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Financial analysis of a biochemical cellulosic ethanol plant and the impact of potential regulatory measures

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Abstract

The financial model presented in this paper analyses which regulations work best in order to incentivise investments into Biochemical Cellulosic Ethanol Plants (BCEP). The production technology utilised in these plants is currently in the decisive development stage called "valley of death". Rather than looking at the whole economy, the financial model is concerned with the "micro level" of an investment in one particular BCEP under variable combinations of assumptions and prevailing economic conditions. To this end, it combines policy and techno-economic analyses by modelling future cash flows under varying input assumptions. Transportation and feedstock costs, as well as bioethanol prices are assumed to be correlated and to follow a random walk. Their impact on the outcome of the financial model is analysed by applying Monte Carlo simulation. The effect of certain regulations is evaluated by economic indicators such as net present value, internal rate of return, payback period, and the relative cost of subsidy. The results show that an "ideally fixed" price policy – a combination of a fixed price component and the variable price development of the relevant input factors – works best in relation to expected returns and cost of subsidy. This implies an important lesson for policy makers, who should favour flexible price mechanisms over simple fixed price regulations.

JEL Codes: E27, G11, G38, Q16

Keywords: Second-generation biofuel, cellulosic ethanol, regulation, policy, investment, technology valley of death, Monte Carlo simulation, financial modelling, techno-economic modelling

Contents

1. Introduction

In 2015, cellulosic ethanol technology seems to come of age as various companies have entered commercial production phase in the previous year. For instance, Beta Renewables opened the world's first cellulosic ethanol plant at commercial scale in Northern Italy[1]. DuPont is currently commissioning its commercial scale cellulosic biorefinery in Iowa[2]. At the same time, various new projects have been announced, for instance in Macedonia[3], using Beta Renewables' technology, or in the Slovak Republic[4], based on DuPont's technology. Contrary to this development, demand for biofuels has been declining in Europe since 2011, caused by adjusted mandates, double counting mandates, and lower fuel use (Flach et al., 2014). Flach et al. (2014) also find that the introduction of advanced biofuels is less far advanced in the EU than in the USA. They mention the uncertainty in future EU policy making as the main reason for lacking investments and commercialisation of advanced biofuel projects.

With available new technology on the one side, but lacking investors on the other side, the advanced biofuel sector seems to be in between two phases of market development: the demonstration and the commercial market phase. Following a theory developed by Grubb (2004), this stage is called the technology "valley of death" (TVoD), graphically depicted in Figure 1. In this stage, R&D has been successfully conducted and demonstration facilities have been built, often financed with public money. The critical task is then to make the transition to the commercial stage. For this transition, private investors are required, because public investors regard their work to be completed with the financing of the R&D phase. Actually, however, Grubb (2004) notices that private investors are often reluctant to invest in new and unproven technologies. This is the reason for the phenomenon of technologies not crossing the TVoD and instead transitioning into a niche market position.

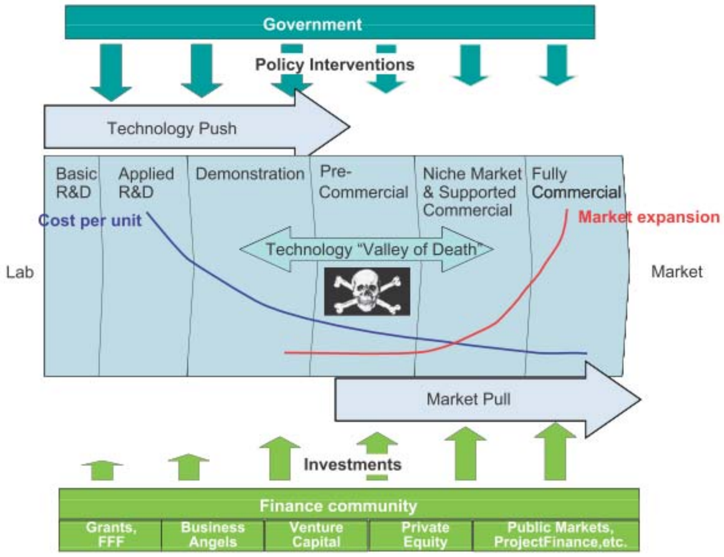

Figure 1 The innovation chain and the technology "valley of death" (from Bürer and Wüstenhagen, 2009, following Grubb, 2004)

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[1] http://www.betarenewables.com/press-release-detail/2/crescentinos-biorefinery-grand-opening

[2] http://ethanolproducer.com/articles/11153/poet-dsm-dupont-abengoa-begin-commissioning-cellulosic-plants

[3] http://www.biofuelsdigest.com/bdigest/2014/10/16/dupont-ethanol-europe-renewables-ink-pact-for-cellulosic-ethanol-in-macedonia/

[4] http://www.biofuelsdigest.com/bdigest/2014/10/06/beta-renewables-biochemtex-ink-deal-for-commercial-scale-cellulosic-biofuels-project-in-slovakia/

Policy makers now face the task of providing a reliable base for private investment into the advanced biofuel industry. As the first country in Europe, Italy introduced a binding target which requires fuel suppliers to include 1.2 percent of advanced biofuels into their fuel products by 2018, rising to a minimum of two percent required in 2022.[5] Apart from this mandate in Italy, policy schemes in the European Union run until 2020 only. This relatively short period of time might be insufficient to incentivise investment into the sector. Currently, industry stakeholders are lobbying for a longer duration of regulation.[6] Despite this ongoing lobbyism activity, the European Union approved a law in April 2015, which limits the use of harmful biofuels – most of first-generation biofuels – to seven percent – and sets an indicative, i.e. non-binding, target of 0.5 percent for second-generation biofuels. These second-generation biofuels count double towards the ten percent renewable energy target until 2020.[7] Also in the USA, regulation currently seems to be at a crossroads. At the end of 2014, the Environmental Protection Agency (EPA) postponed its decision on final biofuel targets for the same year into 2015. The final decision published in May 2015 sets modest goals for cellulosic biofuel: 0.033bn gallons in 2014, 0.106bn gallons in 2015, and 0.206bn gallons in 2016. For comparison, the statutory volume for 2015 was originally set at three billion gallons. A clear sign that the current development falls short of previous expectations.[8] The initial postponement as well as the EPA's proposition to limit renewable fuels at ten percent of gasoline consumption seems to worry the industry and delay investment decisions.[9] Yet, the talk is of research conducted in the USA but finally commercialised elsewhere.[10] A business expert comments on the decision as follows: *The practical goal for the EPA is not to use the RFS2 renewable fuels schedules as a driver to produce investment in capacity-building or infrastructure for distribution. Rather, the EPA opts for a more passive role of providing a market for those capacities that are built based on incremental, if any, changes in infrastructure.*[11]

Regulatory measures are decisive to trigger more investment into the cellulosic ethanol industry. Yet, it remains unclear if any regulatory incentives will be set after expiration of the current regulations in the EU and USA. The financial model (further referred to as the "Model") presented in this paper analyses which regulations work best in order to incentivise more investment into a specific advanced biofuel technology, namely into biochemical cellulosic ethanol plants (BCEP). The production steps in such BCEP are similar to the definition provided by Sanders et al. (2012, p.120): *Lignocellulosic biomass is treated with among others acid or alkaline agents to release cellulose, hemicellulose and lignin, the former being further converted with enzymatic hydrolysis into mainly glucose mannose (C6) and xylose (C5). These C6 and sometimes C5 sugars are further used to produce biofuels (ethanol, butanol, hydrogen) and/or added-value chemicals, lignin being applied for combined heat and power production to be used internally or sold.* The analysis in this paper is focused on two final products only: bioethanol and electricity. Rather than looking at the macro-level of the economy, the Model is concerned with the "micro-level" of an investment in one particular BCEP under different sets of assumptions and conditions. To this end, it combines policy and techno-economic analyses by modelling future cash flows and varying different input assumptions. Transportation costs, ethanol and feedstock prices are assumed to be correlated and follow a random walk. Their im-

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[5] http://www.bloomberg.com/news/2014-10-30/italy-to-require-advanced-biofuels-in-gasoline-and-diesel.html

[6] http://biomassmagazine.com/articles/11294/upm-advocates-for-eu-advanced-biofuel-policy

[7] http://www.euractiv.com/sections/transport/parliament-rubber-stamps-eu-biofuels-reform-amid-final-controversy-314196

[8] http://www.biofuelsdigest.com/bdigest/2015/05/29/epa-slashes-biofuels-targets-for-2014-2015-2016-under-renewable-fuel-standard/

[9] http://www.biofuelsdigest.com/bdigest/2014/11/23/the-2014-rfs-rule-left-out-in-the-cold/

[10] http://www.biofuelsdigest.com/bdigest/2014/12/01/time-for-teddy-talk/

[11] http://www.biofuelsdigest.com/bdigest/2015/05/29/epa-slashes-biofuels-targets-for-2014-2015-2016-under-renewable-fuel-standard/

pact on the outcome of the Model is analysed by Monte Carlo simulation. The effect of certain regulations is analysed by economic indicators like net present value, internal rate of return, the payback period as well as the cost of potential regulatory measures. Due to better availability of data, the Model is based on US historical prices and determined in US dollars.

The remainder of this paper is structured as follows: Chapter 2 reviews the related literature and discusses results and limitations of various methods of analysis. All assumptions of the Model are explained in chapter 3. Chapter 4 presents the results of the Model and discusses how an "ideal" price policy could actually be implemented.

2. Literature Review

Several research papers apply modelling analyses similar to the model analysis discussed in this paper. The Model, however, is different in that it combines techniques from different research paths.

2.1. Techno-economic models

A vast number of research papers uses techno-economic modelling. The results and techniques used in these papers entails important lessons for the model analysis described in this paper. However, none of the papers discussed in the following combine techno-economic analysis with Monte Carlo simulation of feedstock and bioethanol prices in order to examine the effects of certain kinds of regulation measures.

Gnansounou and Dauriat (2010) summarise papers concerned with the techno-economic analyses of lignocellulosic ethanol production. The key parameters for the profitability of lignocellulosic ethanol are identified as the type and price of the feedstock, the plant size, the conversion rate, and investment costs. They also set up an own analysis based on a spread sheet calculation. In their sensitivity analysis they find that production costs are inversely affected by the scale of the plant, largely caused by decreasing relative investment costs. However, transportation costs have the opposite effect, increasing with scale of production due to an increasing collection radius. In relation to the market price of ethanol they predict that with a growing market share of ethanol its price will correlate more closely with the price of petroleum.

Humbird et al. (2011) from the National Renewable Energy Laboratory (NREL) describe in detail the economics of biochemical ethanol production from lignocellulosic biomass by applying a discounted cash flow analysis. For this purpose, they firstly identify the operating and investment cost of a bioethanol plant. Secondly, they discount future cash flows in order to analyse the plant's profitability. However, no regulatory factors are included because they consider the purpose of their analysis to demonstrate the economic viability of the sector without any policy measures. The assumptions in the Model are based to a large extent on the figures published in this paper.

Gonzalez et al. (2012a) calculate the net present value, internal rate of return and payback period for cellulosic ethanol production with different feedstock and conversion paths. They also conduct several sensitivity analyses by varying the alcohol selling price, the alcohol yield, required capital expenditure, and feedstock cost. They find the thermo-chemical conversion to be more effective due to its ability to use several feedstock for oil production, which allows to switch to the lowest-priced feedstock when necessary.

