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# The influence of policy regime risks on investments in innovative energy technology

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**Abstract**

This paper dissects the ways in which policy regime risks influence decisions over innovative energy technology investments. We apply compound real options methodology to evaluate the investment in a virtual power plant platform and distributed energy resource (DER) assets in view of volatile electricity market prices and an uncertain future electricity market design. The analysis reveals two aspects of policy regime risks: a *policy content effect* relating to actual market dynamics resulting from a (new) policy regime, and a *policy process effect* relating to (uncertainty about) the speed and probability of a regime change. The paper underlines the importance of predictable policymaking to stimulate risky investment. It further details the need to account for technology-specific investment responses to different policy regimes and risks, caused by different degrees of market versus subsidy exposure and differences between platform versus non-platform technologies.

*Keywords*: Policy uncertainty; Virtual power plant; Distributed energy; Real option

## 1 Introduction

This paper addresses the effects of policy regime risks in interaction with wholesale market dynamics on investments in innovative energy technology. It is motivated by two observations. First, there is an ongoing debate about power market design reforms in numerous countries, with potentially drastic implications for the economic attractiveness of different energy technologies (see various contributions to this special issue of *The Energy Journal*). Second, there

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is a gap between required and actual investment levels with respect to innovative technologies and business models for low-carbon, smart energy infrastructure. We seek to contribute to a better understanding of this subject matter.

The current annual investments in clean energy technology are far from sufficient to attain climate policy goals; globally, they have to double by 2020 and to multiply sixfold until 2030 (International Energy Agency, 2014). Today, in many countries investment activity in innovative energy technology is tightly coupled to subsidies aimed at fueling their market diffusion. Most notably, global installed capacities of the widely subsidized photovoltaic (PV) and wind power technologies have soared to about 180 GW and 370 GW by 2014, respectively (Global Wind Eenergy Council, 2015; Masson et al., 2014). In Germany, these two sources alone account for about 16% of electricity consumption (Nieder et al., 2015). While this still ranges far from the envisaged market shares in the medium- to longer term, less subsidized technologies have fared much worse. Perhaps most notably, virtual power plants (VPP) are far from fully leveraged, despite the importance assigned to them for the further integration of DER into power markets[1]. VPPs connect and coordinate geographically dispersed DER to operate them as an integrated power plant (Asmus, 2010). This is done based on information and communication technology (ICT), including a control center and remote communication devices, in combination with steering, optimization, trading and back office processes. VPPs increase the transparency over available DER capacities, enable higher efficiency in DER operations and support system stability in view of intermittent renewable energy supply. There is thus widespread agreement that VPPs will be essential to integrate the increasing DER capacities into power markets and leverage their full value potential (Wille-Haussmann et al., 2010; Kok, 2009; You et al., 2009; Pudjianto et al., 2007). Nevertheless, recent estimates indicate that only 5 GW, or less than 1%, of DER are aggregated and optimized within VPPs (Martin, 2014). The importance of the technology to support energy system transformation is thus not reflected in its current market penetration.

A simple explanation might be the challenge of low profitability in wholesale power markets. In recent years, liberalization and the presence of increasing amounts of renewable energy

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[1] Note that we use the term “DER” to refer to actual DER assets, such as a wind or PV power plant.

have put considerable pressure on day-ahead spot market prices (e.g. Hirth, 2013). Further, we know from investment theory that *market uncertainties*, i.e. volatile fuel and electricity prices and other stochastic market-related processes, might lead to investment delays (e.g. Cox et al., 1979). But beyond that, policy regime risk is frequently cited in the energy economics literature as a reason for investment gaps (e.g. Fan et al., 2012; Yang et al., 2008; Jun and Yan, 2004; Jaffe and Stavins, 1994). Moreover, it is considered as the key investment barrier by virtually all top managers of leading utilities in countries affected by clean energy expansion targets. In 2013, the CEOs of 8 major European utilities[2] drafted a letter to the European Council, calling for more political stability regarding power market design to support investments in promising new energy technologies (Wetzel, 2013).

Strikingly, the ways in which policy regime risk interacts with and influences innovative energy technology investments have not been dissected in much detail to date. Given the supposed relevance of the issue, we consider several (to our knowledge) unanswered questions worth addressing. Namely, is the effect of policy regime risk primarily driven by actual differences between policy designs and the impact on power market dynamics, i.e. a *policy content effect*? Or is it determined by (uncertainty about) the process of change, i.e. the speed and probability, i.e. a *policy process effect*? Do policy regime change and uncertainty affect different innovative energy technologies differently? How do investment levels for (partly) subsidized technologies respond to regime change and uncertainty, as opposed to non-subsidized technologies? Ultimately, what should policymakers do about the issue?

In the following, we attempt to add to the existing literature by looking at policy regime risk from a micro-level perspective. We observe the strategy of a risk-neutral, rational investor under different conditions of policy regimes and related uncertainty. Our focus is on the implications of different policy conditions on his investment valuation and timing. In this context, the notion of policy regime risks is scrutinized beyond the existing literature, by distinguishing between content and process. The investments considered are a VPP platform and DER assets that could potentially be operated more effectively within a VPP. We will explicitly discuss the different responses to policy regime risk between technologies, depending on value pools and degrees

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[2] Enel, Eni, E.ON, GDF Suez, Iberdrola, Gasnatural Fenosa, Gasterra and RWE.

of subsidization of technologies. Our aim is to ultimately be able to draw conclusions for policymakers on how to dampen negative investment repercussions of policy regime changes and related uncertainty in a differentiated way. Further, we want to offer a better understanding of how VPPs may eventually create additional value in their role as a platform technology, or rather some additional capability to do business.

As an instrument for investigation, we develop a valuation framework that extends from the traditional discrete time real options (RO) methodology (Cox et al., 1979). The framework formalizes the opportunity to build a VPP by first investing in a platform, and second integrating DER assets[3]. The sequential nature of these investment steps is incorporated through a compound approach following the principles of Majd and Pindyck (1987). Here, each step is considered as a discrete investment step, which unlocks access to the option to enact the following investment step. Further, we incorporate market prices and subsidies as drivers of cash flows as correlated stochastic processes. Correlation is included by applying the multinomial approach from Rohlfs and Madlener (2014), but with standard as well as alternative stochastic processes (e.g., Alexander et al., 2012). We have first applied this approach in a different context – balancing forecast errors – in Garnier and Madlener (2015).

Policy regime risk is introduced through market design alternatives and corresponding probabilities of design change; if change occurs, (stochastic) market parameters are being structurally overhauled. The probability of regime change occurrence is modeled by means of a binomial process picking up elements from Poisson processes. This approach is distinct from works in which policy regime risk presents a (further) stochastic process similar to prices. For instance, Yang et al. (2008) model uncertain climate policy effects on energy asset investments by including a volatile carbon price. Effects of climate policy on other market parameters or possible correlations are not modeled. Jun and Yan (2004) investigate empirical electricity generation investment data for the U.S. between 1996 and 2000. They find evidence for an impact of regulatory uncertainty on investment levels. They suggest that an option value exists due to regulatory uncertainty, i.e. that regulatory uncertainty increases the value of delaying investments relative to investing immediately. Interestingly, they find it difficult to separate the

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[3] Note that we account for the possibility to invest in and operate a DER outside a VPP wherever suitable.

effect of actual uncertainty about a regulatory change process (resembling our *policy process effect*) from the effects of the market design changes resulting from policy change (resembling our *policy content effect*).

Our paper proceeds as follows. We formulate the model in section 2. In section 3, we apply the model to the German market, including information retrieved from actual players. In section 4, we discuss the implications of the model and its application for energy policymakers and investors in innovative energy technology before we conclude.

## 2 Investment valuation model

Assume a risk-neutral, rational actor interested in entering the DER market. His desire is to profitably operate some DER (e.g., wind power plants, PV power plants, biogas power plants, flexible loads) in some value pools (e.g., wholesale power markets, subsidy schemes, balancing market). Some DER can be operated in some value pools in an isolated manner without a VPP platform. For instance, building a local wind power plant and marketing the production either through a feed-in tariff or simple direct marketing does not require a sophisticated operation and optimization infrastructure. On the other hand, the capacity or production of some DER can only be placed in certain markets if operated through a VPP platform. In general, this applies whenever some form of asset pooling and/or coordinated dispatching based on optimization algorithms is needed. Examples would be the placement of biogas power plant capacities in electricity reserve markets, or the pooling of forecast errors from geographically dispersed wind / PV power plants before balancing them in the market. If an actor is keen on maximizing value from DER by pooling them, optimizing their operation and bringing them to all possible markets, he has to take two sequential investment steps: first, develop a VPP platform to operate (aggregate, monitor and manipulate) DER assets; second, integrate the desired DER asset capacities. In our model, the timing of the investments (platform and DER assets) is flexible, but can occur no earlier than $t = 1$ and no later than $T$.

