Economies of Scope in the Agricultural Provision of Ecosystem Services:
A Swiss Case Study

Huber R.[1]

[1] ETH Zurich (Swiss Federal Institute of Technology), Agri-food and Agri-Environmental Economics Group, Switzerland

Abstract— **The purpose of this paper is to evaluate the jointness between agricultural production and ecosystem services using a spatial explicit economic-ecological programming model. Thereby, the consideration of non-agricultural competitors in the provision of ecosystem services allows a simultaneous assessment of economies of scope. A cost-effectiveness analysis for a case study region in Switzerland shows the least costs supplier of ecosystem services and spatial patterns in the supply for these services. Results imply strong jointness between agricultural production and the provision of ecosystem services. However, the potential for cost savings is considerable.**

Keywords— **Economies of Scope, Jointness, economic-ecological programming model**

I. INTRODUCTION

Agriculture produces both commodity and non-commodity outputs. Some of the latter exhibit the characteristics of externalities or public goods [1]. Ecosystem services (ES), such as climate regulation, wildlife conservation or preservation of open space, are an important type of public goods provided by agriculture [2]. Agricultural production can be complementary to, or compete against, environmental services and is often associated with a bundle of multiple positive and negative services (cf. [3][4]). In addition, the jointness between agriculture and ecosystem services is often based on a combination of different sources and cannot be attributed solely to technical interdependencies, non-allocable inputs or allocable fixed inputs. Thus, interactions between agriculture and ecosystem services are complex. Moreover, societal demand varies in space and time even within small regions [5]. This makes a sound analysis of the joint production between agriculture and ecosystem services difficult.

In recent years, several studies investigated the jointness between agricultural production and non-commodity outputs (for an overview: Hodge [6]). However, the modelling of interactions between different environmental non-commodity outputs from an applied perspective is missing [6].

Therefore, the purpose of this paper is to evaluate the jointness between agricultural production and ecosystem services using a spatial explicit economic-ecological programming model. Thereby, the consideration of non-agricultural competitors in the provision of ecosystem services allows a simultaneous assessment of economies of scope. A cost-effectiveness analysis for a case study region in Switzerland shows the least costs supplier of ecosystem services and spatial patterns in the supply for these services.

The existence of societal demand for a certain environmental benefit is a "first order condition" throughout the analysis of economies of scope [2]. Given society's demand, economies of scope represent a framework in order to reveal the least cost supplier of this service.

II. PROBLEM STATEMENT

The OECD framework regards the concept of economies of scope as a policy oriented indicator for the jointness between agricultural production and positive environmental goods and services [7]. Economies of scope occur when the production of two or more products jointly is less costly than the sum of the costs of producing each product individually. According to the concept of the OECD, three steps are necessary to identify economies of scope in agricultural provision of ES: a) assessment whether the provision of ecosystem services can be de-linked from agricultural production; b) if de-linkage is possible, the associated costs must be estimated; and c) these costs must be compared to the cost of agricultural joint provision.

Three main problems emerge from this approach: Firstly, the underlying jointness between agricultural production and ecosystem services is currently disguised by existing support. The extent of agriculture's contribution to ecosystem services in an unsupported situation is unknown and cannot be evaluated empirically. However, economic assessment of jointness requires a reference to this basic situation in order to evaluate efficient provision schemes. Otherwise, the connection between agricultural production and ES may be (over-) underestimated. Therefore, the analysis is based on an agricultural sector supply model using normative scenario techniques (cf. [8]). In relation to property rights, a situation without support refers to the counterfactual position [6]: farmers will select type and intensity of their farming systems in the absence of agricultural policies. Thus, farmers have the right to produce irrespectively of society's demand for public goods. Starting from this outcome, farmers are forced to provide ES (or avoid negative impacts on ES) and can be remunerated for these efforts.

Secondly, alternative providers of ecosystem services are currently still strongly related to agriculture. However, due to the recent development of new technologies in modern biomass conversion, industrial bio-energy production emerges as a new form of land-use. The production of bio-energy thereby obtains a new dimension: instead of competing with fossil resources, non-agricultural bio-energy producers could compete with multifunctional agriculture in the provision of ecosystem services [9]. In this study, the focus lies on the production of electricity through biogas plants in combination with a biorefinery which produces insulation material.

Thirdly, the main advantage of agriculture may lie in providing several ecosystem services simultaneously [10]. Simply adding up the costs for providing ecosystem services based on separate evaluations can result in misleading results. Therefore, an integrated modelling approach is needed which combines economic activities with environmental outcomes.

Above all, spatial differences in demand and supply of ecosystem services play an important role in the assessment of jointness. The spatial distribution of ecosystem services and of returns for competing land-uses are essential when modeling the supply of ecosystem services [11]. In this applied case study, the

assessment of economies of scope in the agricultural provision of ecosystem services is conducted with a spatial explicit sectoral supply model, focusing on the following questions:

- What consequences can be expected for agricultural production in Switzerland given a large reduction in support?
- What costs are associated with higher levels of ecosystem services in a specific Swiss region?
- Given an industrial bio-energy production representing a non-agricultural provision of ecosystem services, how do agricultural economies of scope change when subject to higher prices for bio-energy?

