Policy interaction and the integration of volatile renewable energy

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Abstract

This paper compares the experiences in three countries with the integration of volatile, renewable energy into the electricity mix. The contribution of financially promoted wind and solar power increased substantially, but evoked concerns about the security of supply due to the displacement of conventional producers that provide peak and emergency capacities. The attributes of financial technology promotion, grid management policies, and the development of peak and emergency capacities are analysed for Germany, Spain and Denmark. While promotion and grid management policies were largely similar, peak and emergency capacities developed differently. Denmark's size allows balancing demand and supply via electricity trade. The displacement effect was more pronounced in Germany than in Spain, which is due to differences in the regulatory framework. The institutional framework in Spain implicitly imposed a hierarchy on the politically desired policy targets security of supply, sustainable production and competitive market selection.

JEL Classifications: Q48, Q49, Q55, Q59, Z13.

Keywords: renewable energy, technology diffusion, trade-off

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Introduction

Limiting the man-made contribution to climate change and considerably reducing greenhouse gas emissions is considered as one of mankind's biggest challenges (Stern, 2006; Meinshausen et al., 2009; IPCC, 2014). Incremental technological change is insufficient to limit the global temperature rise (Antal and Hukkinen, 2010). The entire energy system needs restructuring. Technology push and demand pull instruments should accelerate innovation (Moriarty and Honnery, 2012). Such calls for 'radical reform' are echoed by policy targets. For instance, the European Union (EU) provides a set of interdependent goals. It seeks to cut gas emissions by 40% by 2030, and will produce 27% of its energy from renewable sources compared with 1990 levels. These targets are more ambitious than their predecessors of Europe 2020, which were however binding. The 2020 targets *inter alia* saw a reduction in greenhouse gas emissions by 20% and a share of renewable energy in total energy consumption at 20% by 2020.

This paper challenges the assumption that the transition to a new technology base will be as smooth as previous transitions, such as from wood to coal, and subsequently to gas and oil (Moriarty and Honnery, 2012). Policy documents often assume that "smart industrial policy", a mix of regulation and promotion, would suffice to reach a new capital base. For instance, the IPCC (2014) refers to climate change as a collective action problem and recommends more policy collaboration as a possible solution. Technology policies require empirical programme evaluation to provide evidence on the relative effectiveness of different policies to assist with policy design. This paper uses the electricity sector to argue that inherent trade-offs undermine the proposed dirigisme, rendering a frictionless transition impossible given the current technology base.[1] While some policy makers involved have expected frictions and

[1] The European Commission (2011) provides additional targets for the contribution of renewable energy (RE) to the European electricity mix: 37% by 2020. The fraction of electricity in total energy is on average 21$ in the EU. The contributions in the hereafter compared countries amounted to 20.1% in Germany, 18.4% in Denmark 23.9 in Spain in 2010 (IEA data).

anticipated adjustments in the policy mix, it is unclear what role the institutional setting plays for policy effectiveness.

This paper presents a three country case study about the interplay of separate policy fields. The approach was chosen because data is not sufficiently available to implement statistical methods, and the analysed experiences may largely depend on the country-specific environments. Three policy fields are analysed which jointly determine the success of the integration of RE under the condition of maintaining the security of supply (Rykkja et al., 2014). The discussion of the attributes of the subsystems that the policies affect allows identifying causal factors for differences in the performance of the overall system. The study draws on several data sources, including key policy documents, secondary literature and publicly available data.

The fragmentation of the European electricity market is used to analyse cross-country variance in policy making. Germany serves as a showcase that eagerly promoted the diffusion of RE technologies in its electricity sector, but has increasingly faced issues with the grid stability. The guiding question is why other countries remained largely devoid of similar issues. This contribution thereby provides rare cross-country evidence on differences in the policy implementation and institutional architectures (Foxon et al., 2014; Rykkja et al, 2014).

From a conceptual perspective, elements of the microeconomic market selection mechanism, technology policy literature as well as the sector specific regulatory framework will be used to identify cross-country differences. Minding the scope of the study, neither a granular policy discussion, nor the underlying political economy has been included in the discussion. The technological focus is on wind and solar power. Other technologies have largely reached their saturation point (e.g., hydropower) or are not mature enough for large scale diffusion (e.g., tidal power). Biomass is a RE source which potentially provides constant supply. However, its generation costs are significantly higher than for wind and solar power, which currently hampers their deployment.

The remainder is divided as follows. First, a sketch of the inherent trade-offs that the sector is confronted with sets the stage. Second, the choice of the comparison countries is justified. Third, the country specific policies in the three fields are presented. The paper closes with a discussion and summary of the findings.

