POLICY ANALYSIS OF PERENNIAL ENERGY CROPS CULTIVATION AT THE FARM LEVEL: THE CASE OF SHORT ROTATION COPPICE IN GERMANY

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Abstract

Perennial energy crops, in particular short rotation coppice (SRC), have gained an interest among both farmers and policy makers. SRC is characterized by fast growing nature, low-input production and managerial flexibility. In addition, SRC provides environmental benefits compared with competing crops and is essential for the transition process towards renewable energy sources. Yet, the combination of high irreversible costs and uncertainties hampers SRC adoption by farmers. Currently implemented policy instruments have failed to foster SRC adoption. Although a number of policy instruments have been discussed in the literature, there is a lack of studies providing a comprehensive policy analysis. We contribute filling this gap by assessing different policies in terms of their efficiency and farm-level effect, using the real options theory and hence taking into account uncertainties related to SRC cultivation. In particular, we analyse four policy instruments toward SRC cultivation, such as a planting subsidy, a price floor, a fixed price, and increasing the "Ecological Focus Area" weighting coefficient. Our results show that the recently implemented planting subsidy could indeed create incentives to adopt short rotation coppice by causing a substantial increase in farm income. However, the other policy instruments are more efficient in terms of their effect on biomass production and related governmental expenditures. We conclude increasing the "Ecological Focus Area" weighting coefficient to be the most promising instrument.

Keywords

Biomass, policy regulation, real options, stochastic programming, uncertainty

1 Introduction

In the light of increasing global energy demand, non-fossil energy sources including bioenergy become of great importance in various countries (ZEDDIES et al. 2012:7). This is particularly the case for Germany, where the transition process towards renewable energy sources is called Energiewende (BUNDESREGIERUNG 2017b), in the context of which biomass is considered as the most important energy source (BUNDESREGIERUNG 2017a). However, existing biomass programs based on traditional field crops are found to provide limited (if at all) environmental benefits, while being expensive (e.g. BRITZ and HERTEL (2011); BRITZ and DELZEIT (2013)). Therefore, short rotation coppice (SRC) has gained an interest as a source of biomass; the most popular one in Germany is poplar (HAUK, WITTKOPF, and KNOKE 2014:406). 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 2014:5–6). Using fast growing trees and being not clear-cut, SRC can be harvested several times with the intervals between two and five years[1] during its lifetime of up to 20 years[2]. Additionally, SRC is usually harvested in winter season, when the labour resources are not binding. Based on that management flexibility, the main economic advantage of SRC is low competition with other crops for farm labour (FAASCH and

[1] 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.

[2] 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.

PATENAUDE 2012). However, SRC is not attractive for farmers under current German market conditions (see e.g. 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 hurdle (HAUK, KNOKE, and WITTKOPF 2014; WOLBERT-HAVERKAMP and MUSSHOFF 2014). As a consequence of limited attractiveness, in Germany only about 5'000 hectares are currently cultivated (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 different policy instruments have been either introduced or discussed in the literature (see e.g. MOLA-YUDEGO and ARONSSON (2008); FAASCH and PATENAUDE (2012); HAUK, WITTKOPF, and KNOKE (2014); WITZEL and FINGER (2016) for overviews and examples). Despite the potential relevance of SRC and the inability of current policies to foster large scale SRC adoption, there is a lack of studies presenting structured comparisons of the effectiveness, efficiency and farm-level effects (e.g. on income) of different policies. In this paper, we aim to contribute filling this research gap. To this end, a farm-level analysis that accounts for the effects of uncertainties on farmers' investment decision using real option theory is used to assess different policies to increase the adoption of SRC. We present a unique framework which allows an analysis and comparison of policies across various dimensions, such as SRC production, governmental expenditures and farmers' income. We use a case study in Mecklenburg – Western Pomerania (Germany), a region highly suitable of SRC cultivation and with large interest of policy makers to foster SRC adoption.

In order to identify most promising policy measures to be included in our analysis, we used a literature review to identify existing instruments for SRC and other perennial bioenergy crops and policy measures that are suitable to reduce the uncertainties hampering the investment decisions of farmers. These policy measures can be classified into large scale policies that target the economy at large, e.g. the taxation of (MOLA-YUDEGO and ARONSSON 2008) and the quota for fossil energy sources (MITCHELL 2000), or investment in research (e.g. WITZEL and FINGER 2016), or policies that are targeted at the farm-level. Our analysis focusses on the latter. A better understanding of farm-level decisions and policy effects can contribute to improve large scale models in subsequent steps. A set of four policy measures has been identified: (i) environmental requirements (e.g. LINDEGAARD et al. 2016), (ii) planting subsidies (currently introduced in Germany (e.g. MLU-MV 2015)), (iii) guaranteed prices (MITCHELL, BAUKNECHT, and CONNOR 2006; FEIL, MUßHOFF, and ROEREN-WIEMERS 2013), and (iv) price floors (FEIL, MUSSHOFF, and BALMANN 2013).

