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Policy analysis of perennial energy crops cultivation at the farm level: the case of short rotation coppice (SRC) in Germany

Alisa Spiegel[1], Wolfgang Britz[1], Utkur Djanibekov[1], Robert Finger[2]

[1] *Institute for Food and Resource Economics, University of Bonn, Germany*

[2] *Agricultural Economics and Policy Group, ETH Zurich, Switzerland*

Editor: Thomas Heckelei

Institute for Food and Resource Economics

University of Bonn

Nußallee 21

53115 Bonn, Germany

Phone: +49-228-732332

Fax: +49-228-734693

E-mail: thomas.heckelei@ilr.uni-bonn.de

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Abstract

Perennial energy crops such as short rotation coppice (SRC) have gained interest among both farmers and policy makers. SRC is characterized by fast biomass production, low-input use and high managerial flexibility. In addition, SRC provides environmental benefits compared with competing crops and contributes to the transition process towards renewable energy sources. Yet, the combination of high irreversible costs and uncertainties hampers SRC adoption by farmers. Policy instruments that are currently implemented to foster SRC adoption in Germany show limited success. In this study, we therefore assess different policy measures to incentivize the adoption of SRC in terms of their efficiency and farm-level effect while taking into account uncertainties related to SRC cultivation. We use the combination of the stochastic programming and the real options approaches. Our case study focuses on poplar production in Germany. We analyse four policy measures to foster SRC cultivation, i.e. a planting subsidy, a price floor, a guaranteed price and increasing the "Ecological Focus Area" (EFA) weighting coefficient within the Common Agricultural Policy of the European Union. Our results show that the recently implemented planting subsidy could create incentives to adopt SRC by leading to a substantial increase in farm income. However, increasing the EFA coefficient and a price floor are more efficient in terms of governmental expenditures; while a guaranteed price triggers immediate introduction of SRC.

Keywords: biomass; policy regulation; stochastic programming; uncertainty

JEL classification: C63, Q12, Q15, Q18, Q28, Q42, Q48

1 Introduction

In the light of increasing global energy demand, non-fossil energy sources including bioenergy become of growing importance (Zeddies et al. 2012, p.7; Muehlenhof 2013, p.16). This is particularly the case for Germany, where the transition process towards renewable energy sources is strongly supported by legislative changes. In that so-called called Energiewende (Bundesregierung 2017a) biomass[1] is considered as one of the most important energy sources (Bundesregierung 2017b). However, existing biomass programs based on traditional field crops such as maize or rapeseed are found to have limited environmental benefits, while being costly in terms of governmental expenditures (e.g. Britz and Hertel 2011; Britz and Delzeit 2013). Therefore, short rotation coppice (SRC) has gained an interest as a source of biomass; with poplar cultivation being most popular in Germany (Hauk, Wittkopf, and Knoke 2014, p.406). SRC as a perennial crop provides environmental benefits compared to traditional arable field crops such as reduction of soil erosion, increase in biodiversity and landscape diversity (Rokwood 2014, pp.5–6). Using fast growing trees and being not clear-cut at harvest, SRC can be harvested several times with the intervals between two and five years[2] during its lifetime of about 20 years[3]. Additionally, SRC is usually harvested in winter season, when on-farm labour resources are more easily available. The main economic advantage of SRC is hence low competition with other crops for farm labour (Faasch and Patenaude 2012).

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[1] See Brosowski et al. (2016) for a comprehensive overview of potential and utilization of biomass in Germany.

[2] Flexibility in harvesting interval depends on the end product. We restrict ourselves to the most common end product in Germany, namely wood chips, and therefore to the harvesting interval from two to five years.

[3] According to the *Federal Forests Act* (1975), short rotation coppice or any perennial crop, rotated longer than 20 years and intended for logging, is recognized as forest, such that a re-conversion into farmland is legally complex.

However, German farmers do not plant SRC under current market conditions (Musshoff 2012; Schweier and Becker 2013; Kostrova et al. 2016). Considerable risks associated with SRC production due to volatile energy (i.e. output) prices combined with high irreversible planting and reconversion costs of SRC has been identified as major adoption hurdles (Hauk, Knoke, and Wittkopf 2014; Wolbert-Haverkamp and Musshoff 2014). As a result of limited economic attractiveness, SRC is cultivated only on about 5’000 hectares in Germany (Bemmann and Knust 2010), out of more than two Mio. hectares of potential area (Aust et al. 2014).

In order to increase the adoption of bioenergy crops by farmers, a large set of policy instruments have been proposed and discussed (see e.g. Mola-Yudego and Aronsson 2008; Faasch and Patenaude 2012; Hauk, Wittkopf, and Knoke 2014; Witzel and Finger 2016). However, despite the inability of current policies to foster larger area of SRC adoption, there exists no structured comparison of different policy instruments with regard to their performance (e.g. related governmental expenditures), outcome (e.g. energy output), and farm-level effects (e.g. on income). We aim to fill this research gap by using a farm-level analysis that assesses different policies to increase the adoption of SRC. We incorporate the importance of risks for farmers’ investment decisions into SRC using the combination of the real option and stochastic programming approaches. Our framework allows an analysis and comparison of policies across various dimensions, including additional bioenergy production, governmental expenditures and farmers’ incomes (based on Crabbé and Leroy (2012, p.5)). We use a case study in Mecklenburg – Western Pomerania (Germany), a region highly suitable for SRC cultivation and with large interest of policy makers to foster SRC adoption.

In order to identify the most promising policy measures, we conducted a review of studies on existing instruments supporting SRC and other perennial bioenergy crops as well as more generally policy measures reducing uncertainties hampering investment decisions of farmers. These policy measures can be classified into (i) cross-sector instruments such as taxation or quotas for fossil energy use (Mitchell

2000), (ii) investment in research (e.g. Witzel and Finger 2016), and (iii) farm-level policy measures. Our farm-scale analysis focuses on the latter because quantification of farm-level decisions and their impacts is the necessary basis for subsequent analysis at higher scale and across sectors. More specifically, we identify four relevant policy measures: (i) environmental requirements within the Common Agricultural Policy (CAP) of the European Union (e.g. Lindegaard et al. 2016), which favour SRC over conventional arable crops, (ii) planting subsidies, which were recently introduced in our study region (MLU-MV 2015), as well as (iii) guaranteed prices (Mitchell, Bauknecht, and Connor 2006; Feil, Mußhoff, and Roeren-Wiemers 2013) and (iv) price floors (Feil, Musshoff, and Balmann 2013) for SRC biomass.

The remainder of the article is structured as follows. Having described the methodological approach including an overview of the farm-level optimization model, data, and details of the analysed policy scenarios, we present the results and discuss them. Finally, policy conclusions are drawn.

2 Methodology and Data

2.1 *Characteristics of SRC and the resulting simulation model*

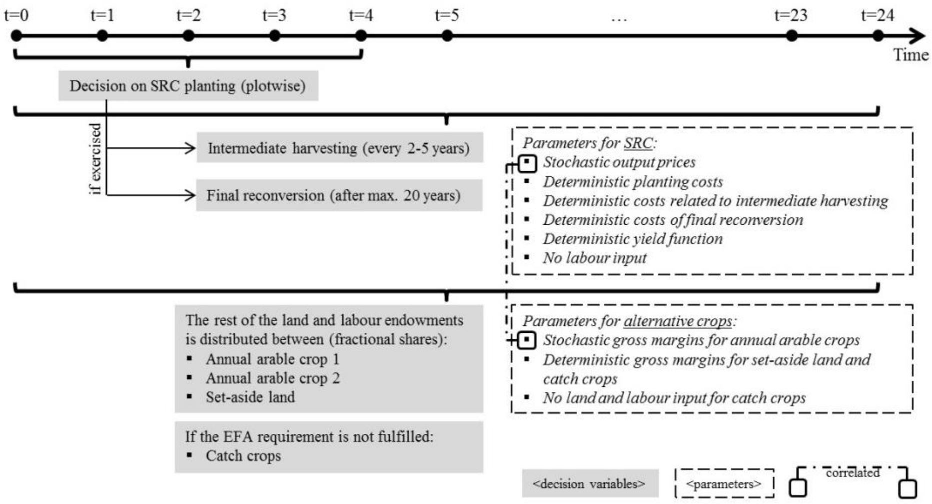
Short rotation coppice (SRC) is characterized by (i) partly irreversible costs of planting and harvesting; (ii) risks throughout the lifetime horizon; and (iii) temporal and spatial flexibility related to planting, harvesting and reconversion. These three aspects imply the existence of an option value, i.e. potential incentives of a farmer to wait and make an investment decision depending on the future states-of-nature (Pindyck 2004, p.199), which is captured by the real options theory. These conceptual advantages of the real options theory over the classical net present value approach for analysis of SRC adoption is also supported in the literature (Hauk, Knoke, and Wittkopf 2014; Fleten et al. 2016). However, the real options approach has been employed so far to analyse policy interventions supporting renewable energy on national level (Boomsma, Meade, and Fleten

2012; Haar and Haar 2017). In contrast, we simulate farm-level decisions related to SRC cultivation under different policy instruments.