Inherent trade-offs

The structure electricity supply sector determines the share of renewable in the electricity mix. Electricity producers that operate different technologies, both conventional and renewable mutually satisfy demand by covering the base and the peak load. In addition, they provide emergency capacities and thereby avoid shortage situations and outages. The electricity mix is set by the distribution of the market shares, which are allocated on the energy-only market, i.e. electricity wholesale. The allocation mechanism relies on cost competitiveness and is implemented against the background of the European electricity policy principles. Implemented nationally, these reflect the politically desired outcomes of the electricity sector: sustainability, security of supply and competitiveness (European Commission, 2006).

The target triangle imposes an inherent trade-off. The achievement of the European strategy targets requires the integration of more RE integrated in the grid. At the same time, the market is required to guarantee electricity supply through a competitive selection mechanism at affordable prices. A trade-off materialises as follows: The static efficiency objective seeks to keep prices low so that sellers cannot excessively benefit at the cost of buyers. The resource allocation for a given set of technologies is optimised. However, the desire for low prices diverges from dynamic efficiency objectives, especially from the security of supply.

Static efficiency on the wholesale electricity market is implemented by the merit order, the main selection mechanism of the energy-only market. The merit order ranks technologies by their marginal costs, and thereby provides a feed-in order. The most cost-competitive technologies obtain a feed-in priority. Wind and solar power are produced at negligible marginal costs and are therefore highly competitive on the energy-only market. As a result, the merit order effect prefers RE and lowers the demand for electricity from conventional producers such as nuclear power, coal, gas and oil plants.

Figure 1 shows stylised supply and demand functions in a merit order setting. Suppliers on the right side of the demand curve lay idle as RE on the left side displaces technologies with higher marginal costs. The exit of relatively ‘dirty’ technologies and the price reduction induced by the deployment of RE are politically desired. The demand curve is rather inelastic.

Figure 1 about here

The displacement effect challenges the design of the energy-only market. RE technologies at no marginal costs outperform conventional power producers. However, wind and solar supply are volatile, and relatively difficult to predict. Since electricity cannot be stored, but only transformed into another energy source, RE technologies need complementary facilities to balance supply and demand. Hence, the growing contribution of RE is reliant on conventional power plants, which are however not cost-competitive due to the merit order effect (Philibert, 2011).

Especially Germany faced dynamic market efficiency issues. Being at the forefront of climate-change policies, the diffusion of renewable energy technologies was strongly promoted, which altered the capital stock of the electricity sector. However, the merit order effect put pressure on the energy-only market to provide security of supply. This was aggravated by the shutdown of nuclear power plants (Bundesnetzagentur, 2011; Fuersch et al., 2012). Two critical situations emerged which were eventually resolved by the emergency purchase of nationally provided cold reserves from a neighbouring country, which sparked a public debate on the overall grid stability and energy policies.[2]

Country selection

We compare German, Spanish and Danish policies. The countries were identified in a qualitative selection process. First, we focused on EU member states to remain in the same legal framework. Second, we considered government ownership of a RE strategy which effectively led to an increase in RE in the power mix. In all three countries policy makers have pursued a RE policy. This excluded EU member states that do not pursue the Europe

[2] For German newspaper coverage see "Kältewelle in Deutschland: Strom wird knapp", Spiegel online, 2 September 2012 (http://www.spiegel.de/wirtschaft/unternehmen/kaeltewelle-strom-in-deutschland-wird-knapp-a-814214.html); „Überlastete Netze: Warum Deutschland Strom aus Österreich braucht", Spiegel online, 5 January 2012 (http://www.spiegel.de/wirtschaft/service/ueberlastete-netze-warum-deutschland-strom-aus-oesterreich-braucht-a-807323.html); "Energieversorgung: Deutschland braucht Hilfe aus Österreich" FAZ, 5 January 2012 (http://www.faz.net/aktuell/wirtschaft/energieversorgung-deutschland-braucht-hilfe-aus-oesterreich-11593220.html). Websites retrieved on 13 June 2013.

2020 targets. Cognisant of possible trade-offs between budgetary and social objectives and ecological targets, some new member states and/or countries implementing austerity programmes increasingly rely on conventional, low-cost sources, and continue to operate largely written-down, conventional plants. Additional costs and more complex governance structures that a broadening of the energy mix brings about are thereby avoided. Third, we identified countries that departed from a high contribution of conventional power sources such as coal, gas or oil, and then increased the share of RE (see Table 1).

Table 1 about here

In Germany, RE as a share of the total electricity production increased from 3.5% in 1990 to 6.2% in 2000 and to 19.9% in 2010. Solar and wind power was almost non-existent in 1990, moderately increased to 1.6% in 2000, and peaked at 11.3% in 2011. The remaining renewable sources were mainly bio-fuels and biogas as well as hydropower. In 2011, the bulk of electricity came from coal and coal products (46%), nuclear plants (18%) and natural gas (14%).