## 2.1 Modeling market and policy regime uncertainties

The driver of complexity in this scenario is the presence of uncertainties and risks. On the one hand, the development of prices, subsidies and related market processes is uncertain within a given policy regime. We refer to these stochastic market processes as *market uncertainties*. On the other hand, the policy regime may change altogether, defined as *policy regime risk*. Regarding policy regime risk, we distinguish between a *policy content effect* and a *policy process effect*. The former determines the extent to which investment valuations are affected by differences in market uncertainties between regimes. In other words, in how far are the assets' valuations influenced by the expected market uncertainties in the anticipated future regime? The latter determines to which extent the uncertainty about the procedure of regime change itself influences the valuations. In other words, is the policy content effect moderated or complemented by a process effect, which alters the optimal investment strategy under policy regime uncertainty?

To deal with market uncertainties, the actor must understand which market dimensions behave stochastically. Then, he can define the matching process types and parameters. For instance, in typical (real) options models, stochastically behaving prices are defined as Geometric Brownian Motion (GBM) processes of the form

$$\frac{dP(t)}{P(t)} = \alpha_P dt + \sigma_P dZ_P \,, \tag{1}$$

where $\alpha$ represents the drift, $\sigma$ describes process volatility, and $dZ_P$ is the increment of a Wiener process. Between any two time steps, prices can either go up or down, based on the volatility element. Possible correlation between any two processes can then be modeled by ensuring correlation in their Wiener processes. In order to be able to handle multiple correlated processes and process types[4], we apply an adapted version of the approach introduced by Rohlfs and Madlener (2014) recently published in Garnier and Madlener (2015). The principles are in line with classical discrete-time options methodology (Cox et al., 1979).

To deal with policy regime risks, however, a different methodology is required. This de-

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[4] Note that the model can accommodate both GBMs as well as Arithmetic Brownian Motions (ABMs) in the form of $dP(t) = \alpha_P dt + \sigma_P dZ_P$

viation in treatment is grounded in the fact that a change in policy regime affects all or at least many market uncertainties profoundly; it may change their drift and volatility parameters, possibly even the correlation between processes[5]. Hence, we suggest a binomial approach, in which at any time step $t$ the current regime either persists or a switch to a different regime state $g$ (with different implications on the market uncertainties) occurs. The risk of policy regime switches is derived by means of an expression extending from Poisson processes, with the expected switching rate defined as $\lambda$. The probability that a switch to any specific regime $g'\{g = 1, \ldots, G\}$ occurs at any time is given by

$$p_{g'} = \frac{1 - e^{-\lambda}}{G - 1} \,. \tag{2}$$

The numerator expresses the probability of an occurrence of a regime change[6]. The denominator divides this probability by the number of possible regimes that may occur. It is thereby assumed that all alternative regimes are equally likely. Notice that, in this general form, the probability of a switch is independent of the specific time. Note further that eq. (2) is a key determinant for a potential policy process effect.

Based on these definitions, we anticipate that policy regime risks affect our valuations through a policy content effect and through a policy process effect. The former is grounded in the difference between market uncertainties in the current and the expected future regime. The more profoundly the future regime is expected to change the parameters of market uncertainties, the more policy regime risks should alter investment valuation. The latter effect is grounded in a lack of transparency about the change process. As the investor can only anticipate the probability and speed of change through his expected $\lambda$, he has to cope with additional uncertainty. This could affect his investment strategy.

Prior to any evaluations or even numerical analyses, a few interesting insights can already be derived from the nature of the uncertainties as defined. First, every additional market uncertainty doubles the range of possible market developments between two time periods. Since

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[5] Indeed, these altercations of process parameters is the basis for the policy content effect.

[6] In a Poisson logic, the probability of no change would be expressed as $\frac{\lambda^0 \times e^{-\lambda}}{0!}$, leading to $e^{-\lambda}$. Note that we are simplifying the Poisson logic by assuming either no change or one change as binomial alternatives, whereas in a true Poisson process, two or more changes would have to be considered as well (albeit with extremely low probability).

every market uncertainty $n$ is expressed in terms of a process moving in either up or down increments, the range of paths the market may take, given its current parameters, equals $2^n$. This implies a doubling of path alternatives with every additional $n$ and a correspondingly wider range of outcomes. Second, every additional policy regime scenario increases the range of possible market developments by $T^n$. This is based on the fact that, within any policy regime, a market may develop into one of $T^n$ states until $T$; thus, adding a scenario leads to the addition of just as many alternative states. However, the relevance of any additional scenario is tightly coupled to its probability of occurrence, given by $p_{g'}$. Further, the degree to which an additional scenario impacts the investment decision should also depend on the degree of differences in parameters between scenarios. Third, increasing the length of the period of uncertainty by augmenting $T$ by 1 increases the number of possible developments by $T^n - (T-1)^n$, implying a wider range as well. The longer the period of uncertainty already is, the greater the impact of further prolongation in terms of the number of possible outcomes.

## 2.2 Evaluating DER assets

As is common with sequential, or compound, real options valuation approaches, our analysis begins with the last rather than with the first investment step (Majd and Pindyck, 1987). Hence, we need to first investigate the opportunity to operate various DER assets, assuming that a VPP platform is already in place.

The investor is keen on acquiring a portfolio of different DER. Both type and capacity of any DER asset investment are specified by $x = 1, \ldots, X$. The assets enable the investor to generate operating profits in various value pools $m = 1, \ldots, M$. Four elements determine the extent of operating profits per $x$: the time of market entry $t^*$, the revenue per unit of asset capacity in any specific value pool, $R(t^*)^x_m$, the share of asset capacity devoted to that value pool $\phi^x_m$, and the operating and maintenance (O&M) costs $C_x$. This yields the total operating profit per asset capacity $x$,

$$S(t^*)_x = \sum_{m=1}^{M} R(t^*)_m \times \phi^x_m - C_x, \;\; s.t. \; \phi^x_m \leq \eta(t^*)_m, \; \sum_{m=1}^{M} \phi^x_m \leq 1 \; . \tag{3}$$

Eq. (3) shows that the share of asset capacity operated in a particular market is limited by the free market share in a value pool at $t^*$, $\eta(t^*)_m$. Usually, we expect $\eta(t)_m$ to decline over time, as first movers have less competition and can establish themselves more easily. In that case, $\eta(t)_m$ should stimulate earlier investments by reducing the market share available upon late entry. This effect is similar to a shortening of the investment period $T$, since the final periods become unattractive as investment periods. However, it may also be inferred that the market grows over time and that later entrants can benefit from providing more advanced services (2nd-mover advantages). Hence, $\eta(t)_m$ may also grow. This should induce further postponement.

Note that market uncertainties influence the calculation of $S(t^*)_x$, through revenues $R(t^*)_m$. As $R(t^*)_m$ is dependent on the start time of operations $t^*$, the price dynamics between $t = 1$ and $t^*$ affect the achievable revenue. Again, these price dynamics are a result of the market uncertainties as defined earlier, which in turn are a direct result of the policy content effect of any given policy regime. Moreover, the revenue $R(t^*)_m$ is not a single static value, but rather the sum of yearly revenues $r(t)_m$ over the lifetime $A$ of the asset, i.e.

$$R(t^*)_m = \sum_{t=t^*}^{t^*+A} r(t)_m \; . \tag{4}$$

Thus, the price dynamics after entry $t^*$ also affect overall revenues obtained. This also implies that possible policy regime changes after market entry could shake up the revenues obtained over the asset's lifetime, meaning that both market uncertainties and possible policy process as well as content effects need to be accounted for when deriving $R(t^*)_m$[7]. Strictly speaking, as these values are subject to uncertainty, they constitute expected rather than definite values. In order to keep notation simple, we assume this to be a common understanding without further highlighting.

Prior to operating DER assets and obtaining $S(t^*)_x$, the DERs need to be built or acquired; in other words, an investment might be necessary. To evaluate the investment, one could very simply deduct the expected investment costs $I_x$ from the total expected operating profit per

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[7] The exact equation to derive $R(t^*)_m$ depends on the respective value pool. For instance, if $m$ refers to offering balancing power in the balancing market, revenue is determined by the fees paid for providing both capacity and, if activated, power. When $m$ describes day-ahead sales of PV or wind power, revenues are subject to subsidies. As subsidies are typically guaranteed once the investment has materialized, they are much less affected by market uncertainties and policy content effects after $t^*$.

asset. However, we refer to a setting in which uncertainty exists and in which the investor has the freedom to postpone the investment decision until $T$. This calls for real options valuation, where the alternative to delay investments into the next period $t+1$ is incorporated as well:

$$O(t)_x = \max \left[ S(t)_x - I_x, \frac{O(t+1)_x}{1+\tau} \right] . \tag{5}$$

Here, the value of the investment opportunity on asset $x$ equals the higher value of either investing now $(S(t)_x - I_x)$ or postponing the investment decision $(\frac{O(t+1)_x}{1+\tau})$, discounted for the time-value-of-money effect through $\tau$, due to the delay of cash flows.

The option valuation is only indirectly affected by policy content effects through $S(t)_x$ for the current and all following periods until $T$[8]. However, policy regime uncertainty impacts the option valuation directly through the policy process effect. More specifically, the postponement value $O(t+1)_x$ needs to account for the fact that the policy regime may or may not switch between $t$ and $t+1$. The probability of such a switch is determined by the switching rate $\lambda$ and the time progressed so far. This increases the volatility of possible outcomes when delaying investment; it thus constitutes a process effect separate from any content details about the anticipated regime change.