III. METHODOLOGY

A. Economic-ecological Model

For this research question the agricultural allocation model S_INTAGRAL was adapted, which was originally developed for the economic evaluation of carbon sequestration potentials, agricultural GHG mitigation strategies and nitrogen reduction potentials ([12][13][14]). S_INTAGRAL is a recursive-dynamic linear optimization model which maximizes the aggregate annual income (labour income plus land rents) of Swiss agriculture under consideration of cropping constraints, plant nutrient requirements, manure production, forage and fertilizer balances, as well as structural constraints. The model includes all important activities with regard to income generation, land-use, livestock, agricultural bio-energy production, as well as GHG and nitrogen emissions.

The base model was originally divided into three major production zones (plains, hills and mountain area) and distinguishes between land suitable for crop rotation and grassland. Within these categories, land is homogenous. For this study, zones are replaced with spatially explicit units of homogenous land. These units are defined by their natural and anthropogenic conditions, but are independent of property rights. As the focus is on a situation without support – which cannot be observed in reality – the recursive element was removed from the model. A static approach suffices for this research questions since the adjustment

processes is not of interest but the comparison of different states of ecosystem levels.

In addition the model has been expanded with bio-energy production activities (production of electricity). Since they should represent a non-agricultural user of land, the focus is on industrial production plants with a capacity of more than 5000t of biomass (dry matter) a year[1]. Due to their size, we assume full working load for their machinery. Marginal production costs in bio-energy production are therefore lower than in agriculture. The model optimizes total regional income over all producers and land units. As we assume a small open economy, agricultural production prices are taken exogenously. Given this research design, we assume European production prices for agricultural products. Production process and structural parameters are based on average Swiss data. The price scenario for food products is based on prognoses of the OECD and FAO for 2016 [15]. Spatial data is based on the geo-databases of the Swiss government.

B. GIS Model

The linkage between S_INTAGRAL and the geographical information is built on a Geographical Information System (GIS) model. Based on the existing land characteristics, the latter forms continuous land units which are homogenous in their agricultural production suitability. In addition these land units contain information on the climatic suitability, average slope and the suitability for biodiversity conservation. To achieve the corresponding land units, the GIS model processes the data in two steps (cf. Figure 1).

Firstly, the model filters the data required for the corresponding region out of data for Switzerland as a whole and dissects the landscape using existing natural and anthropogenic linear elements, such as traffic routes, water/streams and edges of settlement areas or woods. This procedure results in a fragmented landscape with continuous land units (elements I-V, drawing in the middle of Figure 1).

Secondly, more fragmented land units are generated by introducing agricultural suitability information covering a certain zone (Data source: [16]). Once again, this leads to a fragmentation of the land units (elements I-VII, drawing in Figure 2), representing a perfect land fragmentation for agricultural production.

In addition to size and soil suitability, the model adds further characteristics to each land unit:

- climatic suitability for agricultural production (Data source: [17]);
- average slope (Data source: Digital Elevation Model (DEM));
- biodiversity index (BI).

BI refers to the benignity of the parcel for biodiversity conservation which is based on a cost distance calculation. The model calculates the least accumulative cost distance for each land unit to the nearest water body or woodland over a cost surface. As a result, the accessibility of each parcel to natural habitats is quantified.

Afterwards, these land characteristics are integrated into the ecological-economic model. On the one hand, this information influences crop yields and cultivation costs. On the other hand, information regarding the proximity to natural habits helps to assess effects on biodiversity. To simplify model outputs, land units with an area smaller than 400 m^2 are omitted in the optimization. The GIS model does not take into account land tenure. Therefore, constructed land units are bigger than existing parcels. This is in line with the economic model which also does not account for individual farms.

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1. [1] The term "non-agricultural bio-energy producers" may be misleading in countries with large agricultural structures. In this case, there may be no difference between the two. However, in our case we refer to family based farms. Therefore, the size of farms is restricted whereas bio-energy producers can make use of scale economics.
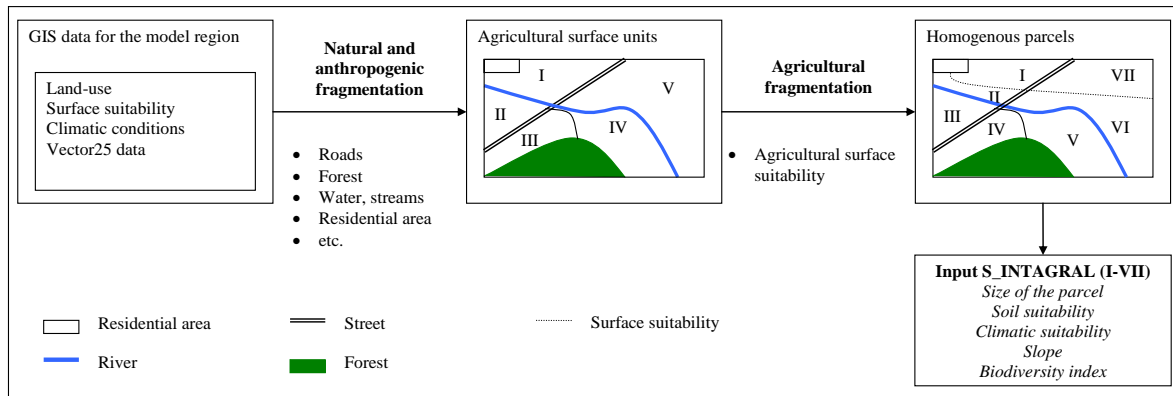
Figure 1: GIS based landscape fragmentation

