Costs, Benefits, and Security of Supply in Bio-Electricity Feed-in Tariff Systems: A Real Options Approach

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Abstract

Renewable energy subsidies in the form of feed-in tariffs implicitly give investors the possibility to shut down their renewable power plants temporarily or permanently. This real option is especially valuable for electricity from biomass, an important pillar of European renewable energy goals. The shut-down option is similar to a put on agricultural commodity prices, while the costs and benefits to the public are similar to underwriting a binary put. We apply our results to biogas plants subsidized by Germany's renewable energy policies and find that the option's share in investment value is sizable, while costs and benefits to the public are much lower than would be assessed by DCF measures but benefits decrease more. Simulations using the historic measure P show that there is a high likelihood that biogas will not contribute to a stable electricity supply or political goals of the share of renewable power sources. We derive suggestions for an improved feed-in legislation for electricity from biomass.

1 Introduction

As many forms of renewable electricity generation cannot (yet) compete with the use of fossil energy sources, governments rely in most cases on feed-in tariffs to set incentives for the investment and use of power plants which produce renewable electricity, see Couture et al. (2010) for a survey. They find the general characteristics that power plants qualifying for the tariff have a guaranteed access to the grid and that purchase agreements are often specified ex ante for long-term periods of 15-20 years. In this article, we analyze a neglected feature of feed-in tariffs which can have disruptive impacts on a stable electricity supply from these renewable energies, especially when combined with long-term fixed feed-in tariffs: while plant owners are entitled to feed-in electricity at the tariff, they are not legally forced to do so, when the operative costs of electricity generation reach unprofitable levels. Therefore, value-maximizing plant owners facing cost pressures can decide to temporarily or permanently shut down the plant.[1] This applies especially in the field of renewable electricity generated from purpose-grown biomass, where the prices of the energy source are relatively high in comparison to investment outlays and determined by volatile world markets. While there is increasing evidence that biofuels and bioenergy have caused the rise in volatility of food prices (See Wright (2014).), we look at the question from a different angle and analyze how large the effect is in the other direction.

Indeed, temporary or permanent shut downs is what happened to the German industry of combined heat and power plants operated by burning plant oils: The installed base of such plants qualifying for the tariffs increased rapidly after being promoted by the feed-in tariffs of the German renewable energy act of 2004, see figure 2. However, despite the tariffs being legally guaranteed for 20 years, less than four years later with the rapid rise in agricultural prices (see figure 1) the industry was in demise. According to Witt & Thrän (2013), at the moment the overwhelming part of the previous installed base is temporarily shut-down, operated with fuels prohibiting current or future qualification for feed-in tariffs, or completely dismantled.

According to Gilbert & Morgan (2010), for many agricultural commodities the rise in prices and volatility from late 2007 to present cannot be considered a singular event, but largely concurring with previous empirical measures of price uncertainty. Therefore, in valuing a biomass-related investment opportunity the possibility to shut down a plant temporarily or permanently should not be neglected. Standard approaches like the discounted cash flow (DCF) approach fail to account for this managerial freedom, while Real Options Analysis (ROA) can deliver consistent results (See Dixit & Pindyck (1994) or Trigeorgis (1998)). To our knowledge, there exists no valuation of biomass plants under feed-in tariffs, which accounts for agricultural price uncertainty in a consistent fashion.

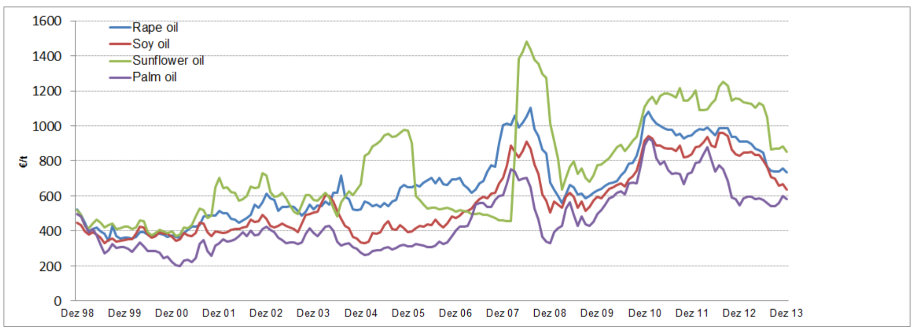
While important to (potential) investors, a consistent valuation is also of high importance to the public and policy makers. Lavish funding of renewable energies with feed-in tariffs may result in investment activity far above desired levels, as Germany and Spain have experienced in the case of photovoltaic electricity, see Mendonca (2009). Next, when feed-in tariffs are set such to cover generation costs, plus a (however defined) *reasonable* return, (as is the case in e.g. Germany, see Couture et al. (2010)), negligence of the real options of a biomass plant would mean an undue transfer of wealth from the public[2] to investors.