Our analysis assumes a farmer managing land plots of predefined sizes that provide a total land endowment of 100 ha. The farmer decides about each plot whether to convert it into SRC. Hence, the land area under SRC is not fractional, but rather can be adjusted in a 5 ha step, i.e. 0, 5, 10, …100 ha. Planting of SRC on each plot is considered as an option that can be postponed for a maximum of three years or never exercised. Each harvesting can be conducted from two to five years after planting or latest harvesting. As mentioned above, the maximum age of a SRC plantation is legally restricted to 20 years, although an earlier reconversion back to annual crops is possible. The time horizon is therefore 24 years (Fig.1). Our model hence considers full managerial flexibility of SRC cultivation, i.e. (1) postponing the decision of setting up the plantation on each plot, (2) investing in different sized plantations by converting different plots, (3) reconversion of the plantation before the maximal age of the plantation is reached, and (4) flexible harvesting intervals.

Land not converted into SRC is devoted to alternative farm activities (as fractional shares). Constraints capture competition for land and labour endowments between SRC and alternative land uses: two annual crops, one of which is more labour intensive and more profitable, as well as set-aside land. The latter is introduced as an option to fulfil the “Ecological Focus Area” (EFA) requirements according to the latest Common Agricultural Policy reform. According to this requirement, large arable farms need to devote 5% of their farmland to EFA (BMEL 2015). Here, each hectare of set-aside land counts with a factor of 1. In contrast, SRC land or catch crops combined with arable crops are considered with a factor of 0.3 (BMEL 2015). However, since catch crops are planted in winter season (Pe’er et al. 2017, Table 1), they are assumed to not compete for land and labour with other crops. Figure 1 visualizes the competition of different farm activities in our model over the considered time horizon.

Figure 1: Overview of the dynamic farm-level model, included decision variables, and assumed parameters



As depicted in Figure 1, we assume that output prices of SRC and gross margins of arable crops are stochastic. For simplicity, we model only one stochastic process for the gross margin of arable crops based on a single mean-reverting process in natural logarithms. The simulated level for each node in the scenario tree is then modified with a simple fixed factor for each of the two crops. A correlation coefficient ρ between the price of SRC biomass and the gross margins of alternative crops enters the stochastic processes as follows (Schwartz and Smith 2000, p.896):

$$\begin{aligned} dP_t &= \mu_{SRC}(\theta_{SRC} - P_t)dt + \sigma_{SRC} dW_t^{SRC} \\ dGM_t &= \mu_C(\theta_C - GM_t)dt + \rho\sigma_C dW_t^{SRC} + \sqrt{(1-\rho^2)}\sigma_C dW_t^C \end{aligned} \quad (1)$$

where

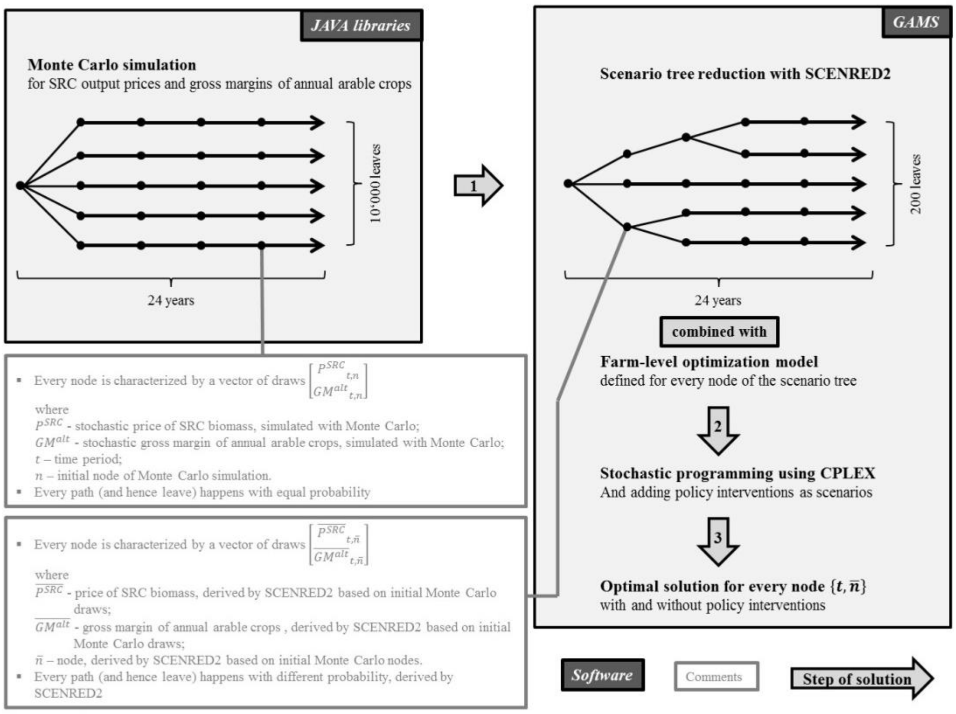
t – years
SRC – short rotation coppice
C – alternative crops (annual crops)
P_t – price of SRC biomass;
GM_t – gross margin of alternative crops;
μ_{SRC} and μ_C – speed of reversion of the stochastic process;
θ_{SRC} and θ_C – long-term average price of SRC biomass and gross margin of alternative crops respectively;

σ_{SRC} and σ_C – volatilities of SRC biomass price and gross margin of alternative crops respectively;
dW_t^{SRC} and dW_t^C – standard independent Brownian motions;
ρ – correlation coefficient between two Brownian motions.

The reason to consider a correlation between SRC biomass prices and gross margins of arable crops is twofold. On the one hand side, output prices for energy and food crops are positively correlated due to global competition for land and other inputs (Fritsche, Sims, and Monti 2010; Song, Zhao, and Swinton 2011, p.770). On the other hand side, prices for energy crops and costs of arable food crops cultivation are positively correlated as energy prices impact prices of intermediate inputs, especially diesel and agro-chemicals.

The simulation approach applied in our analysis consists of three steps. First, we simulate Monte-Carlo draws for the stochastic parameters, i.e. SRC biomass price and gross margins of alternative arable crops. The two stochastic processes yield for each draw both a SRC biomass price and a gross margin of alternative crops which are assigned to the nodes of the scenario tree (Fig. 2). Next, we reduce the obtained scenario tree using SCENRED2 (GAMS 2015) up to 200 leaves (Kostrova et al. 2016, pp.8–9) and combine it with the model described above (see Fig.1), assigned for every node of the reduced scenario tree. Note that every node of the reduced scenario tree is characterized by values for stochastic parameters and a probability of occurring; both result from scenario tree reduction. Finally, we solve the resulting stochastic dynamic problem in order to obtain the optimal solution with and without policy intervention (Fig.2). We use a mixed integer programming farm-level model due to various if-then type binary decisions in our problem. In order to avoid introducing in addition to binary variables also non-linearities, we treat land area under SRC as not fractional. The dynamic stochastic programming approach is solved simultaneously over 24 years, considering many different potential developments of prices for SRC and competing crops.

Figure 2. Solution approach step-by-step and employed software



2.2 *Case study and data*

Our case study is an exemplary farm in the German federal state Mecklenburg – Western Pomerania. Existing support for SRC planting in the region is threefold. First, SRC plantation is recognized as agricultural land and therefore granted with the so-called direct payments of the CAP[4]. Besides, SRC plantation can be recognized as "Ecological Focus Area" with a factor of 0.3. Third, since 2015 planting costs are subsidized.

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[4] Hence, in our settings the direct payments are applied to all of the competing crops and therefore do not influence the farmer's decision. In this regard, the direct payments are excluded from the model.

The mean-reverting process (MRP) for SRC biomass prices is adopted from Musshoff (2012). The parameters of the MRP for gross margins of alternative crops were estimated using data from the CAPRI (2017) model on gross margins of an average hectare of arable land in Germany in 1993-2012, following the procedure described in Musshoff and Hirschauer (2004, pp.271–273). Table 1 summarizes the two stochastic processes.

Table 1. Parameters of the two stochastic processes. Sources: Musshoff (2012), CAPRI (2017)

	Parameters of the mean-reverting process for	
	Natural logarithm of SRC biomass price	Natural logarithm of gross margins of annual crops
Starting value	3.92[a]	6.02[b]
Long-term mean	3.92[a]	6.02[b]
Speed of reversion	0.22	0.32
Standard deviation	0.22	0.28
MRP coefficient for a more labour intensive and more profitable crop		1.05
MRP coefficient for a less labour intensive and less profitable crop		0.95
Correlation coefficient between MRPs for SRC prices and gross margins of annual arable crops is +/- 0.20		

[a] Is equal to ca.50 euro per ton of dry matter yields (€/t DM)
[b] 413 euro per hectare (€/ha)

Note: the starting values are set up equal to the long-term mean, in order to exclude any possible effect of a trend.

