasing economies of scale (Haas et al., 2011).

This trend was somehow reversed in 2007, when the Danish government announced a new energy strategy that aims to increase RE consumption to 30% by 2025. The strategy foresaw a doubling of wind power from the country’s 2006 levels to eventually 6000MW. Municipalities have been required to revise their spatial planning to provide new sites for onshore wind (Munksgaard and Morhorst, 2008).

Municipal co-operatives remain important players in the energy landscape. They usually are set up as fully liable companies due to tax advantages. They are non-profit firms that seek to build up reserves and do not incur debts. Banks are willing to finance the purchase of shares through loans, whereby the shares pose the security for loans (Olesen et al., 2004). In 2013, the largest co-operative energy company was SEAS-NVE. The organisation offers electricity, consulting services and grid products. The customers are connected to the grid that they co-own (except several municipals). The company is run by a co-operative committee, whose members are elected by the approximately 375,000 co-operative owners.[23]

Also consumers have been empowered to change their behaviour. In the Nordic market as a whole, there is a trend towards more spot market-oriented contracts, also for households. In combination with the roll-out of smart meters, spot market contracts are able to increase the demand response (WEC, 2010), at least to a larger extent than elsewhere. In addition, distributed, small-scale production was promoted - as almost everywhere in Europe.

An international grid

While there is very strong public support for RE, the public opinion does not necessarily stretch to the additional transmission infrastructures that RE, in particular wind power, imply. In this regard it is similar to Germany, where the public welcomes ‘energy transition’, but does not support the infrastructural requirements.

Why did the security of supply issue not emerge as it did in Germany? This can be partly explained by early adjustments of promotion policies by policy makers. In addition, Energinet - the publicly owned and country’s single transmission system operator, jointly with the power producers has pioneered practices to manage the complexity that RE induce. Denmark has been one of the biggest innovators of output forecasting techniques, and continues to lead the development of system operation planning tools. Balancing power, however, is insufficient to secure constant supply.

The country does not have storage facilities, and solves its volatility issues by international power trade. Other than Germany, which is a big player, Denmark is a rather small energy market that is strongly connected with its neighbours in the Nordic power market and Germany in the South. Its transfer capacity amounts to approximately 80% of the country’s peak demand, which is able to balance both surpluses and deficits (Cochran et al., 2012). To the north, the Norwegian (99% hydropower) and Swedish (40% hydro) hydroelectric systems balance the variations in Denmark’s wind power. The hydroelectric power plants of the trading partners are continuously adjusted to balance fluctuations. The wholesale market responds by adjusting the spot price. Between 2000 and 2008, West Denmark has exported on average, 57% of its wind power, and East Denmark an average of 45% (CEPOS, 2009).

In addition, Denmark permits negative prices on its electricity wholesale market. If wind turbines run full power at times of low demand, producers pay for their generation. The objective is to provide an incentive to producers to align their production to market needs and vice versa. This occurs for between 20 and 100 hours per year (Cochran et al., 2012). Also, a significant proportion of the distributed generation does not enter the grid. Due to a net-metering scheme the ‘pro-sumers’ tend to consume the electricity that they generate, and rather not feed it into the grid (Haas et al., 2011).

---

[23] See http://www.seas-nve.dk/AboutSeasNve/Company.aspx.

Development of an environmental industry

A co-evolution of several factors spurred a change in the actor constellation. These include policies that promoted RE, technological developments in the wind turbine sector and the professional management of plants and the grid. An equipment producing industry emerged, owners, wind farm owners changed to professional investors that exerted pressure on utility providers to invest into RE (Schreuer and Weismeier-Sammer, 2010; Oleson, 2004).

Local firms benefitted from the technologies that have been implemented. The technologies were largely created in Denmark, where they initially also produced. The incremental technological adaptations of wind turbines gave the producers an early export advantage (Schreuer and Weismeier-Sammer, 2010). The often hand-made systems were produced by local SMEs that exported their products into the US, where wind power was heavily subsidised (Roessner, 1984). This initial advantage was strengthened by public policies that facilitated the creation of environmental firms.

This poses an example of ‘green entrepreneurship’, which the OECD (2011) defines as “activities which produce goods and services to measure, prevent, limit, minimise or correct environmental damage to water, air and soil, as well as problems related to waste, noise and ecosystems. This includes technologies, products and services that reduce environmental risk and minimise pollution and resources”.[24] The share of green enterprises (enterprises as a percentage of total number of enterprises in economy) is among the highest in Europe at about 1.2%, though this proportion declined slightly between 2002 and 2007 (OECD, 2011).

In addition, regional innovation cluster policies that encompassed all key stakeholders were implemented. For instance, the Copenhagen Cleantech Cluster poses a university-industry-government initiative. Half of its budget of EUR 20 million over five years is provided by the European Union Structural Funds; the remaining half is evenly split between the Region Zealand, the Capital Region of Denmark, the founding partner companies and the City of Copenhagen. In 2012, 610 cleantech companies operated in the cluster, which employed 78,000 people, of which half of these directly engaged with cluster activities. The companies reported a total turnover of € 30 billion, of which about EUR 12 billion were directly related to the cluster. The most prominent sectors are energy efficiency and renewable energy, water and wastewater, waste and recycling (OECD, 2011).

4.2.3 Spain

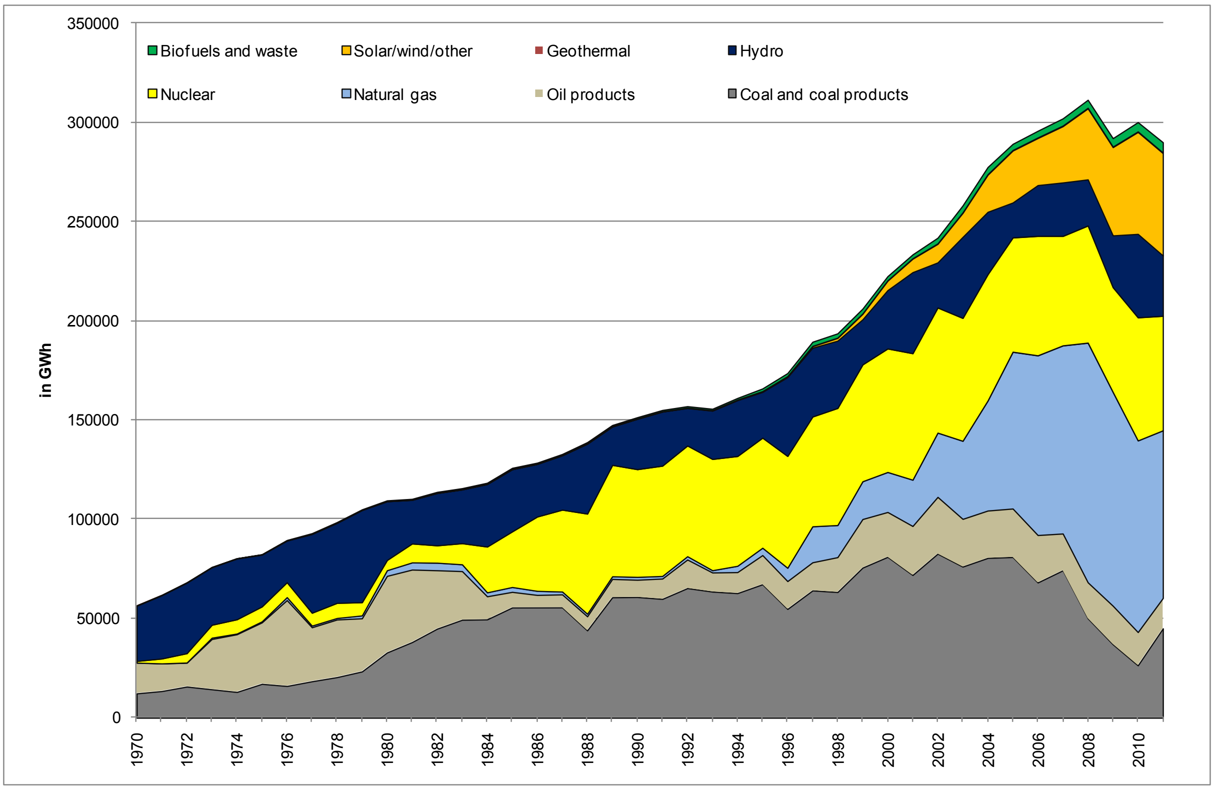
Spain’s efforts to diversify the energy mix have had a difficult starting point. The country heavily depends on oil and gas imports, even though the proportion of these have shown to be decreasing. In 1990, coal accounted for 40% of the country’s power production, which fell to 15% in 2011. There was a shift towards natural gas, from one percent in 1990 to 29% in 2011. Also the contribution of nuclear power dropped from 36% to 20% in the same period. The Spanish policies supported the roll-out of RE on a large scale. Their contribution increased from

---

[24] This comprises NACE 25.12, 37, 41 and 51.57.

17.2% in 1990 to 29.9% in 2011. Wind and solar power increased from nil to 17.8% (see Figure 11).

Figure 11 **Spain's electricity output by sources**



Source: IEA data, own illustration.

The promotion instruments that have been applied resemble the ones elsewhere. RE obtained preferential access to the grid, subsidies were paid and the country's environmental industry was promoted. Spain used a pegged FIT scheme as the main promotion instrument; also grid access was guaranteed. The FIT was first introduced in 1994 as an instrument to achieve the 12% RE target by 2010. The scheme was expanded in 1998 by an alternative payment option, a premium scheme. The applicants could opt for either option in the first year. The pegged tariffs are reduced after 15, 20 or 25 years to encourage learning effects (Haas et al., 2011).

In 2004 a revision of the scheme increased investment security by guaranteeing payments for the lifetime of the plant. The optional premium was converted into a free market sale without a purchase obligation. I.e., RE can be sold on the market either through a bidding system or contractual agreements. By the end of the 2004, the total remuneration level under the market option increased more than expected due to rising market prices - from € 36 per MW him 2004 to € 65 per MWh in 2006. The policies effectively induced the deployment of RE, mainly from onshore wind - 80% of the 30 TWh came from wind in 2006 (Haas et al., 2011).

Spain's National RE Plan 2011-2020 continues to set ambitious targets. The main objective is to reach at least 20% RE of the final energy consumption by 2020 (and 10% RE in the transport sector). It expects wind energy to remain the biggest contributor, followed by solar energy. Other sources, such as biomass, biogas, waste and geothermal energy are expected to gain relevance, even though the plan does not expect those technologies to reach maturity until 2020-2030.[25]

Spain is an interesting showcase of how to integrate a substantial share of mainly on-shore wind into its grid. Yet, the promotion instruments are severely challenged due to the ongoing recession; social pressures to lower energy prices are also mounting. Recent policies see a drastic reduction in promotion efforts, which may exemplify the current dynamics in many crisis countries.

RE in an isolated grid

Spain's electricity grid is embedded in the poorly integrated and mostly isolated Iberian power market. Also in Spain the rapid deployment of RE, in particular wind power challenged the system to accommodate RE without putting the security of supply at risk. While RE has priority access to the electricity grid, the country's TSO, Red Electrica de Espana, created several procedures to overcome technical difficulties. These strongly consider the contribution of RE producers and their effects on security of supply objectives. The Control Centre for Renewable Energies (CECRE) was established, which serves as the pivotal institution that manages the grid and incorporates RE.[26] In 2012, approximately half of Spain's electricity demand could be met by wind energy over the course of several hours.

The grid's voltage is controlled by the TSO. CECRE determines whether the generation scenario is acceptable for the stability of the system operations at any time. Owners of RE installations are obliged to provide real-time telemetry each 12 seconds, which CECRE uses to monitor all available information about RE systems in real-time. Other than in countries that guarantee grid access, the TSO grants access to the grid. It is also in charge to issue connection permits to the high-voltage network. It is eligible to prohibit access if the system's security of supply is at risk. In such a case the issue is handed over to the regulator (Cochran et al., 2012).

Another supporting measure refers to the feed-in load with the aim to reduce the volatility that comes from wind and solar power. RE producers are subject to a predefined range. Non-compliance results in penalties. Also, there are potential bonus payments for maintaining the range. In addition, wind farms with capacities greater than 10 MW must provide reactive power support as of 2006. In 2010 this was extended to solar PV installations with capacities greater than 2 MW (Cochran et al., 2012).

Moreover, back-up capacities are in place, which mainly use combined cycle gas turbines. The replacement mechanism due to the merit order effect also occurred in Spain. Load factors of gas-fired generation fell below 40% in 2009. This was due to the larger proportion of RE in the grid, a recent drop in demand due to the recession as well as excess capacities. This capacity

---

[25] See http://www.investinspain.org/icex/cma/contentTypes/common/records/mostrarDocumento/?doc=4558560.