In Spain the share of nuclear power dropped from 36% to 20%. Departing from a relatively high contribution of RE (hydropower made for 17.2%in 1990), RE technologies accounted for 29.9% of all electricity in 2011. Especially (onshore) wind and solar power were deployed successfully and made for 17.8% in 2011.

In Denmark, RE provided approximately 40% of the electricity output in 2011, of which 28 percentage points came from wind. Coal and coal products accounted for approximately 39% of the total electricity. The rest was produced by natural gas (see Figure 2; Haas et al., 2011).

Figure 2 about here

We sought to fully cover the European electricity market. A single market does not yet exist. Using its fragmentation to identify variances in policy making, we drew the countries from main regional market blocks: (i) Germany in continental Europe, (ii) Denmark in the Nordic, and (iii) Spain in the Iberian, Southwest market. The selection also reflects technological capabilities of the economies. The European Innovation Scoreboard depicts Denmark as an 'innovation leader', Germany as a 'follower', and Spain - a 'moderate innovator' - ranks as the lowest.

Country-specific policies

The large-scale deployment of wind and solar power changed the formerly steady sector in which long-term investments predictably supplied power. Distributed RE technologies substantially increased the sector's complexity. The number of agents has increased, supply became more difficult to predict and the market allocation struggles to provide of emergency capacities. Hence, the emergence of critical situations became more likely. There is a threshold of fluctuating voltage that can be absorbed by a given system (Urry, 2004),[3] which depends on the degree of internationalisation of the market, the characteristics of the grid, the respective technology mix and other idiosyncratic elements, such as the regulatory framework.

This section explores the cross-country difference in policy making. The historical evolution of RE strategies is similar in all countries. Discussions in Germany about a change in the energy mix began as early as the 1980s. The awareness of the effects of climate change emerged amidst anti-nuclear protests, the aftermath of the oil crisis of the 1970s and the acid rain controversy. The general sentiment was moulded into effective policies that initiated a 'greening' process within electricity production, and then spread to the heating and transportation sector.

Denmark sought to diversify its energy mix to reduce its exposure to external supply shocks, especially after the oil crisis in 1973. Initial governmental plans to establish nuclear power plants to reduce the exposure were heavily opposed by civil society, leading the government to abandon its atomic energy policy in favour of support of RE. Wind turbines were suitable for the country's decentralised settlement structure and its natural factor endowments, strong and steady winds.

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[3] See Kauffman's (1993) for a simple formal model that shows how an increase in agents and/or interdependencies renders an overall system more complex, which also complicates policy making.

Spain's energy diversification departed from a 40% share of coal in electricity production in 1990. The greening sought to reduce the dependency on external developments, which however was only partly successful. While the share of coal fell to 15% by 2011, there was a shift towards imported gas, whose contribution to electricity generation rose from only 1% in 1990 to 29% in 2011.

Volatile power in a merit order system challenged the grid stability in all countries. There are several possible remedies for emerging issues, each affecting different building blocks of the electricity sector (Hughes, 1989; Arthur et al. 1997). Relevant policy fields especially comprise technology promotion facilitating the deployment of RE, the additional provision of peak and emergency capacities to lessen the merit order effect and grid management tools and structures that support stabilty.

Germany

Capacities

The capacity allocation is an outcome of competitive processes. The degree of competition on the German electricity market has been fierce after the sector's liberalisation. Producers of conventional power lost market shares and between 2007 and 2012 wholesale peak prices fell by approximately 45%, which was completely absorbed by the profit margins of suppliers. Prices reached a level where coal and gas plants hardly cover fixed operational costs. Wind and solar power further intensified competition, which is mirrored by wholesale price developments. The generated price-quantity curve is flat in the lower load range that is provided by RE (wind, solar, water), nuclear power as well as brown and stone coal plants. Gas, coal and oil facilities are in the upper load range (LBD, 2012).

Producers in the upper load range capacities were affected by the price decline. Especially peak and emergency capacities that cover the difference between the daily base load of approximately 45 GW and the peak demand of approximately 70 GW are under pressure. They lost approximately 70% of their operating hours between 2007 and 2010. At the end of 2012, approximately 15-18 GW were not profitable due to their high marginal costs, and are therefore likely to exit. The role of Germany's energy turnaround (Energiewende) is ambiguous. Its key element, the shutdown of nuclear power plants, reduces the degree of competition in the lower load range, while it also reduces the capacity provided by stable electricity producers. Moreover, the continued deployment of wind and solar capacities is likely to intensify competition again, especially in the upper load range (LBD, 2012).