There is no clear reference in the literature about the sign and the value of the correlation coefficient between the SRC biomass price and the gross margins of annual crops. We therefore consider both a positive and a negative correlation ρ of ± 0.2 (see Eq.1) between the two Brownian motions and compare the results (hereafter referred to as positive and negative correlations)[5]. The gross margins obtained from the respective stochastic process enter the model with the coefficients 1.05 for the more profitable crop and 0.95 for the other one. The gross margin of catch crops is assumed to be -100 €/ha (de Witte and Latacz-Lohmann 2014, p.37) and -50 €/ha for set-aside land (CAPRI 2017).

The yield function for SRC biomass is derived based on Ali (2009) as a linear function for biomass stock that depends on previous year's stock. The so-called harvesting cost function includes all the costs related to harvesting of SRC, e.g. transaction costs for finding a contractor, fertilization, and storing, and is expressed as a sum of (a) costs at farm (fixed) and (b) per plot (quasi-fixed) plus (c) costs per ton of harvested biomass (variable), in order to consider possible economy of scale (Pecenka and Hoffmann 2012; Schweier and Becker 2012). As explained above, the time horizon is 24 years. For simplicity, we assume risk neutrality[6] of the farmer and hence use a market discount rate of 3.87% (Musshoff 2012). We apply a zero social discount rate due to almost zero interest rates currently found in Germany such that governmental expenditures are not discounted. Table 2 summarizes the assumed parameters of the model.

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[5] The assumption is met based on the existing literature. Zilberman et al. (2012) concluded that the correlation between biofuels and commodity food crops is rather limited. Du, Yu, and Hayes (2011) quantified the correlation between volatilities in the world crude oil prices and futures prices of wheat (corn) as 0.09-0.27 (0.07-0.34). Musshoff and Hirschauer (2004) evaluated the correlation between the gross margins of non-food rapeseed and of alternative arable crops to be in the range from -0.01 to 0.65. Diekmann, Wolbert-Haverkamp, and Mußhoff (2014) assume a correlation coefficient between the gross margins of Miscanthus and wheat of 0.29.

[6] There are two crucial issues related to risk-adjusted discount rate if deviating from the assumption about risk neutrality. The first one refers to decreasing risk when approaching the final leaves of the scenario tree and hence different risk-adjusted discount rate for every time period and state-of-nature (Brandão and Dyer 2005). The other one implies application of different risk-adjusted discount rates to various risky farm activities (see e.g. Brandão and Dyer 2005; Finger 2016).

Table 2. Parameters of the simulation model.

Parameter	Units	Assumed value
Short-Rotation Coppice		
Planting costs	€ / ha	2875.00
Biomass growth function		
Multiplier for last year's biomass	-	1.54
Constant increase per year	t DM / ha	6.68
Costs related to harvesting of SRC		
Fixed costs a farm level	€	66.75
Quasi-fixed costs for each plot	€ / ha	272.13
Variable costs, depending on harvested quantity	€ / t DM / ha	10.67
Reconversion costs	€ / ha	1400.00
Density of trees	Number of trees / ha	9000
Labour requirements	Labour units / ha	0
Energy content	GJ / t DM	16.5
Alternative agriculture		
Deterministic gross margins from crops recognized as "Ecological Focus Area" (EFA)		
Set-aside land (EFA greening coefficient 1.0)	€ / ha	-50.00
Catch crops (EFA greening coefficient 0.3)	€ / ha	-100.00
Labour requirements[7]		
A more labour intensive and more profitable crop	Labour units / ha	5.32
A less labour intensive and less profitable crop	Labour units / ha	4.16
Set-aside land	Labour units / ha	1
Catch crops	Labour units / ha	0
Energy absorbed by annual arable crops	GJ / ha / year	40
Farm characteristics		
Land endowment[8]	ha	100
Step for adjusting SRC plantation (i.e. the size of the smallest plot)	ha	5
Labour endowment	Labour units	500
Real risk-free discount rate	%	3.87
Social discount rate	%	0.00

[7] Those include only field work and exclude management work, which is assumed to be limited per farm and hence have no effect on resources' distribution.

[8] The assumption is based on the statistical data, according to which 20% of agricultural farms in 2010 in Mecklenburg-Western Pomerania operated on an area of 50 to 200 Ha (Statistisches Amt Mecklenburg-Vorpommern 2016).

Sources: *Federal Forests Act* (1975); Fritsche, Sims, and Monti (2010); Song, Zhao, and Swinton (2011, p.770); Musshoff and Hirschauer (2004, pp.271–273); Musshoff (2012); Faasch and Patenaude (2012); Wolbert-Haverkamp (2012); Pecenka and Hoffmann (2012); Schweier and Becker (2012); Rottmann-Meyer and Kralemann (2012, p.6); Twidell and Weir (2015, chap. 9.6.4); BMEL (2015); Kuratorium für Technik und Bauwesen in der Landwirtschaft e.V. (2016); Statistisches Amt Mecklenburg-Vorpommern (2016); CAPRI (2017).

2.3 *Policy Scenarios*

In our analysis, we compare four policy instruments promoting SRC adoption in different intensities to a business-as-usual (BAU) scenario without policy interventions (Table 3 summarizes the analysed policy instruments and their intensities). The only policy in place in the BAU scenario is the EFA weighting coefficient of 0.3. Two of the policies – a planting subsidy and increasing the EFA weighting coefficient – are chosen as they already exist and are proposed in literature (MLU-MV 2015; Lindegaard et al. 2016). The remaining two – a price floor and a guaranteed price for SRC biomass – address SRC market risk discussed as a major adoption hurdle (Mitchell, Bauknecht, and Connor 2006; Feil, Musshoff, and Balmann 2013; Feil, Mußhoff, and Roeren-Wiemers 2013). Based on theoretical considerations and the existing literature, the policy instruments should impact SRC adoption as follows. Increasing the EFA weighting coefficient relaxes competition for land between SRC and alternative annual crops, hence lowering the opportunity costs of SRC cultivation (Dixit and Pindyck 1994, p.346). A planting subsidy decreases the sunk costs of the investment (Dixit and Pindyck 1994, pp.33–35), while a price floor increases the expected SRC price by removing downside risk (Feil and Musshoff 2013). A guaranteed price removes all price risks in SRC adoption and thus leaves only the gross margins of the alternative crops as stochastic variables in our model. That decreases incentives to wait and renders the model more similar to a classical net present value approach. Still, the stochastic gross margins of alternative annual crops impact opportunity costs of land and labour and thus might still trigger use of managerial flexibility related to SRC cultivation (Dixit and Pindyck 1994, pp.38–39).

Table 3. Policy instruments, their intensities and the related governmental expenditures chosen for the analysis.

		Intensities	Governmental expenditures	Schedule of policy support
BAU	EFA weighting coefficient [0;1]	0.3	-	-
Policy interventions	Increasing the EFA weighting coefficient, [0;1]	0.5; 0.7; 1.0	-	-
	Planting subsidy, euro per hectare (€/ha)	500; 1000; 1200; 1500	Planting subsidy times land area devoted to SRC.	Paid once SRC is introduced.
	Guaranteed price of SRC biomass, euro per ton of dry matter yields (€/t DM)	50; 55; 60	Difference between the guaranteed price and the market price times harvested SRC biomass.	Paid for each exercised harvesting.
	Price floor for SRC biomass, €/t DM	30; 40; 50	If the difference between the price floor and the market price is positive, than this difference times harvested SRC biomass; otherwise no governmental costs.	Paid for each exercised harvesting.

Where
BAU – business-as-usual (baseline scenario);
EFA – "Ecological Focus Area"

The EFA weighting coefficient considers a range starting from the currently granted support with a factor of 0.3 to a maximum of 1.0, i.e. to a point where one hectare of SRC would be treated equally to a hectare of set-aside land, in 0.1 steps. For the different intensities of the planting subsidies, we focus our assumptions on the existing support in the case study region. Specifically, if the total planting investment exceeds 7500 €, up to 40% of it and at most 10 hectares[9] are subsidized with 1200 euro per hectare (€/ha) in Mecklenburg – Western Pomerania (MLU-MV 2015). For simplicity we ignore any existing requirements and constraints for

[9] An additional requirement – min. 3000 trees per hectare (MLU-MV 2015).

the planting subsidy, but consider different subsidy amounts. Fixing the price as a support instrument makes only sense at or above the long-term price mean for SRC biomass used in our Monte-Carlo analysis (50 €/t DM), hence, we have chosen 50, 55 and 60 €/t DM as possible intensity. Similarly, if a price floor should reduce downside risk, it should be below the expected mean, hence, we have considered 30, 40 and 50 € / t DM in our analysis.