## 2.3 Evaluating the VPP platform

Some DER can only be operated in some value pools if aggregated and dispatched with an optimization and trading infrastructure in the background – i.e. a VPP platform. Building a VPP platform provides the investor with additional options on DER and value pool accesses. Simply put, the present value of platform operation equals the difference between the aggregated value of all additional DER asset options available owing to the VPP $X^*\{X\}$, and the O&M costs of running the platform,

$$S(t)_F = \sum_{x^*=1}^{X^*} O(t)_{x^*} - C_F . \tag{6}$$

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[8] The evaluation of DER assets runs backwards, beginning at the end of the investment period at $T$ rather than at $t=1$. This is grounded in the necessity to apply dynamic programming to solve for the option value. Note that we would not be able to obtain the right-hand side of eq. (7) if we did not start et the end.

As the value of the platform entirely depends on the option values of the DER assets, it is fully exposed to the effects that market and policy regime risks have on DER option valuation. However, we would expect a diversification effect from the fact that the platform can tap multiple DERs and value pools which are exposed differently to different market uncertainties and thus also policy regime uncertainty effects.

Turning towards the initial platform investment, a logic similar to the DER asset investment principle depicted in eq. (7) applies. Specifically, we derive an option value which equals the higher value of either investing in the platform immediately or postponing the decision into the next period, $t+1$. However, a lead time $L_F$ may apply that accounts for the delays often associated with ICT investment and development projects (Schwartz and Zozaya-Gorostiza, 2003). This yields

$$O(t)_F = \max\left[\frac{S(t+L_F)_F}{(1+\tau)^{L_F}} - I_F, \frac{O(t+1)_F}{1+\tau}\right], \tag{7}$$

where $\tau$ describes the rate applied to discount the time-value-of-money effect stemming from either the delay between investment and operation of $F$, or from the postponement of the investment decision.

As can be seen from the left-hand term within squared brackets in eq. (7), ICT development lead time does have an exponential, detrimental impact on the investment value through the discount factor. Further, in the case of policy regime uncertainty, we can expect lead time to amplify the policy process effect. The more time elapses between the decision of market entry and actual entry, the less certainty we have about the policy regime at the time of entry.

# 3 Numerical application

In the following, the previously developed model will be applied to an investment case. The impact of (variations in) different policy regimes, and related risks, will be measured and compared to some of the analytical intuitions derived earlier. Further, the responses of different technologies to different uncertainty dynamics will be looked at.

## 3.1 Problem setting

We evaluate the opportunity to invest in the development of a VPP for operation in German wholesale power markets. An investment period of 8 years ($T = 8$) is assumed, after which market entry is no longer considered possible[9]. Market uncertainties are present. In some scenarios, the policy regime is uncertain, too. More specifically, it is expected that a shift of market design from the base case regime $g^0$ to another regime $g'$ will be enacted within the investment period. In these scenarios, we set the probability of a switch in regimes to $\lambda = 1/T$; this implies that the investor expects the frequency in policy regime changes to be such that one change will occur until $T$. For the sake of simplicity and tractability, we exclude the possibility of more than one policy regime switch, i.e., at any time $t$, we set

$$p_{g'} = \begin{cases} \frac{1-e^{-\lambda}}{G-1}, & \text{for } g_t = g^0, \\ 0, & \text{for } g_t \neq g^0. \end{cases} \tag{8}$$

Based on expert discussions, existing marketing opportunities, and the intent to reasonably scope our analysis, we focus on two value pools: (1) direct marketing of renewable electricity; and (2) marketing of dispatchable capacities and power in the (secondary) balancing market. With respect to (1), we separate between value drivers obtainable without a VPP platform (= subsidized day-ahead direct marketing[10]) and VPP-related value drivers (i.e., forecast error pooling and netting when conducting direct marketing). Regarding (2), we assume that operating DER in balancing markets always requires a VPP platform.

Referring to DER technologies, we limit our analysis to some of the most widespread DER with a track record of financial viability: wind onshore power and biogas power plants. Wind power plants are only considered for direct marketing and biogas power plants are purely considered for capacity marketing[11]. Including other DER, such as PV or small combined heat

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[9] The period is set to 8 years in order to provide a reasonable trade-off between robustness in results and computational tractability. Overall, we consider 8 years to be a reasonable "strategic" time horizon for investment decisions. Other period settings are possible and have been tested to validate the choice made. Extending the period leads to higher relative option values for the VPP platform, but does not yield any significantly different results.

[10] We account for the given subsidy regulation as defined in the 2014 amendment to the German Renewable Energy Sources Act (EEG). An important assumption made in the model is that the subsidy level is locked-in once the investment has been committed.

[11] Note that we leave out direct marketing of biogas power plants, since it would not provide any additional

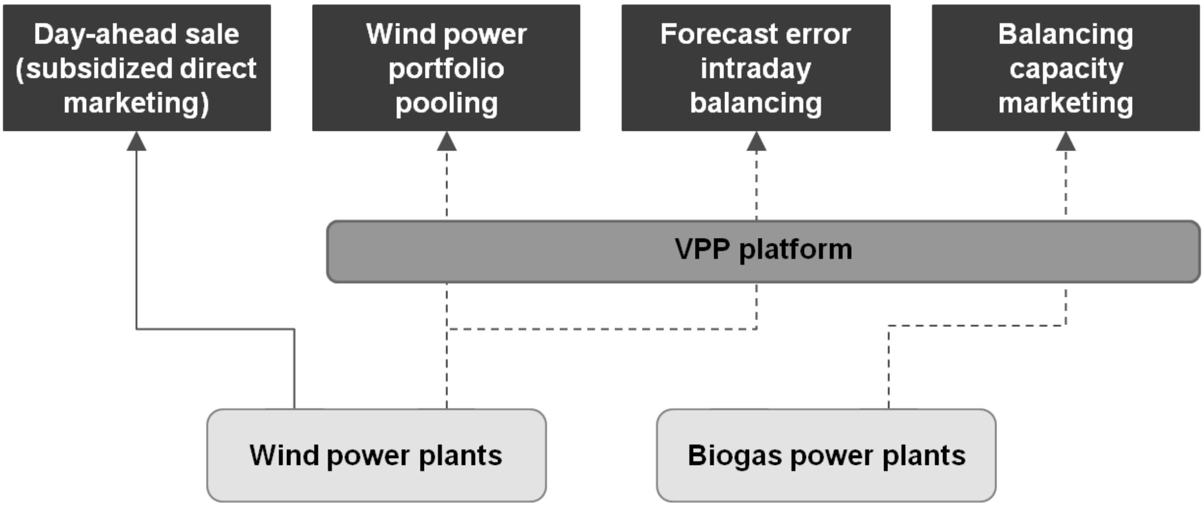

Figure 1: Overview of considered DER and value pools in the simulation (a more detailed description of value pool logics and parameters is provided in table 4 in the appendix).

and power units, would be possible, but at little additional value for the analysis of market and policy regime uncertainty effects. Figure 1 provides an overview of the interaction between value pools, markets, and value drivers.

Finally, regarding the VPP platform, we consider it to be able to operate all the DER mentioned in the day-ahead, intraday, and balancing markets. We estimate initial development costs at € 1,000,000 and yearly O&M costs at about € 1,020,000 (10 full-time equivalent employees at € 100,000 and other operating costs for the control room at € 20,000). Table 1 lists the DER considered in our analysis and the VPP platform with the respective parameters.

Next, one needs to identify the market uncertainties. In our case, we find six relevant stochastic processes: the subsidy level for day-ahead direct marketing, the intraday price level,

Table 1: DER available for VPP portfolio

| DER | Value pools | Installed cap. (MW) | Hours p.a. | O&M costs (million € p.a.) | Invest. costs (million € ) |
|---|---|---|---|---|---|
| Wind onshore | Direct mkt., pooling, balancing[a] | 50 | 1700 | 1.5 | 32.5 |
| Biogas plant | Capacity mkt.[a] | 30 | 250 | 0.25 | 0[b] |
| VPP platform | DER operation | - | - | 1 | 1 |

[a] Only in combination with VPP platform. [b] Regarding biogas power plants, no investment costs are considered. They are assumed to have been born before. The offering of biogas power plant capacity in the balancing market alluded to here constitutes an additional investment-free value pool, made available when connecting an existing biogas power plant to a VPP platform.

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insight. Likewise, we ignore the option to offer negative balancing capacity through wind power plants.

the imbalance price level, the secondary balancing capacity remuneration, and the secondary balancing power activation remuneration.

The subsidy level has a substantial impact on the value obtained from producing renewable electricity. The German regulator subsidizes the sale of power from renewable energy sources in the day-ahead market to match a guaranteed feed-in-tariff level (*direct marketing*). This level is technology-specific, but subject to similar dynamics across technologies. For instance, the support for direct marketing of power from wind onshore and biogas power plants differs in absolute terms, but the planned reduction of tariff levels in the coming years is almost equal in relative terms[12]. Also, volatility is low, since the subsidy level can only be affected by policy regime changes, and not by market dynamics within a given regime.