The remainder of the article is structured as follows. First, the methodological approach including the farm-level optimization model and the specifics of the policy scenarios used are described. Second, the case study and data used are sketched. Third, results are presented and discussed. Fourth, policy conclusions are drawn.

2 Methodology

We simulate farm-level decisions related to SRC cultivation under different policy instruments, using the mixed integer linear programming farm-level model of SRC planting and cultivation developed by KOSTROVA et al. (2016). Based on real options analysis, it combines Monte-Carlo simulation, a scenario tree reduction technique and stochastic programming. The model is advantageous, because it considers the full managerial flexibility of SRC cultivation and takes into account farm-level land and labour endowments and constraints, as well as interaction of SRC with competing crops. It depicts three alternative land use activities besides SRC: two annual crops, one of which is more labour intensive and also more profitable, and set-aside land. The latter is introduced to fulfil the so-called

"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, for which SRC is eligible in Germany with a factor of 0.3 (BMEL 2015). Set-aside land is treated as risk-free while SRC cultivation faces stochastic output prices for SRC.

Besides introducing the four policy instruments, we modify the basic model by considering not only stochastic SRC output prices, but also stochastic gross margins for annual crops due to price and yield variability. 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 (see e.g. SCHWARTZ and SMITH (2000:896)):

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

where
P_t – price of SRC biomass in the period t;
GM_t – gross margin of alternative crops in the period t;
μ_{SRC} and μ_C – speed of reversion of the respective 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 these two Brownian motions.

The two stochastic processes yield for each draw both a SRC biomass price and gross margin of alternative crops which are assigned to the nodes of the scenario tree. The tree is next reduced with SCENRED2 (GAMS 2015).

In our analysis, we compare four policy measures promoting adoption of SRC in different intensities to a business-as-usual (BAU) scenario without policy interventions besides 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. The remaining two – a price floor and a fixed price for SRC biomass – address SRC market risk discussed as a major adoption hurdle.

In order to assess the instruments, SRC biomass produced and farm profits are simulated by the model, while governmental expenditures are defined as follows. For a planting subsidy, the per hectare subsidy is multiplied with the expected planted area. For a price floor, expected harvested SRC biomass is multiplied by the difference between the price floor and the market price, if the latter undercuts the floor. The latter condition is dropped for a fixed floor such that expenditures might be positive or negative. Finally, we assume no governmental expenditures for changing the EFA weighting coefficient. The effect on the farm income is equal to the difference of the net present value of the overall farm with a policy instrument, compared with the net present value under the BAU scenario. The absolute[3] difference between a change in farm income and the respective governmental expenditures provides the policy instrument's transfer efficiency, i.e. how much farm income is generated from governmental expenditures. Note that a policy instrument might be applied not regularly and to different land areas; hence, for the sake of clarity we leave all the metrics as total values, i.e. related to the whole farm for the overall time horizon and the total farmland area.

[3] Due to no governmental expenditures related to increasing the EFA weighting coefficient, relative difference would have deteriorated the comparison of transfer efficiency between different policy instruments.

We assess the instruments based on the metrics proposed by CRABBÉ and LEROY (2012:5), i.e. (i) policy performance, expressed by governmental expenditures; (ii) policy outcome, expressed by additional farm income; and (iii) produced SRC biomass, as well as (iv) land area devoted to SRC. In addition, we check (v) how efficient the governmental expenditures are transformed into additional farm income.

3 Case Study and Data

Our case study is a 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 is therefore granted with the direct payments[4]. Besides, SRC plantation can be recognized as “Ecological Focus Area” with a factor of 0.3, as mentioned above. While the first two support instruments are national ones, the third one, namely (partly) subsidized planting costs, is only found in some federal states and applied since 2015. Specifically, if the total planting investment exceeds 7500 €, up to 40% of it and at most 10 hectares[5] are subsidized with 1200 euro per hectare (€/ha) (MLU-MV 2015). For the sake of simplicity we model the planting subsidy per hectare of SRC plantation without any other requirements and constraints. However, we check different subsidy amounts which could result from additional constraints. Table 1 summarizes the policy instruments and their intensities that are chosen for the analysis.