As the public is generally affected by investors' value-maximizing decision to feed in electricity or not, their stake in electricity from biomass needs to be modelled by a real options approach as well. As the decision to feed-in is up to investors, the public's stake can be considered as an *underwriting position* of

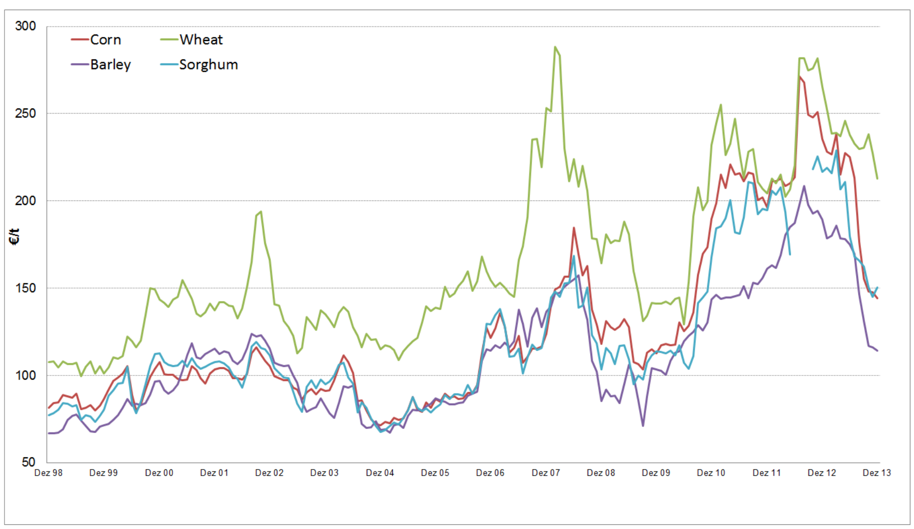
[1] The value-maximizing behavior of individuals or firms may be questioned. But even if feed-in was enforced by law or plant owners would stray far from value-maximizing behavior, sustained losses would eventually lead to bankruptcy of the plant owners and thus to postponed shut-down or abandonment of plants.

[2] Usually, feed-in tariffs are funded by taxes or by allocation to electricity consumers, see Mendonca (2009).

Figure 1: Development of World Markets for Agricultural Products

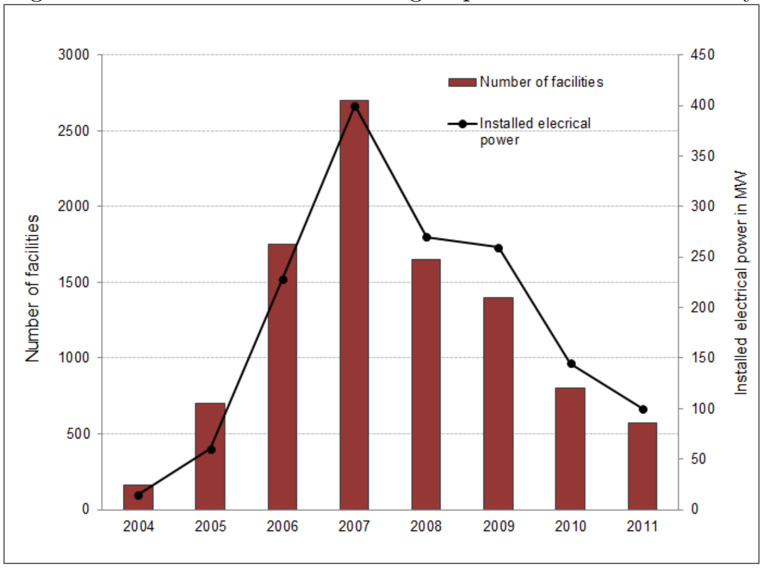


(a) Plant Oils



(b) Cereals

Figure 2: Power Plants Combusting Liquid Biomass in Germany



a real option. This holds true for the liabilities created by the use of biomass (E.g. differential costs[3] , environmental damages e.g. through the loss of biodiversity, political unrest due to reductions of food supply, etc.) as well as for the benefits of electricity from biomass, such as reduced CO2 emissions, independence from foreign sources of fossil sources, etc. In contrast to financial options, the positions of the underwriter and the holder of an option are not zero-sum. As we will see, the position of investors can be described as a put option on agricultural prices, while costs and benefits of renewable energies are best described as underwriting a binary (also called digital) put potion.

We apply our results to the European biogas industry, which is characterized by large growth rates over the last decade. Our calculations show that negligence of the shut-down option can lead to large miscalculations of the positions of investors and the costs and benefits of biogas plants. Since the option characteristic of feed-in not only affects valuations, which can be calculated using risk-neutral probabilities, but can also affect the stability of electricity supply, especially when the feed-in decision is made independently of the demand of electricity. Next, political goals of a certain share of renewable power generation (E.g. the European Commission set a goal of a share of %20 of renewable power generation by 2020.) might be missed when biomass powered plants go out of business. To analyze this issue we simulate the optimal decision of a plant using historical probabilities and estimate probabilities that existing biomass plants will contribute to the European Commission's goals for renewable power generation.

[3]The difference between costs of power generation in absence and presence of feed-in tariffs.

The remainder is organized as follows: section 2 shows the put-like, and binary put-like structure of biogas plants. In section 3, we estimate present values of costs and benefits of within the German biogas industry using the real options approach. In secton 4, we further assess the stability of biogas feed-in under current FIT systems. Section 5 contains a summary of our results.