The intraday price impacts DER valuations as well. Namely, the level of the intraday price relative to the imbalance price alters the value that VPPs can create for the marketing of wind (and PV) power production. Assuming intraday prices to fare below imbalance fees, VPP operators can reduce balancing costs by compensating (a share of their) unforeseen supply deficits or surpluses in the intraday rather than in the imbalance market[13]. Overall, the intraday price is subject to considerable volatility. One reason is the still-limited volatility in intraday markets (Garnier and Madlener, 2015; Hagemann and Weber, 2013; Weber, 2010). It should be noted, however, that liquidity generally increases and therewith drives down absolute price levels as well. Another reason for volatility are the hardly foreseeable dynamics of PV and wind power production forecast errors, which are a driver of intraday trading (von Selasinsky, 2014; Hagemann and Weber, 2013). The imbalance price is subject to uncertainty as well, but we consider its volatility to fare below the volatility of intraday prices. This assumption is grounded in the imbalance price's more regulated price determination process (managed by transmission system operators, TSOs).

Finally, balancing market compensation mechanisms deserve some discussion at this point. Operators of (dispatchable) power plant capacities can offer their capacity as a backup, for temporarily ramping either down (negative) or up (positive) supply or, vice-versa, loads in case the TSOs demand it. In return, they receive a remuneration for capacity provision and power

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[12] Roughly 2% annual reduction according to the 2014 EEG.

[13] This is hardly possible for small operators outside of VPPs, since they lack the required trading capabilities.

activation (if needed). We consider both the provision of capacity and of power to be subject to the same dynamics. Further, since the contracted capacity is the basis for imbalance fees to be paid when incurring them, the correlation between capacity remuneration and imbalance fees is likely high. Prices are volatile, but less volatile than intraday prices due to the more regulated nature of price formation. Further, we expect prices (for secondary negative capacity provision) to decline slightly, in line with the trend of previous years and driven by ever more capacity being offered in the capacity market (Balance Power GmbH, 2014).

Having discussed market uncertainties, we now turn to policy regime risks. The policy regime base case represents the current state of affairs, i.e. market uncertainties behave according to established dynamics. In line with the discussions around possible market design changes in Germany spurred by politicians, scientists, and managers[14], we consider two alternative states. On the one hand, we consider a free market world, in which the markets are highly deregulated. Challenges, such as the integration of more renewable electricity and the assurance of sufficient back-up capacity are left entirely up to price formation and the markets. On the other hand, we consider a more tightly regulated world. Here, price formation is subject to political guidance and volatility in price processes is curbed. Table 2 summarizes the market uncertainty parameters for each of the considered policy regime states.

Table 2: Policy regime states and respective market uncertainties

| | | Base case | | Free market world | | Regulated world | |
|---|---|---|---|---|---|---|---|
| Market uncertainty[a] | $P_0$ | $\alpha_P$ | $\sigma_P$ | $\alpha_P$ | $\sigma_P$ | $\alpha_P$ | $\sigma_P$ |
| Balancing cap. | 35,000 | -0.01 | 0.025 | 0.001 | 0.15 | -0.03 | 0.01 |
| Balancing power | 100 | -0.01 | 0.025 | 0.001 | 0.15 | -0.03 | 0.01 |
| Subsidy level wind[b] | 60 | -0.02 | 0.001 | -0.03 | 0.05 | $\sim 0$ | $\sim 0$ |
| Imbalance price | 45 | 0.001 | 0.05 | 0.02 | 0.15 | -0.01 | 0.01 |
| Intraday price | 38 | -0.01 | 0.075 | 0.02 | 0.2 | -0.01 | 0.025 |

[a] All start values $P_0$ are estimates derived from 2013 and 2014 data. The Intraday price is derived from EPEX data for Germany in 2013, the imbalance and balancing market prices (capacity and power) are derived from 2014 data across the 4 German TSOs. The initial subsidy level an drift is based on 2014 renewable energy regulation in Germany. All volatilities are estimated based on expert discussions and insights previously generated in Garnier and Madlener (2014). [b] The subsidy factor is the only volatile process modeled as an ABM. All other processes are modeled as GBM processes.

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[14] The German Federal Ministry for Economic Affairs and Energy (BMWi) officially announced a market design reform for the end of 2015. The actual changes are yet unclear; still, the presented options resemble the scenarios developed in the following.

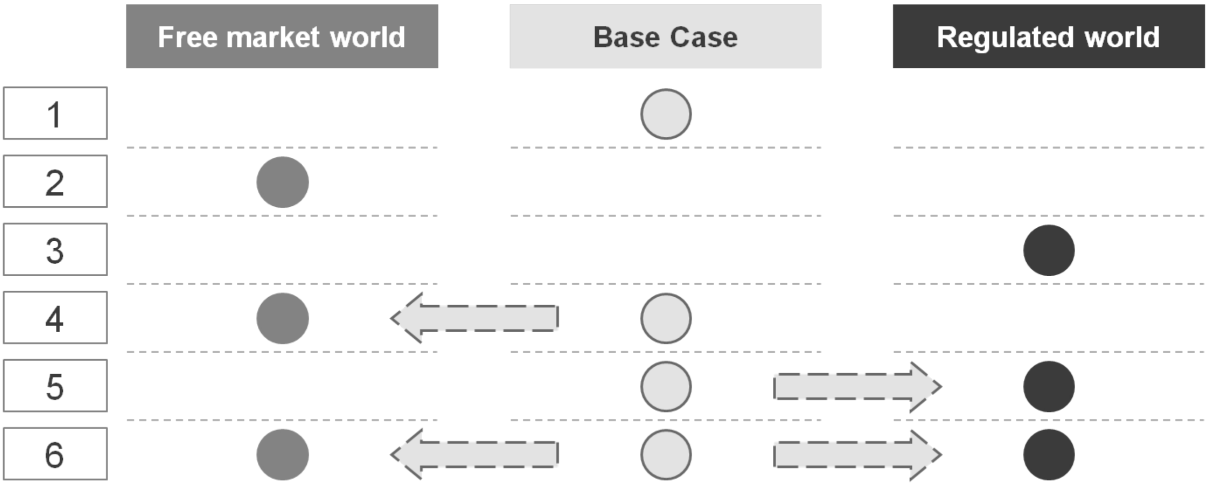

Figure 2: Overview of the six scenarios considered in the simulation.

In order to test the impact of different policy regimes (and risks) on investment value and timing, we construct several scenarios. In scenarios 1 to 3, a specific policy regime is fixed and sure to remain. The individual scenarios then represent the base case, the free market world, and the regulated world, respectively. In scenarios 4 and 5, the base case regime is the starting point, with uncertainty about a switch to either the free market world (scenario 4) oder the regulated world (scenario 5). In scenario 6, the base case is again the starting point. However, this time the investor anticipates a regime switch without knowing whether the switch will introduce the free market world or the regulated world. Figure 2 provides an overview of the considered scenarios.

## 3.2 Results

Across our investigations, to abstract from other influences, we hold all parameters constant except for the policy regime with the corresponding market uncertainties (stochastic processes). This implies constant start parameters at $t = 1$ (initial prices, subsidies, spreads), a fixed risk-free discount rate of 4%, the investigated time period from $t = \{1, \ldots, T = 8\}$, the assets' depreciation period of $A = 16$ years, and the capital costs being set to 8%. Table 2 lists all parameters related to the stochastic processes used and the values they take on in the different policy regimes investigated. Rather than overemphasizing quantitative results, which would imply significant exposure to the chosen parametrization, the analysis focuses on understanding the interaction between parameters and values across scenarios in qualitative terms.

In scenario 1 (base case without policy regime uncertainty), the platform as well as the wind power plant investment have positive NPVs and are immediately executed. Indeed, the wind power plant NPV for immediate investment exceeds the option value of postponing the investment decision by a factor of 2.6. The reason is that obtainable subsidies are expected to decline; meanwhile, once the investment is locked in, subsidies are fixed and guaranteed. Thus, early execution is much more lucrative than delay. Regarding the VPP platform investment, the outcome is less clear. First, the option value of postponement almost reaches the NPV of immediate execution NPV (ratio of just under 95%). This is grounded in the fact that the platform value depends on the option values of market-related rather than subsidy-related value pools and is thus subject to more volatility than the wind power plant investment. Under such uncertainty, postponing the decision becomes more valuable. Interestingly, though, the ratio between option value and NPV of the platform is lower than the same ratios for the underlying value pools (i.e. placing of biogas power plants in the balancing market and pooling as well as netting effects for wind power marketing). There appears to be some diversification effect between the different underlying value pools, as they depend on different stochastic market parameters. Indeed, the lower relative option value indicates that the platform is exposed to less uncertainty relative to its NPV than the individual underlying DER value pools.