We assess the instruments based on the metrics proposed by Crabbé and Leroy (2012, p.5), i.e. (i) policy performance, expressed by governmental expenditures; and (ii) policy outcome, expressed by additional bioenergy produced at farm. In addition, we assess (iii) effect on farm income and (iv) how efficiently the governmental expenditures are transformed into additional farm income. While SRC biomass produced and farm profits are simulated directly by the model, governmental expenditures are calculated as follows (see Table 3). For a planting subsidy, the per hectare subsidy granted to the farmer is multiplied with the planted area. For a price floor, harvested SRC biomass is multiplied in each state-of-nature and year by the difference between the price floor and the market price, if the latter undercuts the floor. The latter condition is dropped for a guaranteed price such that expenditures at each node and in sum might be positive or negative. Finally, we assume no governmental expenditures for changing the EFA weighting coefficient.

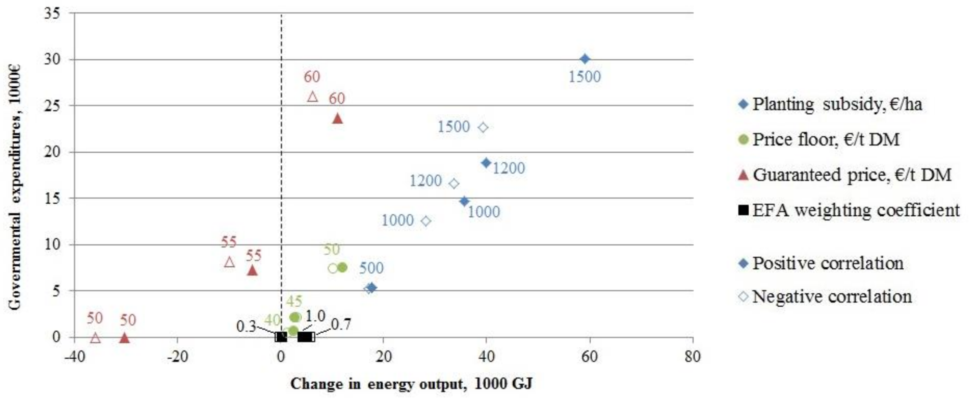
The effect on farm income is equal to the difference of the net present value of the overall farm with a policy instrument minus the net present value under the BAU scenario, i.e. no support besides the currently applied EFA coefficient of 0.3. The ratio between the absolute change in farm income and governmental expenditures provides the policy instrument's transfer efficiency, i.e. how much farm income is generated from each Euro of governmental expenditures. We further translate the harvested SRC biomass into bioenergy, expressed in gigajoules (GJ), subtracting the amount of GJ which annual crops would have provided if they were cultivated on the SRC area.

3 Results and discussion

Before analyzing policy instruments, the results obtained under the BAU scenario are worth additional comments. Assuming a positive correlation between SRC prices and the gross margin of alternative crops, the farmer adopts SRC under the BAU with an expected area of 5.6 ha (see Appendices A and B for an overview of the results expressed in expected values). Planting is not exercised immediately, but once the market conditions would be attractive enough to initiate planting, i.e. in later periods when the highest expected net returns can be generated. We find that with probability of 60.8% the farmer will introduce SRC in one to three years from the initial period. Thus, postponing the planting decision to receive new information on prices and gross margins is an important option for farmers, and hence the option value to wait is positive. Immediate introduction of SRC being not optimal is clearly one core reason for the observed reluctance of farmers towards SRC.

Results under the BAU, but also under the policy scenarios, are not overly sensitive with respect to the correlation coefficient between the price of SRC and the gross margin of alternative crops (see Fig.3). However, assuming a negative correlation coefficient, the use of SRC serves as a hedging strategy for the farmer and thus triggers slightly larger incentives towards SRC and a higher farm income (compare the BAU scenarios in Appendices A and B). Consequently, a guaranteed price, which removes that hedging effect, performs worse under the assumption of a negative correlation in contrast to the BAU case (Fig.3).

Figure 3. Efficiency of different policy instruments, in terms of expected average change in energy production and governmental expenditures.



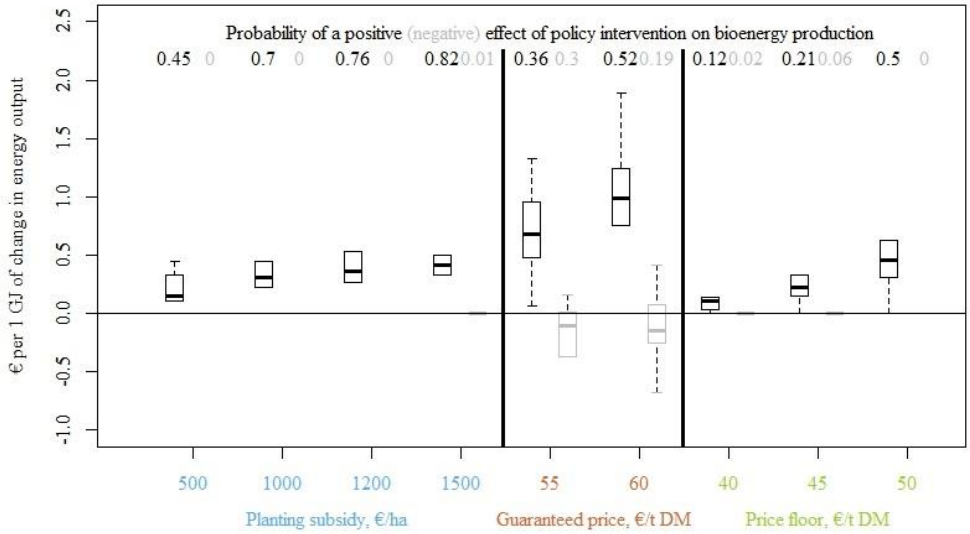
Note: Values show the change compared with the business-as-usual scenario, assuming positive or negative correlation between prices of biomass and gross margins of agricultural crops. The intensity of the policy instruments (see Table 3) is indicated next to the corresponding points.

Our results reveal that the performance of the policy instruments depends on their intensity and differs by metric. A planting subsidy leads to the highest expected average absolute increase in energy produced from biomass, while a guaranteed price of 50 or 55 €/t DM has a negative effect on expected energy production (Fig.3). The latter can be explained by the elimination of stochasticity of biomass prices. That reduces substantially managerial flexibility to adjust SRC plantation and harvesting depending on the states-of-nature. While a guaranteed price might accordingly seem to be the least efficient, it is the only policy instrument that initiates immediate introduction of SRC due to too low incentives to wait. A similar result was obtained by Boomsma, Meade, and Fleten (2012). In particular, comparing renewable energy certificate trading with the fixed feed-in tariff (i.e. a guaranteed price), they found out that a fixed price initiates earlier investment, yet of a smaller capacity. To this end, considering both fluctuations and expectations is essential for a proper policy analysis. Risk reducing policy instruments should differentiate impacts of down- and upside risk as well as aim at optimal intensity of risk reduction, in order to avoid potential negative effects on bioenergy production.

The effects on energy production of both higher EFA weighting coefficients (from 0.3 to up to 1) and of a price floor are rather limited (Fig.3). Yet, with no additional governmental costs, increasing the EFA weighting coefficient is an inviting policy measure. It brings set-aside land otherwise not used for biomass production into an extensive production system which is often depicted as beneficial for other ecosystem services such as bio-diversity. Also, increasing the EFA weighting coefficient is the sole instrument reducing land competition. Opportunity costs of land are essential for adoption of SRC, since, as mentioned above, SRC requires little farm labour and necessary operations in SRC can be conducted outside of typical labour peaks on farms. That removing with higher EFA weighting coefficients opportunity cost of land on a certain share of the farm has nevertheless a limited impact reflects the fact that the total EFA requirement for a farm is only 5%. Accordingly, even the maximal implicit support level for SRC reached with a factor of unity is equivalent to only 5% of SRC land use on total arable farmland[10]. Due to that limited effect on expected energy production and no additional governmental expenditures, increasing the EFA weighting coefficient could be efficiently combined with another policy instrument.

[10] Note that SRC cultivation on permanent grassland is unlikely as conversion of permanent grassland is in most regions either forbidden or restricted under the same law which governs the EFA requirement. To the extent where it is allowed, SRC would again compete directly with alternative land use on arable land.

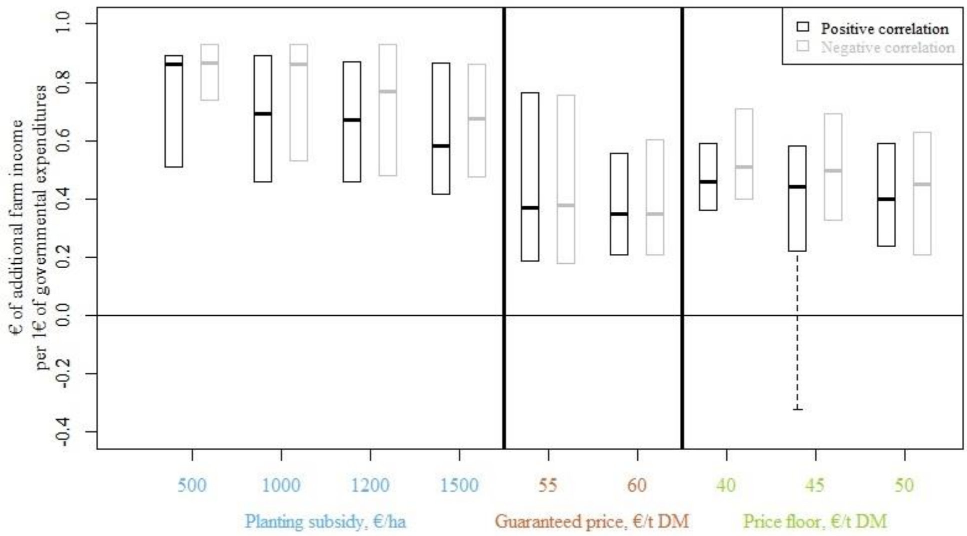
Figure 4. Governmental expenditures for change in energy production, compared with business-as-usual scenario, assuming positive correlation between prices of biomass and gross margins of agricultural crops.