2 Feed-in Tariffs as a Put Option

In this section we give a brief introduction to real options valuation of feed-in tariffs for electricity from purpose-grown biomass, using a simple but nevertheless relevant example. In the later applications we add complexity to increase realism.

Consider that at time $t = 0$ policy makers want to promote electricity generation in $t = 1, 2, 3...T$ from combusting biomass by setting an ex ante fixed and constant tariff E. We subsume the difference of other revenues like sale of waste material and heat, and costs like maintenance etc. under H_t, which develops deterministically. The (opportunity costs) S_t of biomass, are however determined on a competitive world market for agricultural products and evolve stochastically. In general, this investment opportunity could be valued as

$$V_0 = \sum_{t=1}^{T} \exp^{-rt}(E + H_t) - F_{0,t} \tag{1}$$

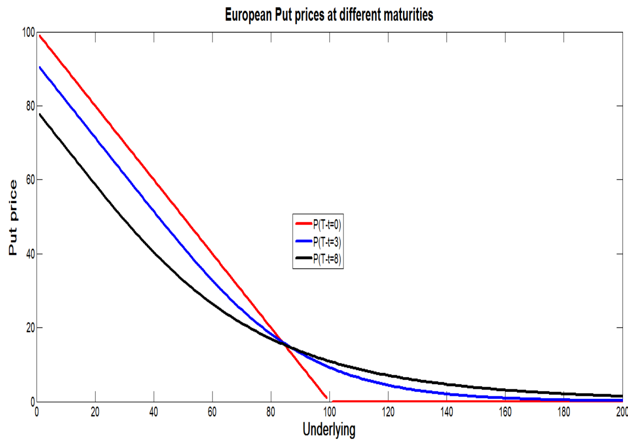
where r is the risk-less interest rate and $F_{0,t}$ is the value of a forward contract written in $t = 0$ on delivery at $t = 1, ..., T$. However, this analysis fails to account for the possibility that future spot prices S_t rise above $E + H_t$. As there is generally only the entitlement, but no obligation to feed-in electricity, profit-maximizing behavior of its owners results in temporary shut down of the plant, neglecting for the moment below-capacity operation, switching costs, or scrap values. The cash flow in a given period from owning a plant that qualifies for FITs is thus

$$P_T^{Investor} = max(0, E + H - S_T) = \begin{cases} E + H_t - S_t, & \text{if } E + H_t - S_t > 0 \\ 0 & \text{else.} \end{cases} \tag{2}$$

This is the payoff structure of a European put option. Its structure is depicted by the red line in figure 3.

Put (Call) options are financial contracts, written at time t between the *option holder* and the *option writer*, which give the option holder the right, but not the obligation, to sell (buy) a specified amount of an asset, the *underlying* S at the specified *strike price* K on a future date T, where $T - t$ is called the *maturity*. When the right can be exercised only in T, the option is called European-style; when it can be exercised at any point between t and T, the option is called American-style. Since this right will only be exercised if it is profitable to do so, at maturity the payoff of a European put option will be $max(0, K - S_T)$.

Figure 3: Put Option Valuations



Assuming that the biomass pays a net convenience yield y, the value of a biogas plant costing $-I_0$ can be expressed in a Black&Scholes fashion:

$$V_0^{Investor} = -I_0 + \sum_{t=1}^{T} (E + H_t) \exp^{-rt} \Phi(-d_{2,t}) - S_0 \Phi(-d_{1,t}) \tag{3}$$

$$\begin{aligned} d_{1,t} &= \frac{\ln(S_0/(E+H_t)) + (r - y + \sigma^2/2)t}{\sigma\sqrt{t}} \\ d_{2,t} &= d_{1,t} - \sigma\sqrt{t} \end{aligned} \tag{4}$$

with r the risk-free rate of interest, σ the volatility of the costs of the biomass, and $\Phi(x)$ the cumulative normal density of x.

Since biomass-electricity's costs and benefits to the public only arise if the plant is operated, they are a function of the value-maximizing behavior of the investors of a biomass power plant. Then, these positions are best understood as underwriting positions of a real option and can be similarly derived by options analysis.

Here, we analyze the financial position of the public, which has to pay the differential costs which arise since electricity generated through the combustion of biomass costlier than electricity generated from conventional sources. The public has to pay the feed-in tariffs E paid to the owners of the biomass power plant; on the other hand, it saves the costs C_t of conventional electricity generation that would have resulted if the electricity was generated in a conventional power plant. The public's payoff structure is

$$PO_t^{Public} = \begin{cases} -E + C_t, & \text{if } E + H - S_t > 0 \\ 0 & \text{else.} \end{cases} \tag{5}$$

Having an all-or-nothing feature, this is the payoff structure of an underwriter of a European binary (also called digital) put option. The red line in graph **??** depicts this structure. In the Black-Scholes case, the value of the plant can thus be calculated as

$$V_0^{Public} = \sum_{t=1}^{T}(-E + C_t)\exp^{-rt}(1 - \Phi(d_{2,t})) \tag{6}$$

$$\tag{7}$$

with $d_{1,t}$ and $d_{2,t}$ as given in as in 3 above. The valuations thus use the same risk-neutral probabilities, but different payoffs.