[26] See http://www.ree.es/ingles/operacion/cecre.asp.

usage is substantially higher than the abovementioned German plants, which were on average only operational for 170 hours. Yet, the back-up capacities are exposed to the same issues in Germany in the medium run – given a continuing increase of RE. It remains unclear whether peak prices will sufficiently increase to provide the incentives to incur the required investment (Federico, 2010).

It may therefore be necessary to reform and strengthen the current system for capacity remuneration, which rewards investments into new capacities for a 10-year period and at a level that roughly covers annualised operation and management costs. Capital and fixed gas transport costs are not included. If regulatory measures are supposed to solve the pricing of congestion management and ancillary service provision, they should allow for a degree of fixed-cost recovery on the part of flexible generation. This assumes that capacity payments are not sufficient to cover fixed costs (Federico, 2010).

Austerity measures and the subsidy halt

The country’s dire economic situation has affected its public budget. Austerity programmes led to a re-thinking of energy policies. The increase in RE was seen as a public good. Pegged FITs are being financed by public budgets to protect consumers from price increases. While this supported the social acceptance, it exerted pressures on the federal budget. In 2012 several regulatory adjustments were made to control the country’s growing electricity tariff deficit. By the end of 2011 the tariff deficit reached € 24 billion, and is expected to continue to rise by an additional € 5 billion. As part of the government’s efforts to reduce its debt burden several measures that limit the funds paid for RE have been implemented. Policies aim at lowering electricity costs to ease the social pressure that the ongoing recession exerts. The rationale is to limit the rising contribution of RE due to the emerging costs, and to consequently reduce the promotion volume. The current government announced that it will provide a (financially) ‘sustainable’ framework for RE (Warren et al., 2012).

In 2012 there was an imposition of a moratorium on RE projects that have not been registered on the ministry’s pre-allocation registry. This de facto halt has been announced as a temporary measure, but it currently seems unlikely that it will be repealed. The possibility to register for new RE systems was abolished; ongoing projects remain unaffected. In addition, the Royal Decree-Laws 13/2012 and 20/2012 of March 2012 put new measures into law to cut energy costs (Warren et al., 2012).

In addition, the policy makers struggle with a budget deficit and look for new income sources. In September 2012, a reform package was passed which includes seven tax measures. *Inter alia* these included a 6% flat tax on all electricity generation, including RE; a “green cent” tax on carbon-based fuels, taxes on nuclear plants and a 22% levy on the use of water for electricity production. The package is expected to generate € 2.94 billion (Warren et al., 2012).

There are signs that the government’s support for RE is fading. Initial plans that considered a higher tax on wind power (11%), solar thermal systems (13%) and PV (18%) were however dropped. Still, the taxation scheme is not technology neutral. Investors into RE are affected asymmetrically. Its compensation is set by law, which precludes suppliers from passing on additional costs by consumers – other than suppliers of conventional power. Large operators of both solar and wind parks have announced job cuts that resulted from the market correction (Warren et al., 2012). Investment demand came to a complete halt.

4.3 Case study summary and discussion

This chapter puts the abstract findings of the social construction of technology exercise into country specific contexts. We elaborated on the experiences of three countries: Germany, Denmark and Spain. We chose these countries based on their political ambition to broaden the energy mix, the wholesale electricity market setting (Nordic, Central European and the Iberian market), their technological capabilities and more general macro-economic factors.

Germany has proven to be a front runner in policies that promote RE. Its policies led to swift diffusion of RE. Jointly with the effects of the sector's liberalisation RE has added to the competitive pressure on conventional suppliers. While the exit of 'dirty technologies' is desired, fierce competition also drives some of the emergency capacities out of the market. The country seeks to guarantee the security of supply by an enhanced grid management, as well as the expansion of the grid to better geographically match supply and demand. These instruments, however, have not yet solved the intensifying issues. Another characteristic of German policies is that the cost incidence model is budget neutral. It assigns all costs to the final consumer; large industrial consumers are exempt. This raises concerns about the social effects and the non-discriminatory nature of state aid of the 'energy transition', the 'Energiewende'. Then again, the increasing participation of citizens in RE parks (e.g., 'Bürgerkraftwerke') points at a 'democratisation' of energy.

Denmark has a long tradition in the generation of RE, in particular in wind power. The 'green movement' was perhaps broadly based in the society from the onset due to the participation of municipal cooperatives that also benefitted from promotion policies. Denmark's rapid deployment met physical limits in the late 1990s, when the country's main reaction was to reduce subsidies, which were increased again in later years. The policies also induced a drop in wind turbines and partly changed the ownership structures; more and more professional developers entered the market and acquired some of the mainly municipally owned sites. The new owners increased the sector's scale economies and optimised the sites' profitability. Yet, recent policy targets spurred a new wave of municipal deployment of RE, and local co-operatives continue to play a pivotal role. In addition, the Danish grid is embedded in the strongly interwoven Nordic market, where any potential mismatch between supply and demand is compensated by its trading partners. Furthermore, demand is more strongly embedded in the transition than in the comparison countries. Retail prices are more flexible, which seems to render consumers slightly more price elastic than in other countries. Net metering schemes provide an incentive to consume than feed power into the grid, thereby lessening the complexity.

In *Spain*, despite being part of the almost completely isolated Iberian market, a massive integration of RE into the grid took place. This required controlled conditions to guarantee security of supply. On the one hand, RE legally enjoys preferential grid access. On the other hand, policy makers can technically interfere through various ways to guarantee the security of supply. Long-term transmission network planning and comprehensive coordination between the various administrations provided the policy makers with a greater amount of flexibility in the ongoing grid design. The country's budgetary crisis, however, led to a reversal of energy policies. It currently seems unlikely that Spain will restore its promotion policies.

Discussion

RE is not supported by all countries. Many new member states opt for low-cost, conventional power; countries that face budgetary crisis tend to halt their promotion as part of ongoing austerity programmes. Even though the targets are EU-wide and country specific goals may differ, this suggests a lack of country ownership of Europe 2020 which puts the target achievement as a whole at risk.

Lack of country characteristics in the policy design. Generally, in countries that follow strategies that promote RE, the design of the promotion instruments seems suboptimal; country characteristics are hardly reflected by promotion policies. For instance, both Germany and Spain subsidise photovoltaic systems and their operation to a large extent, regardless of natural factor endowments.

Technology base. The current technology base is not fully adequate to meet system's requirements. The crux of the issue lies in the missing constancy of power supply of wind and solar power and the market mechanisms. In particular in Germany we find that RE displaces conventional power and their emergency capacities due to the merit order. In combination with infrastructural shortcomings this puts the security of supply at risk. In the long run, policy makers presume a certain degree of technological progress which will eventually render the system sustainable. Progress, however, is hard to anticipate due to non-linearity in technology trajectories.

Natural threshold. The arising issues imply that if markets are seen as one, there is an intrinsic threshold of wind and solar power that can be managed by currently installed emergency capacities without losing the security of supply. This threshold exists, even if it depends on the degree of internationalisation of the market, characteristics of the available grids, the respective technology mix and other idiosyncratic elements such as the regulatory framework. Notably, there is no such threshold for the integration of RE from a technical point of view. With the help of batteries, power to gas and back-up gas turbines (driven by renewable gas) a full provision with RE is feasible. Yet, the cost would increase dramatically.

Flexible policies. In Denmark the promotion of RE led to a rapid deployment of RE, especially of wind power. Wind is an inconstant power source. We asked how the Danish and the Spanish sector could avoid the problems that are evident in Germany. In Denmark, subsidies were reduced drastically which led to a halt of the deployment dynamics of RE. Also a series of grid management tools were implemented and supply of RE is rendered flexible, e.g. through negative prices. These instruments alone would have been insufficient to fully cope with the problems. Yet, the Danish success was possible because the energy market is embedded in the larger Nordic market that balances both power shortage and surplus. The international market partly provides the flexibility in the power management which the currently rolled out RE technologies require. Being an isolated market, Spain applies similar instruments that quintessentially stifle the priority grid access of RE. For instance, the Spanish TSO has a veto in the connection of new RE facilities due to technical reasons. In cases of congestion the TSO can take RE plants off the grid.

Cost allocation. There is strong cross country variance in the cost allocation mechanisms. In Spain and in Denmark, the promotion is quintessentially financed by the general budget. In Germany, costs are allocated via the RE levy to consumers; large industrial consumers are exempt not to harm their competitiveness. This promotion design asymmetrically affects poorer households that spend more of their household income on the consumption of electricity. A price increase allocates a relatively larger share to the least wealthy. It also discriminates in favour of larger firms. If energy provision is seen as a public good, a public funding mechanism that allocates to the general budget is to be preferred, because it allocates costs to society as a whole.

Public ownership and acceptance. Last but not least, the entry of numerous distributed producers induced a substantial shift in ownership structures. The sector used to be dominated by a few large firms which were often subject to antitrust litigation. The deployment of RE led to the emergence of a large number of actors; private households are now acting as pro-sumers, citizens invest into RE plants, or as in the Danish case own municipal utilities that are set up as co-operatives. It seems that the broad involvement has substantially contributed to the social acceptance of RE, which one could describe as the ‘democratisation’ of power provision. The Danish system demonstrates how policy instruments can shape ownership structures and public acceptance.

5. Overall summary and discussion

This working paper presents a case study on the diffusion mechanisms of renewable energy. We explored the dynamics that are involved with a Europe-wide ‘energy transition’. In particular we elaborate on the increase of the proportion of renewable energy (RE) to 20%, a key target of Europe 2020. We embedded the discussion into the concept of ‘systemic industrial and innovation policy’. This poses a recent development in industrial policy concepts, i.e. the promotion of industrial competitiveness beyond the intervention in the presence of market failures. Old industrial policy promoted specific firms and sectors, but was undermined as their competitiveness faded due to inefficiencies arising from the lack of competition; the market selection processes were distorted, and policy makers persistently intervened in decision processes. Then new industrial policies emerged, where horizontal innovation promotion and human capital formation asymmetrically affect firms and industries. The presently used systemic approach seems to rests on the new industrial policy concept, but societal, not purely economic needs justify the intervention.

A broadening of the energy mix is justifiable from both environmental (e.g., climate change) and economic perspectives (e.g., import dependency). Yet, the implementation is not straightforward. The shift in supply structures fundamentally transforms the existing market. Feeding more RE into the grid pushes the market mechanisms to their boundaries. Parts of the existing capital stock become obsolete, which is desired by policies that promote the exit from ‘dirty’ technologies. The arrival of new technologies greatly increases both the industrial and technical complexity. Investments into new facilities, the underlying infrastructure and in on-call capacities are increasingly relevant. Altogether, the objective assigns great hopes to the mix of industrial and technology policies.

Renewable energy as a ‘planned market outcome’

The present study is intriguing from a policy design perspective. The energy policies rest on the principles sustainability, security of supply and competitiveness, i.e. market outcomes. However, policies would have to bias the technological trajectory in an economic planning fashion to effectively achieve the targets. Since the market selection process under-supplies socially desired eco-friendly technologies, public policies subsidise the diffusion of RE technologies. These increasingly displace the current technology stock. RE receives preferential grid access due to the merit order effect, which prefers energy sources with the lowest marginal costs. Hence, RE with quasi no marginal costs compete in a supposedly free market with technologies whose marginal costs are greater than zero. The market selection mechanism does not provide a level playing field.

The merit order itself is a desired component of the market design. It is the key instrument to achieve static, price efficiency. The arrival of RE in the merit order, however, adds to the competitive pressures of the liberalisation, which already reduced conventional suppliers’ profitability, investment incentives and economies of scale. However, given the current technology base, a full supply of RE is not feasible. RE rely on factor endowments which often lack consistency in their provision (especially the availability of wind and solar is volatile).

Conventional power facilities such as gas or storage plants remain required to provide emergency capacities when RE is not available. Germany, for example, faced several emergency situations that required the assistance of neighbouring countries to avoid outages. These led to calls to subsidise conventional capacities. This is insofar paradoxical that subsidies, the instrument that sought to phase-out non-renewable energy and to phase-in RE, would then be used to preserve conventional capacities. The provision of emergency capacities contradicts the competitive selection process of a free market.

There are various instruments that cope with the emerging issues, which again are at least partly in conflict with one another. For instance, the provision of emergency capacity may undermine the incentives to optimise the operational management of the national grid, which again may stand against the international 'target market' that is promoted by the EU. Correspondingly, the international target market hampers the establishment of a spatially split market, because additional layers complicate the integration efforts.

The debate whether market outcomes should be planned or market driven also stretches to the geographic dispersion of production and consumption. The local distribution grid needs to change to accommodate a plethora of distributed power producers that feed electricity into the grid at various nodes. It is unclear how a grid with sufficient flexibility to incorporate emerging producers can be set up. The long-distance transmission grid faces similar issues. These are planned in a top down manner, by central authorities and after a consultation process. The transmission grid is not the outcome of a competitive bottom-up, competitive selection process. This raises the question about how to connect emerging suppliers to a grid which is planned? An electricity grid is not a 'web' that constantly re-emerges, which causes a discrepancy between centrally planned grids at the national level, the increasingly internationally interwoven markets and not systemically designed distributed generation.