The linkage between the economic-ecological model and the GIS data combines two different modelling approaches to land-use issues: Given the static character and the tendency of extreme behavior in normative mathematical programming models, this approach is close to a land rent model. On the other hand, environmental and structural constraints in the model combine a large amount of activities, thereby enlarging the solution space and pushing the characteristics of the model closer to a normative agricultural regional farm type supply model (cf. [18]).

C. Representation of jointness in S_INTAGRAL

The linear structure of the model also implies a linear relation between sectoral income and ES in S_INTAGRAL. In Figure 2, the effect of implementing environmental restrictions into the model is exemplified. The reference situation without environmental restrictions leads to a maximal income (cf. max. dashed line). Activities A - C represent different agricultural production technologies related to ES. If the latter has to be increased to a certain level, the model chooses those activities with the highest contribution to the sectoral income (left side in Figure 2). With increasing environmental standards the sectoral income decreases implying a competitive relationship. The result of this process is a transformation function between the sectoral income and the environmental ES (right side in Figure 2). However, the connection between agricultural production (in contrast to the sectoral income) and the environmental output depends

on the different technologies A-C. For example, activity B may involve a higher agricultural production than A. Therefore, the jointness between agricultural production and the environmental non-commodity output depends on the combination of different linear relationships between agricultural production technologies and non-commodity outputs.
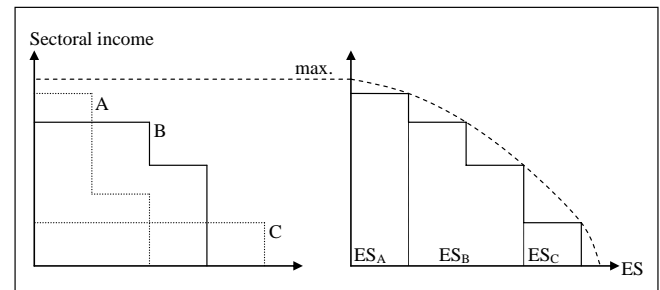

Figure 2: Relation of sectoral income and ES

IV. STUDY DESIGN

A. Research approach

Model framework and output scenarios of the study are illustrated in the upper and lower part of Figure 3 respectively. The core of the model consists of three modules: Livestock, plant and bio-energy production. Outputs of each module either leave the system through markets or serve as an input for another module. Restriction sets over crop rotation, nutrient and fodder balance combine the modules. The lower part

production. The shares for these restrictions are related to the existing land use in this region. In the *ecosystem services scenario*, additional requirements are introduced into the model. Nutrient in- and output must be balanced and the share of environmentally harmful Nitrogen emissions must be reduced to a level of 80% compared to the *reference scenario*. The share of compensation areas is increased to an ecological optimal level of 15% [21]. GHG emissions are limited to 90% of the *reference scenario* level. Table 1 pictures model restrictions and ES indicators for the three scenarios.

Table 1: Model restrictions in scenarios

Indicator for ES	Scenario		
	Reference	Landscape	ES
Cultivated area	-	90%	90%
Crop share in total area	-	26%	26%
ECA (natural habitat)	-	7%	15%
Open crop area	-	-	0%
Nutrient balance	-	-	80%
GHG emissions	-	-	90%

The costs of reaching the different levels of ecosystem services are expressed through the reduction of the total regional income. Given the property rights defined in paragraph x, the difference in income can also be seen as a minimum amount of the required public support for the competitors to provide these services. The price corresponds to the marginal cost of providing the ecosystem service and differs from the existing direct payments which are based on average cost estimations. Finally, without taking transaction and adjustment costs into account, we can estimate the dimension of overall payments for the corresponding region and compare it to the actual expenditure.

The GIS model has been applied to the district of Muri, which serves as a case study region. The region has an area of 112 km2, of which 68% is cultivated by agriculture (mostly mixed farms).

V. RESULTS

A. Reference scenario

Our results show effects on land-use and farm characteristics in a long run perspective. The *reference scenario* refers to an optimal solution under complete rational economic behaviour and the stated parameters which does not represent actual values and structural conditions.