The present value of the deadweight costs to society arising through the feed-in tariffs is then $V^{Deadw.} = V_0^{Public} + V_0^{Investor}$, which is in general negative. While the V_0^{Public} is essentially lost, $V_0^{Investor}$ is only a redistribution from the public to investors and can in principle be regained by auctioning the right to receive feed-in tariffs.

A similar reasoning holds true for the benefits of renewable power generation through biomass, like the reduction of CO2 emissions or political benefits from increased energy autarky. Since pricing CO2 emissions is notoriously difficult (see e.g. Pindyck (2000)), we sidestep this issue by normalizing the environmental benefits of an operating plant's reduced CO2 emissions in a given year to unity. The normalized environmental benefit of a plant is

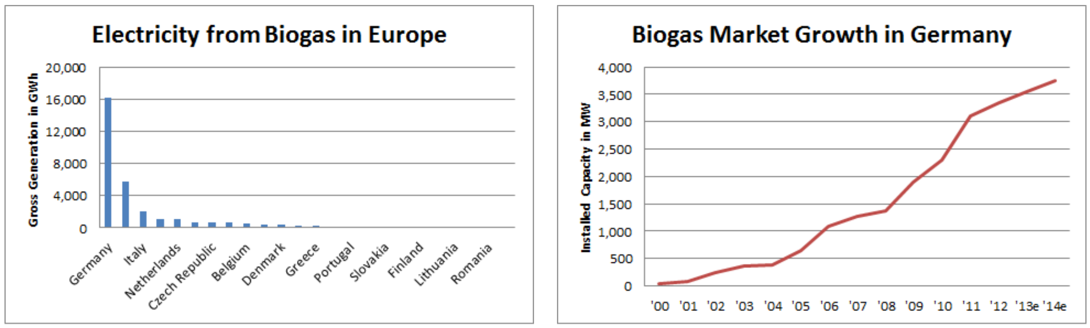
$$P_t^{Environm.} = \begin{cases} 1, & \text{if } E + H - S_t > 0 \\ 0 & \text{else.} \end{cases} \tag{8}$$

for which a similar formula as 6 can be written.

3 Application: The European Biogas Industry

While the industry for liquid biofuels was only short-lived, the biogas industry has become an important part of the German renewable energy industry. Currently it has 52,900 employees, see EurObservER (2013). In a biogas plant, biomass is fermented by anaerobic digestion of bacteria and the resulting methane is collected, purified and used as fuel in a combustion engine for the production of electricity and possibly waste heat. See Seadi et al. (2008) for an overview of biomass production and figure 9. Within Europe, Germany is by far the main producer of biogas, as can be seen in figure 5(a). The German market developed rapidly after 2004 and 2009 with favorable revisions of the German renewable energy act, see figure 5(b). While the market appears to reach saturation in Germany, other European and Asian countries are expected to experience high future growth rates, see EurObservER (2013). They expect the globally installed capacity to grow from 4700GW to 7400GW between 2012 to 2016. Table 5 in the appendix shows feed-in tariffs per kWh and years of guaranteed feed-in tariffs applying to biogas plants with a capacity of 500kW in European legislations as of 2013.

Figure 4: European Biogas Market and Growth in Germany



(a) (b)

Source: *Branchenzahlen - Prognose 2013/ 2014* (2013) and EurObservER (2013).

We model the value-maximizing decisions of the owners of a biogas plant which is supported by the German renewable energy act using real options analysis. We focus on the closely related options to permanently abandon a plant, shut-down and possibly later reactivate a plant, or to produce below technical capacity. Further, large-scale reinvestments can (possibly infinitely) be delayed when the plant is not operating. Trigeorgis (1998) gives a list of further common real options available to firm managers, which we do not model here, however. The option to invest has already been exercised and the option to grow business is not applicable, since it is generally not allowed by the EEG to increase the amount of installed capacity over the initial value. Further, we do not model the option to extend the project's lifetime, since feed-in tariffs are only granted for a pre-specified period.[4]

An option that could be of much higher importance for biogas is the one to switch between inputs (See e.g. Kulatilaka (1993)). Biogas can be generated from many forms of biomass, and even though the EEG restricts the use of several types of raw materials, a large variety[5] of field crops qualifies for receiving the feed-in tariffs. Corato & Moretto (2011) have already analyzed the option to switch between different types of inputs for a biogas plant, finding that it has great influence on firm value. However, their theoretical result is based on the assumption that there is always at least one input cheap enough to justify continuation of operation. We question this assumption on the basis of the observation of the German liquid biomass industry, where the availability

[4]While there might be the possibility that future agricultural prices warrant biomass power generation in return for market prices of electricity, current spot market prices of electricity are only about quarter of the feed-in tariff. So we consider this option too far out the money to be included in the model.