The arising issues imply that if markets are seen as one, there is an intrinsic threshold of wind and solar power that can be managed by the currently installed emergency capacities without losing the desired security of supply. This threshold exists, even if it depends on the degree of internationalisation of the market, characteristics of the available grids, the respective technology mix and other idiosyncratic elements such as the regulatory framework. Hence, this critical point can be shifted to higher levels by a flexible grid management that alleviates the priority access for RE, and international markets that compensate for a supply surplus or shortages. Notably, there is no threshold for the integration of RE from a mere technical point of view. With the help of batteries, power to gas and back-up gas turbines (driven by renewable gas) a full provision with RE is feasible. Yet, the cost would increase dramatically.

Diffusion policies and technological maturity

Policy makers across the EU member states chose to promote the diffusion of existing RE technologies. Technology push measures such as mission oriented R&D programmes are in place, but implemented to a lesser extent - even though their potential for a sustainable change in energy production technologies might be greater. The diffusion fostering instruments directly intervened with the market selection process. Such measures would have been more neutral, and probably been equally effective in the longer term. The direct interventions led to the abovementioned discrepancies and raise the question between outcomes form a market selection process and industrial planning.

In 2012, grid parity of PV has been achieved, or will be achieved shortly. In Germany and Italy, for instance, the optimisation of self-consumption allows for cost efficiency of larger systems without subsidised feed-in tariffs. Also wind turbines are expected to break even in the near future. This is agreeable with the promotion objectives, and has important implications on the design of future policies; subsidies should get reduced where grid parity is in sight.

Furthermore, countries such as Denmark or Spain managed to overcome issues as they occurred in Germany by flexibly adjusting their promotion and grid-management strategies. In Spain, the preferential grid access was weakened by the grid operator that balances the supply and demand structures. In Denmark, promotion policies were adjusted over time to avoid the complications that later emerged in Germany. Hence, policy makers should consider a great degree of flexibility. From a systemic perspective, also the regulatory regime, the underlying market mechanisms and the requirements to the grid need to find consideration in the design of technology policy instruments. This is hitherto not everywhere the case.

The implemented policies successfully accelerated the diffusion time of RE. Evidence on past diffusion processes, however, finds that it takes between 15 and 30 years for a technology to reach a saturation point. RE has hitherto been diffusing extremely fast, which indicates that these estimates are rather conservative when they are applied to RE. Yet, the time span is based on free market economies, i.e. in a different setting. The fast deployment of RE technologies may have shortened the ‘formative phase’ of the diffusion process, which is necessary to generate learning effects and allow for incremental technological improvements. Compressing the timescales further may lead to the deployment of premature technologies.

Cost incidence, public ownership and the democratisation of supply structures

Albeit the net benefits from more RE are assumed positive, the shift itself is not pareto-efficient. Parts of the currently installed machinery and equipment will have to be written down if the book value is positive; TSOs and distribution grid operators will have to finance the grid expansion, and consumers may face higher electricity prices. There is substantial cross country variance in the cost allocation mechanisms. A three country case study reveals that in Spain and in Denmark, the promotion is quintessentially financed by the general budget.

In Germany, additional costs are allocated by a levy system to electricity consumers; large industrial consumers are exempt not to harm their competitiveness. This promotion design asymmetrically affects poorer households that spend more of their household income on the consumption of electricity. A price increase allocates a relatively larger share to the least wealthy. If a green energy provision is seen as a public good, a public funding mechanism that allocates additional costs to the general budget is to be preferred. Society as a whole then finances it.

The entry of distributed producers induced a substantial shift in the industry’s ownership structures. Utilities used to be dominated by a few large firms which often used to be subject to antitrust litigation. The deployment of RE led to the emergence of a large number of actors.

Private households are now acting as pro-sumers, citizens invest into RE plants, or as in the Danish case own municipal utilities that are set up as co-operatives. It seems that the broad involvement of the civil society has substantially contributed to the social acceptance of RE, which one could describe as the 'democratisation' of power provision. Also, the Danish system demonstrates how policy instruments can shape ownership structures and public acceptance.

Country ownership

The RE targets of Europe 2020 are not implemented in all member states. Many new member states opt for low-cost, conventional power. Countries that face budgetary crisis tend to halt their promotion as part of ongoing austerity programmes. This suggests a lack of country ownership of Europe 2020 which puts the target achievement as a whole at risk.

Outlook

The technologies that the 'greening' of the energy mix requires are largely available, even though they do not seem to be fully matured; a full provision with RE is not feasible at socially acceptable costs with the current technology base. Further technology-push efforts are required. In addition, the demand-pull measures, the promotion of diffusion triggers a series of socio-economic questions. How can policies arrange the allocation mechanisms so that security of supply is guaranteed despite unsteady supply? Green energy has a public good character – how can it be provided at an affordable price level? What will be the role for market selection mechanisms in a sector in which any player is heavily subsidised? Will the public accept the new technology base? What institutional adjustments are required?

There is no doubt that these are urging questions. Some potential answers were suggested in the present contribution; questions, however, remain. Nonetheless, the long run prospects are bright. The energy mix has been constantly changing and evolving. Also the utility sector has undergone periods of comparably fundamental shifts. There is no reason why this should cease.

References

Acemoglu, D., Aghion, P., Bursztyn, L., Hemous, D. (2010), "The Environment and Directed Technical Change", NBER Working Paper 15451.

Aiginger, K. (2012), „A Systemic Industrial Policy to Pave a New Growth Path for Europe",WIFO Working Papers 421, 1-16.

Amin, M. (2008), "Upgrading the grid", Nature, 454, 570–573.

Antal, M., Hukkinen, J., (2010), The art of the cognitive war to save the planet, Ecological Economics, 69, 937-943.

Arthur, B. W., Durlauf, S. Lane, D. (1997), "The Economy as an Evolving Complex System II", Addison-Wesley, Reading, Mass., Series in the Sciences of Complexity.

Arthur, B.W. (1989), "Competing Technologies, Increasing Returns, and Lock-In by Historical Events", The Economic Journal, 99(394), 116-131.

Baron, D.P. (1998), "Integrated market and nonmarket strategies in client and interest group politics", Research Paper No. 1480, Stanford University.

Battaglini, A., Komendantova, N., Brtnik, P., Patt, A. (2012), "Perception of barriers for expansion of electricity grids in the European Union", Energy Policy, 47, 254-259.

BDEW (2013), „BDEW-Roadmap - Realistische Schritte zur Umsetzung von Smart Grids in Deutschland", Bundesverband der Energie- und Wasserwirtschaft e.V., http://www.bdew.de/internet.nsf/id/F8B8CCE3B35FF53BC1257B0F0038D328/$file/BDEW-Roadmap_Smart_Grids.pdf

Belkin, P. (2008), The European Union's Energy Security Challenge, Congressional Research Service, Report for Congress.

Bergh, van den, J.C.J.M., Kemp, R. (2008), Transition lessons from economics. Chapter 4 in: J.C.J.M. van den Bergh, F. Bruinsma (eds.). Managing the Transition to Renewable Energy: Theory and Macro/Regional Practice, Edward Elgar, Cheltenham, pp. 81-127.

BESSE (2012), "BESSE Project Resource Book", Brokering Environmentally Sustainable Sanitation for Europe, Project of the Seventh Framework Programme of the European Commission", Project No. 226744, http://www.besse-project.info/viewer/file.aspx?FileInfoID=73.

Bijker, W. E. (2009), Social Construction of Technology, in A Companion to the Philosophy of Technology, eds. J. K. B. Olsen, S. A. Pedersen and V. F. Hendricks, Wiley-Blackwell, Oxford, UK.

Bijker, W. E., Hughes, T.P., Pinch, T.J. (1987), "The Social Construction of Technological Systems: New Directions in the Sociology and History of Technology", MIT Press, Cambridge Massachusetts.

BMU (2011), "Einfluss der Umwelt- und Klimapolitik auf die Energiekosten der Industrie -mit Fokus auf die EEG-Umlage", Bundesministerium für Umwelt, Naturschutz und Reaktorsicherheit (BMU), Berlin. März 2011.

Bowyer, C., Baldock, D., Tucker, G., Valsecchi, C., Lewis, M., Hjerp, P., Gantioler, S. (2009), “Positive Planning for Onshore Wind – Expanding Onshore Wind Energy Capacity while Conserving Nature”, A report by the Institute for European Environmental Policy commissioned by the Royal Society for the Protection of Birds.

Brankera, K., Pathaka, M.J.M., Pearce, J.M. (2011), "A review of solar photovoltaic levelized cost of electricity", Renewable and Sustainable Energy Reviews, 15 (9), 4470-4482

Brennan, G., Buchanan, J.M. (2000), “The Reason of Rules”, The Collected Works of James M. Buchanan, Volume 10, Liberty Fund, Indianapolis.

Breyer, C., Gerlach, A. (2013), “Global overview on grid parity”, Progress in Photovoltaics: Research and Applications, 21(1), 121–136.

Castro, L. de (2011), "The Economics of the Smart Grid.", in Proceedings of IEEE 49th Annual Allerton Conference on Communication, Control, and Computing, 1294-1301.

CEPOS (2009), „Wind Energy – The Case of Denmark“, Center for Politiske Studier Copenhagen, September 2009, http://www.cepos.dk/fileadmin/user_upload/Arkiv/PDF/Wind_energy_-_the_case_of_Denmark.pdf.

Christensen, L.R., Greene, W.H. (1976), “Economies of Scale in U.S. Electric Power Generation”, The Journal of the Political Economy, 84(4), 655-676.

Christiner, G. (2013), “Herausforderungen in neuen Energiemärkten aus der Sicht der Übertragungsnetzbetreiber”, APG presentation at the IEWT 2013, 15 February 2013.

Coase, R. H. (1991), The Institutional Structure of Production, Nobel Prize Lecture, http://www.nobelprize.org/nobel_prizes/economics/laureates/1991/coase-lecture.html, reprinted in 1992, American Economic Review, 82(4), 713-719.

Cochran, J., Bird, L., Heeter, J., Arent, D.J. (2012), “Integrating Variable Renewable Energy in Electric Power Markets: Best Practices from International Experience”, NREL is a national laboratory of the U.S. Department of Energy, NREL/TP-6A00-53732.

Comin, D.A., Hobijn, B. (2010), An Exploration of Technology Diffusion, American Economic Review, 100(5), 2031-59.

Cooke, D. (2011), Empowering Customer Choice in Electricity Markets, International Energy Agency, Information Paper, http://www.iea.org/publications/freepublications/publication/Empower.pdf.

Dale, M., Benson, S.M. (2013), “Energy Balance of the Global Photovoltaic (PV) Industry - Is the PV Industry a Net Electricity Producer?”, Environmental Science and Technology, 47 (7), pp 3482–3489.

Department of Energy and Climate Change (2012), “Annex C: Capacity Market Design and Implementation Update”, London, https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/65637/7104-emr-annex-c-capacity-market-design-and-implementat.pdf.

Doh, J., Lawton, T.C., Rajwani, T. (2012), Advancing Nonmarket Strategy Research: Institutional Perspectives in a Changing World, Academy of Management Perspectives, 26(3), 22-39.

Elberg, C., Growitsch, C., Höffler, F., Richter, J., Wambach, A. (2012), “Untersuchungen zu einem zukunftsfähigem Strommarktdesign”, Studie im Auftrag des Bundesministeriums für Wirtschaft und Technologie (BMWI), http://www.ewi.uni-koeln.de/fileadmin/user_upload/Publikationen/Studien/Politik_und_Gesellschaft/2012/EWI_Studie_Strommarktdesign_Endbericht_April_2012.pdf.

EPIA (2011), “Solar Photovoltaics Competing in the Energy Sector: On the Road to Competitiveness”, http://www.epia.org/fileadmin/user_upload/Publications/Competing_Full_Report.pdf.

EPIA (2012), “Major shortcomings of existing support schemes towards grid parity achievement in target countries - DRAFT”, European Photovoltaic Industry Association, PV-Parity, supported by Intelligent Energy Europe.

Espey, J., Espey, M. (2004), “Turning on the Lights: A Meta-Analysis of Residential Electricity Demand Elasticities”, Journal of Agricultural and Applied Economics, 36, 65-81.

European Commission (2006a), "A European strategy for sustainable, competitive and secure energy", Commission Green Paper of 8 March 2006, COM(2006) 105 final - not published in the Official Journal, http://europa.eu/legislation_summaries/energy/european_energy_policy/l27062_en.htm.