Given the methodological approach of this study, the consequences for agricultural production depend on the level of opportunity costs for land and labour. Figure 4 shows agricultural land-use in the *reference scenario* subject to changing opportunity costs. Above opportunity costs of 15 CHF per labour unit and 700 CHF per ha respectively, agriculture ceases production. With opportunity costs of 10 CHF per hour of labour and 400 CHF per ha of land in production the agricultural income per work unit is similar compared to the actual values. Therefore, the comparison with the two other scenarios is based on these assumptions.
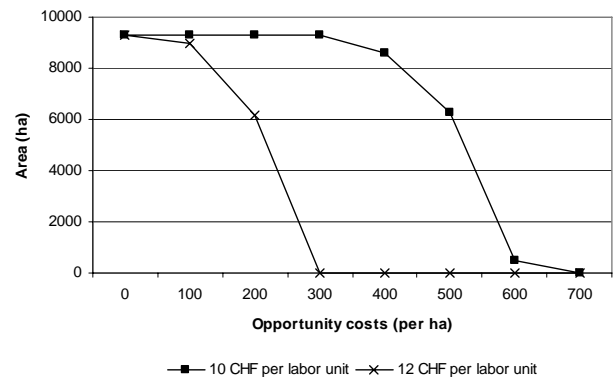
Figure 4: Land in production with changing opportunity costs

Under the stated parameters, the regional income in the *reference scenario* consists of the returns on milk, meat and root crops and amounts to CHF 19 million. Milk production dominates the overall income. Therefore 87% of total area is used for grassland production which is the basic fodder in milk production. For additional feeding purposes, maize is cultivated on 11% of the area. However, a large part of concentrated feed needed for dairy production, is imported. Production intensity is high on all land units. A small share of root crops is cultivated on land units with a high suitability

for agricultural production. From the removal of support for agriculture, less than 1% of fallow land results However, except for the provision of open space, the agricultural contribution to landscape diversity and biodiversity in the *reference scenario* is low. This is expressed by the low values of the Shannon diversity index (H) which can be attributed to dominance effect of the grassland.

Results of the *reference scenario* reflect two economic mechanisms: without support, marginal land units are abandoned and agricultural activities are concentrated on those with a comparative advantage (grassland based milk production).

B. Landscape and Ecosystem services scenario

Table 2 gives an overview to the changing key characteristics of the other scenarios with an increased demand for ecosystem services compared to the *reference scenario*. The last column shows results of the *ecosystem services scenario* with electricity tariffs of 0.25 CHF per kWh. At this level, bio-energy production in connection with a biorefinery starts to displace agricultural production (cf. next section).

The imposed model restrictions lead to a reduction of the sectoral income of approximately 30% in the *landscape* and 40% in the *ecosystem services scenario* respectively. This corresponds to an amount per ha of CHF 595 in the *landscape* and CHF 784 in the *ecosystem services scenario*.

The income loss in the landscape scenario comes from the changed landscape pattern which is assessed by the increased Shannon index. In relation to the reference scenario, farmers have to reduce the area for forage production (grassland) and increase the crop area in order to reach the same allocation as today (26% crop area). As a consequence, the number of animals has to be reduced and milk production decreases to 70% of the level in the *reference scenario*. Therefore, also livestock intensity per ha decreases. In addition, the produced wheat substitutes the imports of concentrated feed. On land units with high agricultural production suitability, cash crops are cultivated. Still, land use is dominated by grassland (60% of total land use). The amount of fallow land increases slightly to the maximal amount of 10%.

Without this open space restriction, farmers would abandon more land in order to minimize the income loss. In addition, the results show that the introduction of constraints concerning land-use already reduces the amount of N-loss and GHG emissions. This indicates cost complementarities in the provision of ecosystem services. With the reduction in livestock density the negative environmental effects also decreases.

This is still more pronounced by the results of the *ecosystem scenario*. Additional requirements in this scenario further reduce income and the amount of work. But, this decline is much smaller than between the *landscape* and the *reference scenario*. The differences between the *landscape* and the *ecosystem services scenario* have two causes: a) the requirements concerning nitrogen loss and GHG emission lead to a reduction in the number of cows and b) the increased share of ECA involves sheep husbandry. The latter enters the solution as sheep can be fed with a higher share of extensive grass in their feeding ration whereas the intake of extensive grass for milk cows is restricted.

C. Bio-energy production in scenarios

The last column in Table 2 shows results given an electricity tariff for non-agricultural bio-energy producers of CHF 0.25. In this case, 27% of the agricultural land is used for the production of electricity and insulation material. The sectoral income and the income per farmer increase slightly compared to the *ecosystem services scenario*. The reason for this is that the extensive grass from the ECA is no longer fed to animals but can be disposed in the energy production. In addition, bio-energy production leads to a further reduction in the nitrogen loss potential and GHG emissions. Again, this results from lower livestock intensity.