Table 1: Policy instruments and their different intensities chosen for the analysis

	Intensities
The EFA weighting coefficient [0;1]	0.3; 0.4; 0.5
Planting subsidy, euro per hectare (€/ha)	500; 1000; 1200; 1500
Fixed price of SRC biomass, euro per ton of dry matter yields (€/t DM)	50; 55; 60
Price floor for SRC biomass, €/t DM	30; 40; 50

The mean-reverting process (MRP) for SRC biomass prices is adopted from MUSSHOFF (2012**)** (as cited in KOSTROVA et al. 2016). The parameters for gross margins MRP were estimated using the data from the CAPRI (2017) model for gross margins of arable land in Germany in 1993-2012 and following the procedure described in MUSSHOFF and HIRSCHAUER (2011:271–273). Table 2 summarizes the two stochastic processes.

Table 2: Parameters of the two stochastic processes.

	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]	6.50[c]
Long-term mean	3.92[b]	6.02[d]
Speed of reversion	0.22	0.32
Standard deviation	0.22	0.28

[a] Is equal to ca.50 euro per ton of dry matter yields (€/t DM)
[b] 50 €/t DM
[c] 663 euro per hectare (€/ha)
[d] 413 €/ha

Source: MUSSHOFF (2012) (as cited in KOSTROVA et al. (2016)), CAPRI (2017)

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

Taking into account that energy crops compete with alternative crops for agricultural land (FRITSCHE, SIMS, and MONTI 2010; SONG, ZHAO, and SWINTON 2011:770)[6], we assume a positive correlation ρ of 0.2 (see Eq.1) between the two Brownian motions. The gross margins obtained from the respective stochastic process enter the model with the coefficients 1.1 for the more profitable crop and 0.9 for the less profitable one.

Moreover, we assume having 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 10 ha step, i.e. 0, 10, 20, …100 ha. Planting of SRC can be postponed for maximum of four years or never exercised. Each harvesting can be exercised from two to five years after planting or latest harvesting. The maximum age of SRC plantation is restricted by 20 years, although an earlier reconversion back to annual crops is possible. The time horizon is therefore 24 years (see KOSTROVA et al. (2016) for details). For the sake of simplicity we assume risk neutrality of the farmer and hence use a market discount rate of 3.87% (MUSSHOFF 2012 (as cited in KOSTROVA et al. 2016)). Following the procedure suggested by KOSTROVA et al. (2016:8–9), we select 200 final leaves in the scenario tree as a trade-off between speed and accuracy.

4 Results and discussion

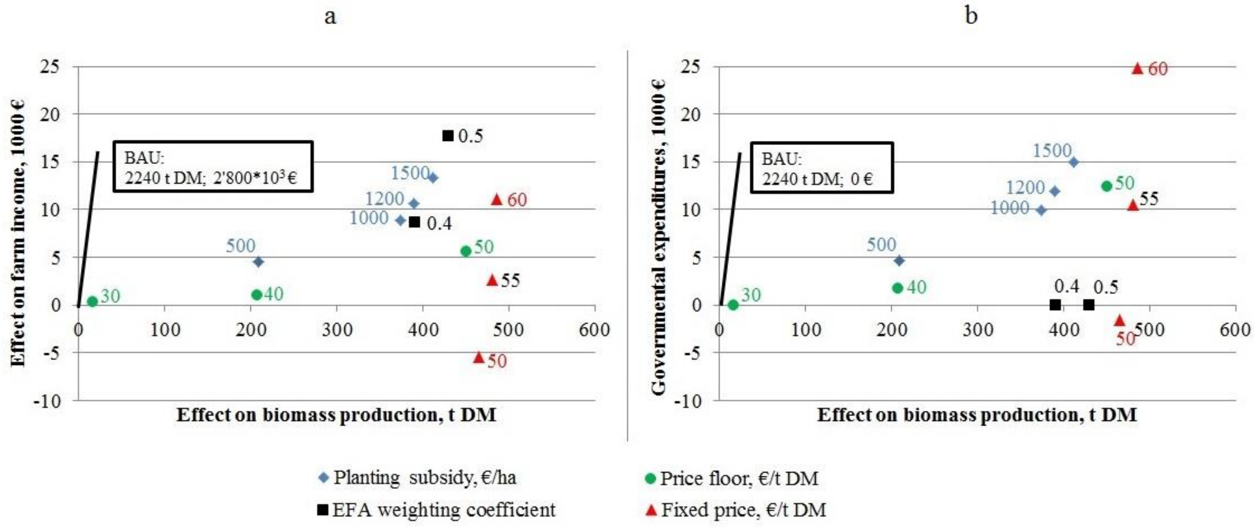
Preceding the analysis of the policy instruments, the results obtained under the BAU scenario are worth additional comments. Although the farmer seems to adopt SRC (expected area under SRC is 7.1 ha), planting is not exercised immediately, but once the market conditions would be favourite enough to initiate planting, i.e. in later periods. Those favourite market conditions do not happen with probability of 15%. With the remaining 85% the farmer will introduce SRC in one to three years from now, i.e. the decision is postponed. This is crucial for further understanding. Operating in the stochastic environment, we provide the expected outcomes, while the actual behaviour and effects of policy instruments depend on the state-of-nature.