The power plant park will expand by the end of 2014. Additional capacities of approximately 8 GW will be operational to primarily supply to Southern Germany. The new plants will improve the provision of the base load, but add to the economic pressure on existing peak capacity plants. Market forecasts predict that capacities between 26 and 31 GW will not be economically feasible by 2022. All currently operational peak capacities are affected (LBD, 2012). It is yet undecided what mechanism will be implemented to cover peak capacities (Monopolies Commission, 2013).

Technology promotion

RE promotion started in 1990 when the electricity feed-in act obliged grid operators to grant access to producers of distributed RE. Two additional goals were included by the "Renewable Energy Act" in 2000: The country's exit of nuclear power and a share of RE in total energy consumption of 12.5% to by 2010. The share of nuclear power decreased substantially, from 28.6% in 2000 to 17.8% in 2011. RE accounted for 11.4% in total energy consumption in 2010.

Pegged feed-in tariffs and soft loans facilitated the increase in RE. The pegged tariffs were adjusted several times. For example, the RE-act of 2000 uncoupled the feed-in tariffs from the electricity retail price, and set prices according to effective generation costs. A differentiated pricing between and within generation technologies was introduced, depending on plant type, size, and external factors (e.g., wind speed, sun hours, fuel type for biomass). A tariff digression was considered to encourage technological learning. The tariffs are fixed for 20 years. In 2004, the volumes of pecuniary promotions were adjusted to the benefit of photovoltaic, biomass and geothermal power, while feed-in tariffs for wind power were reduced (Haas et al. 2011). The deployment remained largely unaffected by these adjustments in the promotion policies.

The transmission grid

The transmission grid is subject to fierce debate. The market for transmission systems is split geographically among four private companies: TenneT TSO GmbH, Amprion, TransnetBW GmbH, Amprion GmbH and 50Hertz Transmission GmbH. The grids are jointly regulated by the Federal Network Agency, Bundesnetzagentur. This split raises the question about the market design. It is unclear where the optimal price zone is. The present structure has not been economically or technically justified, and alternatives have never been assessed. Such options include a single German pricing zone, several price zones or nodal prices. Over and above the price zone, a different grid structure might provide more stability. An expansion of the infrastructure is discussed as a possible remedy that precludes congestions. The establishment of four parallel North-South high-voltage DC lines is planned, which would connect Northern German wind power turbines with large consumers in the South. However, infrastructure requires considerable substantial investments, and more sunk costs may render the system inflexible, and thereby increase its vulnerability. Long distance lines might also *“solidify the structure of a centrally organised power supply from large units for decades” (*cit. Schleicher-Tappeser and Piria, 2012).

It has been argued that the lines affect conventional technologies asymmetrically. The proposed new lines may partly function as “lignite HVDC lines”, because they allow carbon intensive coal plants to increase their capacity utilisation. A weaker grid would favour flexible gas plants that are located close to the bottlenecks. Then again, it can also be argued that only minor grid adjustments would be needed if regulators accepted missing a few hours of wind peaks each year. This would marginally reduce the yearly wind output, and contribute substantially to the system’s security. ′However, this contradicts the legally guaranteed priority access of RE, a cornerstone of German RE policies (Schleicher-Tappeser and Piria, 2012).

Germany’s grid management has made considerable progress in integrating variable generation. Pumped storage facilities were established with capacities amounting to approximately 7 GW in 2013. It decoupled combined heat and power plants, and provided more flexible conventional generators to virtual power plants which increased the system’s flexibility. Yet, the merit order effect ensures that the most variable RE possible is brought to market. This makes more costly flexible capacities more important (Cochran et al., 2012). The wholesale market allows for negative pricing, i.e. operators pay for the load they feed in the grid at times of very low demand. Recently the legal framework incorporated incentives to large electricity producers to sell directly on the energy only market.

Spain

Capacities

The displacement of peak and emergency capacities occurred to a lesser degree in Spain. The Spanish electricity sector primarily uses combined cycle gas turbines as emergency capacities. The deployment of RE caused the load factors of gas-fired generation covering emergencies to fall below a capacity utilisation of 40% by 2009. The decline was intensified by the demand drop due to the economic crisis (Federico, 2010). The utilisation level still remains substantially higher than in Germany, where in 2011 emergency capacities were on average 170 hours operational. Their break-even utilisation is approximately 1,000 hours (LBD, 2012). Spain’s exposure due to the shutdown of critical capacities is therefore smaller than in Germany.