European Commission (2006b), “European Technology Platform: Smart Grids. Vision and Strategy for Europe’s Electricity Networks of the Future”, Directorate-General for Research, EUR22040, Luxemburg.

European Commission (2007), „An Energy Policy for Europe“, Communication from the Commission to the European Council and The European Parliament, COM(2007) 1 final, Brussels.

European Commission (2011a), “A resource-efficient Europe – Flagship initiative under the Europe 2020 Strategy”, Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions, COM(2011) 21, Brussels, http://ec.europa.eu/resource-efficient-europe/pdf/resource_efficient_europe_en.pdf.

European Commission (2011b), “Smart Grids: from innovation to deployment”, Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions, COM(2011) 202 final, SEC(2011) 463 final, Brussels, http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2011:0202:FIN:EN:PDF.

European Commission (2011c), A joint contribution of DG ENER and DG INFSO towards the Digital Agenda. Action 73: Set of common functional requirements of the SMART METER“, Information Society and Media Directorate-General and Energy Directorate-General, http://ec.europa.eu/energy/gas_electricity/smartgrids/doc/2011_10_smart_meter_funtionalities_report.pdf.

European Commission (2011d), Smart Grid Mandate. Standardization Mandate to European Standardisation Organisations (ESOs) to support European Smart Grid deployment, Brussels. Ref. Ares(2011)233514, M/490 EN, Brussels, http://ec.europa.eu/energy/gas_electricity/smartgrids/doc/2011_03_01_mandate_m490_en.pdf.

European Commission (2011f), "Definition, Expected Services, Functionalities and Benefits of Smart Grids", COM(2011) 202 FINAL, SEC(2011) 463 final, Brussels, http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=SEC:2011:0463:FIN:EN:PDF.

European Commission (2012), "Proposal for a Directive of the European Parliament and of the Council amending Directive 98/70/EC relating to the quality of petrol and diesel fuels and amending Directive 2009/28/EC on the promotion of the use of energy from renewable sources (Text with EEA relevance)", SWD(2012) 343 final, http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=SWD:2012:0343:FIN:EN:PDF.

European Union (2009), "DIRECTIVE 2009/28/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 23 April 2009 on the promotion of the use of energy from renewable sources and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC", Official Journal of the European Union, L 140/16.

EWEA (2009), "Wind Energy: The Facts – Executive Summary", http://www.ewea.org/fileadmin/ewea_documents/documents/publications/WETF/1565_ExSum_ENG.pdf

Farrell, J., Saloner, G. (1985), "Standardisation, compatibility, and innovation", Rand Journal of Economics, 16(1), 70-83.

Federico, G. (2010), The Spanish Gas and Electricity Sector: Regulation, Markets and Environmental Policies, Reports of the Public-Private Sector Research Center, http://www.iese.edu/es/files/IESE_num%205_Energy_web%20final%20version_tcm5-58079.pdf.

Felbo, O. (2009), "Older people and technology. Dane Age: an online study about the attitude of older people towards different types of new technology.", Presentation at the Ambient Assistant Living Forum, Vienna, September.

Fontaine, P. (1993), „The Lost Art of Economics", Journal of Economic Perspectives, Correspondence, 7(2), 209–215.

Foxon, T.J., Köhler, J., Michie, J., Oughton, C. (2013), Towards a new complexity economics for sustainability, Cambridge Journal of Economics 2013 (37), 187–208.

Friedl, B., Bliem, M.G., Miess, M.G., Schmelzer, S., Aigner, M., Haber, A., Schmautzer, E. (2013), „Wertschöpfungs- und Beschäftigungseffekte von Smart-Grids-Lösungen", Presentation given at the IEWT 2013 at the University of Technology, 13-15 February 2013, Vienna.

Friesenbichler, K. (2013), Standardisation as an Innovation Policy Tool, Austrian Economic Quarterly, forthcoming. 2013

Frontier Economics, Consentec (2008), „Methodische Fragen bei der Bewirtschaftung innerdeutscher Engpässe im Übertragungsnetz (Energie)" Untersuchung im Auftrag der Bundesnetzagentur für Elektrizität, Gas, Telekommunikation, Post und Eisenbahnen, Bonn, http://www.bundesnetzagentur.de/cae/servlet/contentblob/15262/publicationFile/.

Gawlik, W. (2012), "From Smart Grid to Universal Grid – Generation, Storage and Communication in Hybrid Networks", Keynote speech at ComForEn 2012, Wels, 5 September 2012; in: "OVE - Tagungsband ComForEn 2012", OVE, Schriftenreihe Nr. 65 (2012), ISBN: 978-3-85133-072-4; 8 -12, http://publik.tuwien.ac.at/files/PubDat_211397.pdf.

Gazheli, A., Antal, M., van den Bergh, J. (2012), Behavioural foundations of sustainable transitions, WWW for Europe Working paper no 3, http://www.foreurope.eu/fileadmin/documents/pdf/Workingpapers/WWWforEurope_WPS_no003_MS31.pdf.

Geroski, P.A. (2000), "Models of Technology Diffusion", Research Policy, 29, 603-625.

Getz, K.A. (1997), Research in Corporate Political Action: Integration and Assessment, Business and Society, 36, 32-72.

Giordano, V., Gangale, F., Fulli, G., Sánchez Jiménez, M., Onyeji, I., Colta, A., Papaioannou, I., Mengolini, A., Alecu, C., Ojala, T., Maschio, I. (2011), "Smart Grid projects in Europe: lessons learned and current developments", European Commission, JRC, Energy Institute, Reference Reports, JRC 65215, Brussels, http://ses.jrc.ec.europa.eu/sites/ses/files/documents/smart_grid_projects_in_europe_lessons_learned_and_current_developments.pdf.

Grubler, A., Nakicenovic, N. (1991), Long Waves, Technology Diffusion, and Substitution, Review, 14(2), 313-342.

Haas, R., Panzer, C., Resch, G., Ragwitz, M., Reece, G., Held, A. (2011), "A historical review of promotion strategies for electricity from renewable energy sources in EU countries", Renewable and Sustainable Energy Reviews, 15, 1003-1034.

Haas, R., Resch, G., Panzer, P., Busch, S., Ragwitz, M., Held; A. (2010), "Efficiency and effectiveness of promotion systems for electricity generation from renewable energy sources e Lessons from EU countries", Energy, 36(4), 2186–2193.

Hall, B.H. (2005), Innovation and Diffusion, in: Fragerberg, Mowery and Nelson, "The Oxford Handbook of Innovation", Chapter 17, pp. 459-484, Oxford University Press.

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.

Heckbert, S., Baynes, T., Reeson, A. (2010), Agent Based Modeling in Ecological Economics, Annals of the New York Academy of Science, 1185, 39–53

Hoppe, H.C. (2002), "The Timing of Technology Adoption: Theoretical Models and Empirical Evidence", The Manchester School, 70 (1), 56-76.

ICER (2012), “Experiences on the regulatory approaches to the implementation of smart meters”, International Confederation of Regulators, http://www.energy-regulators.eu/portal/page/portal/EER_HOME/EER_INTERNATIONAL/ICER/Publications/Tab/Brochure_ICER_SM_VWG3_web.pdf

Ipsos MORI (2013), „Quantitative Research into Public Awareness, Attitudes, and Experience of Smart Meters (Wave 2), Research conducted by Ipsos MORI for DECC, https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/86686/1201137301_-_DECC_SM_Tracking_Report_WAVE_2_-_FINAL_-_1_Feb_2013_-_INTERNAL_USE.pdf.

Jäger-Waldau, A. (2007), “Photovoltaics and renewable energies in Europe”, Renewable and Sustainable Energy Reviews, 11, 1414-1437

Jorgensen, U., Karnoe, P. (1995), „The Danish wind-turbine story: technical solutions to political visions?“ in: Rip, A., Misa , T. J. and Schot, J. (Eds.) Managing Technology in Society. London.

Karlin, B., (2012), “Public Acceptance of Smart Meters: Integrating Psychology into Practice”, ACEEE Summer Study on Energy Efficiency in Buildings, http://www.aceee.org/files/proceedings/2012/data/papers/0193-000243.pdf.

Katz, M., Shapiro, C. (1985), "Network Externalities, Competition and Compatibility," American Economic Review, 75(3).

Kerr, S., Newell, R.G. (2003), “Policy induced technology adoption: Evidence from the U.S. Lead phasedown”, The Journal of Industrial Economics, LI, 3, 317- 343.

Klein, H.K., Kleinman, D.L. (2002), “The Social Construction of Technology: Structural Considerations”, Science, Technology & Human Values, 27(1), 28-52.

Knyrim, R., Trieb, G. (2011), “Smart metering under EU data protection law“, International Data Privacy Law, 1(2), Oxford University Press.

Köppl, A., Steininger, K.W. (2012), “The climate challenge for the energy system”, Empirica, 39, 157–163.

Krause, F., Bossel, H., Müller-Reißmann, K.F. (1980), „Energiewende – Wachstum und Wohlstand ohne Erdöl und Uran, S. Fischer Verlag.

Kruse, J. (2006), The End of One Danish Windmill Cooperative, Politiken, 9 February 2006, http://www.energiblog.dk/#category8.

Küchler, S., Meyer, B. (2012), “Vergleich der staatlichen Förderungen und gesamtgesellschaftlichen Kosten konventioneller und erneuerbarer Energien“, Teilstudie des Projekts „Was Strom wirklich kostet“, Langfassung, überarbeitete und aktualisierte Auflage 2012, Forum Ökologisch-Soziale Marktwirtschaft, Berlin, http://www.foes.de/pdf/2012-08-Was_Strom_wirklich_kostet_lang.pdf.

LBD (2012), „Kostenwirkung der strategischen Reserve“, LBD-Beratungsgesellschaft mbH, Presentation given at the IEWT 2013 at the University of Technology, 13-15 February 2013, Vienna.

Lettner, G. (2013), “Photovoltaik: Wirtschaftlich ohne Förderungen”, Presentation at the IEWT 2013, 13-15 February 2013.

Lettner, G., Auer, H. (2012a), “Realistic roadmap to PV grid parity for all target countries”, PV-Parity, Supported by intelligent Energy Europe, Vienna, http://www.pvparity.eu/index.php?eID=tx_nawsecuredl&u=0&file=fileadmin/PVPARITY_docs/documents/PV_PARITY_D3.3__Roadmap_final_2012-10-24.pdf&t=1365586182&hash=05db6ef72d2cf1d971c116fd83f837af5f33804b

Lettner, G., Auer, H. (2012b), “Realistic roadmap to PV grid parity in the commercial sector for all target countries”, PV-Parity, Supported by intelligent Energy Europe, Vienna, http://www.pvparity.eu/index.php?eID=tx_nawsecuredl&u=0&file=fileadmin/PVPARITY_docs/documents/PV_PARITY_D3.3b__Roadmap_Commercial_Industries.pdf&t=1365586182&hash=31c688f3b4436a77bcc2c34430d9d5b66ecfbccb

Lijesen, M.G. (2007), “The real-time price elasticity of electricity,“ Energy Economics, 29(2), 249-258.

Maegaard, P. (2009), “Danish Renewable Energy Policy”, World Council for Renewable Energy.

Malerba, F. (2002), Sectoral systems of innovation and production, Research policy, 31, 247-264.

McCrone, A. (2011), Onshore wind energy to reach parity with fossil fuel electricity by 2016, Bloomberg Energy Finance.

Meinshausen, M., Meinshausen, N., Hare, W., Raper, S.C.B., Frieler, K., Knutti, R., Frame, D.J., Allen, M. (2009), Greenhouse gas emission targets for limiting global warming to 2°C, Nature, Letters, 458, 1158-1163.

Menanteau, P., Lefebvre, H. (2000), Competing Technologies and the diffusion of innovations: the emergence of energy-efficient lamps in the residential sector, Research Policy, 29, 375-389.

Meyer, N.I. (2007), “Learning from wind energy policy in the EU: lessons from Denmark, Sweden and Spain”, Environmental Policy and Governance, 17(5), 347–362.

Moriarty, P., Honnery, D. (2012), “Preparing for a low-energy future”, Futures, 44, 883-892.

Moriarty, P., Honnery, D. (2012b), What is the global potential for renewable energy, Renewable & Sustainable Energy Reviews, 16, 244-252.

Munksgaard, J., Morthorst P.E (2008), “Wind power in the Danish liberalised power market - Policy measures, price impact and investor incentives“, Energy Policy, 36, 3940–3947

Nelson, R.R. (1997), “Bicycles, bakelites and bulbs: Toward a theory of sociotechnical change : Wiebe Bijker, (MIT Press, Cambridge, MA, 1995). [UK pound]26.50, 290 + pp., ISBN 0 262 02376 8, “Research Policy, Elsevier, 26(1), 138-139.

Nemet, G.F. (2009), “Demand-pull, technology-push, and government-led incentives for non-incremental technical change”, Research Policy, 38, pp 700-709.