[5]E.g. maize, grain, beet, sorghum, miscanthus, and grass.

of several types of plant oils (rapeseed oil, palm oil, peanut oil, soybean oil) could not prevent the decline of the industry. The value of an option to switch between agricultural inputs is rather low, since their prices display a strong co-movement, as can be observed in graph 1. Therefore, we do not model the option to switch between different types of input, as it would overburden the model with an additional stochastic risk factor without much benefit.[6] Therefore, we stay agnostic to the type of biomass that is used as input in the plant. Instead we assume that the input price is set by an arbitrage relation between energy crops and marketable agricultural products, for which market prices are observable. Thus, we follow Riessen (2010) and use the price of wheat as reference index for the costs of agricultural inputs.

As production decisions are made at the plant level and optimal output levels are very nonlinear, analysis at the aggregate or average level is not advisable. Instead, we model a typical plant with a capacity of 500kW, which has been installed in the boom year of 2009. This capacity is close to the average of 472kW of newly installed plants in that year.[7] This allows comparison with the results of Riessen (2010), who analyzes the profitability of a German biogas plant of a similar size. While he uses Monte-Carlo methods to analyze the sensitivity of the results to certain parameters, he does not allow for value-maximizing decisions of plant managers and assumes that the prices of agricultural products are i.i.d. in a fixed range, which is incongruent with empirical observation. Indeed, already in 2011 were the observed agricultural prices above his assumed maximum level. The same holds true for the option to extend the life of a facility (See e.g. Pindyck (1988)), since feed-in tariffs are only valid for an ex ante fixed period.

3.1 A Typical plant

In this subsection we describe the technical parameters of the biogas power plant's operation, the calculation of the feed-in tariffs, and the market parameters necessary for valuation of the plant, including a stochastic analysis of wheat prices.

The plant is modelled to have started feeding-in to the power grid on January 1st 2013, receiving feed-in tariffs according to the German renewable energy act in its 2012 revision with an investment outlay of 1,760,000 €. For the technical

[6] As robustness test against the results of Corato & Moretto (2011) on the importance of the possibility to exchange one input for another, we obtained estimates of volatilities and correlations of closest-maturity futures on wheat, corn, and rye and calculated valuations of the biogas plant in three settings: A) A pure Black-Scholes version, in which the biogas plant consists of 20 European put options on the input, which is the cheapest at $t = 0$. B) A Stulz (1982) version, in which the plant consists of a European puts on the cheapest input at maturity date. C) A Margrabe (1978) version, in which the plant value consists of zero-bonds, one maturing each year minus 20 forwards on one input, plus 20 Margrabe (1978) options to exchange it for the cheaper one. We found that the difference between A) and B) was comparably low, but both were far from C). We conclude that the option to switch between agricultural inputs is negligible in the present case.

[7] Another reason, why a size of 500kW can be considered as typical is that in the EEG and several other legislations (Austria, Czech Republic, Great Britain, Luxembourg, and Slovakia.) capacity beyond 500kW receives distinctly lower feed-in tariffs per fed-in kWh.

Annual Costs at full operation	in €
Feed-in $< 150kW$	188,000
Feed-in $> 150kW$	326,000
Bonus Tariff	238,000
Sum Feed-in	752,000
After Degression	745,000
Sale Waste Heat	30,000
Maintenance	68,000
Working Materials	100,000
Labor	14,000
Investment	1,760,000
Replacements	1,100,000
Shut-Down	50,000
Reactivation	50,000
Upkeep when Inactive	10,000
Demolition Costs	176,000

specification of the plant we follow KTBL (n.d.), a provider of market data to the German agricultural industry, which calculates internal rates of return for biogas power plants. The revenues and costs of a biogas plant are given in table 3.1.

The EEG is designed such that smaller power plants receive a higher feed-in tariff per kWh than larger ones. Every kWh fed-in in a given year below a cut-off point representing full annual feed-in of a 150 kW plant receives $.143\,e/kWh$, while every kWh above that threshhold receives only $.123\,e/kWh$. Tariffs above an equivalent of 500kW are reduced even further. A 500kW plant, which is operated for 8000 hours in a year, the rest due for maintenance, is then equivalent to $500kW \times (8000/8760) = 454kW$ power plant, which receives the higher tariff for the first 150kW equivalent and the lower tariff for the remaining 304 equivalent of 304kW. The plant receives thus $150kW \times 8760h \times 0.143\,e/kWh = 188,000\,e$ for power fed-in below an equivalent of 150kW and $304kW \times 8760h \times 0.123\,e/kWh = 326,000\,e$ above this level. Also, it receives a bonus for the use of slurry and energy crops. The cut-off point is above 500kW and does not apply here so the revenue is $454kW \times 8760h \times 0.06\,e/kWh = 238,000\,e$. Other revenues that the biogas plant receives are from the sale of the waste heat. Following KTBL (n.d.), we assume that a moderate share ($\approx 1/3$, 1,500,000 thermal kWh of the waste heat can be sold at market prices of currently $.02\,e$, yielding a revenue of $30,000\,e$.