Technology promotion

The main promotion instrument has been the pegged feed-in tariff. The scheme was introduced in 1994 to achieve the 12% RE target by 2010. Learning effects were considered by tariff reductions after 15, 20 or 25 years of operations. The scheme was expanded in 1998, and in 2004 by a premium payment option. Investors could choose between a pegged feed-in tariff for the lifetime of the plant, and between free market sales with a price premium. The market option allowed both a bidding system, such as the wholesale market, and contractual agreements (Haas et al., 2011). Soft loans to finance investments, tax incentives and regional investment incentives were made available, and RE technologies are granted preferential grid access.

The transmission grid

The rapid deployment of volatile wind power challenged grid stability. In 2012, approximately half of the electricity demand could be met by wind energy over the course of several hours. However, Spanish policies integrated a substantial share of onshore wind in its electricity mix. This is particularly challenging, as the grid is integrated in the mostly isolated Iberian power market, i.e. international compensation for excess supply or demand is hardly possible.

RE enjoys priority grid access. To overcome challenges to grid stability, Spain's single transmission system operator, Red Electrica de Espana, established the Control Centre for Renewable Energies (CECRE), serving as the pivotal institution that manages the grid and balances the policy objectives. The grid is controlled by Red Electrica, while CECRE is in charge of grid stability. It monitors information and determines whether generation scenarios are acceptable. Owners of RE installations are obliged to provide real-time telemetry. Even though there is guaranteed grid access, Red Electrica has an objection right by not issuing connection permits to the high-voltage network. It is eligible to reject grid access if the system's security of supply is seen at risk. Moreover, it regulates the feed-in load. RE producers are obliged to deliver a predefined range. Non-compliance results in penalties and bonus payments for maintaining the range are in place. Large wind farms and solar installations must provide reactive power support (Cochran et al., 2012).

Denmark

Capacities

The Danish electricity sector's emergency capacities are negligible despite its large contributions of wind power. Imbalances are managed by international power trade on the energy-only market. Denmark is a small market that is tightly connected with its neighbours in the Nordic power market, and with Germany to its South. Its transfer capacity amounts to approximately 80% of the country's peak demand (Cochran et al., 2012). Excess electricity is exported. West Denmark exported on average 57% of its wind power, and East Denmark an average of 45% between 2004 and 2007 (CEPOS, 2009). Shortages are absorbed by stable hydroelectric electricity predominantly from Norway and Sweden. The system is optimised by real-time price signals on the wholesale spot market, supporting trading partners adjusting their generation (CEPOS, 2009).

Technology promotion

Also the Danish promotion strategy relies on pegged feed-in tariffs, whose levels have been continuously adjusted. Budgetary restrictions and concerns about the cost competitiveness of wind power led to a reduction in the financial support in the late 1990s and the early 2000s. The deployment of wind turbines dropped, but the sector's scale economies and the sites' profitability increased. In the mid-2000s, the support volume was increased again, spurring a new deployment wave of RE technologies (Haas et al., 2011; Meyer, 2007). Not only the diffusion of wind turbines, but also the technology itself was supported. The installed small-scale turbines underwent a series of incremental innovations that were also promoted. Wind atlases were publicly provided to best use the local potential (Schreuer and Weismeier-Sammer, 2011; Jorgensen and Karnoe, 1995; Maegaard, 2009; Olesen et al., 2004). In addition, demand was strongly considered in policies. Retail prices became more price elastic than in other countries (Olesen et al., 2004).

The transmission grid

Energinet, the country's publicly owned transmission system operator, closely collaborates with the distributed power producers. The grid is regulated by the Danish Energy Regulatory Authority, Energitilsynet. The emergence of the distributed generation has led to gradual expansions of the infrastructure, which was facilitated by the country-specific ownership structures. Facilities are often consumer-owned, which substantially contributed to the public acceptance of expansions of the distribution grid (Olesen et al., 2004).

Albeit grid stability relies on the Nordic market, the Danish electricity regulators have produced several innovations in output forecasting techniques and system planning tools. There are two intraday electricity markets that provide real-time price signals, permitting negative prices. The objective is to incentivise producers to align their production to demand and vice versa. Such situations occur between 20 and 100 hours per year (Cochran et al., 2012). A substantial share of the distributed generation does not enter the grid. Net metering for photovoltaic facilities and retail credit schemes provided incentives to consume rather than feed power into the grid (Haas et al., 2011).

Discussion

All analysed countries were challenged to integrate volatile renewable energy and to maintain security of supply, a key policy objective. The challenges could have been avoided by refraining from the deployment of volatile electricity generation by continuing the use of conventional power. However, the downsides of such a strategy include the prolonged dependency on natural resources and the involved uncertainty about external, often geopolitical developments, the reliance on nuclear power, possible loss of competitiveness in energy technologies, and the man-made contribution to climate change.