Nooij, de, M., Baarsma, B., Bloemhof, G., Slootweg, H., Dijk, H. (2010), “Development and application of a cost–benefit framework for energy reliability. Using probabilistic methods in network planning and regulation to enhance social welfare: The N-1 rule", Energy Economics 32, 1277–1282.

North, D. (1991), "Institutions", Journal of Economic Perspectives, 5(1), 97-112, http://www.econ.uchile.cl/uploads/documento/94ced618aa1aa4d59bf48a17b1c7f605cc9ace73.pdf.

OECD (2011), "GREEN ENTREPRENEURSHIP, ECO-INNOVATION AND SMEs", Working Party on SMEs and Entrepreneurship (WPSMEE), Draft Final Report, 42nd Session of the WPSMEE, 22-23 October 2012, Paris, CFE/SME(2011)9/REV2.

OECD (2012), "Beyond Industrial Policy – Emerging Issues and New Trends", DRAFT STI WORKING PAPER ON INDUSTRIAL POLICY, DSTI/IND(2012)19.

Olesen, G. B., Maegaard, P., Kruse, J. (2004), "Danish Experience in Wind Energy - Local Financing", Working report for the WELFI project, Comité de Liaison Energies Renouvelables, http://www.umass.edu/windenergy/downloads/pdfs/Danish_experience_Local_Financing_Wind.pdf.

Olsen, J.K. B., Pedersen, S. A., Hendricks, V. F. (2009), A Companion to the Philosophy of Technology, Wiley-Blackwell, Oxford, UK.

Philibert, C. (2011), "Interactions of Policies for Renewable Energy and Climate", OECD/IEA, Paris. http://philibert.cedric.free.fr/Downloads/interactions_policies.pdf

Pigou, A. C. (1932), The Economics of Welfare, 4th edn, London, Macmillan.

Pollitt, M. (2009), "Evaluating the evidence on electricity reform: Lessons for the South East Europe (SEE) market", Utilities Policy, 17 (1), 13-23.

Resch, G., Ortner, A., Busch, S., del Rio, P., Ragwitz, M., Steinhilber, S., Klobasa, M., Winkler, J., Gephart, M., Klessmann, C., de Lovinfosse, I., Nysten, J.V., Fouquet, D., Johnston, A., Batlle, C., Linares, P., Knapek, J., Kralik, T., Faber, T., Borasoy, T., Toro, F., Lifschiz, I. (2012), "Inception report beyond 2020 – approaches for a harmonisation of RES(-E) support in Europe", Design and impact for a harmonised policy for renewable electricity in Europe, supported by Intelligent Energy Europe with the support of the EC, www.res-policy-beyond2020.eu.

Roessner, D.J. (1984), "Commercializing solar technology: The government role", Research Policy 13, 235-246.

Rogers, E. (2003), The Diffusion of Innovations, 5th edition, Free Press, New York.

Schleicher-Tappeser, R., Piria, R. (2012), "The grid expansion debate: the issues at stake. Learning from the public consultation on the German network development plan 2012", SEFEP working paper 2012-5, Smart Energy for Europe Platform.

Schreuer, A., Weismeier-Sammer, D. (2010), "Energy cooperatives and local ownership in the field of renewable energy technologies: A literature review", RiCC – research report 2010/4, Vienna.

Schüppel, A., Stigler, H. (2013), “Bewertung historischer und künftiger Investitionen in der Elektrizitätswirtschaft auf Basis des Kapitalstockkonzepts”, Contribution to the IEWT 2013, Vienna, 144-145.

Shah, N. (2012), “Welfare and technology in the network society—Concerns for the future of welfare“, Futures, 44, 659–665.

Shy, O., (2010), A short survey of network economics, Review of Industrial Organization, 38(2), 119-149.

Silva, da P.P., Soares, I. (2008), “EU spot prices and industry structure: assessing electricity market integration“, International Journal of Energy Sector Management, Vol.2, Issue 3, pp.340-350.

Simmons-Süer, B., Atukeren, E., Busch, C. (2011), “Elastizitäten und Substitutionsmöglichkeiten der Elektrizitätsnachfrage - Literaturübersicht mit besonderem Fokus auf den Schweizer Strommarkt“, KOF Studien Nr. 26, Swiss Federal Institute of Technology Zurich, Zurich.

Smart Grids ETP (2010), “Strategic deployment document - final version”, Smart Grids European Technology Platform, Brussels, http://www.smartgrids.eu/documents/SmartGrids_SDD_FINAL_APRIL2010.pdf.

Soete, L. (2007), “From Industrial to Innovation Policy”, Journal of Industry, Competition and Trade, 7, 273-284.

Stacey, R. (2003), 4th Ed. Strategic Management and Organisational Dynamics – The Challenge of Complexity, Harlow: Prentice Hall.

Steiner, F. (2001), “Regulation, Industry Structure and Performance in the Electricity Supply Industry“, OECD Economic Studies, No. 32 (1), 143-182.

Stern, D.I., Cleveland, C.J. (2004), Energy and Economic Growth, Rensselaer Working Papers in Economics, Number 0410.

Stern, N. (2006), “STERN REVIEW: The Economics of Climate Change“, Executive Summary, http://www.hm-treasury.gov.uk/d/Executive_Summary.pdf.

Tomkins, R. (2011), Capacity Markets for Britain?, ECONOMIC CONSULTING ASSOCIATES LIMITED, Presentation at the Sentri Network Breakfast, Institute of Directors, 19 January 2011, http://www.eca-uk.com/pages/publications/Capacity%20markets-ECA%20presentation-Sentri-19Jan11.pdf.

Tosey, P. (2002), “Teaching on the Edge of Chaos – complexity Theory, Learning Systems and Enhancement“, Educational Studies, University of Surrey, http://epubs.surrey.ac.uk/1195/1/fulltext.pdf.

Walras, Léon (1888), Elements d'économie politique pure ou théorie de la richesse sociale. Paris: Economical.

Walras, Léon (1954), Elements of Pure Economics or The Theory of Social Wealth. Translated by William Jaffé. Homewood: Irwin.

Warren, B., Perkins, A., Bouille, A. (2012), “Renewable energy country attractiveness indices”, Ernst and Young, 2012/35, http://www.ey.com/Publication/vwLUAssets/CAI_issue-35_Nov-2012/$FILE/CAI_issue-35_Nov-2012_DE0372.pdf.

WEC (2010), Roadmap towards a Competitive European Energy Market, World Energy Council, London, http://www.worldenergy.org/documents/roadmap2.pdf.

Wilson, C. (2012), “Historical Diffusion and Growth of Energy Technologies. Historical Case Studies of Energy Technology Innovation”, in: Chapter 24, The Global Energy Assessment. Grubler A., Aguayo, F., Gallagher, K.S., Hekkert, M., Jiang, K., Mytelka, L., Neij, L., Nemet, G. & C. Wilson. Cambridge University Press: Cambridge, UK.

Wilson, C., Grubler, A., Bauer, N., Krey, V., Riahi, K. (2011), “Future capacity growth of energy technologies: are scenarios consistent with historical evidence?”, Climatic Change, Springer, https://ueaeprints.uea.ac.uk/40211/1/Wilson_ClimChange_FutureTechDiffusion_Nov12.pdf

Wolsink, M. (2012), “The research agenda on social acceptance of distributed generation in smart grids: Renewable as common pool resources”, 16(1), 822-835, Renewable and Sustainable Energy Reviews.

Yaziji, M., Doh, J. (2009), Corporate-NGO collaboration: Co-creating in new business models for developing markets, Cambridge UK, Cambridge University Press.

The research leading to these results has received funding from the European Community's Seventh Framework Programme FP7/2007-2013 under grant agreement n° 290647.

Annex I: A sketch of the current electricity industry

The discussion of the energy supply industry in Europe hinges on the market structure. Energy suppliers used to operate vertically-integrated companies. Jointly with local distribution companies that also held monopolies they served their respective service territory. This produced substantially varying electricity prices across countries. Cost overruns, over-capacities, inefficiencies and operational mistakes by the energy supplier resulted in higher prices for the consumer. In the 1980s a discussion about the efficiency of state owned utility providers emerged, which eventually led to the liberalisation of the industry in Europe.

The liberalisation led to an increase in suppliers in all countries that operated unbundled networks. Ownership changes only occurred in some – also because the EU does not prescribe the form of ownership in its liberalisation strategy. The main idea was the freedom of customers to choose their electricity supplier. The liberalisation started when there was excess capacity. When markets opened prices initially fell towards short-term marginal costs. However, when old capacity was phased out and demand increased, prices also rose. Hence, the liberalisation did not affect prices to the originally desired extent. In particular, retail prices have shown to be surprisingly stagnant.

Even though there is some evidence on price convergence (WEC, 2010). Other than the expected price decreases, the desired productivity effect commenced. A generally valid assessment is difficult, though. There is significant cross-country variance that is supposedly based on different policy packages, and can only be insufficiently captured by econometric tools (Pollitt, 2009; Steiner, 2001; Hattori and Tsutsui (2004); Silva and Soares, 2008).

Today’s electricity industry in almost any European country is dominated by a few large companies. Privatisations took place. However, the state still holds substantial shares of the largest supplier. Only few countries like the United Kingdom split up the power suppliers and privatised parts of it. Three interregional markets evolved – the UK, the Nordic market and the Central and Western European market that includes France, Luxembourg, Belgium, the Netherlands, Germany, Switzerland and Austria. The remaining countries seem sufficiently integrated at the wholesale level. Retail prices, however, are either distorted due to regulation (e.g., Spain), or have not yet developed competitive markets such as in Eastern Europe (WEC, 2010).

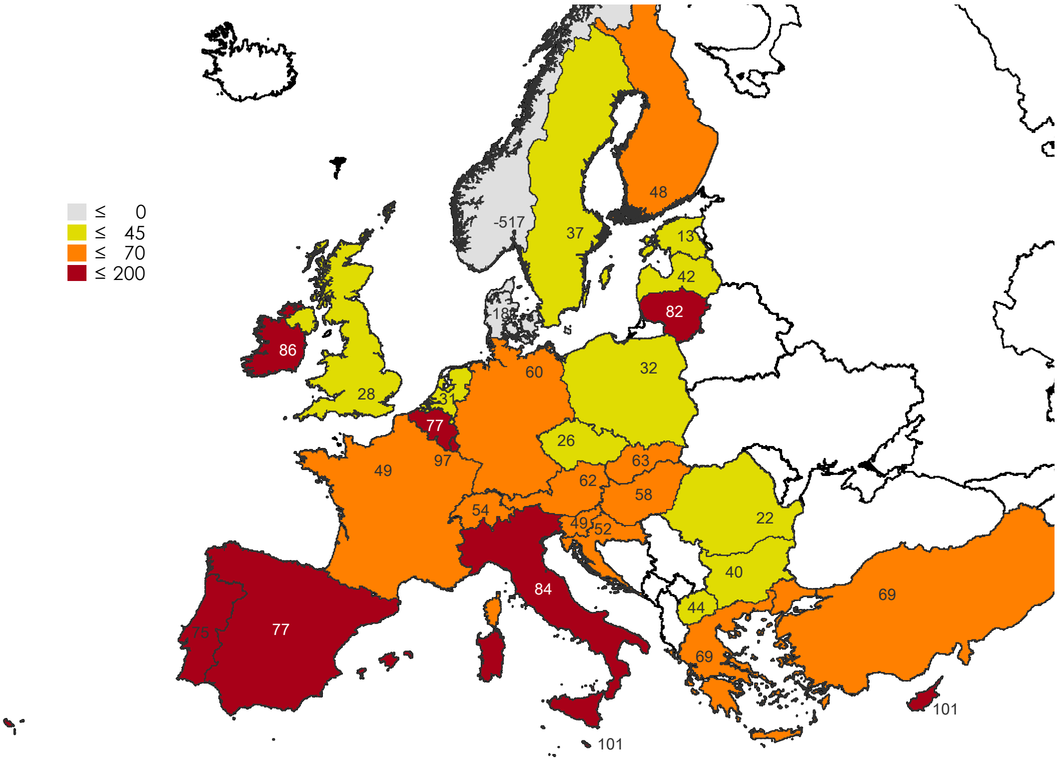
Annex II: A justification for Europe 2020

The energy used per unit of economic output has declined in the long run due to the shift from poorer quality fuels such as coal to the use of higher quality fuels, and especially electricity. A further decrease in energy consumption does not seem feasible if GDP continues to grow, and major technological shifts do not occur (Stern and Cleveland, 2004). Given the current consumption patterns and the expected economic performance, the EU's energy consumption is expected to rise by 1.5% on a yearly average by 2030.