Note: For each policy instrument and for each leave of the scenario tree, the total governmental expenditures are divided over the absolute difference in bioenergy production under this policy instrument compared with the business-as-usual case and are combined with the probability of the leave occurring. Outliers are omitted. Outliers are defined as the points lying outside 1.5*IQR (interquartile range) from the first and third quartiles.

The effect of a policy instrument on bioenergy production is not necessarily positive, but also might be zero or negative, depending on the state-of-nature. Guaranteed prices provide an example already discussed above by eliminating upside risk. Therefore we further compare the policy instruments in terms of governmental expenditures per additional GJ of bioenergy produced, distinguishing between positive and negative effects of every policy instrument on bioenergy production (Fig.4). Not considered are the EFA weighting coefficient as it does not provoke costs and a guaranteed price of 50 €/t DM where no SRC is planted. For all other instruments and intensity levels, less than 2€/GJ per additional bioenergy are spent (Fig.4). To compare, the German Renewable Energy Act requires governmental costs of 9.17 to 77.50 €/GJ for renewable energy from different sources (BMWE 2016, Table 4.2)[11]. A price floor of 40 or 45 €/t DM performs best (Fig.4), however, an increase in energy production only occurs with a low probability of 0.12 or 0.21 respectively. A planting subsidy of 500 €/ha requires comparable governmental costs per increase in energy production, while the probability of a success is at least twice as high (0.45).

Figure 5. Transformation of governmental expenditures into additional farm income, compared with business-as-usual scenario, assuming positive or negative correlation between prices of biomass and gross margins of agricultural crops.



Note: Outliers are omitted. Outliers are defined as the points lying outside 1.5*IQR (interquartile range) from the first and third quartiles.

While advantageous in terms of governmental expenditures, a price floor is however characterized by inefficient transformation of governmental expenditures into additional farm income (Fig.5). The same applies to a guaranteed price. In

[11] Calculated for the year 2013 by transformation of kilowatt-hours (KWh) into gigajoules (GJ).

contrast, a planting subsidy achieves up to 90% of transformation efficiency, meaning that the farmer gets 90 cents from each euro of governmental expenditures. That higher transformation efficiency of planting subsidy reflects also the difference between the individual and social discount rate. The latter is assumed to be zero such that any future discount factor is unity. A planting subsidy is paid in the year when the plantation is set up, in our analysis hence between the first and fourth years, such that the private discount factor is still close to unity and differs little from the social one. Price floors or guaranteed prices shift governmental costs and related income increases for farmers in the future with higher private discount factors, such that the difference between social and private discounting alone reduces the transformation efficiency of these policy instruments. That difference also implies that even a direct income transfer in the future cannot achieve a transfer efficiency of 100%.

Table 4 summarizes the policy instruments' performance based on different metrics. The guaranteed price is the least beneficial instrument in terms of all the metrics, being advantageous only as triggering immediate planting of SRC at high intensities (see Appendices A and B for details). The other three policy instruments perform well. Increasing the EFA weighting coefficient is very attractive due to no governmental expenditures, while being limited in terms of its effect on bioenergy production[12]. The same applies to a price floor. In contrast, a planting subsidy is

[12] Note that an EFA coefficient of 1.0 is less efficient, than the one of 0.7, in terms of its effect on bioenergy production and land area under SRC. This is caused by our assumptions on the total land endowment and on the available plots for introduction of SRC. Five percent of the total land endowment (i.e. five hectares in our case) should be devoted to the ecological focus area. Since the smallest plot is assumed to be of five hectares, devoting it alone to SRC fulfills the requirement under the EFA coefficient for SRC being 1.0. However, if the EFA coefficient is 0.7, ten hectares SRC would fulfill the requirement, while five hectares SRC being not enough. Hence, our assumption of potential land area under SRC being not continuous leads to the decreasing efficiency of increasing the EFA coefficient.

characterized by the largest effect on introduction of SRC and farm income. The efficiency of an investment subsidy over a price floor was also found by Feil and Musshoff (2013) and by Feil, Musshoff, and Balmann (2013), analysing effects of policy interventions on investment and disinvestment decisions of homogenous firms in a competitive environment.

Table 4. Overview of the expected policy instruments' performance compared with the business-as-usual scenario, assuming positive correlation between prices of biomass and gross margins of agricultural crops.

Policy intervention	Intensity	Performance of policy instruments (expected values compared with the BAU scenario)				
		Effect on bioenergy production, GJ	Governmental expenditures per 1 GJ of increase in bioenergy production, €/GJ	Effect on farm income, €	Increase in farm's income per 1 € of governmental expenditures, €	Effect on land area devoted to SRC, ha
Planting subsidy, €/ha	500	17689.22	0.20	3758.82	0.71	3.94
	1000	35697.37	0.39	9116.07	0.66	8.00
	1200	40008.32	0.41	11698.12	0.64	8.93
	1500	59152.11	0.44	16199.09	0.60	13.34
Guaranteed price, €/t DM	50	-30197.50	0.00	-8441.67	−∞*	-6.73
	55	-5414.20	0.70	-2830.71	0.29	-1.21
	60	10971.94	0.97	2826.29	0.51	2.45
Price floor, €/t DM	40	2509.05	0.11	110.74	0.78	0.58
	45	2711.58	0.25	248.55	0.50	0.60
	50	12073.17	0.48	2562.49	0.86	2.69
Increasing the EFA coefficient	0.5	4467.72	0.00	3534.75	+∞**	1.00
	0.7	5167.49	0.00	6865.08	+∞**	1.15
	1.0	435.11	0.00	11584.65	+∞**	0.10

* (**) The result comes from a negative (positive) change in bioenergy production compared with the business-as-usual scenario and no governmental costs.

Note: two best and two worst results are highlighted with green and red colours respectively.

A price floor also has other disadvantages. It requires that some government agency acts directly or indirectly as a buyer in markets. Furthermore, government expenditures cannot be planned in advance as the government takes over the price risk. Price floors can also trigger unwanted strategic decisions by market actors. Finally, the program must be maintained over the full lifetime of the subsidized plantations, while a planting subsidy can be granted for a limited number of years.

The disadvantages of a price floor hold even more for a fully guaranteed price, as it removes the benefits of managerial flexibility in SRC planting and harvesting as discussed above. However, both a price floor and a guaranteed price address market risk as a potential hurdle to adopt SRC plantation. For example, for other renewable sources (solar, wind, and biogas), the guaranteed input price under the German Renewable Energy Act has been found as highly relevant instrument to stipulate adoption (Mitchell, Bauknecht, and Connor 2006; Feil, Mußhoff, and Roeren-Wiemers 2013). However, in these cases, electricity was produced such that the legislation could set-up mechanisms to charge the costs of the program to the final electricity consumers. That was considered to be additionally beneficial as it raises the costs of electricity which can foster energy saving measures and help to reduce further the fossil energy use. Driving up final demand prices for woody biomass may not be an option, because the market for wood products such as heating with wood chips or non-traditional use of woody biomass needs to be developed in parallel to the primary production side (Rokwood 2014). Accordingly, both a price floor and guaranteed prices are hardly promising measures.

It is often argued that SRC requires coordinated action at regional scale (Rokwood 2014), for instance, to ensure that service contractors invest in quite expensive harvesting equipment and investors set-up processing facilities to produce wood chips from SRC biomass. The different actors of the not yet existing supply chain might be trapped in a kind of a prisoner’s dilemma as waiting can turn out as the optimal strategy for anybody. Farmers, to give an example, might not invest as they have no partners to market their products nor can hire contactors to harvest their plantations. Here, a regionalized planting subsidy might help to trigger the development of local supply chains. Also, a planting subsidy only granted for a limited period and/or on a first-come-first-serve basis increases the costs of waiting and initiates earlier introduction of SRC. A first-come-first-serve-basis allows furthermore setting an upper limit on maximal spent. It also does not require market interventions such as price floor. It might hence be seen as a complement to an increase of the EFA weighting factor.