The results reveal that policy instruments’ performance differs by intensity and metric how the policy effects are measured. A fixed price and increasing the EFA weighting coefficient show a rather non-elastic response to biomass production when they are increased (Figure 1). In contrast, a planting subsidy and a price floor have an elastic effect: even a rather moderate adjustment of those policy measures can provoke larger differences in biomass production. For instance, a price floor of 50 €/t DM has one of the largest positive effect on expected biomass production, while a 30 €/t DM has the smallest one. Comparing the policy instruments in terms of their effect on farm income, a planting subsidy and increasing the EFA weighting coefficient are the most efficient (Figure 1a). The income effect of a price floor is weaker for the same increase in biomass production. A fixed price is the only policy measure with a potential negative effect on farm income by eliminating not only downward, but also upward price risk. As real option analysis considers management flexibility, income gains from an upward price movement are systematically higher than income losses from downward movements of the same size. A fixed price of 50 €/t DM, which is equal to both the starting value and the long-term mean of the respective mean-reverting process, does not influence the price expectation, but eliminates any price risk related to SRC cultivation. The option value to wait related to SRC depends now only on the remaining stochastic process for gross margins of annual crops and turns to be zero. This leads to immediate introduction of SRC and no benefits from managerial flexibility. Note that management flexibility does not only relate to postponed planting or earlier re-conversion, but also to adjusting the harvesting period to expected prices. The negative effect on farm income of a fixed price is stronger than

[6] There is no clear reference in the literature about the sign and the value of the correlation coefficient between SRC biomass price and gross margins for annual crops.

some limited government gains (Figure 1). 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 farm income or unnecessary government spending.

Figure 1. Effect of different policy instruments on farm income (a), governmental expenditures (b), and biomass production, compared with the business-as-usual (BAU) scenario. The intensity of each policy measure is indicated next to the corresponding points.