In scenario 2 (free market world without policy regime uncertainty), both investments again have positive NPVs. However, only the wind power plant investment is immediately executed – the immediate NPV exceeds the option value by a factor greater than 10. The reason is that subsidies are expected to decline even more steeply than in the base case, implying a further reduced value of postponement. Contrary to that, the VPP platform investment is indeed postponed, as the option value slightly exceeds the immediate NPV. Maybe more interestingly, the ratio between option value and NPV of the platform is higher than the same ratio for the underlying value pools in scenario 2. The reasons may be that the stochastic processes of the underlying market parameters are less heterogeneous and more volatile than in the base case (where there was a diversification effect). Instead of a diversification effect, the similarly structured and volatile processes of the underlying value pools appear to reinforce the value obtainable from postponing the VPP platform investment.

Scenario 3 (regulated market without policy regime uncertainty) invokes yet different results. Within this regime, the wind power plant investment is nearly postponed (option value at 96% of the immediate NPV). The reason is that the subsidy level is expected to remain constant with nearly no volatility. Postponing does not yield any additional benefits, neither does it lead to any value losses – except for a time discount on the present value. The platform investment is immediately executed, albeit with a lower NPV than in any other scenario – the NPV is less than half as high as in the free market world. The reason is that lower volatility and fewer upsides make both the investment generally, and the postponed investment in particular, less attractive. Similarly to the base case, a diversification effect can be observed, implying that a postponement of the platform investment is less attractive than the postponement of accessing the underlying value pools.

A couple of findings are worth mentioning with respect to scenarios 4 to 6, in which policy regime uncertainty is assumed. In scenario 4, it is assumed that the base case regime (as in scenario 1) will eventually be replaced by the free market (as in scenario 2), but with uncertain timing. Indeed, the values of NPVs and options for both the wind power plant and the VPP platforms lie in between those observed in scenarios 1 and 2. For the VPP platform, about 60% of the NPV and option value differentials between scenarios 1 and 2 are reflected in the corresponding values for scenario 4, respectively. In other words, the value impact of the anticipated free market regime on NPV and option values is reflected quite heavily in the valuation. This does not apply to the wind power plant investment at all. While the NPV of immediate investment remains unchanged, only 11.8% of the change in option valuation between scenarios 1 and 2 are reflected in the option valuation for scenario 4. It appears that, given the lock-in effect due to the subsidy, an anticipated policy regime in the future affects the current investment decision much less than it does in the case of the VPP platform. A similar observation can be made for scenario 5. Here, it is assumed that the base case regime (as in scenario 1) will eventually be replaced by the regulated market (as in scenario 3). Again, values lie between scenarios 1 and 3; the values for the VPP platform account much more strongly for the effects of the anticipated regulated regime than do the values for the wind power plant.

Table 3: Initial NPV ($t = 1$) vs. postponement value by scenario and technology (million €)

| | VPP platform | | Wind power plant | |
|---|---|---|---|---|
| Scenario | Initial NPV | Postponement | Initial NPV | Postponement |
| 1 - Base case | 4.8 | 4.5 | 1.6 | 0.6 |
| 2 - Free market world | 6.6 | 6.6 | 1.6 | 0.2 |
| 3 - Regulated world | 3.4 | 3.0 | 1.6 | 1.6 |
| 4 - From 1 to 2 | 5.9 | 5.8 | 1.6 | 0.6 |
| 5 - From 1 to 3 | 4.0 | 3.6 | 1.6 | 0.8 |
| 6 - From 1 to 2/3 | 5.0 | 4.7 | 1.6 | 0.7 |

In scenario 6, a regime shift from the base case (as in scenario 1) to either the free market world or the regulated world is anticipated, with equal probability of occurrence. For the VPP platform, both the NPV and the option values are the exact averages between scenarios 4 and 5. For the wind power plant, the option value is slightly below the average of the values of scenarios 4 and 5. Table 3 summarizes the NPVs and options values for both assets across scenarios.

# 4 Discussion and conclusion

Both the model development and the application to the investment opportunity for a VPP in Germany offer interesting new insights. We can observe both a policy content as well as a policy process effect. Both the anticipated content as well as the assumptions about the process of policy regime change influence rational investment decisions. The impacts could be separately quantified in our approach.

The content effect becomes obvious in scenarios 1 to 3. More specifically, the value of investing in a VPP platform as a market-dependent technology is strongly affected by the contents of the given policy regime. For instance, the high volatility and expected increases of underlying stochastic parameters in the free market world induce a particularly high NPV for the platform. Meanwhile, they also lead to investment postponement, since volatility is high and further upsides are anticipated. The implication is that investments in technologies whose value depends on market rather than subsidy developments are postponed whenever the current or anticipated market design implies great volatility – be it for reasons of a higher expected profit or due to the risk of unfavorable market developments. In other words, the often called-for free market design may not always be the energy technology investment catalyst it is believed to be. The more volatile market prices are expected to be, the more postponement can be expected regarding non-subsidized technologies.

Maybe even more strikingly, our analysis shows that investment decisions regarding (partly) subsidized technologies are more likely to be postponed under regimes with stable subsidies than in regimes with declining subsidies (scenario 3 versus scenarios 1, 2). As a consequence for policymakers, regressing subsidy schemes might turn out to be more effective after all: they stimulate investment front-loading, which may speed up technological learning curves and thereby reduce future investment costs; eventually, less subsidies might be necessary to spur investment in the future. All in all, the treatment of (partly) subsidized innovative energy technologies requires caution.

Next to the policy content effect, we could identify the policy process effect as a further effect on rational investment decisions. Namely, the degree to which NPV and option value are affected by anticipated changes in market design is strongly influenced by expectations about timing. The assumptions that investors make about the speed of change affects their expected values significantly. Again, a differentiation is required regarding subsidized technologies; in case a lock-in effect is present and the expected NPV is positive (as for wind power plants in our analysis), anticipations about future regime changes do not matter, Obviously, this finding rests on the assumption that future regime changes do not reverse any lock-in effects.

A limitation of our exploratory work, particularly with respect to the policy process effect, is that we focused on a rational investor, a pre-condition of the real options methodology used. In reality, investors tend to not act perfectly rationally. This certainly applies to instances of policy regime uncertainty. Some of the optimal strategies identified in this research are counter-intuitive. Since not all managers, and certainly not the public, rely on these or similar analysis approaches, more intuitive choices might be made. Further, especially the policy process effect depends heavily on assumptions about type and time of change. This points us to the critical role of sound policymaking: the more transparency and the less ambiguity regarding regime changes policymakers ensure, the more informed the decisions of investors will be. Consequentially, if more investment is to be stimulated, the process of policy regime amendments matters just as the actual content does.

Finally, the analysis revealed some particularities referring to VPP platform investments. On the one hand, VPP platforms present an innovative energy technology with great exposure to markets and ultimately policy regime risks which (may) influence market parameters. This stands in contrast to heavily subsidized innovative energy technologies, like wind power plants, which have fared much better regarding investment levels so far, partly because they were not burdened with the external costs they incur. The results of our numerical example confirm that, indeed, market exposure and policy regime risks may be a reason that potential investors have preferred to postpone VPP investments. On the other hand, VPP platform investments are not exposed to the commercial success of any individual business model. Rather, they can be understood as a claim on various DER and value pool options, implying a valuable diversification in the presence of policy regime risks. In our example, we have only touched upon a fraction of the value pools a VPP platform could provide access to. For instance, further value pools could be demand response with flexible loads or storage or negative balancing capacity offered by wind or PV power plants. As a consequence, it could be that potential investors underestimate some of the (long-term) value potential of VPP platforms owing to the platform role of VPP technology with access to a number of value pools.

This, in turn, implies that VPP platform development may better be interpreted as a capability development (capacity building for new business, or doing business in new ways) rather than a one-off investment. The ability to efficiently operate different kinds of DER in different kinds of markets or value pools could then be seen as a capability at the core of utility business in a world of ever-increasing shares of DER. The implication would be that, with respect to VPP platform development, high flexibility to accommodate many DER and access many value pools would become a key success factor. Future research could shed further light on this aspect by more deeply investigating the value of platform flexibility when operating DER business models.

# References

Alexander, D. R., M. Mo, and A. F. Stent (2012). Arithmetic brownian motion and real options. *European Journal of Operational Research 219*(1), 114 – 122.

Asmus, P. (2010). Microgrids, virtual power plants and our distributed energy future. *The Electricity Journal 23*(10), 72 – 82.

Balance Power GmbH (2014). Regelleistung Kurzvorstellung. Report, Balance Power GmbH.

Cox, J. C., S. A. Ross, and M. Rubinstein (1979). Option pricing: A simplified approach. *Journal of Financial Economics 7*(3), 229–263.

Fan, L., C. S. Norman, and A. G. Patt (2012). Electricity capacity investment under risk aversion: A case study of coal, gas, and concentrated solar power. *Energy Economics 34*(1), 54 – 61.

Garnier, E. and R. Madlener (2014). Day-ahead versus intraday valuation of flexibility for photovoltaic and wind power systems [full version]. FCN Working Paper No. 17/2014: https://www.fcn.eonerc.rwth-aachen.de/go/id/emvl/lidx/1.

Garnier, E. and R. Madlener (2015). Balancing forecast errors in continuous-trade intraday markets. *Energy Systems*, doi: 10.1007/s12667–015–0143–y.