Wang et al. (2013) evaluate the economic viability of bioethanol produced from various waste papers. They apply a model developed by the National Renewable Energy Laboratory (NREL) and run several sensitivity analyses for the production process. Based on a discounted cash flow model with an assumed 20 year plant life and a ten percent discount rate they calculate the minimum selling price for the produced bioethanol. They find most of the waste papers to be economically superior to petrol derived from fossil fuel. In their sensitivity analysis, total capital costs, electricity prices and the cost of biomass have the biggest impact on these results (Wang et al., 2013, p.1179).

Littlewood et al. (2013) assess the economic feasibility of bioethanol production from wheat straw with various pre-treatment methods in the UK. They evaluate different scenarios based on the resulting minimum ethanol selling price. For their analysis, they use AspenPlus™ software and the NREL corn stover-to-bioethanol process. The most important cost drivers for the price of ethanol are identified as the prices of the feedstocks and the enzymes used in the production process. None of the analysed ways of production yields bioethanol at a competitive price to the petrol pump price. However, they state that a tax exemption for bioethanol would improve the price competiveness of bioethanol and allow to set its price below the price of petrol. Littlewood et al. (2013) take this as an indication for policy makers to exempt bioethanol from taxes in order to raise the incentives for bioethanol production. They also show that straw at a cost of less than 35 GBP/ton makes cellulosic bioethanol production from this feedstock competitive to petrol.

Sanchez et al. (2013) analyse total costs and energy efficiency of enzymatic ethanol production from wheat straw. They vary the polysaccharides content – by choosing different feedstocks – and the plant capacity in order to understand the implications on the profitability of a biorefinery. Their rationale is that in times of limited feedstock availability lower feedstock quality with less polysaccharides content will be used. Their results confirm previous publications which stress the importance of feedstock and enzyme prices for the profitability of cellulosic ethanol production.

Treasure et al. (2014) compare the profitability of cellulosic ethanol production from natural hardwood, Eucalyptus, loblolly pine, corn stover, switchgrass, and sweet sorghum. They calculate the price required in order to achieve an internal rate of return of 12 percent. For the technical forecasting they use a process simulation software used by the pulp and paper industry and export the results into an Excel spread sheet for the financial forecast. They use Monte Carlo simulations to analyse the risk associated with variations in cost and revenue drivers as well as biomass composition variability. They find that the minimum ethanol revenue is most sensitive to variations in ethanol yield, biomass cost, capital investment, and enzyme production cost. The profitability of a project is also very sensitive to changes in the compositional variability of the feedstock, e.g. the proportion of lignin to hemicellulose.

Qureshi et al. (2013) analyse the economics of a conversion of straw to butanol and find a production price of 1.23 USD/kg of butanol with wheat straw as feedstock with a price of 18 USD/ton. This assumption for the feedstock price seems very inexpensive in comparison to the assumptions in other papers.

		Capacity:		
Average…	Unit:	Small	Medium	Large
yield values	litre EtOH/kg feedstock	0.26 ± 0.04	0.30 ± 0.04	0.30 ± 0.03
feedstock production costs	USD/litre EtOH	0.26 ± 0.03	0.23 ± 0.02	0.23 ± 0.08
enzyme production costs	USD/litre EtOH	0.13 ± 0.02	0.10 ± 0.05	0.12 ± 0.08
total production costs	**USD/litre EtOH**	**0.94 ± 0.11**	**0.78 ± 0.12**	**0.69 ± 0.12**

Table 1 Average costs as found by Sanchez and Gomez (2014)

Sanchez and Gomez (2014) compare production costs of cellulosic ethanol produced with biochemical platforms published in 15 papers between 1995 and 2013. The comparison is based on the ethanol yields, feedstock prices, and the per litre cost contributions of feedstock and enzymes. Outdated data is updated to 2013 price levels with the annual US Producer Price Index for all commodities. Their results are summarised in Table 1. By applying least-squares regressions to the normalised (by means of inflation and average raw material costs) large-capacity total production costs from January 2001 to May 2013 they find that a linear model best fits the data. Following this linear model, the total production costs are scheduled to increase to 1.15 USD/litre of ethanol in 2020 and 1.48 USD/litre of ethanol in 2029. This estimated increase is mainly caused by rising feedstock prices in the last years of the forecast period.

Chovau et al. (2013) use results from various studies to calculate an average production cost for cellulosic ethanol of USD 651/m^3. Based on their own analysis, they estimate that in the near future the minimum ethanol selling price can reach USD 511/m^3. They find varying conversion yields in a range from 197 up to 385 litres of ethanol per ton of feedstock in the literature. For working capital required in a cellulosic ethanol plant, the literature uses different estimators, ranging from ten to 35 percent of yearly operating cost and from ten to 20 percent of the total capital investment. They also find estimates that put the contribution of the feedstock price to the production costs in the range from 30 to 40 percent. They cite Perlack et al. (2005), who predict that the percentage of the grower payment will rise from 32 percent in 2008 to 47 percent in 2017 and that the price of one ton of corn stover will rise to USD 72.2/ton in 2017. This price includes grower payment, harvesting and collection, storage, handling and transportation as well as receiving and pre-processing. Chovau et al. (2013) find that most techno-economic studies assume cellulase enzymes being bought from external sources instead of being produced onsite. The study cites information from Novozymes (2010)[12], an enzyme developer, who claims it can supply enzymes at a cost of about USD 132/m^3 of ethanol. They also mention that in the last years Novozymes has continuously achieved substantial cost reductions. For their own analysis, they use a tax rate of 39 percent, an operational plant life of 20 years, three years of construction and a start-up period which is 25 percent of the respective construction period, but six months at most.

In summary, the comparison of various papers applying techno-economic modelling shows that the range of possible production costs is very wide. This is caused by substantial differences in assumptions about yield rates as well as costs for feedstocks and production processes. The Model uses several of the input assumptions described above. By applying Monte Carlo simulation, the Model also obtains a wide range for feedstock prices and accordingly for possible minimum ethanol selling prices.

2.2. Transportation and location optimisation models

The Model simplifies the supply side by assuming a circular sourcing area. It does not take into consideration whether optimal plant locations with such conditions actually exist. For comparison, this section exemplarily presents three papers which are concerned with the optimisation of the transport supply and plant locations, often applying mixed-integer linear programming.

Akgul et al. (2012) present an optimisation framework for designing a hybrid first and second-generation bioethanol supply chain and apply their findings to a case study in the UK. Their steady-state mixed integer linear programming model aims at optimising the cultivation rate, the location and scale, the flows of biomass type, and the type of transportation in order to minimise the total cost of the supply chain. They find that wheat straw can be a good addition to the biomass supply in order to reduce overall supply chain cost. The use of wheat straw is to a large extent determined by the opportunity cost of straw, which is in turn determined by the demand for wheat straw from other sectors like animal bedding or power generation.

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[12] http://www.cleantechinvestor.com/portal/bioenergy/5164-enzymes.html

Walther, Schatka and Spengler (2012) analyse the planning problem of the optimal location for synthetic biodiesel production facilities and look at potentially interested investors for this kind of second-generation biofuels. For their analysis, they develop a problem specific model for facility location planning: a multi-period, multi-stage facility location model, which is also extended into a scenario based planning approach. They apply their model to a region in northern Germany. Biomass production, demand for biodiesel and other input factors are estimated by measures like linear extrapolation based on current statistics. The possible model solutions show a focus on the centralised plant concept equipped with the Fischer-Tropsch-Synthesis technology. Based on their findings, they provide certain policy recommendations: A market for synthetic biofuels has to be created in order for plants to be built. Centralised plant concepts are more advantageous in regions with a high biomass potential. Also, transportation costs for biomass and final products – in this case biodiesel – are a very important factor for location planning.

Focusing on the Midwestern region of the USA and a biochemical conversion path for five types of agricultural residues, Marvin et al. (2012) optimise the net present value of the biomass-to-ethanol supply chain. For the optimisation process they use mixed-integer linear programming. They optimise the location and capacity of the biorefineries as well as the harvest of residues and their distribution. Using publicly available data, they model several steps of the value chain in detail, e.g. costs of trucks delivering the residues to the refineries as well as the costs of distributing the bioethanol to fuel stations. For the biochemical conversion process they assume different costs for proven and first-of-kind or pioneer-plant technology. The project lifetime is set to 20 years. They identify 65 optimally located biorefineries within the region. The accumulated production capacity of these refineries is 4.7 billion gallons of ethanol per year, and the internal rate of return is 12.1 percent per year. They conduct a sensitivity analysis by changing single parameters, like ethanol prices, or operating and investment costs, and applying Monte Carlo simulations. The minimum price of ethanol is calculated at 2.7 USD/gallon in order to achieve an internal rate of return of at least ten percent. They find a 21.5 percent chance that the industry does not develop at all and a 15 percent chance that it could become uneconomical once it actually has developed.

2.3. Literature concerned with prices of biofuel and feedstock

In the Model, prices of feedstock and bioethanol are modelled assuming they follow a Brownian motion under a certain set of assumptions relying on the historical development of these prices. Correlations, drift rates, and standard deviations of the prices for corn, gasoline and ethanol are assumed not to change over the course of operation. This, of course, is a simplification of the price behaviour, which indeed changes over time as discussed in several papers related with biofuel prices.

McPhail (2011) assesses the impact of ethanol in the USA on fossil fuel markets by developing a joint structural vector auto regression approach. He distinguishes between supply and demand shocks and hypothesises "that a policy-driven ethanol demand shock affects fossil fuel markets, while a shock to ethanol supply driven by feedstock price variation does not affect fossil fuel markets" (McPhail, 2011, p.1). Ethanol demand expansion is found to lead to a decline in crude oil and gasoline prices, whereas supply expansion has no statistically significant effect. This result illustrates how biofuel policies have implications for the whole economy, which underlines the importance of policies being well targeted.

Hassouneh et al. (2012) compare the price relationship of biodiesel, sunflower oil, and crude oil prices in Spain, where biodiesel is produced mainly from sunflower oil. They find a long-run equilibrium relationship between the three prices with only biodiesel deviating from this relationship and sunflower and crude oil prices driving the price of biodiesel. In regard to the food versus fuel debate they observe only a limited capability of biofuel prices to drive sunflower oil prices. Biofuel prices also adjust more quickly to increases than to decreases in sunflower and crude oil prices, thus putting biofuel consumers at disadvantage.

Anderson (2012) is concerned with the demand for ethanol as a gasoline substitute and to what extent households are willing to consume ethanol (E85 – which means a gasoline ethanol blend with 85 percent ethanol) instead of gasoline (E10 – which means a gasoline ethanol blend with 10 percent ethanol). He finds that demand for E85 is sensitive to relative fuel prices: "a $0.10-per-gallon increase in ethanol's price relative to gasoline leads to a 12-16% decrease in the quantity of ethanol demanded" (Anderson, 2012, p.166). This sensitivity, however, is less than would normally be expected. Anderson's explanation is that some consumers are willing to pay a premium for ethanol. Policy makers should take this into account as this willingness to pay premium prices has the potential to mitigate deadweight losses.