Import dependency

At the same time, it is resource and energy dependant. It imports approximately half of its overall energy needs, which exposes consumers to external shocks. The European Commission (2007) extrapolates this figure, and barring any change, expects this ratio to rise to approximately two thirds by 2030. Its dependence is equally strong in inputs to 'dirty technologies', i.e. oil, gas and coal. Reliance on imports of gas is expected to increase from 57% in 2005 to 84% by 2030, of oil from 82% to 93%. Yet, the dependency rates vary greatly at the country level (see Figure 12).

Figure 12 **Import dependency across Europe (total energy consumption)**



Source: Eurostat.
Note: Gross inland consumption is calculated as follows: primary production + recovered products + total imports + variations of stocks - total exports - bunkers. It corresponds to the addition of final consumption

Approximately half of all natural gas imports and almost a third of the EU's imported oil is delivered by Russia. This has geopolitical implications. Europe's depends on Russia, which is rumoured that it may use its energy policies to influence European foreign and economic policy (Belkin, 2008). EU member states are among the many players that compete for these scarce resources. A shift from the current technology base towards less resource intensive technologies is likely to ease some the pressure of these competitive dynamics.

Climate change

A key argument for a change in the energy use is mankind's struggle against the effects of the global climate change. The Stern review (2006) suggests that the stock of greenhouse gases could more than treble by the end of the century. The likelihood of global average temperature to rise by 5°C is more than half. This implies serious challenges to mankind as a whole. A 5% increase corresponds to the increase from the last ice age to today. Global warming would substantially transform the physical geography, the living conditions and the global economic production. Models that consider the risk of abrupt and large-scale climate change estimate an average 5-10% loss in global GDP. In particular least developed economies suffer the most; estimates anticipate costs in excess of 10% of GDP.

The EU targets respond to these challenges by setting reduction goals for greenhouse gas emissions. By 2020 these should fall compared to the levels of 1990 by 20%. The EU is prepared to go further and reduce by 30% if other developed countries make similar commitments, and developing countries contribute according to their abilities as part of a comprehensive global agreement. In addition, the share of renewable energy in final energy consumption should increase to 20% for the Union as a whole. This target is accompanied by a 20% increase in energy efficiency.[27]

20% renewable energy

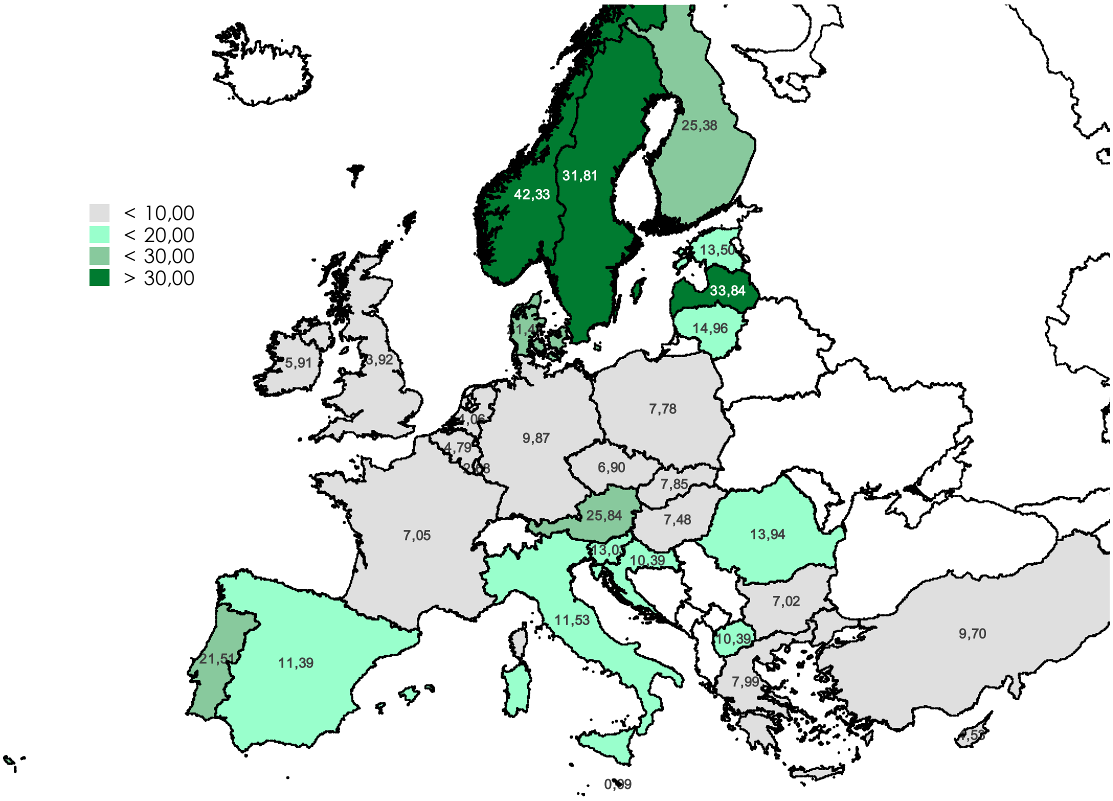
The EU-27 dynamics show a doubling of the portion of renewable energy in the energy mix from 5% in 1995 to 10% in 2011. Extrapolating the average growth rate of circa 5.4% for this period until 2020 leads to an expected contribution of RE of approximately 15%. This, however, does not consider advances in eco-technologies or price developments of conventional energy sources. Both are expected to accelerate the diffusion of RE technologies. This suggests that the Europe 2020 targets are on a macro-level not very ambitious. The targets will be reached through an extension of recent dynamics.

From a cross country, cross section perspective we find that at 42.3% Norway has the largest share of RE. The Scandinavian countries tend to have a RE share of approximately 30% in their energy mix, while most other countries oscillate around 10%. Malta has the lowest contribution (.1%), followed by Luxemburg (2.7%) and the UK at 3.9% (see Figure 13).

---

[27] See http://ec.europa.eu/europe2020/europe-2020-in-a-nutshell/priorities/sustainable-growth/index_en.htm.

Figure 13 **Share of RE across the EU in total energy consumption**



Source: Eurostat.

A key determinant of the share of RE is the electricity industry, which on average makes for 21% of the total energy consumption in Europe's OECD member states (Germany: 20.1%; Denmark: 18.4%; Spain: 23.9%). The sector's liberalisation and unbundling of the networks allowed RE suppliers to enter the supply market. This occurred to a varying degree. The energy mix statistics reveal progress in the contribution of renewable energy. However, the performance is mixed across member states. Path dependency matters in favour for countries like Denmark. Other countries like Germany struggle with a rather low share of RE despite strong promotion efforts that nonetheless succeeded in their efforts to change the energy mix.

Industrial competitiveness

The underlying technologies are assumed to be globally available. European firms were visible first movers in eco-friendly technologies. Yet, they increasingly struggle to remain competitive against fierce competition from suppliers and innovators from Asia and North America. Maintaining a competitive industrial basis is also important for achieving the interrelated social targets of Europe 2020 (e.g., social inclusion or an employment rate of 75%).

The agenda was released at a time where the global energy markets are in fundamental transition. Europe decided to take another strategic route than especially the US. The model of the EU promotes new technologies that it hopes will solve the challenges ahead. In the United States of America, on the contrary, shale gas extraction is being deployed on a large scale. This will drive down energy prices and may turn the US into a gas exporter by 2020. For energy intensive industries, the low electricity prices are expected to give the United States a huge cost advantage over Europe. However, and contradicting some media reports, the US is likely to remain a net importer of energy.

According to the annual energy outlook of the US in 2013, the net import share is forecasted to fall from 19% in 2011 to 9% by 2040.[28] In addition, China seems to implement a multi-pronged approach. It promotes RE in a similar way as in Europe. In addition, it heavily subsidises of eco-friendly industries to gain them an international competitive advantage. At the same time it has a large untapped shale gas potential; agreements to share technologies with US based extraction firms have been set up, and there are plans to begin the extraction in the near future.

---

[28] See http://www.eia.gov/forecasts/aeo/er/executive_summary.cfm and http://www.eia.gov/pressroom/presentations/sieminski_01212013.pdf; retrieved on 26 June 2013.

Annex III: An overview of relevant concepts and methods

At the core of this research is the policy-induced deployment of a group of technologies. We depart from Rogers' (2003) general definition of diffusion as a process by which an innovation is communicated through certain channels, over time and among members of a social system. In the present setting of RE both innovation and communication channel are policy induced, and the policy goals set a time frame. Hence we focus on the reaction of the agents of the social system.

Technology scholars, in particular those who study environmental sustainability topics, use interdisciplinary approaches to capture the complexity that is involved in diffusion processes. They have developed a multitude of partly overlapping models that describe technology diffusion processes at various levels (e.g., Foxon et al., 2013; Doh et al., 2012). Many of these approaches are merely descriptive, perhaps because a causal relationship is hard to prove, or does not even exist in a world of co-evolution (e.g., Klein and Kleinman, 2002).

The following sketches the main models that affect the dynamics that we describe. We note that this is by no means an exhaustive survey of relevant approaches.[29] We draw on both economic and sociological approaches that we deem to be useful for the reader to be aware of, even if we do not explicitly use them. The only exception is the social construction of technology, which we will elaborate on in greater detail.

Economic approaches

We first sketch neoclassical (micro-)economics as a starting point and gradually move away from the concept of equilibrium, homogeneous agents, or uniform micro patterns. Jointly with network economics, these constitute the foundations of regulatory economics that is relevant to some aspects of a change in the energy mix. Since the shift towards RE is largely policy induced, new institutional economics sheds some light on how policy makers act. Eventually, evolutionary economics are a useful description of how the interplay of several dimensions shapes an industry.

Marginal utility and market failures: Neoclassical approaches

We use *neoclassical economics* as a starting point. Changes in marginal utilities often pose the main decision criterion. In particular cost efficiency determines technology adoption. The marginalism of neoclassical economics assumes a steady stream of incremental adjustments, which may not be the case in the energy sector. Similarly, in a sector that faces fundamental structural change, marginalism may hamper the 'bird's eye view' of the manager in others (Foxon, et al., 2013).

---

[29] For more comprehensive overviews, see for instance Ghazeli et al. (2012), van den Bergh and Kemp (2008), or Olson et al. (2009).

Neoclassical economics also attempted to consider environmental costs through 'external effects'. These are not paid for by those responsible for the economic activities that create those costs (Pigou, 1932). When trying to allocate or internalise externalities, policies have struggled to provide an adequate estimate due to measurement and prediction issues. Another relevant strand of the neo-classical thinking is the regulation of networks. Critical parts of networks are infrastructure whose duplication is economically not viable, and thus a monopoly that needs to be regulated to avoid unacceptably high costs to consumers.

Technology diffusion in networks

An expansion to neoclassical diffusion dynamics that is based on a vague utility concept is offered by *network economics*. It finds that the bigger the network the more beneficial the participation for both suppliers and consumers. In network industries, production exhibits economies of scale and scope (e.g., due to R&D expenditures). Consumers benefit from bigger networks due to positive consumption externalities, because the bigger the network the greater the chance of interaction with another participant. Hence, the utility of a good depends on the number of other participants. Apart from these direct network externalities there are also indirect benefits, which include the greater availability of complementary goods such as spare parts or a bigger second hand market. In the diffusion process there is the concept of the critical mass, i.e., a tipping point where a sufficient number of consumers emerged to render the network self-sustainable (e.g., Katz and Shapiro, 1985; Shy, 2010; Friesenbichler, 2013). Network economics underlie the diffusion dynamics, and are of particular relevance when assessing the diffusion speed.

The policy maker dimension: New institutional economics and public choice

The diffusion of an innovation cannot be reduced to the interplay of suppliers, customers and competitors. Albeit economic forces matter for the eventual adoption of ecological-innovations, the energy transition is not primarily shaped by market forces, but by public policies. Even more so: If they were privately driven, expected revenues would be insufficient to instigate change. The institutional settings shape market outcomes, and are thus not distinct from market mechanisms, but take place in parallel (Baron, 1998). Hence, we consider a deeper going explanation is offered by *new institutional economics*, where the underlying social and legal norms, the institutions, determine the behaviour of organisations such as firms, interest groups, unions etc.

Dependable, stable and predictable institutions reduce costs and foster economic development. This view differs from economics by not looking at the economic effects of regulations, but instead by analysing the changes in the way contracts are being made in different institutional settings (e.g., North, 1991; Coase, 1991; Doh et al., 2012). New institutional approach resembles public choice theory, which blends economics and political science. It describes the rules that determine societal activities as a result of a political process, where politicians that are mainly interested in their own re-election maximise their own utility. Public choice also offers explanations for the variation in systemic outcomes by means of different political institution (e.g., Brennan and Buchanan, 2000). This may shed light on the cross-country differences of the implementation of the policies that seek to alter the energy mix.