4 Conclusion

SRC cultivation provides multiple environmental advantages and benefits to the transition process towards renewable energy. However, farmers' adoption of SRC is the crucial bottleneck from a policy maker's perspective. In particular, high sunk costs related to planting, harvesting, and final reconversion of SRC, as well as risk during the lifetime of a SRC plantation are crucial for this adoption decision. Our comparison of policy instruments based on a number of efficiency metrics, i.e. increase in produced bioenergy, effect on farm income and governmental expenditures, allows for a comprehensive analysis. Yet a final decision about policy measures and their intensity requires setting out priorities among these metrics which is beyond the scope of our paper.

We find the policy instruments' efficiency and performance to differ by intensity of the measures and metrics used to assess their effects. A low price floor is attractive due to low governmental expenditures per unit of additional bioenergy produced. However, its effect on absolute increase in bioenergy production is rather limited. Moreover, both a price floor and a guaranteed price are related to substantial transaction costs, such as involving the state as a trading agent or sustaining the regulation over the whole lifetime of a SRC plantation. A guaranteed price, overall the least efficient policy instrument, is advantageous only in triggering immediate introduction of SRC. A planting subsidy, recently introduced in our study area, is found to be indeed an effective policy instrument with regard to increased bioenergy production by reducing irreversible costs related to SRC planting and in terms of transfer efficiency. It turns one Euro of governmental expenditures into up to 90 cent of additional farm income. Generally, we found that farmers have high incentives to postpone the SRC planting decision due to the large uncertainties in the returns from this investment. Thus, the incentives to introduce SRC caused by a planting subsidy could be additionally increased if the total amount of subsidies is restricted or/and if it is granted for a limited period of time, i.e. if the option value to wait is reduced.

However, increasing the EFA weighting coefficient is superior because no governmental expenditures are required. Since the policy instrument only reduces the competition for land resources between SRC and annual crops, addressing neither sunk costs nor risk associated with SRC cultivation, it might be combined with other policy instruments, in order to achieve even larger positive effect. Overall, our results suggest that supporting SRC cultivation by the different policy instruments analyzed is a relatively cheap option to increase bioenergy production compared with the governmental costs for renewable energy from different sources currently required by the German Renewable Energy Act, while also leading to environmental benefits.

Our results also underline that taking into account uncertainties and their effect on investment decisions is essential for a proper policy analysis of perennial energy crops. As discussed on the example with a guaranteed price, neglecting fluctuations might obscure the effect of managerial flexibility on investment behavior. Although a high risk related to SRC cultivation is often discussed in the literature as one of the main factors preventing SRC, our results underline that upside risk for SRC can be beneficial if it can be exploited by managerial flexibility. Its reduction or complete elimination might hence lead to reduced planting of SRC.

This paper focuses on policy instruments targeted at farm level. Our findings improve understanding of farm-level decisions on SRC and can inform policy makers for a larger scale perspective. Expansions of the framework presented in here in various directions can be envisaged. First, the model can be further specified, e.g. introducing transaction costs of policy implementation. Second, the effect of risk preferences can be evaluated. Third, combinations of different policy instruments can be considered. Finally, the model results could be up-scaled and integrated into modelling efforts to quantify the effect of bioenergy policy on traditional agricultural crops and energy markets, including international trade.

References

Ali, W. 2009: Modelling of Biomass Production Potential of Poplar in Short Rotation Plantations on Agricultural Lands of Saxony, Germany. Technische Universität Dresden. http://www.qucosa.de/recherche/frontdoor/?tx_slubopus4frontend[id]=345.

Aust, C., J. Schweier, F. Brodbeck, U.H. Sauter, G. Becker, and J.-P. Schnitzler. 2014: Land Availability and Potential Biomass Production with Poplar and Willow Short Rotation Coppices in Germany. *GCB Bioenergy* 6 (5): 521–33. doi:10.1111/gcbb.12083.

Bemmann, A., and C. Knust. 2010: *Kurzumbetriebsplantagen in Deutschland und europäische Perspektiven*. Berlin, Germany: Weißensee Verlag. http://www.weissensee-verlag.de/autoren/Bemmann_159/Bemmann_159_kurz.pdf.

BMEL. 2015: EU-Agrarpolitik - FAQ zur Agrarreform und der nationalen Umsetzung. http://www.bmel.de/DE/Landwirtschaft/Agrarpolitik/_Texte/GAP-FAQs.html;jsessionid=0D73EAAFA1620445FB82F36E765C5694.2_cid296#doc4121226bodyText8.

Boomsma, T. K., N. Meade, and S.-E. Fleten. 2012: Renewable Energy Investments under Different Support Schemes: A Real Options Approach. *European Journal of Operational Research* 220 (1): 225–37. doi:10.1016/j.ejor.2012.01.017.

Brandão, L.E., and J.S. Dyer. 2005: Decision Analysis and Real Options: A Discrete Time Approach to Real Option Valuation. *Annals of Operations Research* 135 (1): 21–39. doi:10.1007/s10479-005-6233-9.

Britz, W., and R. Delzeit. 2013: The Impact of German Biogas Production on European and Global Agricultural Markets, Land Use and the Environment. *Energy Policy* 62 (November): 1268–75. doi:10.1016/j.enpol.2013.06.123.

Britz, W. and T.W. Hertel. 2011: Impacts of EU Biofuels Directives on Global Markets and EU Environmental Quality: An Integrated PE, Global CGE Analysis. *Agriculture, Ecosystems & Environment*, 142 (1–2): 102–9. doi:10.1016/j.agee.2009.11.003.

Brosowski, A., D. Thrän, U. Mantau, B. Mahro, G. Erdmann, P. Adler, W. Stinner, G. Reinhold, T. Hering, and C. Blanke. 2016: A Review of Biomass Potential and Current Utilisation – Status Quo for 93 Biogenic Wastes and Residues in Germany. *Biomass and Bioenergy* 95 (December): 257–72. doi:10.1016/j.biombioe.2016.10.017.

Bundesregierung. 2017a: Energiewende im Überblick. Accessed January 17. https://www.bundesregierung.de/Content/DE/StatischeSeiten/Breg/Energiekonzept/0-Buehne/ma%C3%9Fnahmen-im-ueberblick.html.

———. 2017b: Bioenergie. Accessed January 17. https://www.bundesregierung.de/Webs/Breg/DE/Themen/Energiewende/ErneuerbareEnergien/bioenergie/_node.html.

CAPRI. 2017: Common Agricultural Policy Regionalized Impact (CAPRI) Modelling System. Accessed January 25. http://www.capri-model.org/dokuwiki/doku.php?id=start.

Crabbé, A., and P. Leroy. 2012: *The Handbook of Environmental Policy Evaluation*. Earthscan.

Diekmann, A., M. Wolbert-Haverkamp, and O. Mußhoff. 2014: Die Bewertung der Umstellung einer einjährigen Ackerkultur auf den Anbau von Miscanthus: Eine Anwendung des Realoptionsansatzes. Working Paper 1406. Diskussionspapiere, Department für Agrarökonomie und Rurale Entwicklung. https://www.econstor.eu/handle/10419/97613.

Dixit, A.K., and R.S. Pindyck. 1994: *Investment Under Uncertainty*. Princeton University Press.

Du, X., C.L. Yu, and D.J. Hayes. 2011: Speculation and Volatility Spillover in the Crude Oil and Agricultural Commodity Markets: A Bayesian Analysis. *Energy Economics* 33 (3): 497–503. doi:10.1016/j.eneco.2010.12.015.

Faasch, R.J., and G. Patenaude. 2012: The Economics of Short Rotation Coppice in Germany. *Biomass and Bioenergy* 45 (October): 27–40. doi:10.1016/j.biombioe.2012.04.012.

Federal Forests Act. 1975. *BWaldG*. http://www.gesetze-im-internet.de/bwaldg/.

Feil, J.-H., and O. Musshoff. 2013: Modelling Investment and Disinvestment Decisions under Competition, Uncertainty and Different Market Interventions. *Economic Modelling* 35 (September): 443–52. doi:10.1016/j.econmod.2013.07.026.

Feil, J.-H., O. Musshoff, and A. Balmann. 2013: Policy Impact Analysis in Competitive Agricultural Markets: A Real Options Approach. *European Review of Agricultural Economics* 40 (4): 633–58. doi:10.1093/erae/jbs033.

Feil, J.-H., O. Mußhoff, and T. Roeren-Wiemers. 2013: Einzelbetriebliche Auswirkungen Politischer Reformen in Der Landwirtschaft: Erste Empirische Erkenntnisse. *Zeitschrift Für Politikberatung (ZPB) / Policy Advice and Political Consulting* 6 (3/4): 159–66.

Finger, R. 2016: Assessment of Uncertain Returns from Investment in Short Rotation Coppice Using Risk Adjusted Discount Rates. *Biomass and Bioenergy* 85 (February): 320–26. doi:10.1016/j.biombioe.2015.12.028.

Fleten, S.-E., K. Linnerud, P. Molnár, and M. Tandberg Nygaard. 2016: Green Electricity Investment Timing in Practice: Real Options or Net Present Value? *Energy* 116, Part 1 (December): 498–506. doi:10.1016/j.energy.2016.09.114.