The case studies have illustrated that the electricity sector has two interacting policy layers. On the one hand, the operational grid management agencies are in charge for maintaining the security of supply. These collect as much information as possible, forecast demand and supply and decide if re-dispatch measures are to be implemented. This operational layer is the executive branch of the sum of the country-specific institutions that are part of the architecture of policy makers. On the other hand, promotion policies determine plant park, *inter alia* by setting investment incentives. The implemented instruments are similar, often identical across countries. However, there are institutional differences that shape the sector's outcomes and indirectly affect the public debate about security of supply (Table 2).

Table 2 about here

Implicit target hierarchies

All compared countries implement sophisticated grid management tools that control the feed-in load, i.e. re-dispatch instruments. For instance, regulators are entitled to stop the feed-in of electricity from specific producers as a last resort. Self consumption is increasing, especially for small-scale distributed producers. In addition to re-dispatch instruments, there are instruments that affect the plant park.

Adjusting the supply structure equates to the relaxation one of the three objectives of the electricity policy triangle and its inherent trade-offs. The equal pursuit of the three objectives imposes mounting challenges to policy makers. This has been acknowledged by policy makers such as the German Monopolies Commission (2013), which concludes that the affected policy layers should be adjusted, including include promotions of RE technologies, the design of the market for emergency capacities, and the physical grid.

Yet, there is no single systemic builder of the electricity sector that plans the supply structures, imposing unity onto an otherwise diverse system (Hughes, 1989). A sectoral planner would design a frictionless system with few interdependencies and little uncertainty (Morcol, 2012). Multidimensional policy making requires target hierarchies to rule out politically undesired sector outcomes like the loss of grid stability. Target hierarchies are provided by regulatory structures, which is to be preferred over institutional coordination mechanisms. Especially in Germany there is a substantial degree of policy coordination. However, the institutional fragmentation challenges the systemic orientation of policies (e.g., Edler and Kuhlmann, 2008).

Spanish policies eased trade-offs by its regulatory structures prioritising the security of supply over other policy targets, enabling the integration of a large amount of RE into the rather isolated Iberian market. While RE enjoys priority grid access, a control centre is able to reject connecting the facility if grid stability is at risk. Hence, a "local controller" not only balances demand and supply, but also controls the supply structure. In addition, the Spanish grid operator requires RE producers to deliver within a certain load range, which reduces the system's volatility, which also implies that security of supply is ranked higher than the sustainability objective.

Danish promotion policies affected the plant park by continuously adjusting its promotions. The deployment of RE technologies even came to a temporary halt, allowing the system to stabilise. Then again, this was the result of budget constraints and not technology policy. Efforts in Germany and Spain to adjust the promotion policies hardly affected the pace of the deployment of RE. Albeit the temporary promotion halt in Denmark supported the integration of RE, the predominant factor was still Denmark's small and open economy that is embedded in the Nordic energy-only market, and enabled the sector to compensate imbalances.

Economic planning versus competitive markets

Intervening in supply structures leads to the underlying question about how much planning the electricity sector requires. The energy-only market does not provide the required emergency capacities. In Germany, the Federal Network Agency (Bundesnetzagentur, 2011) points out that the exit of steady nuclear power rendered the n-1 principle of the security of supply unfeasible, i.e. the system cannot provide enough stability to compensate for one failing unit. This leads to regulatory interventions on the supply side, replacing the *"... competitively structured market result by more or less centrally planned approach. From an energy policy perspective this is questionable, economically inefficient and ecologically harmful, yet tolerable and necessary for a transition period."* (cit. Bundesnetzagentur, 2011, own translation). Regulators could avoid demand-side load management, i.e. disconnecting consumers, which is however politically undesired.

The implementation of a reserve or a guaranteed capacity utilisation poses a planned outcome, which by definition interferes with the aspired market mechanisms. Alternatively, German policy makers could directly intervene in the plant park by subsidising conventional emergency capacities, which would however partly reverse the desired exit of conventional technologies, further undermining the competitive market. The phase-in promotion of RE would be combined with the promotion of undesired technologies which policy makers sought to phase-out. Quintessentially, publicly funded subsidies would turn the state into the old and new key player. This strategy would stabilise supply by relaxing the two other objectives, sustainability and competitive selection.

Planning also affects the physical grid and its operation. Electricity provision used to rely on few centralised large-scale producers, and a grid that distributes power to many end-users. A great number of entrants partly reversed this pattern. Dispersed generation facilities require grid, raising the question about how to connect electricity producers that emerge in seemingly erratic fashion while maintaining the security of supply. The power grid is not a 'web' that constantly re-emerges in a bottom-up fashion, causing discrepancies between centrally and nationally planned infrastructures, the increasingly internationally interwoven markets, and erratically emerging distributed generation. This illustrates that the hypothetical grid structure changes with the policy objectives that are pursued. For instance, a widely available infrastructure and secure supply is as desirable as low prices.