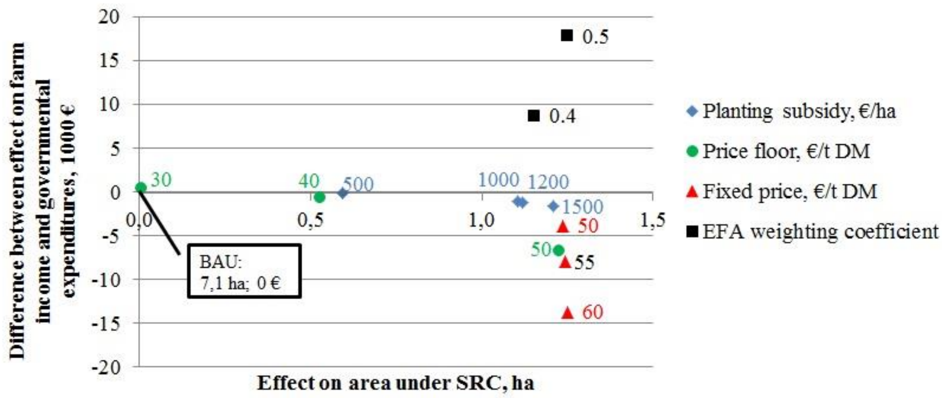


With no additional governmental costs, increasing the EFA weighting coefficient is a quite inviting measure. It brings set-aside land otherwise not used for biomass production into an extensive production system which is often depicted as beneficial for other ecosystem services such as bio-diversity. Our analysis suggests that already considering 0.5 ha of SRC land equivalent to 1 ha set-aside has the largest impact on farm income and also leads to one of the highest increases in biomass output compared to any other considered measure at any intensity level. These positive effects are linked to the fact that competition for land is reduced when the EFA weighting factor is increased. Furthermore, as stated above, SRC requires little farm labour, while, necessary operations in SRC can be conducted outside of typical labour peaks on farms. SRC production hence has a minor if at all impact on labour competition on farm, such that indeed mostly land competition matters. Here, the other policy instruments perform worse than EFA as they require more arable land for SRC. Hence, under these instruments, the manifold disadvantages found for the first generation biofuels or biogas production from silage maize would also hold to a large degree for SRC. Larger EFA weighting coefficients can reduce these impacts; a factor of unity (not considered in here) would remove them fully.

If increasing the EFA coefficient is not possible, a price floor requires less budget compared to a planting subsidy to stipulate the same increase in SRC biomass produced. But a price floor also leads to lower additional farm income. That effect increases if a higher increase in biomass is targeted (Figure 2). Clearly, a price floor 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 and such policy can affect strategic decisions by market actors. Not at least, the program must be maintained over the full lifetime of the subsidized plantations.

The disadvantages of a price floor hold even more for a fully fixed price, which is additionally characterized by low transfer efficiency, as it removes the benefits of managerial flexibility in SRC planting and harvesting as discussed above. However, both a price floor and a fixed 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 prices under the German Renewable Energy Act has been found a 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 legislation could set-up mechanisms to charge the costs of the program to the final electricity consumers. That was thought as additionally beneficial as it raises the costs of electricity which can foster energy saving measures and help to reduce fossil energy use further. Driving up final demand prices for woody biomass would not make sense, as 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 (see e.g. ROKWOOD 2014). Accordingly, both a price floor and fixed prices are hardly promising measures, especially given past experiences with guaranteed prices for agricultural outputs.

Figure 2. Effect of different policy measures on expected area under SRC and the difference between the effects on the farm income and governmental expenditures, compared with the business-as-usual (BAU) scenario. The intensity of each policy measure is indicated next to the corresponding points.



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 planting subsidy might help if it is only granted for a limited period and/or on a first-come-first-serve basis to increase the costs of waiting. A first-come-first-serve-basis allows furthermore setting an upper limit on maximal spent. It is 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.

5 Conclusion

SRC provides multiple environmental advantages and benefits to the transition process towards renewable energy, while affecting the farm income. Comparing policy instruments based on a number of efficiency metrics provides a comprehensive analysis, yet the final decision about policy regulation and its intensity requires determining relative weights for the metrics, i.e. setting out priorities among increase in produced biomass and additional land area, effect on farm income, and governmental expenditures. Determining a trade-off between the requirements and causes of policy regulation is allied to the issue of societal aims, which is beyond the focus of the paper.

We find the policy instruments' efficiency and performance to differ by intensity of the measures and metrics used to assess their effects. Putting the focus on area under SRC and produced biomass, a high price floor and a fixed price are the most efficient instruments. However, both have a low or even negative effect on additional farm income. Moreover, a price floor and a fixed 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. Also, taking into account the previous experience, both instruments are rather not promising. A planting subsidy is indeed an effective policy instrument in terms of its effect on both biomass production and farm income due to reduction of irreversible costs related to SRC planting. This hints that the planting subsidy, recently introduced in some German federal states, can create additional incentives for farmers to adopt SRC. 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. However, increasing the EFA weighting coefficient up to 0.4 would have led to a similar effect on farm income and biomass production without any governmental expenditures. In general, increasing the EFA weighting coefficient is identified as the best option. More specifically, it implies zero governmental costs, the largest positive effect on farm income, and a substantial increase in biomass production. Since the policy instrument only reduces the competition for land resources between SRC and annual crops, addressing neither the sunk costs nor the risk associated with SRC cultivation, it might be combined with other policy instruments, in order to achieve even larger positive effect.

Our results also show that taking into account uncertainties and their effect on investment decisions is essential for a proper policy analysis of perennial energy crops. As was demonstrated in the example with a fixed price, neglecting fluctuations might obscure the effect of managerial flexibility on farm behaviour and income. Although a high risk related to SRC cultivation is often discussed in the literature as one of the main factors preventing SRC, our results show that the risk can increase the temporal flexibility in managing the SRC, while its complete elimination might lead to a lower farm income.