Fritsche, U.R., R. E.H. Sims, and A. Monti. 2010: Direct and Indirect Land-Use Competition Issues for Energy Crops and Their Sustainable Production – an Overview. *Biofuels, Bioproducts and Biorefining* 4 (6): 692–704. doi:10.1002/bbb.258.

GAMS. 2015: GAMS Documentation 24.6; Tools; Data Transformation; SCENRED2. http://www.gams.com/latest/docs/tools/scenred2/index.html.

Haar, L.N., and L. Haar. 2017: An Option Analysis of the European Union Renewable Energy Support Mechanisms. *Economics of Energy & Environmental Policy* 6 (1). doi:10.5547/2160-5890.6.1.lhaa.

Hauk, S., T. Knoke, and S. Wittkopf. 2014: Economic Evaluation of Short Rotation Coppice Systems for Energy from biomass—A Review. *Renewable and Sustainable Energy Reviews* 29 (January): 435–48. doi:10.1016/j.rser.2013.08.103.

Hauk, S., S. Wittkopf, and T. Knoke. 2014: Analysis of Commercial Short Rotation Coppices in Bavaria, Southern Germany. *Biomass and Bioenergy* 67 (August): 401–12. doi:http://dx.doi.org/10.1016/j.biombioe.2014.05.027.

Kostrova, A., W. Britz, U. Djanibekov, and R. Finger. 2016: Monte-Carlo Simulation and Stochastic Programming in Real Options Valuation: The Case of Perennial Energy Crop Cultivation. *Agricultural and Resource Economics, Discussion Paper* 2016 (3). http://purl.umn.edu/250253.

Kuratorium für Technik und Bauwesen in der Landwirtschaft e.V. 2016: Leistungs-Kostenrechnung Pflanzenbau. Database. http://daten.ktbl.de/dslkrpflanze/postHv.html#Ergebnis.

Lindegaard, K.N., P.W.R. Adams, M. Holley, A. Lamley, A. Henriksson, S. Larsson, H.-G. von Engelbrechten, G.E. Lopez, and M. Pisarek. 2016: Short Rotation Plantations Policy History in Europe: Lessons from the Past and Recommendations for the Future. *Food and Energy Security* 5 (3): 125–52. doi:10.1002/fes3.86.

Mitchell, C. 2000: The England and Wales Non-Fossil Fuel Obligation: History and Lessons. *Annual Review of Energy and the Environment* 25 (1): 285–312. doi:10.1146/annurev.energy.25.1.285.

Mitchell, C., D. Bauknecht, and P.M. Connor. 2006: Effectiveness through Risk Reduction: A Comparison of the Renewable Obligation in England and Wales and the Feed-in System in Germany. *Energy Policy*, 34 (3): 297–305. doi:10.1016/j.enpol.2004.08.004.

MLU-MV. 2015: *Richtlinie zur Förderung von Investitionen landwirtschaftlicher Unternehmen zur Diversifizierung*. http://www.landesrecht-mv.de/jportal/portal/page/bsmvprod.psml?doc.id=VVMV-VVMV000007610&st=vv&showdoccase=1&paramfromHL=true#focuspoint.

Mola-Yudego, B., and P. Aronsson. 2008: Yield Models for Commercial Willow Biomass Plantations in Sweden. *Biomass and Bioenergy* 32 (9): 829–37. doi:10.1016/j.biombioe.2008.01.002.

Muehlenhof, J. 2013: Anbau von Energiepflanzen. Umweltauswirkungen, Nutzungskonkurrenzen und Potenziale. Report. April. http://www.unendlich-viel-energie.de/media/file/166.65_Renews_Spezial_Energiepflanzen_apr13.pdf.

Musshoff, O. 2012: Growing Short Rotation Coppice on Agricultural Land in Germany: A Real Options Approach. *Biomass and Bioenergy* 41 (June): 73–85. doi:10.1016/j.biombioe.2012.02.001.

Musshoff, O., and N. Hirschauer. 2004: Optimization Under Uncertainty with Stochastic Simulation and Genetic Algorithms – Case Study for a Crop Farm in Brandenburg. *Agrarwirtschaft* 53 (7): 264–79.

Pecenka, R., and T. Hoffmann. 2012: Harvest Technology for Short Rotation Coppices and Costs of Harvest, Transport and Storage. *Agronomy Research* 13 (2): 361–71.

Pe'er, G., Y. Zinngrebe, J. Hauck, S. Schindler, A. Dittrich, S. Zingg, T. Tscharntke, et al. 2017: Adding Some Green to the Greening: Improving the EU's Ecological Focus Areas for Biodiversity and Farmers. *Conservation Letters*. Accessed February 22. doi:10.1111/conl.12333.

Pindyck, R.S. 2004: Irreversibility, Uncertainty, and Investment. In *Real Options and Investment Under Uncertainty: Classical Readings and Recent Contributions*, 871. London, england: MIT Press.

Rokwood. 2014: Findings of the SWOT Analysis." Centre for Sustainable Energy. http://rokwood.eu/public-library/public-project-reports/send/5-public-project-reports/19-findings-of-the-swot-analysis-rokwood.html.

Rottmann-Meyer, M.-L., and M. Kralemann. 2012: Holzpellets, Hackschnitzel Und Stückholz - Fachinformationen Für Verbraucher." 3N-Kompetenzzentrum Niedersachsen Netzwerk Nachwachsende Rohstoffe e. V. http://3-n.info/media/4_Downloads/pdf_WssnSrvc_Srvc_Fstbrnnstff_3NHolzbroschuere_1210.pdf.

Schwartz, E., and J.E. Smith. 2000: Short-Term Variations and Long-Term Dynamics in Commodity Prices. *Management Science* 46 (7): 893–911. doi:10.1287/mnsc.46.7.893.12034.

Schweier, J., and G. Becker. 2012: New Holland Forage Harvester's Productivity in Short Rotation Coppice: Evaluation of Field Studies from a German Perspective. *International Journal of Forest Engineering* 23 (2): 82–88. doi:10.1080/14942119.2012.10739964.

———. 2013: Economics of Poplar Short Rotation Coppice Plantations on Marginal Land in Germany. *Biomass and Bioenergy* 59 (December): 494–502. doi:10.1016/j.biombioe.2013.10.020.

Song, F., J. Zhao, and S.M. Swinton. 2011: Switching to Perennial Energy Crops Under Uncertainty and Costly Reversibility. *American Journal of Agricultural Economics* 93 (3): 768–83. doi:10.1093/ajae/aar018.

Statistisches Amt Mecklenburg-Vorpommern. 2016: Statistic database. http://www.statistik-mv.de/cms2/STAM_prod/STAM/de/ep/Regionaldaten%2c_Datenbanken/index.jsp.

Twidell, J., and T. Weir. 2015: *Renewable Energy Resources*. Routledge.

de Witte, T., and U. Latacz-Lohmann. 2014: Was Kostet Das Greening? *Topagrar*, 4/2014 edition.

Witzel, C.-P., and R. Finger. 2016: Economic Evaluation of Miscanthus Production – A Review. *Renewable and Sustainable Energy Reviews* 53 (January): 681–96. doi:10.1016/j.rser.2015.08.063.

Wolbert-Haverkamp, M.. 2012: Miscanthus Und Pappelplantagen Im Kurzumtrieb Als Alternative Zum Klassischen Ackerbau — Eine Risikoanalyse Mittels Monte-Carlo Simulation.

Wolbert-Haverkamp, M., and O. Musshoff. 2014: Are Short Rotation Coppices an Economically Interesting Form of Land Use? A Real Options Analysis. *Land Use Policy* 38 (May): 163–74. doi:10.1016/j.landusepol.2013.10.006.

Zeddies, J., E. Bahrs, N. Schoenleber, and W. Gamer. 2012: Globale Analyse Und Abschätzung Des Biomasse-Flächennutzungspotentials. Report. August. https://www.uni-hohenheim.de/i410b/download/publikationen/Globale%20Biomassepotenziale%20_%20FNR%2022003911%20Zwischenbericht%202012.pdf.

Zilberman, D., G. Hochman, D. Rajagopal, S. Sexton, and G. Timilsina. 2012: The Impact of Biofuels on Commodity Food Prices: Assessment of Findings. *American Journal of Agricultural Economics*, June, aas037. doi:10.1093/ajae/aas037.