Summary

This paper compared the experiences of three countries with the integration of volatile, renewable energy into the electricity mix. The contribution of financially promoted wind and solar power increased substantially, which evoked concerns about the security of supply due to the functioning of the wholesale market, the merit-order. The selection process ranks electricity sources by their marginal costs. Wind and solar facilities outperform conventional technologies such as gas or coal due to their lower, often negligible marginal costs. Some conventional power plants may exit, a desired outcome in the case of 'dirty' technologies. However, conventional electricity producers provide peak and emergency capacities, and are essential for maintaining a security of supply. The promotion of 'sustainable' solar and wind power therefore undermines the 'competitive' market selection that does not provide a level playing field for competing technologies. This affected the 'security of supply', putting the European energy policy principles in question.

The attributes of interrelated policy fields are analysed in Germany, Spain and Denmark. Policies analysed are the financial promotion of renewable energy, the grid management and the provision of peak and emergency capacities. The implemented policies in the compared countries have shown to be remarkably similar. The promotion strategies led to a sharp increase in the contribution of electricity from renewable sources. Sophisticated grid management tools were implemented to balance supply and demand, and the physical grid was expanded. However, peak and emergency capacities developed differently.

Denmark's deployment of wind turbines hardly required emergency capacities, because the international electricity trade on the Nordic energy-only market allows balancing supply and demand by capacities from neighbouring countries. Substantial parts of Germany's power plant park are likely to exit. Albeit pumped storage capacities have been established, it is unclear if emergency capacities are sufficient if the deployment of volatile wind and solar power continues. This effect was also observable in Spain, but was less pronounced.

It was argued that multidimensional policy making requires target hierarchies to rule out politically undesired sector outcomes like the loss of grid stability. Grid policies in Spain differed from Germany due to the institutional structures. The Spanish transmission system operator reserves the right to reject connecting a facility if the added capacities put the grid stability at risk. This goes further than the grid-management tools and re-dispatch instruments that are implemented in all countries. The instrument directly affects the supply structures, thereby implicitly imposing a hierarchy on the policy targets. Security of supply was effectively ranked above the sustainability objective and competitive market selection. While German policies consider security of supply as a key objective, there is a legal obligation to grant grid access to renewable energy plants. Operators therefore cannot ex ante the influence plant structures, but only intervene ex post via re-dispatch mechanisms.

The presently depicted trade-offs raise several questions. For instance, it is unclear how competitive markets on the generation side interact with economic planning of infrastructure. Furthermore, the results feed-back on industrial policies. In "systemic industrial and innovation policy", policy makers seek to generate incentive structures that are sufficient for the achievement of all societal and ecological goals (Aiginger, 2012). While insular policies achieved their objective to diversify the supply sources, their success aggravated existing trade-offs, and incentive based interventions alone are likely to be insufficient to resolve them.

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Table and Figures

Table 1: Country overview

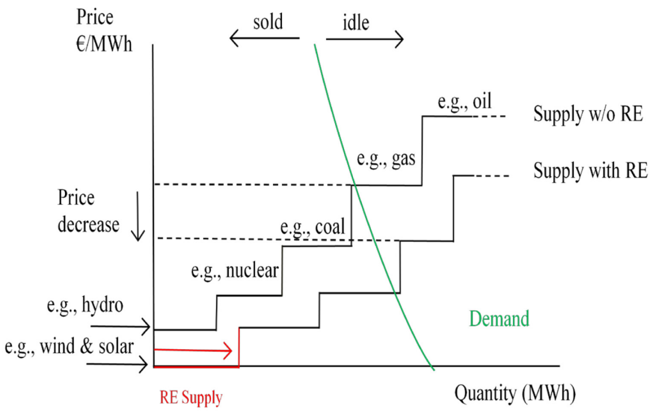
	Denmark	*Germany*	*Spain*
GDP per capita 2010 in Euro[1)]	30,954	29,005	24,422
Average annual GDP per capita growth 2010/1995[1)]	3.20%	2.91%	4.08%
Population size 2012[2)]	5,580,516	81,843,743	46,196,276
RE sources as a percentage of total electricity production in 2011[3)]	40.1%	19.9%	29.9%
RE sources as a percentage of total electricity production in 1995[3)]	5.1%	4.9%	14.7%
Regional electricity market	Nordic	Central European	Iberian
Technological capability	Leader	Follower	Moderate innovator
Energy dependency in 2010[2)]	-18.21%	59.78%	76.69%