In a literature review on time-series of biofuel and agricultural prices, Serra and Zilberman (2013) address the criticism of partial and general equilibrium models: "*The academic literature has extensively relied on partial and general equilibrium models as a methodological approach to characterize the economic impacts of biofuels. These models have however been widely criticized for not being sufficiently validated against historical data and perform poorly. Further, since they are usually calibrated using annual data, they are unable to assess short-run price dynamics.*" (Serra and Zilberman, 2013, p.2). Instead, time-series models rely mostly on historical price data. Serra and Zilberman (2013) distinguish between papers allowing for price volatility links and papers focusing on price level interactions only. Most of the papers reviewed find that biofuel and/or crude oil prices have a long-run impact on agricultural prices. Also volatility is found to transfer existing instability in energy markets to food markets. The authors conclude that biofuel promoting policies may increase agricultural feedstock prices. Taking their criticism into consideration, the Model analysis discussed in this paper models future potential prices based on historical price behaviour.

Several studies are concerned with the feedstock for cellulosic ethanol and its availability. Kretschmer et al. (2012a) specifically look at the use and potential of straw for the production of cellulosic ethanol. Firstly, they stress the importance of other main uses of straw like animal bedding, soil improver, or mulch use in vegetable and mushroom production. Secondly, they find an already existing competition for straw with other sectors like biogas, biochemicals, or biomaterials. Also, it is unclear how much of the straw should remain on the soil as fertiliser, respectively organic matter. They lament that existing European regulation does not take this into account when calculating the lifecycles of advanced biofuels. On average, competitive cellulosic ethanol production facilities should run on 200,000 tons of straw per year and produce approximately 50 million litres of ethanol. These values are based on information gathered in expert interviews with representatives from Clariant, DONG Energy and Beta Renewables. Flexible arrangements with straw suppliers are also essential for the competitiveness of ethanol production. Currently, they find five key types of barriers which are negatively affecting the supply with straw (see Kretschmer et al., 2012a, p.6): "Underdeveloped markets and lack of information in EU (except Denmark)", "competing existing uses of straw", "lack of guidance on optimal use of straw as a soil improver and associated farming practices", "lack of infrastructure", and "variability of straw supply". In order to incentivise farmers to source their straw to biorefineries, they see a need for adequate pricing. They cite an unpublished report from the Deutsche Biomasse Forschungszentrum (DBFZ) and Oeko-Institut which sees a straw potential in the EU ranging from 50 to 110 million tons of straw per year. For information of the reader: with a specific conversion factor this translates into a potential ethanol production of 2.7 to 16.6 million tons of oil equivalent (toe) per year.[13] For comparison, the total consumption of transportation fuels in Germany in 2011 was approximately 52.7 million tons.[14] In order to attract more in-

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[13] For the lower bound the assumed conversion factor is 110l/ton and for the upper bound 300l/ton dry matter of straw.

[14] http://www.biomasse-nutzung.de/kraftstoffverbrauch-menge-diesel-biokraftstoffe/

vestment into the advanced biofuel industry, Kretschmer et al. (2012a) see a justification for more policy action: “Although some companies have invested in the establishment of biorefineries for advanced biofuels, it is likely that greater financial investment in this area would be seen if the policy signals promoted this form of bioenergy production” (p.45). According to them, possible policy options are the introduction of a subquota for advanced biofuels, tax incentives or enhanced production support. Importantly, most of the interviewed industry experts do not see a need for policy support on the supply side, but reckon that usual market mechanisms will eventually lead to the functioning of straw supply.

Glithero et al. (2013a) conducted a survey with farmers and found a potential of 2.5 million tons of cereal straw for bioenergy purposes in England. However, this potential is concentrated in mainly three regions, which limits the regional prospects for lignocellulosic bioethanol plants with a feasible production capacity to 478-549 million litres of bioethanol. Several forms of possible price mechanisms in long-term contracts are identified. For instance, the price can be linked to the price for nutrients like phosphor and potassium, or to the oil price. The market price of straw will be substantially impacted by large-scale demand for straw by biofuel plants. They find a need for policy intervention in order to establish a well-functioning market for straw. However, these policies should take into consideration sustainability issues like maintaining of soil quality or nutrient retention. These sustainability issues are the reason why the Model assumes comparatively conservative rates for usage of corn stover for cellulosic ethanol production.

3. The Setup of the Financial Model

The Model calculates the quarterly financial cash flows of a biochemical cellulosic ethanol plant (BCEP) under a certain set of assumptions and various regulatory measures. Different scenarios are evaluated in terms of payback period, Internal Rate of Return (IRR), Net Present Value (NPV) and the cost of the regulatory measure. The currency used in the Model is USD. The next sub-chapter provides a small summary of the biochemical cellulosic ethanol production process. In the following sub-chapter, all assumptions in the Model are explained. The last sub-chapter introduces the various regulatory measures analysed with the financial model.

3.1. General information on the biochemical production of cellulosic bioethanol

Humbird et al. (2011) structure the production process into nine areas: Feed handling, pre-treatment and conditioning with dilute sulfuric acid catalyst and finally ammonia, enzymatic hydrolysis and fermentation, cellu-

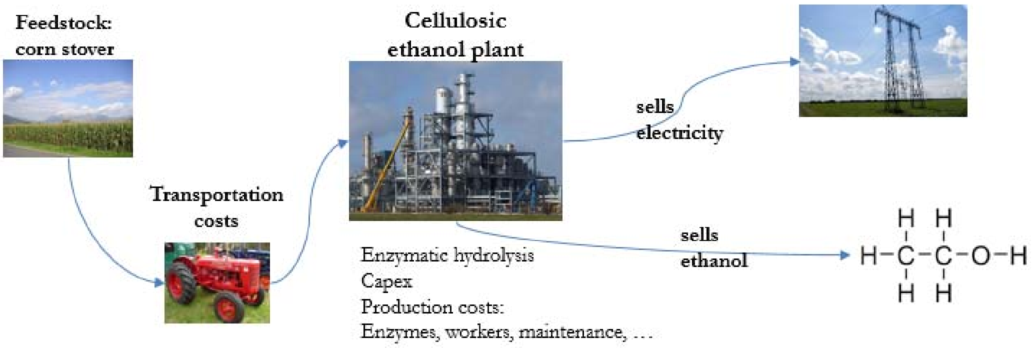

Figure 2 Flow diagram of biochemical cellulosic ethanol production

lase enzyme production, product recovery, wastewater treatment by anaerobic and aerobic digestion, storage, combustor, boiler, and turbogenerator, and utilities. The Model follows this production scheme, except for the production of enzymes, which in the Model are assumed to be purchased from external providers. Due to better availability of data, the plant is assumed to be located in the USA. As shown in the flow diagram in Figure 2, the feedstock of choice is corn stover which is widely available in the USA. When delivering the feedstock to the BCEP, transportation costs arise. Finally, after the production stages described, the final products are ethanol and excess electricity. However, revenue generated from excess electricity is significantly minor in comparison to revenue generated by ethanol. Thus, in the following, the analysis is focused on the economic effects of ethanol price changes, whereas prices for electricity are assumed to follow a fixed price scheme.

3.2. Assumptions in the model

The assumptions in the Model are based on information gathered from various research papers and calibrated by expert consultation as well as by incorporating publicly available data from companies like Abengoa, Beta Renewables, Dong Energy, Borregard, Clariant, or Iogen Raizen. Most of the assumptions are based on Humbird et al. (2011) and adjusted when considered necessary. The simulation is based on the nth-plant assumption, which means that the technology has been proven to work properly and no extraordinary long ramp-up phases are to be expected (compare Humbird et al., 2011, p.6).

Item	**Duration**	**Unit**
Construction phase	2	years
Ramp-up phase	1	year (production is assumed to increase each quarter by 25%)
Operation phase	20	years (including ramp-up phase, i.e. 19 years of full production)
Depreciation of fixed assets	20	years

Table 2 Time schedule of biochemical cellulosic ethanol plant

3.2.1. Timing, capital expenditures and scale of the plant

The Model is split into three phases: construction, ramp-up and operating phase. Construction is assumed to last for two years, afterwards a ramp-up phase of one year marks the beginning of the operating phase. During the ramp-up phase, the production increases by 25 percent per quarter until reaching full production capacity in the fourth quarter. The construction phase is similar to Humbird et al. (2011, p.68). For simplification, the Model assumes the same construction and ramp-up phases for various plant sizes. Finally, the operating time is assumed to last for 20 years (please refer to Table 2). This is a conservative assumption in comparison to Humbird et al. (2011), who assume a plant life of 30 years (p.65). For ease of reference, the Model assumes start of construction on 1 January 2016 and start of operation respectively ramp-up phase in January 2018.

Capex costs are broken down into several items as described in Table 3. In order to take scale effects into account, the Model uses an exponential scaling factor of 0.7 to calculate the selected plant size (similar scaling factors are used in the literature, for instance

Item	**Cost**	**Unit**
Planning	11	USD/ton prod. cap.
Pretreatment	162	USD/ton prod. cap.
Neutralization and conditiong	16	USD/ton prod. cap.
Saccharification and fermentation	169	USD/ton prod. cap.
Distillation and solids recovery	121	USD/ton prod. cap.
Wastewater treatment	268	USD/ton prod. cap.
Storage	27	USD/ton prod. cap.
Bolier/Turbogenerator	358	USD/ton prod. cap.
Utilities	37	USD/ton prod. cap.
Total capex	**1,160**	**USD/ton prod. cap.**
Exponential scaling factor for capex	0.70	factor
Indirect costs	82%	%age of total capex
Original plant size	184,279	Ton prod. cap. / year
Original capex	390	million USD (not considering on site-enzyme prod.)+planning costs
Capex for 100k liter plant	133.0	million USD
Capex for 500k liter plant	666.4	million USD
Replacement capex	2%	of original capex every 5.25 years

Table 3 Capex items, source: Humbird et al., 2011, except for planning costs (educated guess) and replacement capex. No own enzyme production modeled.

by Leboreiro and Hilaly, 2011, p.2, and 2013, p.2). This scaling factor increases the relative capex for plants smaller than the original plant size and decreases the relative capex for plants larger than the original plant size. The effect of this scaling factor is graphically depicted in Figure 3. Indirect capex are assumed to be 45 percent of direct capex. The depreciation period of the initial investment in fixed assets is 20 years. As some of the fixed assets will need to be replaced after a certain time of operation, the Model assumes replacement capex of two percent of the original capex every 5.25 years.

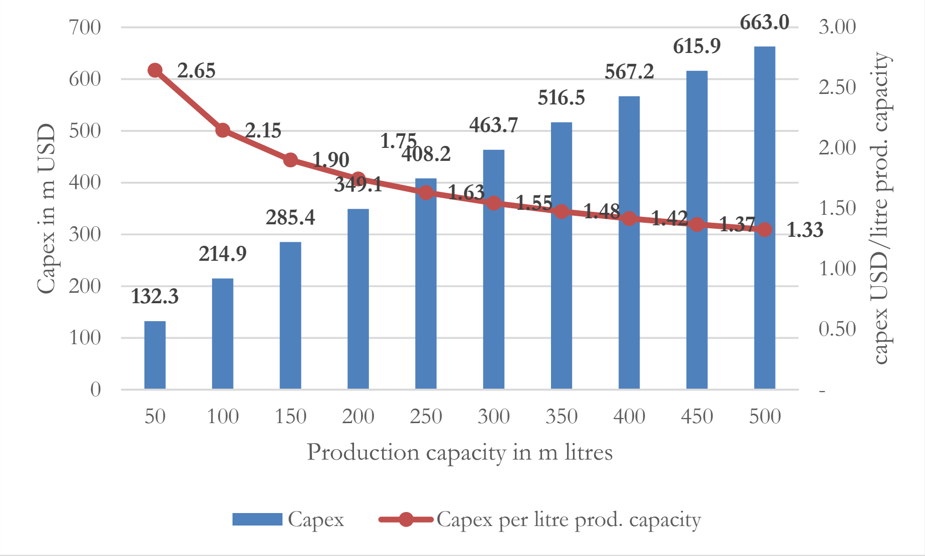

Figure 3 Relative and absolute capital expenditures for various plant sizes

The scale of the plant can be varied in the model. So far, Du Pont's Nevada plant is supposed to be the largest commercial biochemical cellulosic ethanol plant with a production capacity of almost 90,000 tons of ethanol per year.[15] The analysis in this paper considers sizes of 50, 100, 150, 200, 250, 300, 350, 400, 450 and 500 million litres production capacity per year respectively. Sizes lower than 50 million litre production capacity per year are not considered as the profitability of these plants is too low due to the relatively high capex required.