Appendices

Appendix A. Overview of the results assuming the correlation coefficient between prices of SRC biomass and gross margins of annual crops being equal to +0.2

Policy intervention	BAU	Planting subsidy, €/ha				Guaranteed price, €/t DM			Price floor, €/t DM			Increasing the EFA coefficient		
Intensity		500	1000	1200	1500	50	55	60	40	45	50	0.5	0.7	1.0
Farm income (net present value over 24 years), 1000 €														
Max	932.431	967.189	1001.946	1015.849	1036.704	856.853	856.771	860.971	932.431	932.431	932.431	932.431	932.431	932.431
Expected	643.002	646.761	652.118	654.700	659.201	634.561	640.172	645.829	643.113	643.251	645.565	646.537	649.867	654.587
Min	500.708	500.708	502.589	502.589	502.589	500.708	509.937	511.988	500.708	500.708	503.513	502.589	503.602	508.843
Probability of planting SRC														
Immediately	0.00	0.00	0.00	0.00	0.00	0.00	1.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00
In one year	0.19	0.27	0.34	0.37	0.47	0.00	0.00	0.00	0.25	0.30	0.38	0.29	0.43	0.48
In two years	0.21	0.32	0.30	0.32	0.29	0.00	0.00	0.00	0.18	0.16	0.28	0.26	0.30	0.29
In three years	0.21	0.22	0.25	0.25	0.21	0.00	0.00	0.00	0.26	0.26	0.34	0.26	0.25	0.21
Never	0.39	0.19	0.11	0.06	0.03	1.00	0.00	0.00	0.31	0.28	0.00	0.19	0.01	0.02
Land under SRC, ha														
Max	75.00	75.00	75.00	75.00	75.00	0.00	15.00	15.00	75.00	75.00	75.00	75.00	75.00	75.00
Expected	5.61	8.90	12.24	13.04	16.60	0.00	4.60	7.65	6.08	6.11	7.85	6.44	6.57	5.69
Min	0.00	0.00	0.00	0.00	5.00	0.00	5.00	5.00	0.00	0.00	5.00	0.00	0.00	0.00
SRC bioenergy production, GJ														
Max	339424.91	339424.91	339424.91	339424.91	339424.91	0.00	67884.98	67884.98	339424.91	339424.91	339424.91	339424.91	339424.91	339424.91

Expected	30466.78	48313.74	66484.29	70832.32	90152.39	0.00	25004.30	41536.56	32998.89	33202.54	42647.61	34974.34	35680.35	30905.77
Min	0.00	0.00	0.00	0.00	16971.25	0.00	22628.33	22628.33	0.00	0.00	22628.33	0.00	0.00	0.00
Change in bioenergy production compared with BAU, GJ (including energy absorbed by annual arable crops)														
Expected	-	17689.22	35697.37	40008.32	59152.11	-30197.50	-5414.20	10971.94	2509.05	2711.58	12073.17	4467.72	5167.49	435.11
Age of SRC plantation, years														
Expected	20.00	20.00	19.98	19.98	19.91	0.00	20.00	20.00	19.92	20.00	20.00	20.00	20.00	20.00
Expected area under alternative crops, ha														
More profitable arable crop	83.93	83.79	81.71	81.77	78.68	80.01	89.86	88.12	84.59	84.96	87.42	86.17	88.34	87.22
Less profitable arable crop	8.79	6.03	5.00	4.21	3.83	17.21	4.53	3.60	7.81	7.48	3.79	6.19	4.12	6.53
Set-aside	1.67	1.27	1.05	0.98	0.89	2.79	1.00	0.63	1.53	1.45	0.94	1.19	0.97	0.55
Catch crops	6.83	6.42	6.05	5.66	5.44	7.38	8.74	6.90	6.84	7.06	7.06	4.32	2.78	1.16
Total governmental expenditures, €														
Max	0.00	37500.00	75000.00	90000.00	112500.00	0.00	74993.40	99825.67	9935.02	17620.94	43334.95	0.00	0.00	0.00
Expected	0.00	5337.75	14735.50	18795.00	30104.25	0.00	7323.19	23672.29	592.38	2118.48	7549.51	0.00	0.00	0.00
Min	0.00	0.00	0.00	0.00	7500.00	0.00	-42384.29	-91348.48	0.00	0.00	0.00	0.00	0.00	0.00
Governmental expenditures per 1 GJ of increase in bioenergy production compared with BAU, €/GJ (only states-of-nature with increase in bioenergy included)														
Max	-	0.45	0.89	1.07	1.00	0.00	1.33	1.89	0.39	0.70	1.18	-	-	-
Expected	-	0.20	0.39	0.41	0.44	0.00	0.70	0.97	0.11	0.25	0.48	-	-	-
Min	-	0.11	0.22	0.27	0.33	0.00	-0.05	-1.13	0.00	0.00	0.00	-	-	-

Appendix B. Overview of the results assuming the correlation coefficient between prices of SRC biomass and gross margins of annual crops being equal to -0.2

Policy intervention	**BAU**	**Planting subsidy, €/ha**				**Guaranteed price, €/t DM**			**Price floor, €/t DM**			**Increasing the EFA coefficient**		
Intensity		**500**	**1000**	**1200**	**1500**	**50**	**55**	**60**	**40**	**45**	**50**	**0.5**	**0.7**	**1.0**
Farm income (net present value over 24 years), 1000 €														
Max	830.556	862.941	895.327	908.281	927.712	832.519	833.697	837.897	830.556	830.556	831.752	835.066	835.066	851.629
Expected	643.462	647.205	652.233	654.884	658.771	636.230	641.841	647.701	643.290	644.439	646.115	647.490	650.052	655.820
Min	497.914	497.914	493.233	494.092	495.381	495.122	502.246	516.402	497.914	496.994	500.742	492.957	496.976	503.370
Probability of planting SRC														
Immediately	0.00	0.00	0.00	0.00	0.00	0.00	1.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00
In one year	0.23	0.20	0.30	0.35	0.35	0.00	0.00	0.00	0.20	0.23	0.43	0.25	0.36	0.42
In two years	0.20	0.29	0.28	0.30	0.32	0.00	0.00	0.00	0.22	0.25	0.26	0.30	0.32	0.34
In three years	0.27	0.25	0.27	0.30	0.28	0.00	0.00	0.00	0.29	0.34	0.30	0.33	0.32	0.22
Never	0.31	0.25	0.14	0.04	0.06	1.00	0.00	0.00	0.29	0.17	0.01	0.13	0.00	0.02
Land under SRC, ha														
Max	75.00	75.00	75.00	75.00	75.00	0.00	15.00	15.00	75.00	75.00	75.00	75.00	75.00	75.00
Expected	5.98	8.73	10.50	11.53	12.56	0.00	4.80	7.90	6.24	6.50	7.97	7.09	7.20	6.25
Min	0.00	0.00	0.00	0.00	0.00	0.00	5.00	5.00	0.00	0.00	0.00	0.00	5.00	0.00
SRC bioenergy production, GJ														
Max	339424.91	339424.91	339424.91	339424.91	339424.91	0.00	67884.98	67884.98	339424.91	339424.91	339424.91	339424.91	339424.91	339424.91
Expected	32498.80	47415.40	57032.44	62642.00	68232.33	0.00	26045.20	42916.89	33867.82	35303.58	43273.85	38486.26	39101.75	33915.34
Min	0.00	0.00	0.00	0.00	0.00	0.00	22628.33	22628.33	0.00	0.00	0.00	0.00	22628.33	0.00
Change in bioenergy production compared with BAU, GJ (including energy absorbed by annual arable crops)														

Expected	-	14750.91	24179.95	29747.53	35147.42	-32180.86	-6354.62	10380.74	1346.89	2783.74	10676.90	5957.26	6570.35	1435.39
Age of SRC plantation, years														
Expected	20.00	20.00	20.00	19.97	19.99	0.00	20.00	20.00	19.93	19.96	19.91	20.00	19.97	20.00
Expected area under alternative crops, ha														
More profitable arable crop	84.63	82.92	82.98	83.49	82.41	80.20	89.79	87.97	84.77	86.09	86.99	86.54	87.97	86.99
Less profitable arable crop	7.78	6.88	5.24	3.99	4.04	16.94	4.44	3.52	7.44	6.08	4.04	5.21	3.82	6.15
Set-aside	1.60	1.47	1.28	0.98	0.99	2.86	0.98	0.61	1.56	1.34	1.00	1.17	1.01	0.62
Catch crops	7.21	6.68	6.24	6.13	5.56	7.14	8.61	6.73	7.15	7.40	7.33	4.22	2.62	0.90
Total governmental expenditures, €														
Max	0.00	37500.00	75000.00	90000.00	112500.00	0.00	83059.97	105891.24	8076.75	16771.97	32327.14	0.00	0.00	0.00
Expected	0.00	5238.50	12602.00	16624.20	22622.25	0.00	8210.59	25989.43	442.85	2079.53	7392.52	0.00	0.00	0.00
Min	0.00	0.00	0.00	0.00	0.00	0.00	-38837.36	-50795.99	0.00	0.00	0.00	0.00	0.00	0.00
Governmental expenditures per 1 GJ of increase in bioenergy production compared with BAU, €/GJ (only states-of-nature with increase in bioenergy included)														
Max	-	0.33	0.67	0.81	1.01	0.00	106.68	115.14	4.44	4.88	1.16	-	-	-
Expected	-	0.21	0.36	0.40	0.49	0.00	2.81	3.26	0.31	0.27	0.43	-	-	-
Min	-	0.11	0.22	0.27	0.33	0.00	-127.78	-0.51	0.00	0.00	0.00	-	-	-