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

Table 2: Overview of policies across countries

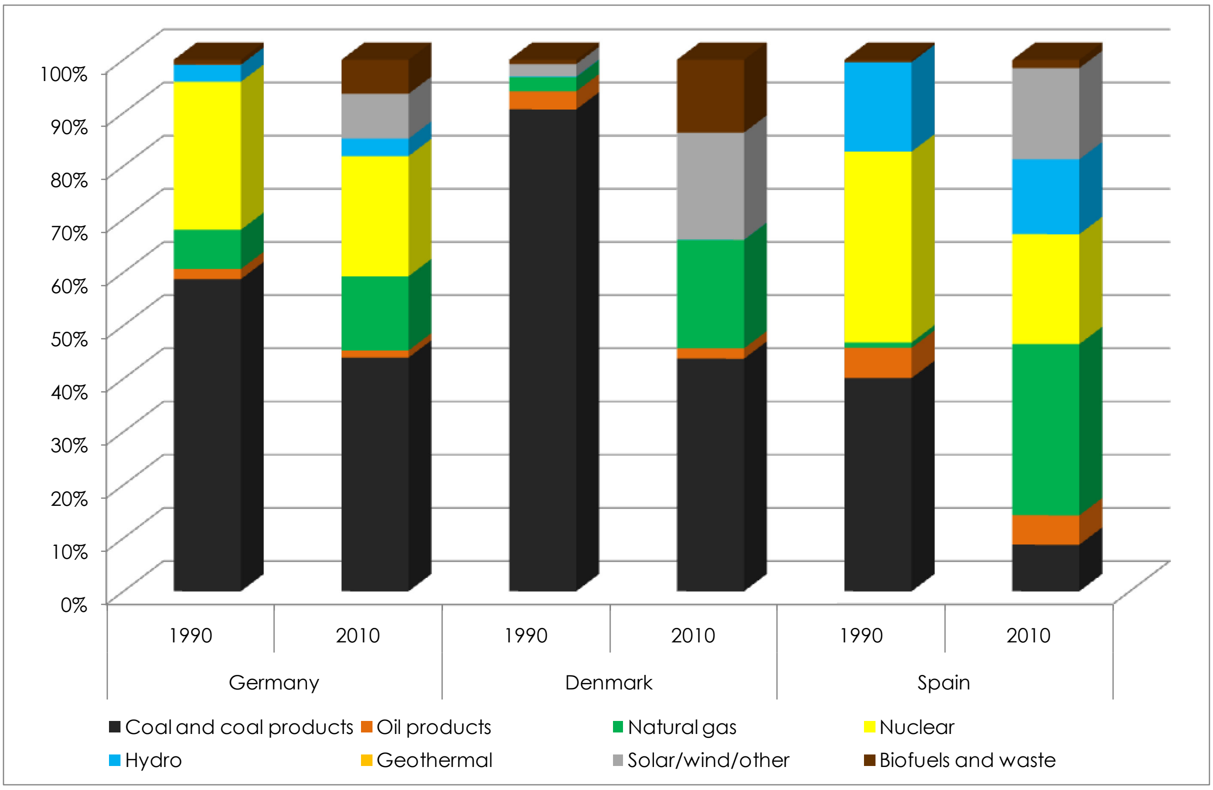
	Policy field	*Denmark*	*Germany*	*Spain*
Operational / ad-hoc	Implemented stability supporting instruments	Demand forecasting tools Negative pricing Intraday electricity markets Net metering and retail credit scheme incentivise self consumption; CHP	Demand forecasting tools Storage facilities	Demand forecasting tools Pre-defined feed-in range and penalties when non-compliant Large RE facilities required to have reactive power
	Promotion policies	Pegged FiT Adjustments of the promotions in the late 1990s / early 2000s which led to a temporary halt in deployment of RE. Tax support and soft loans	Pegged FiT Adjustments of the promotions with no effect on deployment dynamics Tax support and soft loans	Pegged FiT Premium option in 1998, revised 2004 Tax support and soft loans
Institutional Arrangements instruments	Peak and emergency capacities	Stability through international energy-only markets	Capacity use of emergency plants below break-even point Peak capacities at break-even point	Capacity use above break-even point
	Grids	Publicly owned TSO Open access for RE Collaboration between regulator and producers to guarantee grid stability	Geographically split grid owned by four private TSOs Connecting RE facilities is compulsory for grid operators	Publicly owned TSO Open access for RE Control centre can reject connection of facilities if stability at risk

Figure 1: Supply and demand in the electricity wholesale market: The merit order effect



Source: Adapted from Philibert (2011).

Figure 2: Germany's electricity output by source



Source: IEA data, own illustration.