Global Wind Eenergy Council (2015). Global wind statistics 2014. Report, Global Wind Energy Council, Brussels.

Hagemann, S. and C. Weber (2013). An empirical analysis of liquidity and its determinants in the German intraday market for electricity. EWL Working Papers 1317: http://ideas.repec.org/p/dui/wpaper/1317.html.

Hirth, L. (2013). The market value of variable renewables: The effect of solar wind power variability on their relative price. *Energy Economics 38*, 218–236.

International Energy Agency (2014). World energy investment outlook. Report, International Energy Agency.

Jaffe, A. B. and R. N. Stavins (1994). Markets for energy efficiency the energy-efficiency gap what does it mean? *Energy Policy 22*(10), 804 – 810.

Jun, I. and J. Yan (2004). Investment under regulatory uncertainty: U.s. electricity generation investment since 1996. UC Berkeley: Center for the Study of Energy Markets: http://escholarship.org/uc/item/50f4d8mr.

Kok, K. (2009, June). Short-term economics of virtual power plants. In *20th International Conference and Exhibition on Electricity Distribution - Part 1, 2009. CIRED 2009.*, pp. 1–4.

Majd, S. and R. S. Pindyck (1987). Time to build, option value, and investment decisions. *Journal of Financial Economics 18*(1), 7 – 27.

Martin, R. (2014). Capacity of virtual power plants worldwide expected to more than quintuple by 2023. Navigant Research: http://www.navigantresearch.com/newsroom/capacity-of-virtual-power-plants-worldwide-is-expected-to-more-than-quintuple-by-2023.

Masson, G., S. Orlandi, and M. Rekinger (2014). Global market outlook for photovoltaics 2014-2018. Report, European Photovoltaic Industry Association, Brussels.

Nieder, T., P. Bickel, and F. Musiol (2015). Development of renewable energy sources in Germany 2014. Charts and figures based on statistical data from the Working Group on Renewable Energy-Statistics (AAGEE-Stat), as at February 2015. Report, German Federal Ministry for Economic Affairs and Energy, Working Group on Renewable Energy-Statistics (AAGEE-Stat).

Pudjianto, D., C. Ramsay, and G. Strbac (2007, March). Virtual power plant and system integration of distributed energy resources. *Renewable Power Generation, IET 1*(1), 10–16.

Rohlfs, W. and R. Madlener (2014). Multi-commodity real options analysis of power plant investments: discounting endogenous risk structures. *Energy Systems 5*(3), 423–447.

Schwartz, E. S. and C. Zozaya-Gorostiza (2003). Investment under uncertainty in information technology: Acquisition and development projects. *Management Science 49*(1), 57–70.

von Selasinsky, A. (2014). The Integration of Renewables in Continuous Intraday Markets for Electricity. Working Paper, SSRN: http://dx.doi.org/10.2139/ssrn.2405454.

Weber, C. (2010). Adequate intraday market design to enable the integration of wind energy into the European power systems. *Energy Policy 38*(7), 3155–3163.

Wetzel, D. (2013). Energie-Bosse warnen vor dem Strom-Kollaps. Die Welt: http://www.welt.de/wirtschaft/article116413761/Energie-Bosse-warnen-vor-dem-Strom-Kollaps.html.

Wille-Haussmann, B., T. Erge, and C. Wittwer (2010). Decentralised optimisation of cogeneration in virtual power plants. *Solar Energy 84*(4), 604 – 611. International Conference CISBAT 2007.

Yang, M., W. Blyth, R. Bradley, D. Bunn, C. Clarke, and T. Wilson (2008). Evaluating the power investment options with uncertainty in climate policy. *Energy Economics 30*(4), 1933 – 1950.

You, S., C. Traeholt, and B. Poulsen (2009, June). A market-based virtual power plant. In *International Conference on Clean Electrical Power, 2009*, pp. 460–465.

# Appendix

Table 4: Value pool explanations

| Value pool $m$ | Explanation | Value at start |
|---|---|---|
| Direct marketing subsidies | Support for sale of renewable electricity in day-ahead market; compensation for difference between granted feed-in-tariff and wholesale price | 60€ /MWh for wind power (other subsidized technologies not considered in example) |
| Portfolio pooling | Savings in forecast error balancing costs obtainable from pooling multiple non-dispatchable assets in VPP (only for wind) | Estimated 10% savings of imbalance fees for assumed forecast error of offered volumes (10%) |
| Intraday balancing | Savings in forecast error balancing costs obtainable from using VPP to trade errors also in the intraday market rather than only in the imbalance market (only for wind) | Estimated based on spread between intraday and imbalance prices, for 20% of the assumed forecast error of offered volumes (10%) |
| Capacity remuneration | Compensation for the provision of negative capacity in the secondary balancing market | Estimated at 35,000€ p.a. |
| Power activation remuneration | Compensation for the activation of negative power in the secondary balancing market | Estimated at 100€ /MWh for about 250 hours p.a. |

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## 2014

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Madlener R., Reismann T. (2014). The Great Pacific Garbage Patch: A Preliminary Economic Analysis of the ‘Sixth Continent’, FCN Working Paper No. 6/2014, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, May.

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Garbuzova-Schlifter M., Madlener R. (2014). Risk Analysis of Energy Performance Contracting Projects in Russia: An Analytic Hierarchy Process Approach, FCN Working Paper No. 10/2014, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, October.

Kumar S., Madlener R., Suri I. (2014). An Energy System Analysis on Restructuring the German Electricity Market with New Energy and Environmental Policies, FCN Working Paper No. 11/2014, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, October.

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Oberst C.A., Madlener R. (2014). Prosumer Preferences Regarding the Adoption of Micro-Generation Technologies: Empirical Evidence for German Homeowners, FCN Working Paper No. 22/2014, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, December.

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## 2013

Grieser B., Madlener R., Sunak Y. (2013). Economics of Small Wind Power Plants in Urban Settings: An Empirical Investigation for Germany, FCN Working Paper No. 1/2013, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, January.

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Kroniger D., Madlener R. (2013). Hydrogen Storage for Wind Parks: A Real Options Evaluation for an Optimal Investment in More Flexibility, FCN Working Paper No. 3/2013, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, February.

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Oberst C.A., Oelgemöller J. (2013). Economic Growth and Regional Labor Market Development in German Regions: Okun's Law in a Spatial Context, FCN Working Paper No. 5/2013, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, March.

Harmsen - van Hout M.J.W., Ghosh G.S., Madlener R. (2013). An Evaluation of Attribute Anchoring Bias in a Choice Experimental Setting. FCN Working Paper No. 6/2013, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, April.

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Rosen C., Madlener R. (2013). An Experimental Analysis of Single vs. Multiple Bids in Auctions of Divisible Goods, FCN Working Paper No. 8/2013, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, April (revised November 2013).

Palmer J., Sorda G., Madlener R. (2013). Modeling the Diffusion of Residential Photovoltaic Systems in Italy: An Agent-based Simulation, FCN Working Paper No. 9/2013, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, May.

Bruns S.B., Gross C. (2013). What if Energy Time Series are not Independent? Implications for Energy-GDP Causality Analysis, FCN Working Paper No. 10/2013, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, June.

Bruns S.B., Gross C., Stern D.I. (2013). Is There Really Granger Causality Between Energy Use and Output?, FCN Working Paper No. 11/2013, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, August.

Rohlfs W., Madlener R. (2013). Optimal Power Generation Investment: Impact of Technology Choices and Existing Portfolios for Deploying Low-Carbon Coal Technologies, FCN Working Paper No. 12/2013, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, August.

Rohlfs W., Madlener R. (2013). Challenges in the Evaluation of Ultra-Long-Lived Projects: Risk Premia for Projects with Eternal Returns or Costs, FCN Working Paper No. 13/2013, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, August.

Michelsen C.C., Madlener R. (2013). Switching from dFossil Fuel to Renewables in Residential Heating Systems: An Empirical Study of Homeowners' Decisions in Germany, FCN Working Paper No. 14/2013, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, October.

Rosen C., Madlener R. (2013). The Role of Information Feedback in Local Reserve Energy Auction Markets, FCN Working Paper No. 15/2013, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, November.

Himpler S., Madlener R. (2013). A Dynamic Model for Long-Term Price and Capacity Projections in the Nordic Green Certificate Market, FCN Working Paper No. 16/2013, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, November.

Weibel S., Madlener R. (2013). Cost-effective Design of Ringwall Storage Hybrid Power Plants: A Real Options Analysis, FCN Working Paper No. 17/2013, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, December.

Budny C., Madlener R., Hilgers C. (2013). Economic Feasibility of Pipeline and Underground Reservoir Storage Options for Power-to-Gas Load Balancing, FCN Working Paper No. 18/2013, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, December.

Johann A., Madlener R. (2013). Profitability of Energy Storage for Raising Self-Consumption of Solar Power: Analysis of Different Household Types in Germany, FCN Working Paper No. 19/2013, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, December.

Hackbarth A., Madlener R. (2013). Willingness-to-Pay for Alternative Fuel Vehicle Characteristics: A Stated Choice Study for Germany, FCN Working Paper No. 20/2013, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, December.