Table 2: Key figures in scenarios

	Unit		Reference	Landscape	ES	ES (0.25)
Sectoral income	m CHF		19.12	13.55	11.78	11.98
% of Reference	%			71%	62%	63%
Income per farmer (work unit)	CHF		36'940	34'812	32'743	33'467
Fulltime farmer	2800 h/y		518	389	360	288
Provision cost per ha	CHF			595	784	763
Milk production	Bn kg		93	64	57	42
Dairy cows	nr.		11564	8028	7155	5215
other animals (sheep)	nr.		0	0	1845	0
Livestock units	nr.		14'234	9'882	9'046	6'419
Livestock unit / ha			1.65	1.17	1.07	1.08
Import of fodder crops	kt TS		15	4	2	2
Land use agriculture	ha	Root crops	165	462	452	578
		Wheat, barley	0	1'193	1'378	1'644
		Maize	935	650	579	400
		Oil seeds	0	777	602	210
		Ley (Grassland)	1'650	2'114	2'085	1'649
		Permanent grassland	5'872	3'224	3'323	1'438
Total land use agriculture	ha		8621	8420	8420	5919
Land use bio-energy production	ha		-	-	-	2501
						27%
Fallow land	ha		735	936	936	936
Ecological compensation areas	ha		0	589	1263	1263
N-loss	kt		0.87	0.74	0.69	0.63
	%		*100%*	*85%*	*79%*	*73%*
GHG emissions (CO2 equiv.)	kt		1403.36	1284.35	1199.38	1162.35
	%		*100%*	*92%*	*85%*	*83%*
Shannon diversity index	H		0.91	1.67	1.72	1.73
	DOM		1.04	0.27	0.23	0.22
	EVEN		0.47	0.86	0.88	0.89

Figure 5 shows effects on land-use with increasing electricity tariff. At a level of CHF 0.15 per kWh one bio-energy plant enters the optimal solution. At this price level, sheep husbandry is substituted with the production of electricity and insulation material. The spatial implication of this result is that marginal land units are used by non-farmers and areas with high agricultural production suitability remain in agricultural production (cf. Figure 8 in the Annex).

With a tariff higher than CHF 0.2, bio-energy substitutes further agricultural activities. At a level of CHF 0.25 more permanent grassland is used for bio-energy than for milk production.

In reality, existing market based electricity tariff in Switzerland is CHF 0.09 [22]. Therefore, a substi-

tution of agricultural production would entail a triplication of actual electricity tariffs. This implies that agriculture still has lower costs in the provision of ecosystem services than non-agricultural competitors. This in turn can be interpreted as indication for strong jointness according to the concept of the OECD.

Calculations without the production of insulation material in a biorefinery show that the trigger price at which non-farmers get competitive is increased at CHF 0.2. Substitution of farm activities beyond the provision of ECA starts at CHF 0.25. This indicates that without technological improvement in biomass conversion technologies, economies of scope in the agricultural provision of ES persist.
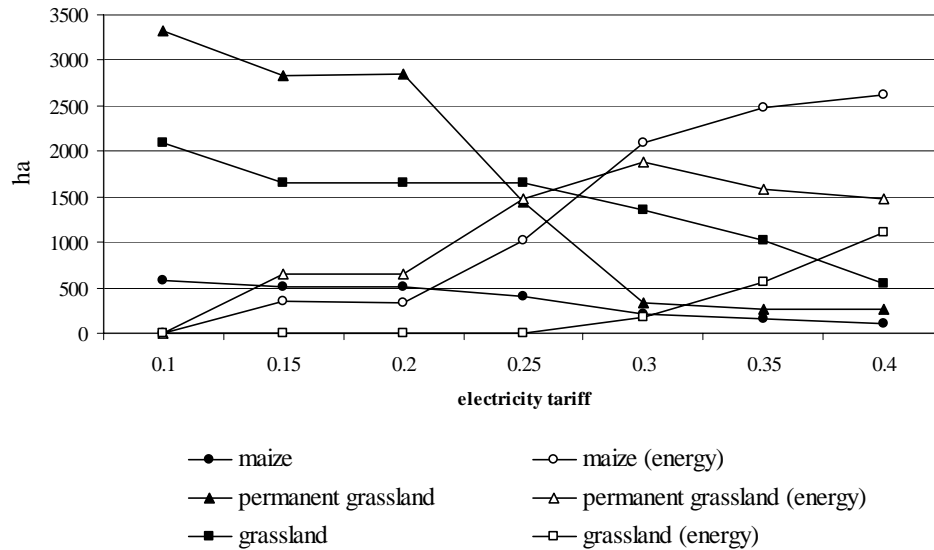

Figure 5: Land-use with increasing electricity tariff

VI. DISCUSSION

The modelling of Swiss agriculture with European production prices and no additional direct payments shows considerable changes in agricultural production. This is not surprising since Switzerland still has the highest producer support estimate (PSE) worldwide [23]. Given complete economic rational behaviour, farmers would concentrate on milk production and abandon marginal land.