This paper focuses on policy instruments targeted at the farm level. Our findings contribute to understand the farm behaviour and can be used for policy analysis on a larger scale. Future research hence might be conducted in multiple directions. 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. Next, the model can be extended to a macro-level, quantifying the effect of bioenergy policy on traditional agricultural crops and on energy market, as well as analysing interregional policy regulation. Finally, alternative renewable (bio)energy sources can be compared with SRC in terms of their response to policy instruments.

References

AUST, C., SCHWEIER, J, BRODBECK, F., SAUTER, U. H., BECKER, G., and SCHNITZLER, J.-P. (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 KNUST, C. (2010). Kurzumbetriebsplantagen in Deutschland und europäische Perspektiven. Berlin, Germany: Weißensee Verlag.

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. (Last access: 17.01.2017)

BRITZ, W., and DELZEIT, R. (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 HERTEL, T.W. (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.

BUNDESREGIERUNG. (2017a). Bioenergie. https://www.bundesregierung.de/Webs/Breg/DE/Themen/Energiewende/ErneuerbareEnergien/bioenergie/_node.html. (Last access: 17.01.2017)

———. (2017b). Energiewende im Überblick. https://www.bundesregierung.de/Content/DE/StatischeSeiten/Breg/Energiekonzept/0-Buehne/ma%C3%9Fnahmen-im-ueberblick.html. (Last access: 17.01.2017)

CAPRI. (2017). Common Agricultural Policy Regionalized Impact (CAPRI) Modelling System. http://www.capri-model.org/dokuwiki/doku.php?id=start. (Last access: 25.01.2017)

CRABBÉ, A., and LEROY, P. (2012). The Handbook of Environmental Policy Evaluation. London, UK: Earthscan.

FAASCH, R. J., and PATENAUDE, G. (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). http://www.gesetze-im-internet.de/bwaldg/. (Last access: 30.03.2015)

FEIL, J.-H., MUSSHOFF, O., and BALMANN, A. (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., MUßHOFF, O., and ROEREN-WIEMERS, T. (2013). Einzelbetriebliche Auswirkungen Politischer Reformen in Der Landwirtschaft: Erste Empirische Erkenntnisse. Zeitschrift Für Politikberatung / Policy Advice and Political Consulting 6 (3/4): 159–66.

FRITSCHE, U. R., SIMS, R. E. H., and MONTI, A. (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). http://www.gams.com/latest/docs/tools/scenred2/index.html. (Last access: 25.01.2017)

HAUK, S., KNOKE, T., and WITTKOPF, S. (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., WITTKOPF, S., and KNOKE, T. (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., BRITZ, W., DJANIBEKOV, U., and FINGER, R. (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. (Last access: 17.01.2017)

LINDEGAARD, K. N., ADAMS, P. W. R., HOLLEY, M., LAMLEY, A., HENRIKSSON, A., LARSSON, S., VON ENGELBRECHTEN, H.-G., LOPEZ, G. E., and PISAREK, M. (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., BAUKNECHT, D., and CONNOR, P. M. (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.

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.

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. (Last access: 17.01.2017)

MOLA-YUDEGO, B., and ARONSSON, P. (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. http://www.unendlich-viel-energie.de/media/file/166.65_Renews_Spezial_Energiepflanzen_apr13.pdf. (Last access: 09.02.2015)

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 HIRSCHAUER, N. (2011). Optimization Under Uncertainty with Stochastic Simulation and Genetic Algorithms – Case Study for a Crop Farm in Brandenburg. SSRN Scholarly Paper ID 1931559. Rochester, NY: Social Science Research Network. https://papers.ssrn.com/abstract=1931559. (Last access: 19.01.2017)

ROKWOOD. (2014). Findings of the SWOT Analysis. http://rokwood.eu/public-library/public-project-reports/send/5-public-project-reports/19-findings-of-the-swot-analysis-rokwood.html. (Last access: 17.01.2017)

SCHWARTZ, E., and SMITH, J. E. (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 BECKER, G. (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., ZHAO, J., and SWINTON, S. M. (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.

WITZEL, C.-P., and FINGER, R. (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., and MUSSHOFF, O. (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., BAHRS, E., SCHOENLEBER, N., and GAMER, W. (2012). Globale Analyse Und Abschätzung Des Biomasse-Flächennutzungspotentials. https://www.uni-hohenheim.de/i410b/download/publikationen/Globale%20Biomassepotenziale%20_%20FNR%2022003911%20Zwischenbericht%202012.pdf. (Last access: 09.02.2015)