In comparison, the plant incurs costs of 67,800 € for maintenance including repairs, 99,800 € for working materials and working capital, 14,000 € for labor of plant operators. Given the amortization allowances in KTBL (n.d.), replacements amount to 1,100,000 € over the full 20 years of guaranteed feed-in. Next to these costs which arise when the plant is operated constantly, there are costs which occur when the plant is not operated for the full 20 years of guaranteed feed-in. These are costs for shut-down, keeping the plant inactivated but operable, and reactivation which we assess with 50,000 €, 10,000 €, and 50,000 €, respectively.[8]

Most importantly, the biogas plant has to secure the input for the fermentation process. In the biogas plant 2000 and 3050 metric tons of silage of the whole plants of cereals and maize, respectively, are used annually, the amount of biomass grown on approximately 110ha. The current market price for this amount of biomass is assessed by KTBL (n.d.) at 360,000 €. Further, 2400 metric tons of slurry are sourced at zero cost from local cattle feeders. Despite the fact that generally higher shares of slurry are possible, their low yield of biogas compared to high transport costs prohibits profitable use.

Contrary to globally traded agricultural products such as the grains of cereals, where the price is determined on agricultural exchanges, there is no central market for energy crops used in biogas plants. This lies in the fact that energy crops contain a high amount of water which makes transport costs over long distances prohibitively high. On the other side, traded agricultural products can be used for digestion in biogas plants, but yield a relatively low amount of gas compared to their price. In effect, energy crops for use in biogas plants are sourced from local agricultural producers without reliably observable prices. We therefore assume that the prices for the energy crops are set by an arbitrage relation between cultivation of energy crops and marketable products.

3.2 Real Options Stakeholder Analysis

In standard real options analysis (See e.g. Dixit & Pindyck (1994) and Trigeorgis (1998)), valuations are built on the spot prices following geometric Brownian motion. However, commodities in general do not follow such a process, as Gibson & Schwartz (1990) find. Instead, spot prices can be represented as the sum of a long-term equilibrium price process and a short-term deviation. We therefore follow Sorensen (2002) and estimate the parameters for the price process of wheat by a Kalman-filter including seasonalities, using monthly data of the 5 wheat futures closest to maturity traded on the MATIF Paris from November 2005 to December 2012.

Given that a biogas plant is a long-term investment of up to 20 years, we use the short-term/long-term model of Schwartz & Smith (2000) who find that while short term deviations need to be accounted for in estimating the stochastic properties of commodity price processes, they are irrelevant to valuing long-term investment projects.

This is especially warranted given that the presence of costs for shutting down and reactivation, and the possibility to delay lumpy replacements do not allow for a closed form solution. We therefore use the risk-neutral valuation method of Cox et al. (1979) to give a stakeholder analysis of the biogas plant, i.e. the positions of investors, the public, and environmental benefits that arise

[8]For initial heating of the fermenters, Riessen (2010) assesses costs 20,000 €. Also, the fermentation process needs to be started gradually. In an optimal reactivation plan for a 500kW plant according to Schmitz (2006), approximately 7% of a given year's output in gas is lost.

with construction of the biogas power plant modelled above. The uncertainty in the long-term development of agricultural prices is captured by a recombining binomial lattice. Due to the highly nonlinear payoff structure of digital options, each year was divided into 100 subperiods. However, given that the crop cycle in the German and European agricultural industry is one year, the option to shut-down or reactivate the plant can only be exercised at every 10th branching, so the option is of European nature.

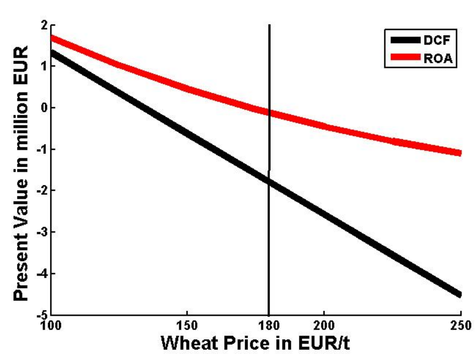
We analyze the net present value of an existing biogas plant for its owners, calculate the present value of the liabilities it creates for the public and give an estimate of the (market-rate) discounted environmental benefits a biogas plant is expected to deliver (in terms of CO2-reduced power generation). As feed-in tariffs in the German renewable energy act are not inflation indexed, it is necessary to adjust for inflation. In the calculations, we use an inflation rate of 2%, the target rate of the European Central Bank and a real interest rate of 1.8%. To assess the costs to the public, we set the cost at which electricity could be produced by conventional power generation to 0.05 €/kWh. In order to assess the sensitivity of the results to our parameter assumptions, figures 6(a) to 6(c) give the valuations across ranges of parameter values. The figures contain as reference scenario a DCF-based valuation. As the figures show, biogas plants are hardly profitable without the option to shut down in times of high agricultural prices. Also, costs to the public and the environmental benefits of CO2-reduced power generation are much lower when the real options of operators are acknowledged.

Interestingly, the benefits are reduce reduced more than the costs. For costs to the public, the ratio of ROA valuation to DCF valuation is 62.34%, while for the benefits of CO2 reduced generation the ratio is 52.60%. In a simple cost/benefit analysis, the negligence of the shut down option leads to a bias in favor of biogas of about 19%. This effect is due to inflation and does not apply to other renewable power sources where marginal generation costs are negligible. While e.g. existing photovoltaic plants are subsidized by high tariffs in Germany, they will still feed in electricity when inflation has narrowed the difference between feed-in tariffs and costs of conventional power generation. For biogas, however, this gap is unlikely to be closed, because with rising prices, biogas plant owners will stop receiving feed-in tariffs exactly when these are cheapest for electricity consumers.