Agricultural contribution to ES in the reference scenario is rather low since farmers have no incentives to provide these services. Indeed, farmers provide open space by cultivating the agricultural surface. However, additional services (e.g. habitat or regulation functions) are neglected. This is in line with current observations that even with high pay-

ments for ecological compensation areas, the environmental goals in the Swiss lowlands are not attained [24]. And Peerlings and Polman [25] illustrate for Dutch dairy farms that only few farms exhibit economies of scope in the provision of milk and landscape services.

Through the provision of ecosystem services, agricultural income is reduced due to the imposed model restrictions. Targeted payments of approximately CHF 600 (780) per hectare of land would offset these imposed costs in the *landscape* and the *ecosystem services scenario* respectively. This in turn corresponds to 70% of the actual decoupled area payment (CHF 1080) and 40% of average total direct payments per ha in the Swiss lowlands (approximately CHF 2000). The extent of these differences can be explained by the historical development of the actual payments, which are rather based

on political income requirements than on the provision of public goods. Therefore, the extent of actual support can not be solely attributed to the provision of environmental services. Hence, in a long perspective the potential for cost savings in the provision of ecosystem services is considerable. This is in line with the study of Brunstad et al. [26]. Their results based on a partial equilibrium model show similar savings for the Norwegian agriculture sector in the provision of landscape services and food security.

Nevertheless, there may be a need for additional policy instruments (e.g. welfare payments per farm household) in order to achieve acceptable levels of farm income irrespectively of the compensation for the provision of ES.

The differences between the two scenarios show that livestock reduction leads to the highest sectoral income loss. This is due to the comparative advantage of grassland based dairy production in Switzerland. Therefore, livestock is only reduced as a last option. This may hold for our scenarios in which different ES are combined as well as for the provision of separate ES, as Neufeldt and Schäfer [27] show for GHG mitigation in Germany and Peter [14] for Switzerland. In addition, the small differences between the two scenarios refer to strong cost complementarities in the agricultural provision of ES.

However, the level of the savings must be put into perspective. We are aware that the economic modelling approach (sector model) overestimates factor substitution. In reality different farm types have different provision costs for ES (cf. for Switzerland [28]). Costs may differ whether a high or low cost farm provide these services. This has spatial impacts [29] and ecological consequences [30]. In addition, the nature of jointness (complementary or competitive) can change with the level of intensity in production of the farm [31]. In addition, the spatial differences in the provision imply high expenditure for the implementation of targeted policies which are needed in order to achieve these savings. In the model, environmental goals are easily achieved by introducing constraints. But in reality, the achievement of these goals would depend on complex contracts between government and farmers. Whether these contracts would provide the expected ES

needs to be assessed [6]. Thereby, the specific instrument chosen and the implementation of the targeted policy is a crucial task [32].

The introduction of non-agricultural competitors into the model shows that electricity tariffs must increase considerable in order to displace an agricultural provision of ES. This implies a strong jointness between agricultural production and the provision of ES. However, the development of new types of biorefineries could alter this picture. The insertion of a side product (insulation material) lowers the trigger point at which the non-agricultural competitor gets competitive. Therefore, future technologies could weaken the jointness between agriculture and ES. Thereby, the development of the second generation of conversion technologies such as cellulosic ethanol production [33] is a crucial aspect. For example, Tilman et al. [34] show that a low input and high diversity biomass can be combined with the production of biofuels. This is of importance, since our results show that land with high agricultural production suitability tends to remain in agriculture and particularly marginal land would enter the bioenergy production. In this case, non-farmers would provide ES on sensitive land-units without the negative impacts of agriculture.

Therefore, the introduction of non-farmers adds an important aspect in the assessment of economies of scope. Otherwise, if non-farmers lack the opportunity for the production of a market product but use the same production technology as the farmers, there will always be economies of scope in the agricultural provision [35].

From an efficiency perspective, there is no reason why a farmer should be remunerated for the provision of ES, whereas biorefineries are not. The policy implication of our study is, that agricultural policies which try to promote the provision of ES must take into account technological development of non-agricultural competitors.

VII. CONCLUSIONS

This study investigates agricultural economies of scope in the provision of ecosystem services in the Swiss lowlands. Results from a spatial explicit economic-ecological programming model show that

under the stated parameters, output prices for non-farmers (electricity and fibre) would have to increase considerable in order to compete with agriculture in the provision of ecosystem services. Thus, agriculture still is the least cost supplier of these services. In relation to the concept of the OECD, the conclusion is that agriculture reveals a strong jointness regarding ecosystem services. However, new technologies will reduce the gap for non-farmers. As the results in this study imply, this is of particular interest on land with low agricultural production suitability. Therefore, in the provision of ecosystem services agricultural policy should take into account technological development beyond food production.