3.2.2. Production

The conversion rate from corn stover to ethanol is assumed to be 30 percent, similar to the assumptions in Humbird et al. (2011), Gnansounou and Dauriat (2010), Treasure et al. (2014), as well as company information from Dong Energy, and Borregard (Lersch, 2014). Humbird et al. (2011) state that "sugar yields from pre-treatment and enzymatic hydrolysis have been steadily increasing" (p.34). In the Model, this is reflected by an assumed technological learning rate of 0.5 percent per annum, leading to a conversion rate of approximately 33.5 percent in 2037. Although in future, lignin might be processed to biochemical products in more advanced production processes, the Model assumes that it is simply burned and converted into electricity. A proportion of 68 percent of this electricity is used within the plant, the rest is sold at market prices of 0.05 USD/KWh.[16] The power production capacity is 0.22 KW/ton production capac-

Item		**Explanation**
Conversion rate	30%	Of feedstock to ethanol
Technological learning rate	0.5%	Improvement of conversion rate per annum
Electricity required for production	68%	Remaining 32% sold at market price
Power production capacity	0.22	KW/ton prod. cap.
Operating time	2,103	Hours each quarter

Table 4 Assumptions in relation to production

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[15] http://ethanolproducer.com/articles/11153/poet-dsm-dupont-abengoa-begin-commissioning-cellulosic-plants

[16] Compare Humbird et al. (2011)

ity; for the calculation of KWh the Model calculates with an operating time of 2,103 hours in each quarter (similar to Humbird et al., 2011). All produced bioethanol is assumed to be sold at market prices – if no other regulatory measure adjusts this market price – and all feedstock required in the process is assumed to be fully available. This assumption is similar to Gnansounou and Dauriat (2010). Table 4 summarises the assumptions in relation to production.

3.2.3. Production costs

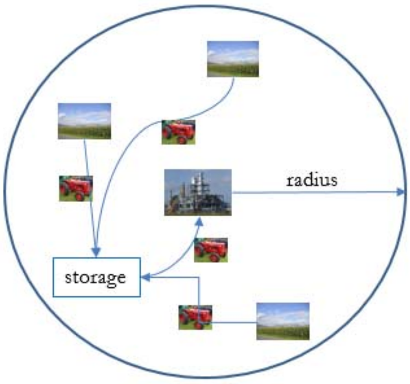

Figure 4 The setup of the plant and sourcing area

The production costs are separated into three main areas: feedstock costs, transportation costs and finally the actual cost of production resulting from the production process in the BCEP.

As shown in the literature review, the price range for one ton of corn stover is very wide. In some cases the transportation cost to the plant is already incorporated, in others it is not. The main reason for this inconsistency and wide range is the fact that currently no transparent market for corn stover is existing. For instance, Thompson and Tyner (2014) assume a cost of 33.26 USD/ton for loading and unloading as well as transportation. They estimate the stover price at 88.19 USD/ton, i.e. the total feedstock price is 121.45 USD/ton. This comparatively high price compares unfavourably to the assumption by Humbird et al., who estimate the total feedstock cost at 58.50 USD/ton. Internet research yielded a price of approximately 30 USD/bale, which is approximately 50 USD/ton.[17] This is also the starting price in the Model for one ton of corn stover excluding processing, storage, and transportation. The subsequent price behaviour is described later in this paper.

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[17] http://www.extension.iastate.edu/agdm/crops/html/a1-70.html

Item	Cost	Unit	Source
Feedstock corn stover	50	USD/ton	Internet research
Processing and storage costs	12.74	USD/ton	
Area with corn production	10%	of circle area	Gnansounou and Daruiat, 2010
Corn stover used for biorefinery	15%	Of corn stover produced	Conservative assumption
Corn stover output per hectare	2.98	ton/hectare	Average of Leboreiro and Hilaly (2011) and Thompson and Tyner (2014)

Item	Cost	Unit	Source
Pretreatment	0.04	USD/litre produced	Humbird et al., 2011
Enzymes bought from external provider (in 2016)	0.11	USD/litre produced	Humbird et al., 2011
Variable operating costs	0.06	USD/litre produced	Humbird et al., 2011, pretreatment decreased by appr. 20%
Maintenance costs	0.01	USD/litre produced	Humbird et al., 2011
Property insurance	0.01	USD/litre produced	Humbird et al., 2011
Workers	0.298	workers per 1,000 ton prod cap (24 for 100,000 litre capacity)	Humbird et al., 2011, decreased by appr. 8% because no integrated enzyme production
Wage costs per worker	3,472	USD/month	Humbird et al., 2011
Labour burden and overhead costs	90%	of personnel cost	Humbird et al., 2011
WC requirement	25%	of operating costs	Chovau et al., 2013

Table 6 Operating production costs

The main assumption in relation to the transportation cost is that the plant is located in the centre of a circular catchment area (please refer to Figure 4). In this area, farmland is uniformly distributed (compare assumptions in Leboreiro and Hilaly, 2011). Not all of the feedstock required has to be transported along the maximum radius. Thus, it is assumed that the average feedstock needs to travel 0.85 times the radius of the catchment area. This follows the idea of a non-dimensional transportation factor as described in Leboreiro and Hilaly (2011 and 2013). They design a detailed model of ethanol production from corn stover by considering the biomass supply chain in detail and calculate a non-dimensional transportation parameter of 0.85, which is also used in the Model. The radius of the supplying area is adjusted accordingly to the scale of the plant respectively the required feedstock. It is assumed that corn is grown on ten percent of the surrounding circular area (similar to Gnansounou and Dauriat, 2010) with a productivity rate of 2.98 tons of corn stover per hectare. This number is the average of the rather optimistic estimate of 3.4 ton/hectare by Leboreiro and Hilaly (2011) and the more conservative estimate by Thompson and Tyner (2014) of 2.56 ton/hectare. Instead of using 37 percent of all stover produced in the catchment area as assumed by Leboreiro and Hilaly (2011), the assumption in the Model is that only ten percent can be used sustainably. Under these assumptions, a plant with a capacity of 50 million litres requires a catchment area with a radius of 96 kilometres in 2020 – i.e. one year after start of full production – in order to reach full production capacity. For plants of 250 million and 500 million litres of production capacity this catchment radius increases to 215 km and 304 km respectively. Transportation costs per kilometre are 0.14 USD per ton and kilometre (similar to Leboreiro and Hilaly, 2011) and vary with the same percentages as the simulated movements of the price for gasoline as described below. Additionally to this variable transportation cost the Model adds a fixed cost for collection, processing, and storage of 12.74 USD/ton. This is similar to the storage costs assumed by Leboreiro and Hilaly (2011). Only the operation and transportation part of their assumed storage cost (in total 21.05 USD/ton) is adjusted by taking only 50 percent of their value. The reason for this adjustment is that this cost part is assumed to be partly included in the variable transportation costs described above.

Under the assumptions described above, the Model yields a range of total feedstock prices, i.e. incorporating transportation costs, from approximately 70 to 140 USD/ton in 2020 (i.e. after two years of operation), depending on the variability of prices (as described in the following chapters). This compares quite well to the estimated cost of delivered corn stover of 101.25 USD/ton by Leboreiro and Hilaly (2011). The assumptions regarding transportation and feedstock costs are summarised in Table 5.

The actual operating costs of the production facility are assumed as listed in Table 6 and mainly follow the assumptions in Humbird et al. (2011) except for the following adjustments: the number of workers is decreased from 60 to 55 for the original plant size in order to adjust for the lack of integrated enzyme production. After expert consultation, the variable operating costs are decreased, due to improvements in the pretreatment step. Finally, enzyme costs bought from external providers are adjusted downward due to further assumed improvements. Working capital requirements foresee a minimum need of one million USD to be left as cash in the company – additional cash is distributed as dividend. Further, 25 percent of operating costs are assumed to be required for working capital. This assumption follows Chovau et al. (2013, p.310), who use a range from ten to 35 percent. When showing the operating costs in terms of USD per litre produced, the actual operating production costs add up to approximately 0.16 USD/litre plus 0.10 USD/litre for enzymes in 2020 (compare chapter 3.2.6).

3.2.4. Economic and financial assumptions

The corporate tax rate is assumed to be 35 percent. Corporate taxes are only paid in case the company makes a profit and after pre-tax profits have been reduced by losses carried forward. It is possible to carry losses forward for five years in order to set them off against the tax base. After five years, unused tax losses expire. Additionally to corporate taxes, the Model applies a regional tax of five percent, which needs to be paid on profits. It is not possible to use tax losses to lower the tax base of the regional tax. Cash on hand earns an interest of one percent, and the inflation rates are as outlined in Table 7. The required return for the calculation of the NPV is eight percent. This is slightly lower than the discount rate of ten percent used for instance by Marvin et al. (2012) or Humbird et al. (2011) in order to incorporate the currently prevailing historically low interest rates.

Further to financing from equity sources, the Model allows for a certain percentage of debt financing in relation to initial capex. The interest rate for this debt is assumed to be a fixed rate. For the default analyses, the Model uses a 40 percent debt rate with an interest rate of six percent. The loan is drawn in linear tranches over the construction phase and has a loan life of ten years after full disbursement. The inflation rates of ethanol, transportation costs, and corn stover are similar to the drift rates as explained in chapter 3.2.5. Electricity prices are assumed to remain flat, reflecting the current downward pressure on prices for electric power.

Inflation rates of		**Sources**
Ethanol	2.02%	Drift rate ethanol prices
Corn stover	2.20%	Drift rate corn prices
Transportation costs	4.93%	Drift rate gasoline prices
Electricity	0.00%	Conservative guess
Wages	2.28%	Inflation rate of average hourly earnings from 2006-2014
Production costs	3.19%	PPI-Chemicals
Enzyme costs	-0.50%	Educated guess
Assumptions regarding debt financing		
Debt rate	40%	of initial investment
Interest rate	6%	Fixed rate
Duration of loan	10	years

Table 7 Inflation rates and assumptions on debt financing

Inflation rates of production costs follow the average annual inflation rate of the Producer Price Index for the Chemical Industry.[18] Wages are inflated with the annual inflation rates of the average hourly earnings of production workers for the chemicals manufacturing industry for labour cost, published by the US Department

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[18] The quarterly prices of corn, gasoline, and ethanol from March 1982 to December 2014 are downloaded from: http://download.bls.gov/pub/time.series/pc/pc.data.14.Chemicals

of Labor.[19] Enzyme costs are modelled to be decreasing by 0.5 percent per annum, which is based on company information from Novozymes, who claim that enzyme prices will continue to decrease significantly in the coming years (Chovau et al., 2013, p. 314). In this regard, the estimate of a negative annual inflation rate of 0.5 percent seems rather conservative.