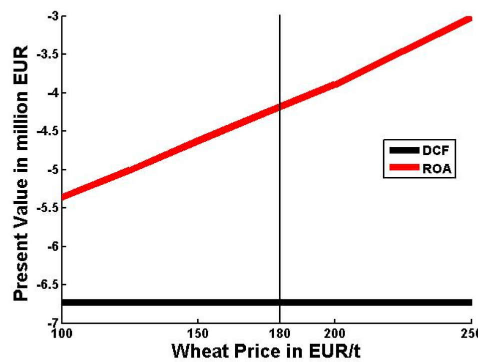
4 Stability of Supply from Biogas

Despite the idiosyncracies that apply to different biogas plants, they are all exposed to the risk in agricultural prices, which is determined on world markets. A systematic shut-down of biogas plants in the face of high agricultural prices may have a disruptive effect on the stability of electricity supply in regions where these plants are over-represented. For example, a high share of German biogas plants is located in the state of Bavaria, which is also affected by the fact that three of its nuclear power plants are about to be phased out in the wake

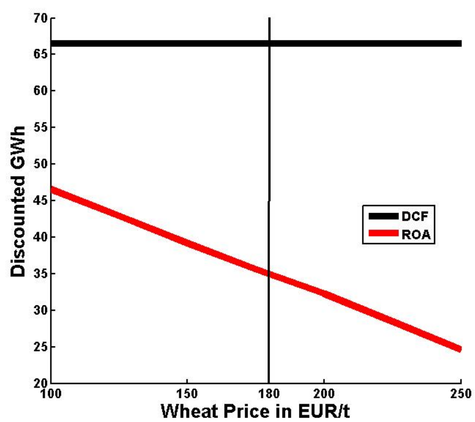
Figure 5: Valuation w.r.t. Input Prices



(a) Value to Investors



(b) Costs to Public

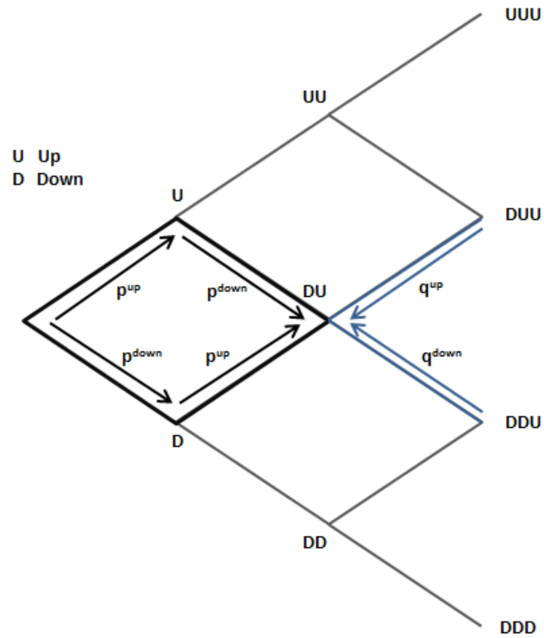


(c) Environmental Benefits

of the *Energiewende*. Further, with feed-in of biogas uncertain, the European Commission's goal of reaching a share of 20% in renewable power generation by 2020 may be jeopardized.

To analyze the probability that biogas plants will shut down and not contribute to power generation, we use a Monte Carlo analysis to assess the likelihood that the given biogas plant generates power in a state contingent on time and price. To do so, we analyze the binomial tree forwards and backwards. We simulate a trajectory in the binomial tree forwards to a specific point of interest using physical probabilities p. Upon reaching this point, we determine the value-maximizing action of the plant owner using risk-neutral probabilities q and backward induction. Graph 6 illustrates this for the probability of a plant owner producing in a hypothetical state UD.

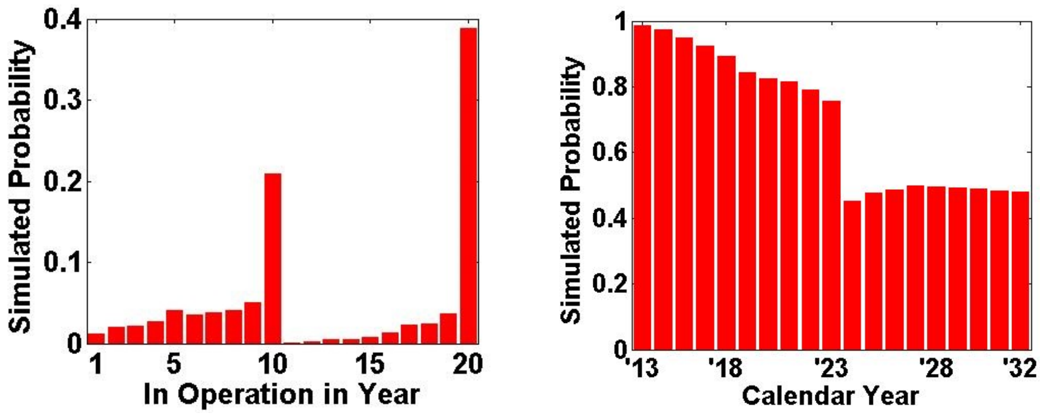
Figure 6: Forwards- and Backwards-Solution in a Monte Carlo Simulation



Using the same parameters as above, we simulate 10,000 random trajectories through the binomial tree and observe in each trajectory, wether the plant is active or not. Then, we compute empirical distributions over the cumulative number of years that the plant feeds in electricity and over the simulated probability that the plant is operated in a given calendar year. For the simulation of the price path, we assume that the expected price of agricultural products rises by the rate of inflation.