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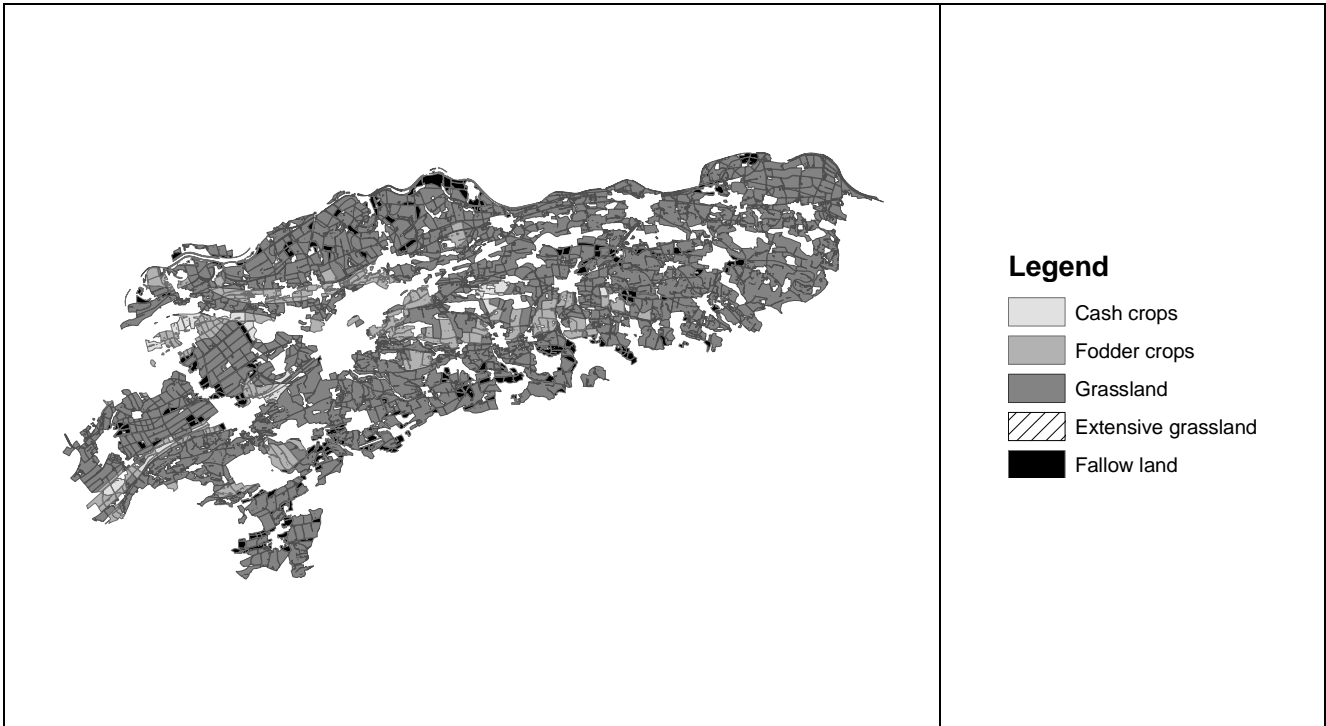
ANNEX