3.2.5. Prices and Monte Carlo simulation

Prices for	Drift rate	SD	Starting price
Ethanol	2.02%	11.8%	0.63 USD/litre
Transportation	4.93%	17.1%	0.14 USD/ton/km
Feedstock	2.20%	16.3%	50 USD/ton

Table 8 Input parameters for price simulation

The BCEP is assumed to be a price taker (compare Gnansounou and Dauriat, 2010), which is selling the ethanol and electricity produced at the prevailing market price – unless regulation provides for a different price. Currently, no market with transparent and long term prices for feedstock like corn stover exists. For this reason, the price behaviour of corn stover is assumed to follow the price behaviour of corn. Also, gasoline prices respectively their historical movements determine the development of the transportation costs. The behaviour of ethanol prices is assumed to be simply based on the historical prices of ethanol.

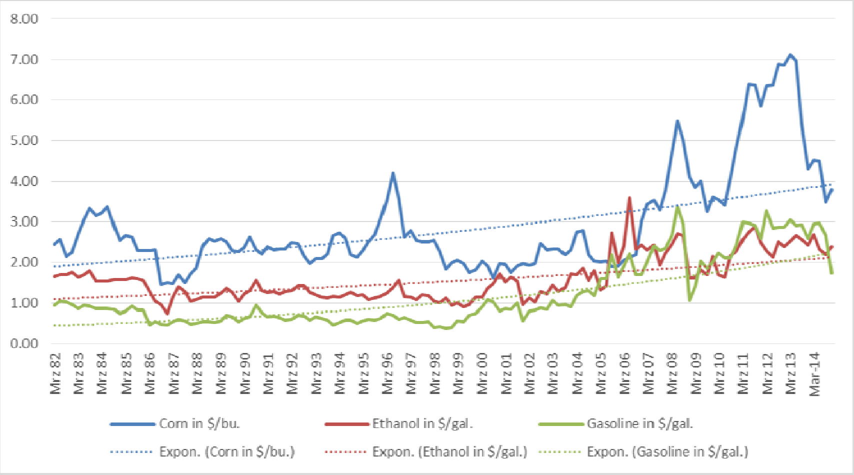

Figure 5 Historical prices of ethanol, corn, and gasoline

The previously mentioned drift rates of ethanol, transportation, and feedstock prices are calculated by applying least square estimates to estimate the values for an exponential trend line (as depicted in Figure 5). These rates – please refer to Table 8 – are used as drift rates for a stochastic price modelling via Brownian motion. Additionally required input, like the standard deviation and the correlation between each of the prices are also calculated from the historical prices.[20]

By applying Cholesky factorisation, the final stochastic price formulas are the following:

$$E_{(t+1)} = E_t \times (1 + drift\ rate_E \times 0.25) + E_t \times \sigma_E \times \sqrt{0.25} \times N_E(0{,}1)$$

$$T_{(t+1)} = T_t \times (1 + drift\ rate_T \times 0.25) + T_t \times \sigma_T \times \sqrt{0.25} \times (N_T(0{,}1) \times \sqrt{(1 - {\rho_{TE}}^2} + \rho_{TE} \times N_E(0{,}1))$$

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[19] http://www.bls.gov/web/empsit/compaeheu.txt

[20] Prices are downloaded from United States Department of Agriculture, http://www.ers.usda.gov/data-products/us-bioenergy-statistics.aspx

$$F_{(t+1)} = F_t \times (1 + drift\ rate_F \times 0.25) + F_t \times \sigma_F \times \sqrt{0.25} \times (N_F(0,1) \times \sqrt{(1-\rho_{FE}{}^2 - \frac{(\rho_{TF}-\rho_{FE}\times\rho_{TE})^2}{\sqrt{(1-\rho_{TE}{}^2}}} + N_T(0,1) \times \frac{(\rho_{TF}-\rho_{FE}\times\rho_{TE})}{\sqrt{(1-\rho_{TE}{}^2}} + \rho_{FE}\times N_E(0,1))$$

With E_t, T_t, and F_t for the prices of ethanol, transportation, and feedstock (i.e. corn stover) at time t; σ_E, σ_T, and σ_F are the respective standard deviations. $N_{E,T,F}(0,1)$ is a standard normal distribution and $\rho_{TE}, \rho_{FE}, \rho_{TF}$ the correlation coefficients between transportation, ethanol and feedstock prices. All relevant input data for these formulas are shown in Table 8 and Table 9.

Correlation	Ethanol	Transp.	Feedstock
Ethanol	1	-	-
Transportation	0.46	1	-
Feedstock	0.20	0.18	1

Table 9 Correlation matrix showing correlation for March 1982 to December 2014

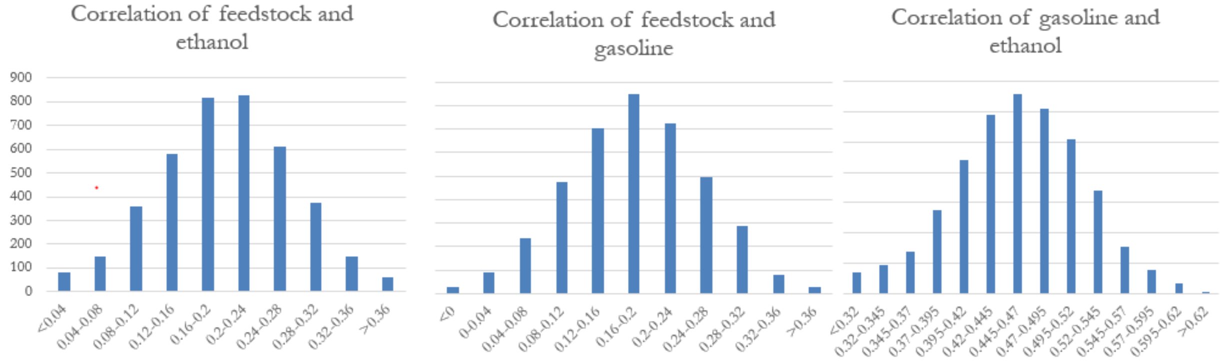

Figure 6 Distribution of correlation of ethanol, feedstock, and gasoline after 4,000 simulation runs

Based on these assumptions, the Model performs Monte Carlo based randomised simulations of feedstock, bioethanol and transportation prices. The Model is developed on Microsoft Excel. As the calculation of several thousand simulations requires a lot of computing power, the analysis is limited to 4,000 iterations. Other model analyses, like for instance in Treasure et al. (2014), use 20,000 iterations.

To understand how the correlations incorporated into the formulas above influence the modelled price development, Figure 6 shows

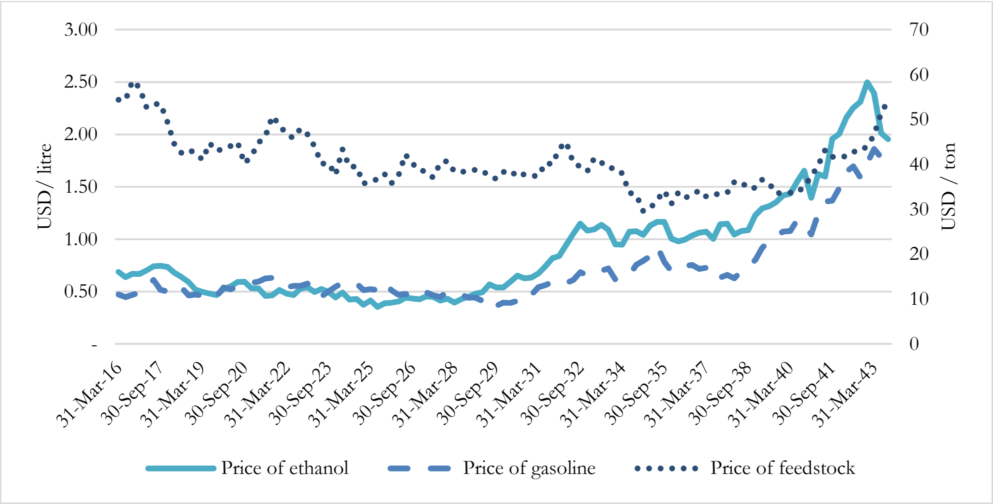

Figure 7 Exemplary development of ethanol, gasoline, and feedstock prices

the distribution of the correlations after 4,000 simulation runs. The averages of these correlations are – as to be expected – normally distributed around the values in Table 9. As a summary of this chapter on price developments, Figure 7 shows an exemplary development of these prices.

3.2.6. Minimum Ethanol Selling Price

The assumptions described in Chapter 3 imply the production costs as shown in Table 10, separated into cost types for the smallest and the largest modelled plant sizes. The minimums and maximum values presented in the table are for the year 2020, the second modelled year of full operation. Due to the variability of prices, no exact values can be determined. Thus, the minimum and maximum values shown in the table are approximate values. It is possible that some outliers have higher or lower costs than shown in the table.

	50m litre plant		**500m litre plant**	
In 2020, in USD/litre produced	circa min	circa max	circa min	circa max
Feedstock costs:	0.12	0.28	0.12	0.28
Transportation costs:	0.03	0.10	0.05	0.22
Feedstock costs total:	0.15	0.38	0.17	0.50
Enzyme costs:	0.10			
Production costs (fixed):	0.16			
Direct production costs:	0.41	0.64	0.43	0.76
Depreciation:	0.13		0.07	
Production costs before interest and taxes:	0.54	0.77	0.50	0.83
Interest expenses:	0.05		0.03	
Taxes	0.03	0.05	0.04	0.07
Prodcution costs before rate of return:	0.62	0.87	0.57	0.93
Rate of return (8%)	0.05	0.07	0.05	0.07
Minimum Ethanol Selling Price (MESP)	**0.67**	**0.94**	**0.62**	**1.00**
Contribution of feedstock to MESP:	37%	51%	44%	60%

Table 10 Range of production costs in USD per liter produced in 2020

The variability of the final Minimum Ethanol Selling Price (MESP) is higher in case of the larger plant. This is caused by the increased variability of prices stemming from the higher feedstock and transportation costs due to the necessary larger catchment area. The MESP of the Model are approximately in line with MESP currently discussed by market experts. For instance, Novozymes sees the total production costs of cellulosic ethanol in a range from 0.53 to 0.92 USD/litre (Nielsen, 2012). Bloomberg estimates that the MESP will decline to 0.67 USD/litre by 2016.[21] The contribution of feedstock to the MESP is ranging from roughly 37 up to 60 percent, which is in line with the range described by Sanchez and Gomez (2014), who observed a range of 40 to 60 percent of raw material contributions (feedstock and enzymes) to total production in most of the papers they reviewed.

3.3. Regulatory measures analysed with the financial model

The Model provides a powerful analysis tool to understand the implications of various policy measures. Its aim is to find policy and finance measures which improve the profitability and thereby the financeability of BCEPs of various sizes. Although the Model enables simulation runs with policies in place for only a certain period of time, it was found that most of the policies should be in place for the whole operating time.