As figure 8(a) shows, the simulated probability, that the plant is operated for the full 20 years is very low. Also, even for the relatively recently installed plant 8(b) shows that the probabilities that it is operated in 2020 or 2030 are

Figure 7: Simulated Probabilities



(a) Cumulative Years in Operation (b) Probability of Operation vs. Calendar Year

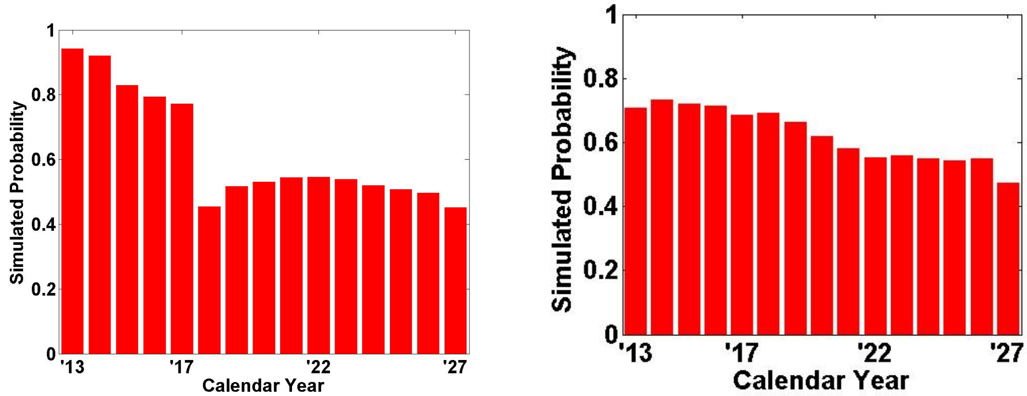
only 80% or 50%, respectively. For the plant going into business in 2013, the lumpy replacement outlays leading to the drop in the simulated probability of operation are beyond 2020. For already existing plants, the probability of going out of business before 2020 is even higher, especially when lumpy replacements have to be incurred before that date. This can be seen in figure 9(a), where we modelled a plant that started operation in 2008 and which receives feed-in tariffs according the the German renewable energy act of 2004. We reduced the amount of replacements due in 2018 to 600,000 € to account for the fact that not all replacements occur at a fixed instant. In 9(b) replacements are spread uniformly over all periods. Nevertheless, the probabilities of feed-in are comparably low across the entire remaining guaranteed period of feed-in.

Given the results above we consider it highly uncertain whether biogas can contribute to Germany's energy supply and the European Commission's goal on renewable power generation in 2020 and 2030. The implications are dramatic when one considers that all biogas plants are largely dependent on the same source of uncertainty. When in the face of high agricultural prices biogas experiences similar developments like power plants using liquid biomass, biogas may have to be replaced by very CO2-inefficient power sources.

5 Conclusion

In this article, we analyzed biomass and biogas within a risk-neutral setting from three different views of stakeholders. Using simulations, we further estimated physical probabilities for the likely future of the biogas industry. The impact of volatile world markets for agricultural products can have large effects on electricity generation from biomass. Not only is the profitability of existing

Figure 8: Simulated Probabilities of Operation for Feeding in since 2008



(a) Lumpy Investment of 600,000 € (b) Amortization of Replacements

plants in danger, also other stakeholders of the industry are affected. Policy makers thus need to acknowledge the special volatile role of biomass which sets it apart from other sources of renewable energy. Contrary to other renewable energies, there is no such thing as an intertemporal cross-subsidization. Under value-maximizing behavior of plant owners, excessively high tariffs for feed-in of electricity in early periods are not honoured in later periods when volatile input prices or general price inflation will have eroded profitability. Our analysis suggests that relatively easy instruments like indexing to general or agricultural price indices can reduce the burden of bio-gas on the public and on electricity supply. Future research should find ways to optimize the benefits of biomass as energy source, while reducing disadvantages,

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Table 1: Feed-in Tariffs in Europe

Country	$Ct.e/KWh$	Feed-in Period (years)
Austria	19.6	15
Bulgaria	23.2	15
Croatia	15.8	14
Czech Republic	13.7	20
Germany	18.7	20
Greece	22.2	20
Ireland	15.6	15
Lithuania	15.6	12
Luxembourg	13.0	15
Slovakia	13.4	15
Slovenia	14.1	15
Estland	14.5	15
United Kingdom	16.8	20

Figure 9: Biogas plant