A holistic approach: Evolutionary economics

A joint reflection of both economic and sociological approaches is provided by Malerba (2002), who introduces the concept of *sectoral innovation systems*. This approach defines the 'sector' a set of products and of agents that carry out both market and non-market interactions to create produce and sell those products. Hence, it incorporates findings of industrial organization. A sectoral system shares a knowledge base, technologies, inputs and demand in which the same agents interact through given processes of communication, exchange, co-operation, competition and command. A sectoral system undergoes change and transformation through the co-evolution of its various elements. This insight is essential to the energy transition – policies are only one component, and require a systemic surrounding.

Complexity theory in economic

Complexity theory is a descriptive approach to describe the dynamics in a multi-agent setting that set interconnected actions. It is not a closed theoretical concept, but rather paraphrases a set of approaches that has been used to explain interdependencies of many elements that comprise subsystems or an overall system. The first applications were found in natural sciences such as physics, computing and biology (for an overview see Miller et al, 2009) - and later in arts and social sciences such as education (e.g., Tosey, 2002), economics (e.g., Arthur et al., 2003) and management (e.g., Stacey, 2003).

Arthur et al. (2003) assign a series of characteristics to complex systems. These are (i) dispersed interactions between heterogeneous agents; (ii) the lack of a central planner or 'global controller' which renders the system as a whole uncoordinated; (iii) hierarchies are cross-cutting in a way that the joint action of agents and units create building blocks that feed into a hierarchical organisation; (iv) actions are permanently adapted; (v) the system is re-inventing itself by novelty niches; and (vi) the system is permanently changing – an equilibrium is out of sight. A global optimum tends to exist only in theory, and agents would have to accept less efficient states to reach it.

Sociological approaches

Simultaneously we consider sociological approaches. A straightforward theory depicts social networks as the drivers of technology diffusion. This seems relevant to the creation of single markets. A far reaching approach that captures the complexity of a multi-layer and multi-agent social system is offered by the social construction of technology. Eventually neo-institutional perspectives explain the social factors that determine the political - and policy - setting.

An agent perspective: Social network theory

Social network analysis focuses on agents, and investigates how technological or market niches grow through its involved actors that may share interests and complementary expertise coming together, leading to increasing returns to scale and non-linear growth (Foxon et al., 2013). The computational interpretation of this approach may be seen as agent based modelling, where autonomous entities, each with dynamic behaviour and heterogeneous characteristics interact with each other and their environment, simultaneously determining outcomes (Heckbert et al., 2010).

Agents define outcomes: Social construction of technology

Bijker et al. (1987) depict technology itself as an endogenous social construct. The *social construction of technology, SCOT,* concept offers a set of interdisciplinary and versatile heuristics to analysts of technology development. In a nutshell, it describes how the implementation of a technology results from the interplay of actors and a given technology in a certain environment, which shares key concepts and current theories. The process is embedded in a social context and political milieu. The concept provides an alternative to technological determinism that strands of economics follow. SCOT sees technologies as determinants of societal development which develop autonomously. In this approach, society itself shapes technology, thereby capturing a feedback effect on itself. It provides a multi-actor and multi-layer view on technological development, and has been applied to a series of technology fields in various ways, such as the political construction of radioactive waste or the clinical budgeting in the British National Health System (Bijker, 2009), or more normatively, in a study that seeks to overcome the factors that hinder sustainable sanitation in Europe (BESSE, 2012).

SCOT requires a common understanding of a technology in order to diffuse, and hence is a key component for the communication channel thought that links two adopting units and hence form the diffusion process (Rogers, 2003; Hall, 2005). Although the concept provides a highly useful frame when social groups are required to agree on the implementation of a technology, the original concept does not consider power asymmetries (e.g., due to different economic resources, or the agents' capacity to shape political outcomes). This leads to differences in the relevance of agents (e.g., Klein and Kleinman, 2002), which can be considered in the framework, but has not been explicitly noted.

How institutions are shaped: Neo institutional perspectives

The *neo-institutional perspective* describes the formation of institutions as a social process. Both private contracts and public policies are a result of the interaction of stakeholders' social obligations. These enable and constrain political actors to enforce public policies. Firms are viewed as embedded within the social environment, which is the main external factor that determines performance. It asks questions about how social forces 'constrain' political actors and constrain policy outcomes (e.g., Getz, 1997; Yaziji and Doh, 2009; Doh et al., 2012).

If one combines Bijker's SCOT with new institutional perspectives, a 'darker', yet relevant side emerges. When institutions are constructed by social dynamics, which again shape market outcomes, then outcomes are affected by rent-seeking behaviour. This implies that the analysis of non-market settings should incorporate agents that lobby legislators or regulators, make campaign contributions and provide information to relevant institutions (Doh et al., 2012).

Annex IV: Technological showcasing - From smart metering to smart homes

The structural reform of energy systems hinges on the roll-out of a variety information and communication technology (ICT) services – the grid management, the operation of RE systems and smart metering are key elements of a new capital stock. Their deployment is embedded in broader technological developments.

The aim of the following is to sketch the effects of selected ICT solutions on their users. In particular, we seek to identify the social and environmental implications involved. We chose technologies to which policy makers assign a great potential despite their developmental development stage.

The starting point is the 'smart meter' and how it can affect the electricity consumption. We then broaden the discussion to the 'intelligent home', and use this context to focus on ICT based, health-related applications. We depict the first experiences from available pilot projects, and attempt to extract some general policy conclusions.

Showcasing of ICT applications

Smart meters

'Smart electricity metering' is a key component of a 'smart grid'. Smart meters are the end-consumer devices that in their simplest form provide detailed information on consumption. Smart metering potentially goes much farther, though. An 'advanced meter infrastructure' links prices to end-consumer devices to price developments, which allows for electricity optimisation routines at the household level. Generally, smart metering makes usage patterns more transparent, and may help reduce the overall electricity consumption. Smart meters are a necessary technology for real time pricing, i.e. the price setting according to the present market conditions.

Functionalities

The European Commission (2011c) sets an obligatory target of an 80 % roll-out of smart metering by 2020. It provides a list of technical functionalities that meters must meet.

For consumers and installed devices, they should provide information on power consumption in an understandable form, and sufficiently often update the data to better control their energy consumption.

For the grid and network operators, they allow for the remote meter reading. They establish a two-way communication between the meter and external networks such as energy suppliers and grid operators, which can be used for maintenance and control purposes. They deliver regular information on power quality to the grid operators. Hence, energy suppliers obtain access to advanced tariff systems, such as multiple tariffs, time of use registers, block tariff registers, remote tariff control, etc. They support energy supply (e.g., by pre-payment and on credit), and enable remote on and off control of the supply and/or flow or power limitation.

In addition, smart meters are a basis for the automation of distributed power generation. They provide information on imports and exports of the local system. They operate reactive metering, which again has feedback effects on the system's internal use. Smart meters should guarantee secure data communications, which supports the prevention and detection of fraud.

First experiences

Little evidence yet exists on smart meters. A study by Ipsos MORI (2012), a research firm, analysed interview data (n: 4,455) of adults who were at least jointly responsible for paying their household energy bills. The interviews were held in 2012 across Great Britain. The aim was to examine users' attitudes on smart meters and in-home displays (IHDs), including their information needs. The support pattern is in line with evidence on first movers: younger and larger households express greater support and interest; larger households are more affected since they are heavier consumers. Half of all respondents remained undecided about the installation of smart meters in every home in the country. Support showed little evidence of change with around three in ten bill-payers (29%) expressing support for the roll-out, and one in five bill-payers remaining opposed (19%). Some perceived benefits were mentioned, including being able to budget a bit better (31%) by monitoring and reducing of energy use, to help avoid waste (26%) and produce a greater accuracy of billing (19%). The perceived disadvantages included cost (17%; regardless of whether the respondent herself, the taxpayer, the government or the energy company incurred it and data security (9%).

The study also finds that only one in six bill payers reports to have an in-home display (or is aware of it), which renders consumption reactions impossible. Over half of those who reported to have a display installed said they looked at it at least occasionally, checking either the energy use or the money display. Customers rather received displays from their utility firm than have actively requested, let alone purchased displays. Those customers who checked the displays were generally positive about the devices effectiveness.

The International Confederation of Energy Regulators (ICER, 2012) summarises the first experiences made in France, Italy, Great Britain, Sweden, Canada (Ontario) and the US (Colorado). The findings confirm the expected technology diffusion pattern. For example it suggests that the full implementation of smart metering may take years, or that learning processes and knowledge spillovers lessen the demand for pilot exercises.

The implementation was particularly successful where an impact assessment shaped regulatory or governmental policies that supported the diffusion and owner- and leadership of the policy process was clarified from the onset. The technical framework should be clearly set out in harmony with the roles and responsibilities of market participants.

A major concern on the suppliers' side refers to the technological flexibility – will the proposed smart metering be able to accommodate future developments that smart or universal grids impose? Several concerns remain on the consumers' side. What if the collected data are not adequately protected? Suppliers will have to offer a pricing scheme that provides different rates over the day. These schemes may easily become too complex to rationally base consumption decisions on them. Hence, consumer involvement in the policy setting process should be given.

The European Commission prescribes an economic analysis prior to the roll-out which incorporates four steps: 1) tailoring to local conditions, 2) cost-benefit analysis, 3) sensitivity analysis, and 4) performance assessment, externalities and social impact.[30] Interestingly, the deployment targets have already been set, which casts doubts on the objectiveness of the outcomes.

Consumer reaction

Policy makers hope that smart meters will affect consumption behaviour once smart meters and displays are installed. The current electricity demand, however, is quite inelastic. Simmons-Süer et al. (2011) establish in a survey for private households an average elasticity range between -0.2 in the short and -0.6 in the medium run. Lijesen (2007) examines real-time prices, i.e. the real-time relationship between total peak demand and spot market prices, and finds a diminishing value for the real-time price elasticity ranging from -0.0014 to -0.0043. This may partly be explained by asymmetric information since not all users observe the spot market price, but rather base their decision on average costs. Yet, the coefficients remain extremely low after correcting for the unequal distribution of information.

Currently, most suppliers offer little price variation; in some countries day and night tariffs are different. It is unclear if the inelastic consumption reaction would continue if prices fluctuated more strongly. Considering developments in the wholesale price in retail prices is not an easy exercise, which is why suppliers are concerned about the complexity that might evolve (ICER, 2012).

The impetus for a reduction in electricity consumption is unlikely to come from smart metering. In Germany for instance, private households only make for a quarter of the electricity consumption. The business sector, in particular industrial manufacturing, makes for the remaining three quarters. Large consumers already optimise their consumption according to prices.

Another concern is what a new consumption pattern that is aligned with price swings implies socially? For instance, if the electricity price reaches its low around noon, people who work full time are in work and are not ready to consume; insurance regulations require household appliances not to be left alone when turned on (e.g., washing machines), or noise pollution rules out their operation at night, which constraints the automation potential.

Then again, what if consumers are not required to change their own behaviour? What if their actions are automated?

Smart homes

A smart electricity meter and the envisaged shift in the electricity consumption pattern are embedded in a broader discussion on smart homes. Through the integration of ICT applications in the home environment systems and appliances are able to exchange information in an integrated fashion, which has many implications on the way people live.

---

[30] See http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2012:073:0009:01:EN:HTML.

Applications

A smart home operates networked solutions that incorporate both the building automation as well as the control of domestic activities. Their aim is to increase the residents' convenience, for instance by dimming lights in a home theatre, or maintaining product inventories, even automatically order replacements. The solutions offer benefits to safety. For example, smoke detectors detect fire or smoke conditions, or intelligent appliances send signals if they require service or maintenance. Also living costs are optimised, for instance through the energy use; lights are automatically shut down at a specific time at night, and motion sensors activate lights when necessary.

The control itself either takes place through a computer or through remote access devices that use the internet (e.g., on smart phones, tablets or web browsers). The potential applications cover a wide range that includes the control of the heating, ventilation, air conditioning; blinders and lights, household devices; locks and security devices, plant and yard watering or pet feeding.

Market development

The smart home market is currently in its infancy. Households with greater wealth and technological affinity already cover niches. The mass market remains untapped, and due to the breadth of applications, firms offer a 'one stop shop' has not yet evolved.

To put together a package of smart home applications for a wider deployment, different providers of devices and services will need to collaborate. There are various companies that have an entry point to households, such as energy suppliers through smart meters, broadband companies via modems and IT companies through their computing systems and devices. It is unclear which industry will take the lead.

Equally broad are the technical requirements of smart homes. These *inter alia* include sensors, controllers, actuators, interfaces. Interconnecting these devices is challenging. Various suppliers that operate different and partly incompatibly standards compete for the market, which hampers the diffusion process and the formation of a critical mass. Establishing a common standard seems to be a critical challenge, which will involve inter-firm and cross-industry collaboration.