EBTP (2012) distinguish three types of regulatory measures in order to "bring advanced biofuel technologies across the 'valley of death' between R&D and commercialization" (p.1): demand, supply, and investment side measures. The discussion below follows this logic and summarises the regulations analysed with the model.

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[21] http://about.bnef.com/press-releases/cellulosic-ethanol-heads-for-cost-competitiveness-by-2016/

3.3.1. Demand side measures

Binding blend-in target for advanced biofuels – Cellulosic waiver

Blend-in targets require an obligated party – for instance oil companies selling gasoline – to use a certain percentage of biofuels when selling transportation fuels. In the EU, only Italy requires a binding blending target for advanced biofuels. In other EU countries, up to now binding blending targets exist only for biofuels in general. The following scenarios are considered in the Model:

a) A binding blending target for biofuels in general. In this case, cellulosic ethanol competes with other biofuels, for instance with ethanol from sugar beet or corn. It is assumed that the BCEP can sell all its produced cellulosic ethanol at the prevailing market prices for ethanol. This is the no policy case in the Model.
b) A binding blending target for advanced biofuels. In this case, cellulosic ethanol competes with other advanced biofuels. It is assumed that the BCEP can sell all its produced cellulosic ethanol at the prevailing market prices for ethanol plus a certain add-on. This add-on is assumed to be the price of a cellulosic waiver credit, which represents a possibility for obligated parties to waive their obligation. Thus, one litre of gasoline divided by 1.5 in order to adjust for the different calorific values of ethanol and gasoline plus the price of the waiver for one cellulosic waiver equals the price for one litre of cellulosic ethanol. The Model follows the calculation method for a cellulosic waiver in the USA: one waiver credit for one gallon of cellulosic ethanol is calculated as the maximum of either 3 USD/gallon less the wholesale price of gasoline or 0.25 USD/gallon, where both options are adjusted for inflation.

Double counting of advanced biofuels including cellulosic bioethanol

As previously mentioned, the current EU regulation allows the double counting of certain feedstock, among others of straw. To model the effect of double counting, the Model assumes that cellulosic ethanol can be sold with a certain percentage add-on to ethanol prices. A numerical example explains the rationale behind this assumption: If regulation requires a ten percent blending quota of for instance first-generation bioethanol, five percent of cellulosic ethanol would be sufficient under double counting. The Model calculates the prices for both of these blends, considering the calorific value of ethanol. Then, the price difference between the ten percent blend with first-generation biofuels and the five percent blend with cellulosic ethanol yields the theoretical maximum add-on a buyer is willing to pay for cellulosic ethanol. As previously indicated, the prices of both ethanol and gasoline are simulated in the model. Thus, it is possible to calculate the potential price add-on in case of double counting. However, as the results discussed in chapter 4 prove, this incentive only works well if gasoline prices are actually lower than ethanol prices in calorific values. Otherwise, in case ethanol prices are lower than gasoline prices, this incentive becomes ineffective, because the obligated parties have an incentive to blend as much ethanol as possible.

Production support / feed-in tariff / minimum price

Going beyond the previously introduced measures, a fixed price for cellulosic ethanol, similar to feed-in tariffs often paid for solar or wind energy, can provide a strong incentive. A regulatory fixed price is very similar to long term contracts with customers at a certain price. Similar to this, the US military and Navy demands a certain amount of advanced biofuels by 2012 (Air Force) and 2020 (Navy) respectively.[22] The Navy also pays a fixed price substantially above fossil fuel prices.[23] This kind of demand management can also offer a strong

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[22] http://www.americansecurityproject.org/dods-biofuels-program/

[23] http://www.wired.com/2011/12/navy-biofuels/

incentive to invest in advanced biofuels. The fixed price scenario in the Model starts with a price of 0.63 USD/litre increasing with 2.5 percent annual inflation. A similar idea is to introduce a minimum price insurance, which only pays out in case the market price is below the insured minimum price. The analysis in the Model applies an annual inflation rate of 2.5 percent on the minimum price of 0.63 USD/litre. Comparing minimum and fixed price policies, the main difference is that minimum price incentives leave all the upside potential to the BCEP, whereas fixed price incentives limit both, the upside as well as the downside potential.

Tax incentives

Tax incentives can be provided in several ways:

1. By lowering local business taxes (e.g. the Gewerbesteuer in Germany) or corporate taxes on corporate profits for BCEPs.
2. By lowering the energy taxes on cellulosic ethanol. For instance, Germany grants tax reliefs for cellulosic ethanol when blended with fossil fuels (compare paragraph 50 of the German Tax on Energy Act)[24].
3. By providing a certain tax credit for a certain amount of produced bioethanol. In 2014, producers of biodiesel in the USA received a tax credit of one USD for each gallon produced.[25] The analysis in the Model follows this logic by applying a certain tax credit. In case the company pays less taxes in the respective quarter, the tax credit can be carried forward to later periods. The specific assumptions are: for each litre produced a tax credit of 0.20 USD/litre is provided, which can be used to offset corporate taxes of the BCEP. In case no corporate taxes arise, the credit can be carried forward. After two years, the credit expires if not used in the meantime.

3.3.2. Supply side measures

Feedstock collection and supply-chain incentives

A potential supply side measure is to contractually fix the price paid for feedstock. For instance, the BCEP can negotiate long term contracts with farmers. In order to facilitate such contracts, regulatory agencies can intervene in the market. The Model can replicate such policies by simply decreasing the variability of the feedstock, i.e. corn stover, to zero. In this case, the cost arising from the subsidy is the difference between the market price and the fixed feedstock price.

Climate credit for CO_2 savings

In 2015, the legislation in Germany changed from a binding blending target to a binding CO_2 savings target. The initial target of 3.5 percent CO_2 savings in comparison to fossil fuels is scheduled to increase to six percent by 2020.[26] The assumed percentage savings of CO_2 follow a fixed calculation method with reference figures. Due to the difficulties of modelling such legislation, this regulatory measure is not replicated in the Model analysis.

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[24] Energiesteuergesetz

[25] http://www.biodieselmagazine.com/articles/260748/senate-passes-tax-extenders-biodiesel-credit-to-be-reinstated

More information on US tax incentives: http://www.ethanolrfa.org/pages/tax-incentives

[26] BioKraftQuG and Biokraftstoff-Nachhaltigkeitsverordnung

3.3.3. Investment side measures

Investment support / grants

Governments can attract more investment into BCEPs by providing direct subsidies for the initial capital expenditures. The Model assumes a grant of 20 percent of the total initial capital expenditure. With distribution of the grants, the same amounts are activated on the balance sheet as deferred income. After start of operation, they are amortised as a taxable profit.

Debt guarantees

In terms of financing, the Model allows to analyse implications of a bank debt with various sizes and interest rates. By providing guarantees for debt repayment, governments can lower the interest rates required by lenders respectively increase the size of the debt.[27] Whenever guarantee payments are triggered in order to repay outstanding debt or to make interest payments, the amount is provided by the guarantor in form of a zero-interest loan, which is repaid whenever possible and senior to dividend payments. Under the standard scenarios, the Model calculates with a 40 percent debt rate at an interest rate of six percent. For scenarios with a very high probability that the investor will receive a relatively high rate of return, the debt rate is elevated to 60 percent and the interest rate lowered to four percent. In case of a debt guarantee from the government, the debt rate is 60 percent at a three percent interest rate.

Depreciation

Lowering the tax burden of a BCEP by allowing for different schemes of depreciation can be an attractive policy tool. The Model uses two kinds of depreciation schemes: linear and accelerated depreciation. Accelerated depreciation schemes normally have a higher depreciation in the first years of operation and a lower depreciation in the later years. This lowers the tax burden in the first years and tentatively increases taxes later on, thereby often increasing the internal rate of return due to higher dividend flows in early periods. However,

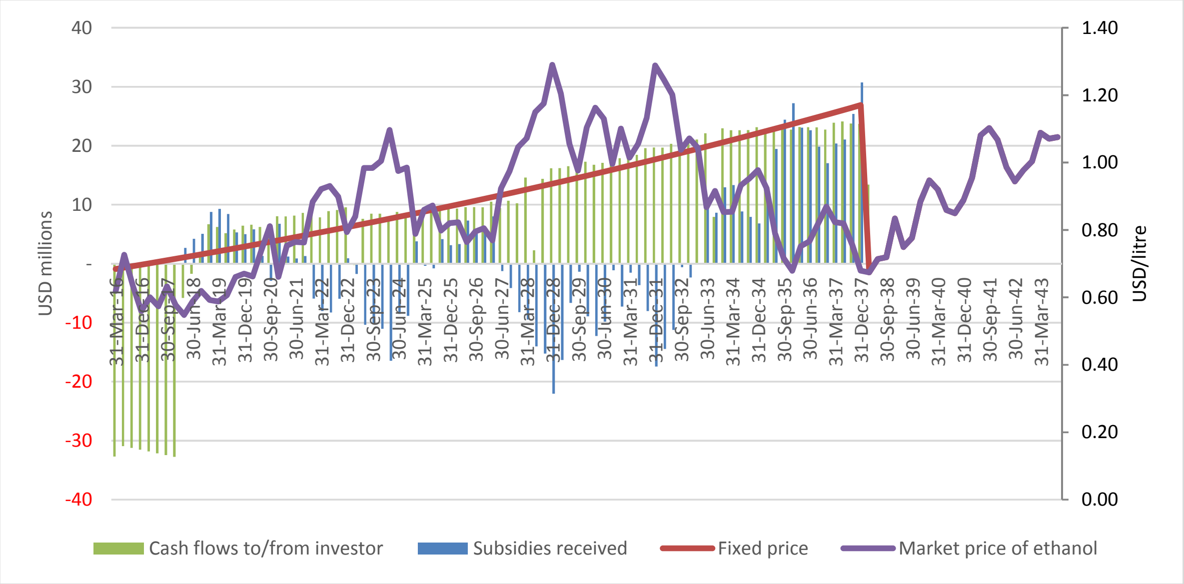

Figure 8 Prices of ethanol, feedstock, and transportation costs under fixed price policy

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[27] In the US, a loan program from the DOE provides guarantees for advanced biofuels under the "Biorefinery Assistance Program" (http://www.afdc.energy.gov/laws/8502).

the total tax burden might in fact be elevated.

4. Results & Discussion

This section compares the effect of the previously described regulatory measures by running Monte Carlo simulations and calculating NPV, IRR, the payback period, as well as the cost of the respective regulation. An "ideal" price policy is developed, which works best in terms of elevating the expected return and reaching break-even at a comparatively low cost.

4.1. Evaluation of potential regulatory measures

The columns in Table 11 show the resulting financial key figures for each of the discussed regulations with a plant size of 250 million litres production capacity. The second column shows the no policy case. For this case, although the average IRR seems to be quite acceptable at 6.7 percent, a look at the frequency of negative expected rates of return reveals that the Monte Carlo simulation does not deliver attractive results for investors: 2,141 of 4,000 simulation runs have a negative IRR, 1,994 of 4,000 never reach break-even. As to be expected, the high variability of input and output prices leads to this unfavourable result. In the following, the effects of the various policies are discussed.