Katatani T., Madlener R. (2013). Modeling Wholesale Electricity Prices: Merits of Fundamental Data and Day-Ahead Forecasts for Intermittent Power Production, FCN Working Paper No. 21/2013, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, December.

Baumgärtner M., Madlener R. (2013). Factors Influencing Energy Consumer Behavior in the Residential Sector in Europe: Exploiting the REMODECE Database, FCN Working Paper No. 22/2013, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, December.

Charalampous G., Madlener R. (2013). Risk Management and Portfolio Optimization for Gas- and Coal-Fired Power Plants in Germany: A Multivariate GARCH Approach, FCN Working Paper No. 23/2013, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, December.

Mallah S., Madlener R. (2013). The Causal Relationship Between Energy Consumption and Economic Growth in Germany: A Multivariate Analysis, FCN Working Paper No. 24/2013, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, December.

## 2012

Ghosh G., Shortle J. (2012). Managing Pollution Risk through Emissions Trading, FCN Working Paper No. 1/2012, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, January.

Palzer A., Westner G., Madlener M. (2012). Evaluation of Different Hedging Strategies for Commodity Price Risks of Industrial Cogeneration Plants, FCN Working Paper No. 2/2012, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, March (revised March 2013).

Sunak Y., Madlener R. (2012). The Impact of Wind Farms on Property Values: A Geographically Weighted Hedonic Pricing Model, FCN Working Paper No. 3/2012, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, May (revised March 2013).

Achtnicht M., Madlener R. (2012). Factors Influencing German House Owners' Preferences on Energy Retrofits, FCN Working Paper No. 4/2012, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, June.

Schabram J., Madlener R. (2012). The German Market Premium for Renewable Electricity: Profitability and Risk of Self-Marketing, FCN Working Paper No. 5/2012, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, July.

Garbuzova M., Madlener R. (2012). Russia’s Emerging ESCO Market: Prospects and Barriers for Energy Efficiency Investments, FCN Working Paper No. 6/2012, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, July (revised September 2012).

Rosen C., Madlener R. (2012). Auction Design for Local Reserve Energy Markets, FCN Working Paper No. 7/2012, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, July (revised March 2013).

Sorda G., Madlener R. (2012). Cost-Effectiveness of Lignocellulose Biorefineries and their Impact on the Deciduous Wood Markets in Germany. FCN Working Paper No. 8/2012, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, September.

Madlener R., Ortlieb C. (2012). An Investigation of the Economic Viability of Wave Energy Technology: The Case of the Ocean Harvester, FCN Working Paper No. 9/2012, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, October.

Hampe J., Madlener R. (2012). Economics of High-Temperature Nuclear Reactors for Industrial Cogeneration, FCN Working Paper No. 10/2012, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, October.

Knaut A., Madlener R., Rosen C., Vogt C. (2012). Effects of Temperature Uncertainty on the Valuation of Geothermal Projects: A Real Options Approach, FCN Working Paper No. 11/2012, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, November.

Hünteler J., Niebuhr C.F., Schmidt T.S., Madlener R., Hoffmann V.H. (2012). Financing Feed-in Tariffs in Developing Countries under a Post-Kyoto Climate Policy Regime: A Case Study of Thailand, FCN Working

Paper No. 12/2012, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, December.

Blass N., Madlener R. (2012). Structural Inefficiencies and Benchmarking of Water Supply Companies in Germany, FCN Working Paper No. 13/2012, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, December.

Madlener R., Schabram J. (2012). Predicting Reserve Energy from New Renewables by Means of Principal Component Analysis and Copula Functions, FCN Working Paper No. 14/2012, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, December.

Harzendorf F., Madlener R. (2012). Optimal Investment in Gas-Fired Engine-CHP Plants in Germany: A Real Options Approach, FCN Working Paper No. 15/2012, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, December.

Schmitz M., Madlener R. (2012). Economic Feasibility of Kite-Based Wind Energy Powerships with CAES or Hydrogen Storage, FCN Working Paper No. 16/2012, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, December.

Dergiades T., Madlener R., Christofidou G. (2012). The Nexus between Natural Gas Spot and Futures Prices at NYMEX: Do Weather Shocks and Non-Linear Causality in Low Frequencies Matter?, FCN Working Paper No. 17/2012, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, December (revised September 2013).

Rohlfs W., Madlener R. (2012). Assessment of Clean-Coal Strategies: The Questionable Merits of Carbon Capture-Readiness, FCN Working Paper No. 18/2012, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, December.

Wüstemeyer C., Bunn D., Madlener R. (2012). Bridging the Gap between Onshore and Offshore Innovations by the European Wind Power Supply Industry: A Survey-based Analysis, FCN Working Paper No. 19/2012, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, December.

Fuhrmann J., Madlener R. (2012). Evaluation of Synergies in the Context of European Multi-Business Utilities, FCN Working Paper No. 20/2012, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, December.

## 2011

Sorda G., Sunak Y., Madlener R. (2011). A Spatial MAS Simulation to Evaluate the Promotion of Electricity from Agricultural Biogas Plants in Germany, FCN Working Paper No. 1/2011, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, January (revised October 2012).

Madlener R., Hauertmann M. (2011). Rebound Effects in German Residential Heating: Do Ownership and Income Matter?, FCN Working Paper No. 2/2011, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, February.

Garbuzova M., Madlener R. (2011). Towards an Efficient and Low-Carbon Economy Post-2012: Opportunities and Barriers for Foreign Companies in the Russian Market, FCN Working Paper No. 3/2011, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, February (revised July 2011).

Westner G., Madlener R. (2011). The Impact of Modified EU ETS Allocation Principles on the Economics of CHP-Based District Heating Networks. FCN Working Paper No. 4/2011, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, February.

Madlener R., Ruschhaupt J. (2011). Modeling the Influence of Network Externalities and Quality on Market Shares of Plug-in Hybrid Vehicles, FCN Working Paper No. 5/2011, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, March.

Juckenack S., Madlener R. (2011). Optimal Time to Start Serial Production: The Case of the Direct Drive Wind Turbine of Siemens Wind Power A/S, FCN Working Paper No. 6/2011, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, March.

Madlener R., Sicking S. (2011). Assessing the Economic Potential of Microdrilling in Geothermal Exploration, FCN Working Paper No. 7/2011, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, April.

Bernstein R., Madlener R. (2011). Responsiveness of Residential Electricity Demand in OECD Countries: A Panel Cointegration and Causality Analysis, FCN Working Paper No. 8/2011, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, April.

Michelsen C.C., Madlener R. (2011). Homeowners' Preferences for Adopting Residential Heating Systems: A Discrete Choice Analysis for Germany, FCN Working Paper No. 9/2011, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, May (revised January 2012).

Madlener R., Glensk B., Weber V. (2011). Fuzzy Portfolio Optimization of Onshore Wind Power Plants. FCN Working Paper No. 10/2011, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, May.

Glensk B., Madlener R. (2011). Portfolio Selection Methods and their Empirical Applicability to Real Assets in Energy Markets. FCN Working Paper No. 11/2011, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, May.

Kraas B., Schroedter-Homscheidt M., Pulvermüller B., Madlener R. (2011). Economic Assessment of a Concentrating Solar Power Forecasting System for Participation in the Spanish Electricity Market, FCN Working Paper No. 12/2011, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, May.

Stocker A., Großmann A., Madlener R., Wolter M.I., (2011). Sustainable Energy Development in Austria Until 2020: Insights from Applying the Integrated Model “e3.at”, FCN Working Paper No. 13/2011, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, July.

Kumbaroğlu G., Madlener R. (2011). Evaluation of Economically Optimal Retrofit Investment Options for Energy Savings in Buildings. FCN Working Paper No. 14/2011, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, September.

Bernstein R., Madlener R. (2011). Residential Natural Gas Demand Elasticities in OECD Countries: An ARDL Bounds Testing Approach, FCN Working Paper No. 15/2011, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, October.

Glensk B., Madlener R. (2011). Dynamic Portfolio Selection Methods for Power Generation Assets, FCN Working Paper No. 16/2011, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, November.

Michelsen C.C., Madlener R. (2011). Homeowners' Motivation to Adopt a Residential Heating System: A Principal Component Analysis, FCN Working Paper No. 17/2011, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, November (revised January 2013).

Razlaf J., Madlener R. (2011). Performance Measurement of CCS Power Plants Using the Capital Asset Pricing Model, FCN Working Paper No. 18/2011, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, November.

Himpler S., Madlener R. (2011). Repowering of Wind Turbines: Economics and Optimal Timing, FCN Working Paper No. 19/2011, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, November (revised July 2012).

Hackbarth A., Madlener R. (2011). Consumer Preferences for Alternative Fuel Vehicles: A Discrete Choice Analysis, FCN Working Paper No. 20/2011, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, December (revised December 2012).

Heuser B., Madlener R. (2011). Geothermal Heat and Power Generation with Binary Plants: A Two-Factor Real Options Analysis, FCN Working Paper No. 21/2011, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, December.