Another component of the market development is the estimation and enlargement of the current market potential. Several privately-led technology platforms exist, which assign great potential to the market. Yet, pilot homes that exhibit experiences, successes or failures of the implementation are rare, and it is uncertain whether the mass-market will accept them.

The technology base is provided by the private sector. Policy makers have an interest in its socio-environmental components, which strongly affects the public sector, or its area of influence. It is unclear how regulations in utilities and healthcare affect the roll-out of proposed smart home concepts.

Infrastructural needs

The networked structures of smart homes require connection to data grids. Currently, the high-speed broadband lines that are required are not sufficiently available in any member state for a nationwide roll-out of sophisticated smart home applications. In January 2012, not a single member state had a high-speed broadband penetration rate (at least 30 Mbps) of over 10%. Only Belgium, Latvia, Netherlands, Romania, Lithuania, Sweden and Denmark reached a penetration between five and ten percent.[31]

Another concern refers to the connection speed. The Broadband Program Office for New York State assigns applications to the bandwidths.[32]

- 1-4 Mbps: Basic email, web browsing, music streaming, standard definition video (SD), remote surveillance, telecommuting
- 4-6 Mbps: File sharing (small/medium files), IPTV (Internet TV services)
- 6-10 Mbps: Online gaming, video on demand (on a single device)
- 10-15 Mbps: Telemedicine (health care via telecommunication), remote Education (distance education programming), IPTV High Definition (HD TV programming)
- 15-50 Mbps: HD video surveillance
- 50+ Mbps: Video conferencing (multiple users), remote supercomputing, real-time data collection, real-time medical image consultation

The Digital Agenda of Europe 2020 sets a target to fully cover the EU with broadband above 30 Mbps by 2020 and 50% of the EU to subscribe to broadband above 100 Mbps by 2020. The list indicates that a full achievement of the coverage targets of the Digital Agenda will suffice to cover some applications with strong social impact (e.g., telemedicine or remote education). Yet, it will not be enough to satisfy connection needs of over 50 Mbps that applications such as real-time medical image consultation require.

Smart home applications for an aging society

While smart homes may add to the convenience of users, they also bear potential to contribute to some urging societal challenges. The following gives a brief overview of health and aging related solutions that these incorporate.

Products

In an online survey Felbo (2009) examined the attitudes of people over 50 towards several ICT applications. The examined products were health and age related:

- Sensor technologies that assess the condition of a patient. For instance, these set off an alarm in the bathroom when the patient falls. The control of lights, heaters, doors, windows etc. occurs automatically.
- Scales and medical test kits such as inhalators or sphygmomanometers transfer data to a central information system which medical experts can access and make remote assessments. The interpretation of the results is discussed with the patient in a video conference. Remote medicine is a cost-efficient solution for the chronically ill which

---

[31] See https://ec.europa.eu/digital-agenda/sites/digital-agenda/files/KKAH12001ENN-PDFWEB_1.pdf.

[32] See http://homes.yahoo.com/news/choose-the-best-internet-speed-for-you-224440280.html.

supports the independence of the patient, and facilitates the work of nurses and/or family members.

- Automated toilets and bathrooms clean the patient without the involvement of nurses or relatives. Hygiene is assured under the protection of privacy.
- Recall technologies easy the every-day life of dementia patients in the early phase by providing information such as appointments, shopping lists or addresses.
- Various robot solutions exist, ranging from an automated vacuum cleaner to robot animals that stimulate dementia patients.

Attitudes

The study also enquired about the assessment of these technologies, whether they were thought of as a very good – good – neutral – bad or very bad idea. Toilet, recall and sensor technologies were supported (i.e. judged as very good or good) by more than 70%, robot vacuum cleaners by 60%, bathing and stimulating robots by 50% of the respondents. Despite the high approval rates, the fear of the loss of contact persons and technical breakdowns lower the willingness to adopt. This particularly affects personal services. Only an eighth would have been willing to replace current body cleaning by automated solutions.

Asked about the expected requirements, respondents said that they should be easy to handle and must not replace interpersonal contact (both 78%), should be affordable (68%), technical assistance must be ready (62%), increase the living standard (60%) and the use of data should be laid out (41%).

The survey was fielded in Denmark. Two thirds of the 1,044 respondents were between 60 and 74 years old. The results were weighted proportionally according to sex and annual household income.

A summary and thoughts towards policies

Smart metering constitutes one component in an ongoing trend of the deployment of ICT. The products depicted here can increase citizens' convenience and safety, while at the same time it can reduce the cost of living. This affects both the environment – e.g., though energy costs, and social aspects, for instance through applications in fields like healthcare or the aging society. Hence we argue that the plethora of still emerging applications bears potential to contribute to solutions for environmental and societal challenges.

The innovations that we described are provided by private firms that face to expand a market that is still in its infancy. It is uncertain which technologies will eventually prevail. In many cases it is a product bundle whose implementation hinges on technical developments, user acceptance, and a policy mix that provides infrastructure, adequate regulation or skills.

This implies that public policies are restricted; actions by the private sectors eventually shape outcomes. Hence we distinguish between the technology formation processes that are purely private on the one hand and the public sector on the other hand.

Public sector policies that support the private sector

The objective for public policies should be to best support the private sector in a non-discriminatory way. The range of policy options comprises fields like infrastructure, standardisation or regulation:[33]

- Many of the desired applications draw on infrastructure such as access to broadband lines that currently are only insufficiently installed. The public sector should provide investment incentives to sufficiently stimulate the deployment of a high-speed data grid.
- A great challenge is to interconnect the various electronic devices that emerge, which requires standardised protocols. Due to incomplete information and the risk of adverse selection, standardisation processes should be rather market driven. Policy makers should provide a discussion platform where required (Friesenbichler, 2013).
- It is unclear whether the current regulatory framework – in both the utility and the health sector – is adequate to facilitate the roll-out of ICT solutions with socio-environmental benefits. Studies should provide relevant evidence.
- Policies should be evidence based. Before mandatory regulations shape market outcomes, a sufficient amount of knowledge on the socio-economic and environmental effects of the respective policy should be gathered. This might seem straightforward, but is not always adhered. For instance, smart metering is a novel technology whose roll-out has been prescribed in a compulsory fashion, even though only few pilot studies are currently available. The European Commission’s recommendation for smart meters foresees a cost-benefit assessment whose result seems predetermined.

Diffusion in the public sector

Not all of the emerging applications address the private sector. There are areas in which the public sector is the main, sometimes the only source of demand. In some cases a blend of the public and private sector is the main player, i.e. the third sector. The absence of the private sector framework has several implications on the technology formation process that differs in the public sector, whose peculiarities need to be considered.

Much of the diffusion literature discusses learning effects in the early stages of a diffusion process (e.g., Rogers, 2003; Wilson et al., 2011; Geroski, 2000) This evidence, however, refers to the private sector where firms incrementally improve their products and compete on a free market. Competition has positive feedback effects on the technology diffusion. It offers choice to consumers and reveals their preferences. In the public arena or in the ‘third’ sector, however, competition is not desirable due to the monopoly of the state and the use of tax money.

Similarly, private companies discriminate among their customer base. They may explicitly target customer segments, aiming to attract first movers to later achieve a critical mass. These initial users, however, are not the needy; they are often highly educated, male, wealthy urban users (e.g., Katz and Shapiro, 1985; Rogers, 2003; Shy, 2010; Hoppe, 2002; Friesenbichler, 2013).

---

[33] This list is non-exhaustive.

This contradicts the implicit objective of publicly provided social technologies. Firms should not discriminate if the goal is to generate a general availability of certain services, let alone a more egalitarian income distribution. The lack of competition and choice, however, hampers the identification process, decelerates the time to saturation, and hampers the ability to continuously improve the technology base.

These issues cannot be easily overcome. There are several approaches that at least partially mitigate the problems:

- A one size fits all' solution does not exist. There is great variance across regions and countries in their technological and funding capabilities, as well as acceptance for innovation. Social challenges equally differ, ranging from an aging society, unemployment to integration. Hence, policy models should be regionally customised and demand driven. This requires strong regional autonomy.
- Inter-regional policy learning can be facilitated through macro-level platforms. A regionally differentiated approach also spreads risks geographically.
- Technologies seem to find better public acceptance if there is a form of 'societal ownership'. Hence, co-operative ownership models could be established (if applicable).
- The first-move issue relates to the state as a risk-taker. Incorrect investment decisions equate to the waste of public money; the notorious problem of public risk-taking emerges. Where applicable, risks should ideally be shared with beneficiaries (e.g., through matching grants).
- Technology diffusion in the private sector occurs voluntarily. Adopters can choose between an established, and at least one new technology. Technology fields that involve security are particularly delicate. For instance, online banking was adopted voluntarily, even though highly sensitive data was used. Such opting-in – perhaps combined with adoption incentives - is to be preferred over opting out solution, where agents can choose not to partake if they wish.
- Public procurement is a cardinal point in creating first movers. On the one hand, civil servants are required to efficiently use public money and are by definition risk averse. They minimise risk by opting for larger lots of established products. On the other hand, the 'third sector' (i.e. the intersection of the public and the private sector that is common in health or social services) requires a pioneering public sector to enhance innovative activities. To encourage an innovative public procurement, risks need to get allowed for, yet minimised. Similarly, smaller lots for demonstration and reference projects are an option to increase product diversity and generate learning effects through experimentation.
- Policy makers should be aware that their actions will continue to affect both the public and the private sector – not always in an intended or desired way (e.g., Shah, 2012). The adoption of ICT itself has changed many processes. The labour market reacted. For instance, the demand for higher qualification increased, work processes became more efficient and faster due to modern means of communication. At the same time, automated process steps made employees redundant while new forms of employment evolved.

The research leading to these results has received funding from the European Community's Seventh Framework Programme FP7/2007-2013 under grant agreement n° 290647.

Project Information

Welfare, Wealth and Work for Europe

A European research consortium is working on the analytical foundations for a socio-ecological transition

Abstract

Europe needs a change: The financial crisis has exposed long neglected deficiencies in the present growth path, most visibly in unemployment and public debt. At the same time Europe has to cope with new challenges ranging from globalisation and demographic shifts to new technologies and ecological challenges. Under the title of Welfare, Wealth and Work for Europe – WWWforEurope – a European research consortium is laying the analytical foundations for a new development strategy that enables a socio-ecological transition to high levels of employment, social inclusion, gender equity and environmental sustainability. The four year research project within the 7th Framework Programme funded by the European Commission started in April 2012. The consortium brings together researchers from 33 scientific institutions in 12 European countries and is coordinated by the Austrian Institute of Economic Research (WIFO). Project coordinator is Karl Aiginger, director of WIFO.

For details on WWWforEurope see: www.foreurope.eu

Contact for information

Kristin Smeral

WWWforEurope – Project Management Office

WIFO – Austrian Institute of Economic Research

Arsenal, Objekt 20

1030 Vienna

wwwforeurope-office@wifo.ac.at

T: +43 1 7982601 332

Domenico Rossetti di Valdalbero

DG Research and Innovation

European Commission

Domenico.Rossetti-di-Valdalbero@ec.europa.eu

Partners

Austrian Institute of Economic Research	WIFO	Austria
Budapest Institute	Budapest Institute	Hungary
Nice Sophia Antipolis University	UNS	France
Ecologic Institute	Ecologic	Germany
University of Applied Sciences Jena	EAH Jena	Germany
Free University of Bozen/Bolzano	FUB	Italy
Institute for Financial and Regional Analyses	GEFRA	Germany
Goethe University Frankfurt	GUF	Germany
ICLEI - Local Governments for Sustainability	ICLEI	Germany
Institute of Economic Research Slovak Academy of Sciences	IER SAVBA	Slovakia
Kiel Institute for the World Economy	IfW	Germany
Institute for World Economics, RCERS, HAS	KRTK MTA	Hungary
KU Leuven	KUL	Belgium
Mendel University in Brno	MUAF	Czech Republic
Austrian Institute for Regional Studies and Spatial Planning	OIR	Austria
Policy Network	policy network	United Kingdom
Ratio	Ratio	Sweden
University of Surrey	SURREY	United Kingdom
Vienna University of Technology	TU WIEN	Austria
Universitat Autònoma de Barcelona	UAB	Spain
Humboldt-Universität zu Berlin	UBER	Germany
University of Economics in Bratislava	UEB	Slovakia
Hasselt University	UHASSELT	Belgium
Alpen-Adria-Universität Klagenfurt	UNI-KLU	Austria
University of Dundee	UNIVDUN	United Kingdom
Università Politecnica delle Marche	UNIVPM	Italy
University of Birmingham	UOB	United Kingdom
University of Pannonia	UP	Hungary
Utrecht University	UU	Netherlands
Vienna University of Economics and Business	WU	Austria
Centre for European Economic Research	ZEW	Germany
Coventry University	COVUNI	United Kingdom
Ivory Tower	IVO	Sweden