Minimum price: A minimum price of 0.63 USD/litre increasing with an inflation rate of 2.5 percent substantially increases the IRR and decreases the number of simulation runs where break-even is not reached to 117 (of 4000). Although this result is positive, the cost of the subsidy – 1.53 USD on average per litre of produc-

	For 250 million litres production capacity									
IRR	**No policy**	**Minimum price**	**Fixed price**	**Double counting**	**Waiver credit**	**Ideal policy**	**Grants (capex)**	**Tax credits**	**Debt guarantee**	**Declining depreciation**
≤ 0 (frequency of 4000)	**2141**	**126**	**210**	**1453**	**30**	**0**	**2095**	**2033**	**2101**	**2194**
Average	**6.7%**	**12.2%**	**9.9%**	**16.7%**	**14.3%**	**8.6%**	**7.9%**	**9.4%**	**8.2%**	**7.3%**
Median	0.0%	11.0%	10.8%	14.4%	13.3%	8.2%	0.0%	0.0%	0.0%	0.0%
SD	9.3%	6.9%	3.7%	16.7%	6.5%	2.6%	10.7%	12.3%	11.3%	10.4%
NPV										
Negative (frequency of 4000)	2627	900	909	1670	479	1832	2497	2392	2474	2599
Average	-139.8	164.3	60.5	296.6	246.3	24.9	-92.8	-35.1	-51.5	-125.1
Median	-179.0	85.0	78.4	138.2	164.9	6.5	-144.2	-149.0	-124.1	-182.5
SD	494.6	303.3	110.3	835.9	324.5	85.4	496.8	621.3	445.7	526.8
Payback period										
Never (frequency of 4000)	**1994**	**117**	**180**	**1170**	**26**	**0**	**1927**	**1878**	**1958**	**2018**
Average	45	47	49	30	44	56	42	39	43	40
Median	41	48	47	25	43	56	38	34	39	34
SD	17	13	9	15	12	6	18	17	18	18
Average, median, and standard deviation are calculated only for simulation runs with an actual payback period.										
Subsidies received										
Average of disc. subsidies in mln	-	381.7	204.3	689.0	492.1	130.1	47.8	101.2	52.6	-
Subsidies received (frequency of 4000)	-	3,731	2,751	3,994	3,810	2,660	4,000	2,893	3,982	-
Average of disc. sub./lit. prod. cap.	**-**	**1.53**	**0.82**	**2.76**	**1.97**	**0.52**	**0.19**	**0.40**	**0.21**	**-**

Table 11 Results of Monte Carlo simulation runs for no policy and various policy cases. Plant size: 250 million litres production capacity.

tion capacity – is comparatively high.

	For 250 million litres production capacity									
IRR	**No policy**	**Minimum price**	**Fixed price**	**Double counting**	**Waiver credit**	**Ideal policy**	**Grants (capex)**	**Tax credits**	**Debt guarantee**	**Declining depreciation**
≤ 0 (frequency of 4000)	**2204**	**45**	**80**	**1454**	**0**	**0**	**2104**	**2009**	**2182**	**2144**
Average	**6.6%**	**12.2%**	**10.1%**	**16.7%**	**14.2%**	**10.2%**	**7.9%**	**9.3%**	**8.0%**	**7.5%**
Median	0.0%	10.0%	10.8%	14.7%	12.9%	9.8%	0.0%	0.0%	0.0%	0.0%
SD	9.7%	6.6%	2.6%	16.7%	6.2%	2.3%	10.9%	12.3%	11.4%	10.6%
SD if greater zero	9.0%	6.5%	2.1%	13.7%	6.2%	2.3%	10.1%	11.0%	10.6%	9.9%
NPV										
Negative (frequency of 4000)	2668	793	569	1642	407	662	2493	2389	2551	2589
Average	-136.7	162.5	63.2	291.0	243.6	70.5	-94.2	-38.9	-59.2	-120.7
Median	-197.0	56.8	79.0	143.4	149.8	51.7	-151.7	-142.8	-140.3	-162.8
SD	508.7	315.3	75.0	832.2	325.7	84.3	520.2	616.1	467.3	535.0
Payback period										
Never (frequency of 4000)	**2051**	**36**	**69**	**1178**	**0**	**0**	**1957**	**1835**	**2012**	**1949**
Average	45	47	49	30	44	51	42	39	43	40
Median	41	51	48	25	44	52	38	34	39	34
Average, median, and standard deviation are calculated only for simulation runs with an actual payback period.										
Subsidies received										
Average of disc. subsidies in mln	-	382.7	205.7	679.4	485.9	216.3	47.8	101.3	54.2	-
Subsidies received (frequency of 4000)	-	3,746	2,769	3,993	3,821	2,812	4,000	2,893	3,990	-
Average of disc. sub./lit. prod. cap.	**-**	**1.53**	**0.82**	**2.72**	**1.94**	**0.87**	**0.19**	**0.41**	**0.22**	**-**

Table 12 Results of Monte Carlo simulation runs for no policy and various policy cases and zero variability of input prices. Plant size: 250 million litres production capacity.

Fixed price: A cheaper alternative is the fixed price policy, which sets a fixed price of 0.68 USD/litre increasing with an inflation rate of 2.5 percent. This policy elevates the average IRR and, in most of the simulation runs, payback is reached within the twenty years of operation. Also the cost of subsidy – 0.82 USD on average per litre of production capacity – is comparatively cheap. The reason for this is the methodology of the fixed price policy. This policy obligates the company to always sell at the prevailing fixed price. In case the market price is below this fixed price, the company receives a subsidy as in the minimum policy case. However, in case the market price is higher, the company could actually sell its product at this higher price. The obligation to still sell at the fixed price causes a "negative" subsidy, which on average decreases the cost of this subsidy. Figure 8 shows an exemplary simulation run for a fixed price policy with "positive" and "negative" subsidies.

Double counting: As explained before, the double counting policy works very well in case the market prices for ethanol and gasoline are favourable. In this case, the policy increases the IRR extraordinarily. However, the policy fails to lower the simulation runs to an acceptable level where no break-even is reached. Additionally, the subsidy is very expensive in comparison to other policies.

Waiver credit: This policy works very well in terms of IRR and making the company reach payback. Only the cost of this policy is very high.

"Ideal" policy: This policy uses the lessons learned by applying the previous price policies and combines them to form an "ideal" price policy, which will be explained in more detail in the next section.

Grants, tax credits, debt guarantee, and change in depreciation method: None of these policies achieves an acceptable increase in simulation runs where break-even is reached. Although these policies cause the expected returns to increase due to less investment cash flows or income taxes being required at the beginning of the project, they fail to lower the variability of prices. This failure quite often leads to an economic failure of the simulated BCEP. Thus, policies which are aiming only at the initial investment and not at the prices throughout the operating phase are economically unsustainable.[28]

Fixed feedstock prices: The same analysis of the impact of the described regulatory measures with zero variability of input prices, i.e. fixed contracts which are only increasing with the drift rate, yields approximately the same results. The "ideally fixed" price policy is modified in order not to depend on the variability of the feedstock prices. Table 12 shows the results for all regulative measures and the no policy case with zero variability in feedstock prices. Only the minimum and the fixed price policies show a clear improvement in comparison to the previous case with fluctuating feedstock prices. The "ideal" price policy shows improvements in terms of average IRR and NPV. However, the missing smoothing effect of the feedstock prices elevates the cost of the subsidy.

4.2. The "ideal" price policy

The "ideal" price policy follows the idea of the fixed price policy, but is smoothed according to the development of the prices for feedstock used for production. It is also possible to see the fixed part of the "ideal" price as representing the linearly increasing production costs, whereas the rest of the price is adjusted following the price movements of gasoline and the feedstock. A combination of the following price elements yields the "ideal" price:

- 60 percent of the "ideal" price follows a fixed price path starting at 0.63 USD/litre and increasing with an inflation rate of 2.5 percent
- 20 percent of the "ideal" price is the prevailing gasoline price in USD/litre multiplied by a factor of 1.5
- 20 percent of the "ideal" price is the prevailing corn stover price in USD/ton divided by 100

If no market price for corn stover is observable, as is currently the case, a predefined starting price, e.g. 100 USD/ton, could be assumed to follow the price movements of corn. Due to the huge size of the corn market, it would not be possible for market actors in the cellulosic biofuel industry to influence market prices in their

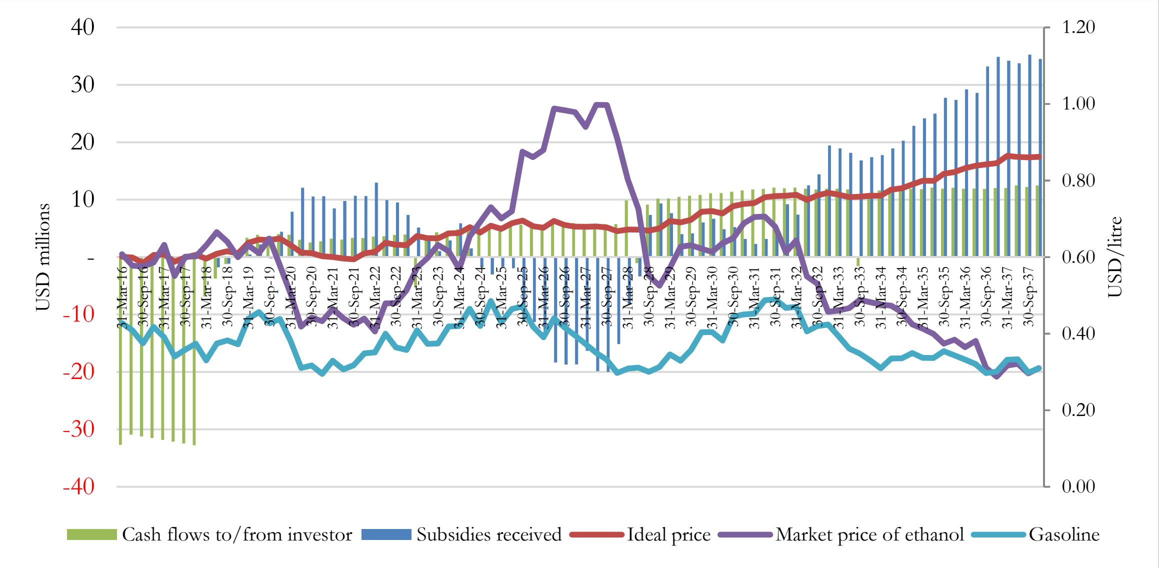


Figure 9 Prices of ethanol, feedstock, and transportation costs

favour.

An exemplary simulation run of such an “ideal” price policy is shown in Figure 9. Again, “negative” and “positive” subsidies are created, when the market price of ethanol is above respectively below the “ideal” price. This price is not linearly increasing as in the case of the fixed price policy, but is rather smoothed according to the development of the gasoline and corn stover prices.