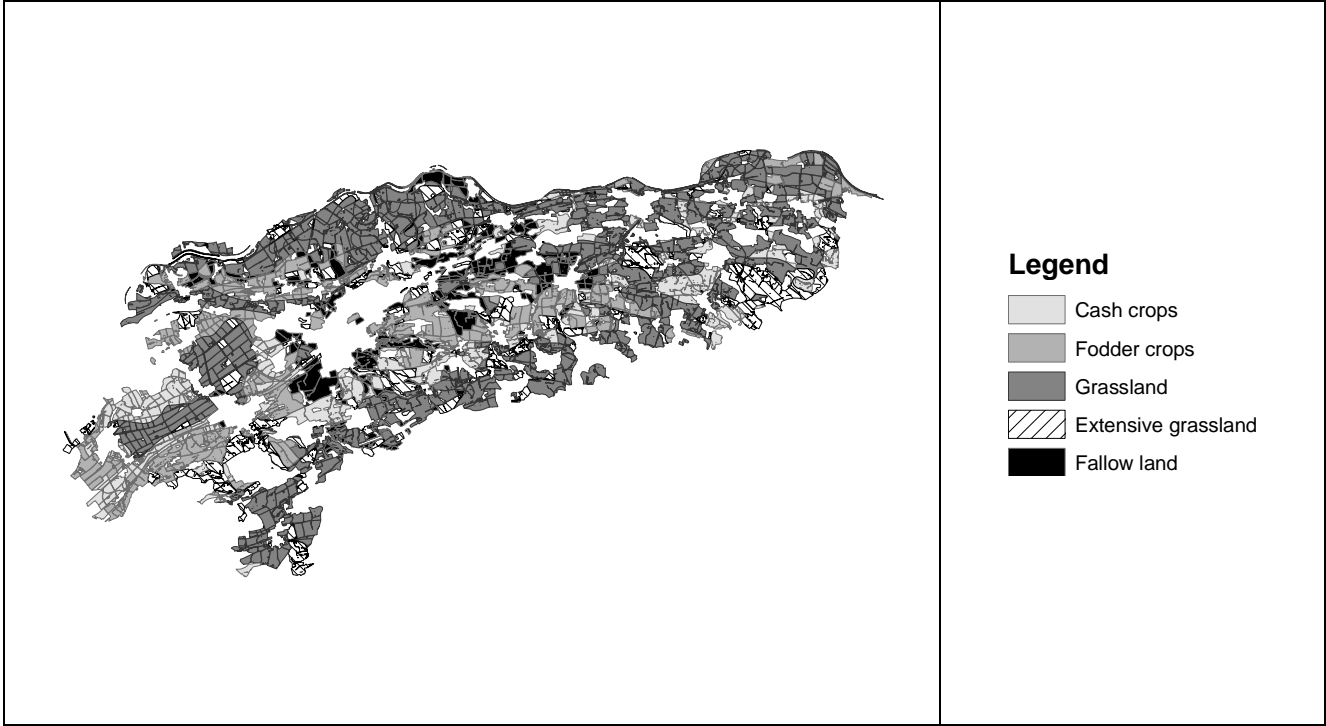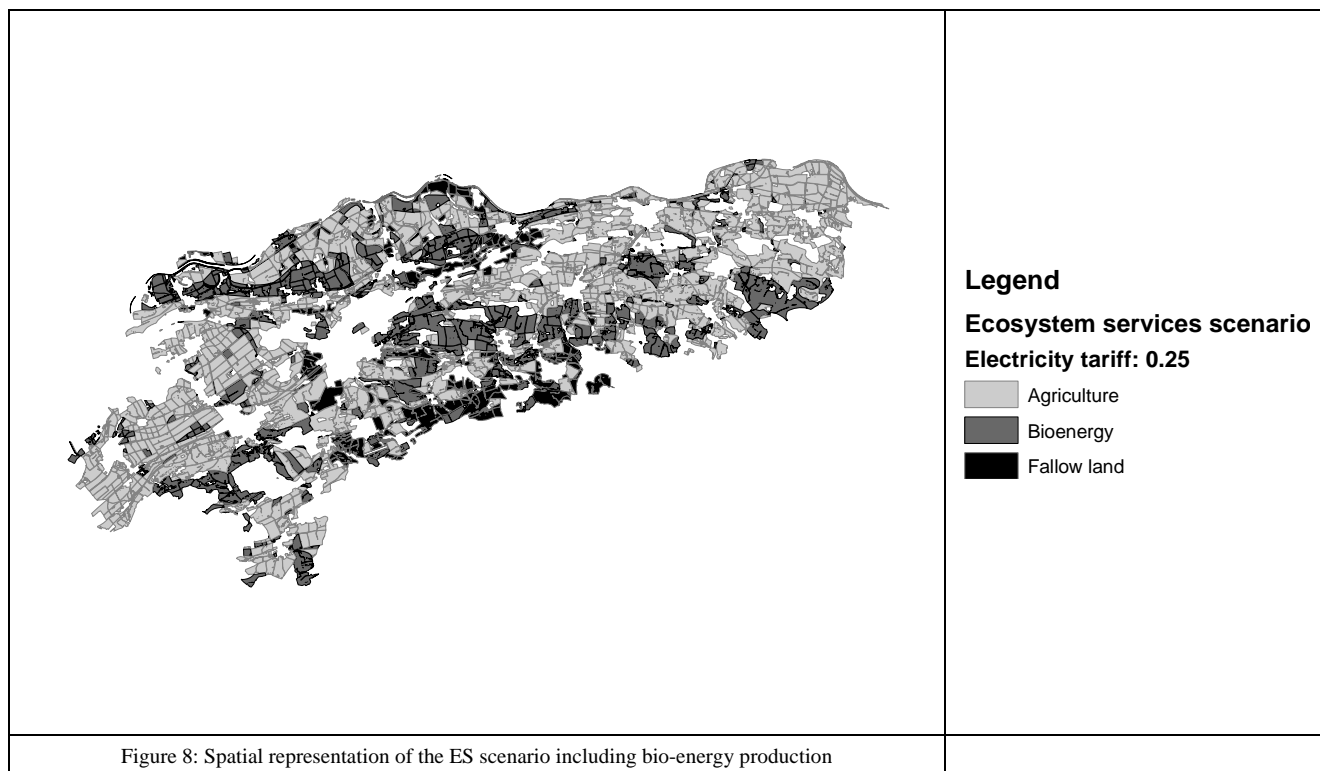
Figure 6: Spatial representation of the reference scenario

Legend
- Cash crops
- Fodder crops
- Grassland
- Extensive grassland
- Fallow land

Figure 7: Spatial representation of the ES scenarios

Legend
- Cash crops
- Fodder crops
- Grassland
- Extensive grassland
- Fallow land

Figure 8: Spatial representation of the ES scenario including bio-energy production

Address of the corresponding author:
- Author: Huber Robert
- Institute: ETH Zurich (Swiss Federal Institute of Technology), Agri-food and Agri-environmental Economics Group
- Street: Sonneggstrasse 33
- City: 8006 Zurich
- Country: Switzerland
- Email: robehube@ethz.ch