Rohlfs W., Madlener R. (2011). Multi-Commodity Real Options Analysis of Power Plant Investments: Discounting Endogenous Risk Structures, FCN Working Paper No. 22/2011, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, December (revised July 2012).

## 2010

Lang J., Madlener R. (2010). Relevance of Risk Capital and Margining for the Valuation of Power Plants: Cash Requirements for Credit Risk Mitigation, FCN Working Paper No. 1/2010, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, February.

Michelsen C.C., Madlener R. (2010). Integrated Theoretical Framework for a Homeowner's Decision in Favor of an Innovative Residential Heating System, FCN Working Paper No. 2/2010, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, February.

Harmsen - van Hout M.J.W., Herings P.J.-J., Dellaert B.G.C. (2010). The Structure of Online Consumer Communication Networks, FCN Working Paper No. 3/2010, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, March.

Madlener R., Neustadt I. (2010). Renewable Energy Policy in the Presence of Innovation: Does Government Pre-Commitment Matter?, FCN Working Paper No. 4/2010, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, April (revised June 2010 and December 2011).

Harmsen - van Hout M.J.W., Dellaert B.G.C., Herings, P.J.-J. (2010). Behavioral Effects in Individual Decisions of Network Formation: Complexity Reduces Payoff Orientation and Social Preferences, FCN Working Paper No. 5/2010, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, May.

Lohwasser R., Madlener R. (2010). Relating R&D and Investment Policies to CCS Market Diffusion Through Two-Factor Learning, FCN Working Paper No. 6/2010, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, June.

Rohlfs W., Madlener R. (2010). Valuation of CCS-Ready Coal-Fired Power Plants: A Multi-Dimensional Real Options Approach, FCN Working Paper No. 7/2010, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, July.

Rohlfs W., Madlener R. (2010). Cost Effectiveness of Carbon Capture-Ready Coal Power Plants with Delayed Retrofit, FCN Working Paper No. 8/2010, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, August (revised December 2010).

Gampert M., Madlener R. (2010). Pan-European Management of Electricity Portfolios: Risks and Opportunities of Contract Bundling, FCN Working Paper No. 9/2010, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, August.

Glensk B., Madlener R. (2010). Fuzzy Portfolio Optimization for Power Generation Assets, FCN Working Paper No. 10/2010, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, August.

Lang J., Madlener R. (2010). Portfolio Optimization for Power Plants: The Impact of Credit Risk Mitigation and Margining, FCN Working Paper No. 11/2010, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, September.

Westner G., Madlener R. (2010). Investment in New Power Generation Under Uncertainty: Benefits of CHP vs. Condensing Plants in a Copula-Based Analysis, FCN Working Paper No. 12/2010, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, September.

Bellmann E., Lang J., Madlener R. (2010). Cost Evaluation of Credit Risk Securitization in the Electricity Industry: Credit Default Acceptance vs. Margining Costs, FCN Working Paper No. 13/2010, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, September (revised May 2011).

Ernst C.-S., Lunz B., Hackbarth A., Madlener R., Sauer D.-U., Eckstein L. (2010). Optimal Battery Size for Serial Plug-in Hybrid Vehicles: A Model-Based Economic Analysis for Germany, FCN Working Paper No. 14/2010, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, October (revised June 2011).

Harmsen - van Hout M.J.W., Herings P.J.-J., Dellaert B.G.C. (2010). Communication Network Formation with Link Specificity and Value Transferability, FCN Working Paper No. 15/2010, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, November.

Paulun T., Feess E., Madlener R. (2010). Why Higher Price Sensitivity of Consumers May Increase Average Prices: An Analysis of the European Electricity Market, FCN Working Paper No. 16/2010, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, November.

Madlener R., Glensk B. (2010). Portfolio Impact of New Power Generation Investments of E.ON in Germany, Sweden and the UK, FCN Working Paper No. 17/2010, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, November.

Ghosh G., Kwasnica A., Shortle J. (2010). A Laboratory Experiment to Compare Two Market Institutions for Emissions Trading, FCN Working Paper No. 18/2010, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, November.

Bernstein R., Madlener R. (2010). Short- and Long-Run Electricity Demand Elasticities at the Subsectoral Level: A Cointegration Analysis for German Manufacturing Industries, FCN Working Paper No. 19/2010, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, November.

Mazur C., Madlener R. (2010). Impact of Plug-in Hybrid Electric Vehicles and Charging Regimes on Power Generation Costs and Emissions in Germany, FCN Working Paper No. 20/2010, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, November.

Madlener R., Stoverink S. (2010). Power Plant Investments in the Turkish Electricity Sector: A Real Options Approach Taking into Account Market Liberalization, FCN Working Paper No. 21/2010, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, December (revised July 2011).

Melchior T., Madlener R. (2010). Economic Evaluation of IGCC Plants with Hot Gas Cleaning, FCN Working Paper No. 22/2010, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, December.

Lüschen A., Madlener R. (2010). Economics of Biomass Co-Firing in New Hard Coal Power Plants in Germany, FCN Working Paper No. 23/2010, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, December (revised July 2012).

Madlener R., Tomm V. (2010). Electricity Consumption of an Ageing Society: Empirical Evidence from a Swiss Household Survey, FCN Working Paper No. 24/2010, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, December.

Tomm V., Madlener R. (2010). Appliance Endowment and User Behaviour by Age Group: Insights from a Swiss Micro-Survey on Residential Electricity Demand, FCN Working Paper No. 25/2010, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, December.

Hinrichs H., Madlener R., Pearson P. (2010). Liberalisation of Germany’s Electricity System and the Ways Forward of the Unbundling Process: A Historical Perspective and an Outlook, FCN Working Paper No. 26/2010, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, December.

Achtnicht M. (2010). Do Environmental Benefits Matter? A Choice Experiment Among House Owners in Germany, FCN Working Paper No. 27/2010, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, December.

## 2009

Madlener R., Mathar T. (2009). Development Trends and Economics of Concentrating Solar Power Generation Technologies: A Comparative Analysis, FCN Working Paper No. 1/2009, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, November (revised September 2010).

Madlener R., Latz J. (2009). Centralized and Integrated Decentralized Compressed Air Energy Storage for Enhanced Grid Integration of Wind Power, FCN Working Paper No. 2/2009, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, November (revised September 2010).

Kraemer C., Madlener R. (2009). Using Fuzzy Real Options Valuation for Assessing Investments in NGCC and CCS Energy Conversion Technology, FCN Working Paper No. 3/2009, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, November.

Westner G., Madlener R. (2009). Development of Cogeneration in Germany: A Dynamic Portfolio Analysis Based on the New Regulatory Framework, FCN Working Paper No. 4/2009, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, November (revised March 2010).

Westner G., Madlener R. (2009). The Benefit of Regional Diversification of Cogeneration Investments in Europe: A Mean-Variance Portfolio Analysis, FCN Working Paper No. 5/2009, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, November (revised March 2010).

Lohwasser R., Madlener R. (2009). Simulation of the European Electricity Market and CCS Development with the HECTOR Model, FCN Working Paper No. 6/2009, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, November.

Lohwasser R., Madlener R. (2009). Impact of CCS on the Economics of Coal-Fired Power Plants – Why Investment Costs Do and Efficiency Doesn’t Matter, FCN Working Paper No. 7/2009, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, November.

Holtermann T., Madlener R. (2009). Assessment of the Technological Development and Economic Potential of Photobioreactors, FCN Working Paper No. 8/2009, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, November.

Ghosh G., Carriazo F. (2009). A Comparison of Three Methods of Estimation in the Context of Spatial Modeling, FCN Working Paper No. 9/2009, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, November.

Ghosh G., Shortle J. (2009). Water Quality Trading when Nonpoint Pollution Loads are Stochastic, FCN Working Paper No. 10/2009, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, November.

Ghosh G., Ribaudo M., Shortle J. (2009). Do Baseline Requirements hinder Trades in Water Quality Trading Programs?, FCN Working Paper No. 11/2009, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, November.

Madlener R., Glensk B., Raymond P. (2009). Investigation of E.ON's Power Generation Assets by Using Mean-Variance Portfolio Analysis, FCN Working Paper No. 12/2009, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, November.

## 2008

Madlener R., Neustadt I., Zweifel P. (2008). Promoting Renewable Electricity Generation in Imperfect Markets: Price vs. Quantity Policies, FCN Working Paper No. 1/2008, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, July (revised November 2011).

Madlener R., Wenk C. (2008). Efficient Investment Portfolios for the Swiss Electricity Supply Sector, FCN Working Paper No. 2/2008, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, August.

Omann I., Kowalski K., Bohunovsky L., Madlener R., Stagl S. (2008). The Influence of Social Preferences on Multi-Criteria Evaluation of Energy Scenarios, FCN Working Paper No. 3/2008, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, August.

Bernstein R., Madlener R. (2008). The Impact of Disaggregated ICT Capital on Electricity Intensity of Production: Econometric Analysis of Major European Industries, FCN Working Paper No. 4/2008, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, September.

Erber G., Madlener R. (2008). Impact of ICT and Human Skills on the European Financial Intermediation Sector, FCN Working Paper No. 5/2008, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, September.

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