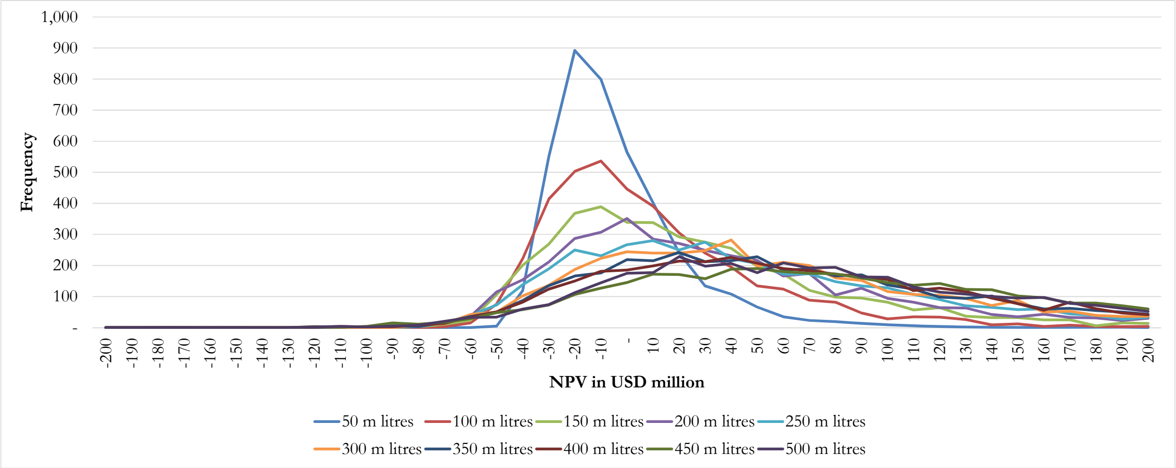


Figure 10 NPV for various plant sizes with “ideal” price policy at eight percent discount rate

Calculating the simulation outcome for various plant sizes, as done in Table 13, shows that payback is always reached for plant sizes larger or equal to 100 million litres of production capacity. Both IRR and the discounted cost of the subsidy divided by the production capacity remain roughly the same for sizes equal or larger to 250 million litres. Thus, a subsidy in this case should aim at a production capacity of 200 million litres or larger. As it might be very difficult to actually find regions with a sufficiently large sourcing area for plants as big as 400 million litres of production capacity, it might be preferable to specifically support medium-sized plants. Please note that due to the substantially decreased probability of economic failure as a result of the

IRR	**50 m litres**	**100 m litres**	**150 m litres**	**200 m litres**	**250 m litres**	**300 m litres**	**350 m litres**	**400 m litres**	**450 m litres**	**500 m litres**
≤ 0 (frequency of 4000)	**10**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Average	**6.3%**	**8.0%**	**9.0%**	**9.4%**	**9.7%**	**9.9%**	**10.0%**	**10.0%**	**10.8%**	**10.1%**
Median	5.9%	7.6%	8.5%	8.9%	9.3%	9.5%	9.6%	9.7%	10.4%	9.7%
SD	3.2%	3.1%	3.1%	3.1%	2.8%	2.7%	2.6%	2.5%	2.9%	2.3%
SD if greater zero	3.2%	3.1%	3.1%	3.1%	2.8%	2.7%	2.6%	2.5%	2.9%	2.3%
NPV										
Negative (frequency of 4000)	2931	2215	1710	1480	1207	1005	900	839	638	673
Average	-9.2	4.7	21.4	36.4	48.2	59.5	70.2	76.6	101.0	89.9
Median	-14.9	-4.6	8.6	18.2	29.5	39.2	49.4	55.8	77.6	66.4
SD	25.5	42.5	61.0	75.8	81.5	89.4	94.6	102.0	116.8	109.0
Payback period										
Never (frequency of 4000)	**6**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Average	65	60	58	57	56	55	55	55	50	55
Median	65	60	58	57	56	56	56	56	52	56
SD	9	8	7	7	6	6	6	5	8	5
Average, median, and standard deviation are calculated only for simulation runs with an actual payback period.										
Subsidies received										
Average of disc. subsidies in mln	25.9	51.7	71.8	113.7	145.1	151.3	191.3	199.0	245.0	275.2
Subsidies received	2,674	2,665	2,661	2,671	2,670	2,649	2,670	2,637	2,671	2,665
Average of disc. sub./lit. prod. cap.	**0.52**	**0.52**	**0.48**	**0.57**	**0.58**	**0.50**	**0.55**	**0.50**	**0.54**	**0.55**

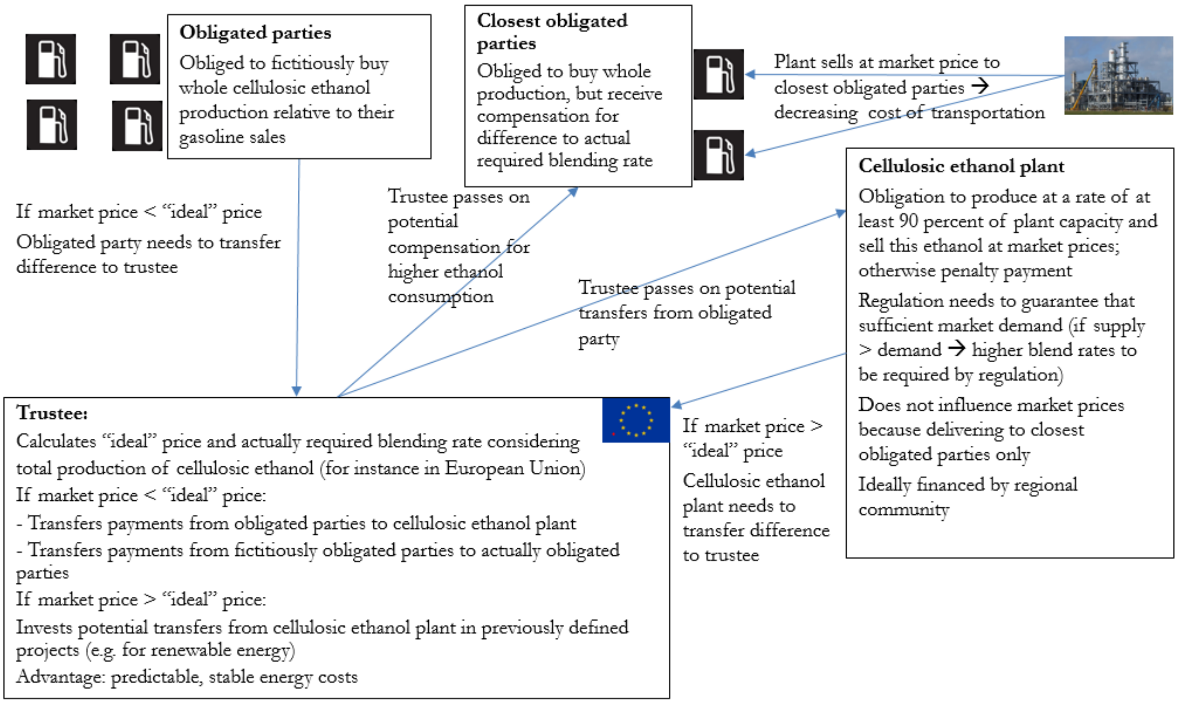
Table 13 Results of “ideal” price policy for various plant sizes and 60 percent debt financing

subsidy in place, an increased debt financing of 60 percent at only four percent interest rate is assumed.

Figure 10 shows the distribution of the NPVs for the "ideal" policy at various plant sizes. The shape of the distribution curves gets flatter with increasing plant size and the curves are skewed to the right. This graphically confirms the limited downward risk in case of this policy.

4.3. How to actually implement an "ideal" price policy

Although the "ideal" price policy provides favourable results, the actual implementation of such policy would encounter various difficulties. Realistically, such policy could only be implemented with a limited time frame and probably also a limited share of the production capacity. Fixed prices are also prone to fraud by market actors. Taking these limitations into consideration, Figure 11 presents a possibility how an "ideally" fixed price policy could be implemented on a regional scale. The following bullet points provide some additional explanations:



Obligated parties
Obliged to fictitiously buy whole cellulosic ethanol production relative to their gasoline sales

Closest obligated parties
Obliged to buy whole production, but receive compensation for difference to actual required blending rate

Plant sells at market price to closest obligated parties → decreasing cost of transportation

Cellulosic ethanol plant
Obligation to produce at a rate of at least 90 percent of plant capacity and sell this ethanol at market prices; otherwise penalty payment
Regulation needs to guarantee that sufficient market demand (if supply > demand → higher blend rates to be required by regulation)
Does not influence market prices because delivering to closest obligated parties only
Ideally financed by regional community

If market price < "ideal" price
Obligated party needs to transfer difference to trustee

Trustee passes on potential compensation for higher ethanol consumption

Trustee passes on potential transfers from obligated party

If market price > "ideal" price
Cellulosic ethanol plant needs to transfer difference to trustee

Trustee:
Calculates "ideal" price and actually required blending rate considering total production of cellulosic ethanol (for instance in European Union)
If market price < "ideal" price:
- Transfers payments from obligated parties to cellulosic ethanol plant
- Transfers payments from fictitiously obligated parties to actually obligated parties
If market price > "ideal" price:
Invests potential transfers from cellulosic ethanol plant in previously defined projects (e.g. for renewable energy)
Advantage: predictable, stable energy costs

Figure 11 Possible implementation of the "ideal" price policy on regional scale

- The BCEP is obligated to sell all ethanol produced at market prices to the regionally closest obligated parties. By keeping the transportation distances small, the environmental impact should be minimised.
- All obligated parties in the territory where the obligation applies, e.g. the USA or the European Union, are obligated to buy all produced cellulosic ethanol at the monthly calculated "ideal" price. However, in order to minimise the impact of transportation, only the closest obligated parties physically blend the cellulosic ethanol. All other obligated parties transfer the difference between "ideal" price

and market price for their fictitious obligation to a governmental trustee. Of course, such transfers take place only if the “ideal” price is higher than the market price.

- The trustee passes on the transfers received from the obligated parties to the closest obligated parties as compensation for their higher blending obligation. The main part of the transfers goes to the BCEP respectively the investors.
- If the “ideal” price is lower than the market price, the BCEP is still obligated to sell all its production at market prices, but has to transfer the price difference back to the governmental trustee. These amounts are then used for a predefined regulatory measure, for instance the development of renewable energy.
- The underlying assumption is that cellulosic ethanol production is too small to influence the market prices of ethanol. As long as no market prices for the feedstock are observable it might be necessary to stick to the price movements of corn or grain as a proxy.

Ideally, the BCEP was financed by regional investors, in order to increase the regional awareness and acceptance of the plant. Also a financial involvement by the state is possible. For instance, the state could hold a minor equity stake with a golden share and sell the rest of the shares to institutional and local investors. The dividends received by the government could again be used for a predefined specific target. By doing so, a part of the future regulatory burden borne by society would be reused for public interests.

4.4. Conclusion

A model of a Biochemical Cellulosic Ethanol Plant (BCEP) uses Monte Carlo simulation of the main input and output factors to analyse the impact of various regulations. Its results show that non-pricing related regulations fail to improve the economic prospects of a BCEP. Only price-related regulations achieve a serious improvement of the economic key figures.[29] Of all price-related regulations, a specifically designed, “ideally” fixed price scheme works best. This “ideal” price policy consists of three price elements: the main component is a fixed price increasing linearly with inflation. Two smaller components follow the development of the gasoline price and the feedstock price respectively.

Although it might be difficult to implement such policy in the current economic and regulatory environment, this result entails important lessons for policy makers. Fixed price policies should be bound to a certain extent to the input prices. For instance, in case of the feed-in tariff system for photovoltaic installations, the price fixated at the onset of the project operating time, could be bound to the currently prevailing price for silicon or an average of this price over a certain period of time. Of course, this relationship does not necessarily have to be linear and can be capped so that it does not exceed a certain maximum allowance of subsidy payments.

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[29] A combination of non-price and price related regulations increases costs substantially whereas the improvement in economics is only marginal.

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