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How Much Should Swiss Farmers Contribute to Greenhouse Gas Reduction? A Meta-Analytical Approach

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The debate about future climate policy involves the question about the contribution of agriculture in meeting overall greenhouse gas mitigation targets. From an economic perspective, this calls for assessing and equalizing marginal mitigation costs across different sectors. To this end, we employ a meta-analytical approach that is based on results from different studies, and that allows us to assess the optimal level and economic value of agriculture's contribution to meeting national policy targets.

A numerical example for Switzerland shows that, even without any legal commitment to greenhouse gas emissions reduction, Swiss agriculture will contribute 17 to 28 % to the national Kyoto target until 2010. This reduction corresponds to an economic value in the range of 30 to 106 Mio CHF/year and diminishes the expected total abatement costs in the rest of the economy in the same magnitude. This is primarily an effect of the current agricultural policy, whereas targeted incentives and soil carbon sequestration may only marginally contribute within the same time frame. Moreover, the results of our meta-analytical assessment underline that it would be efficient to participate in international emissions trading.

From a methodological point of view, our analysis explicates how the results about greenhouse gas mitigation costs from a highly detailed allocation model of the agricultural sector and those from an energy model of the overall economy can be connected in a meta-analytical framework.

Keywords: agriculture, climate policy, greenhouse gas emissions, abatement costs, economic evaluation.

JEL classification: Q1, Q4, Q5, D61

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1. Introduction

The stabilization of greenhouse gas concentrations at a level that would prevent dangerous anthropogenic interference with the climate system is the objective in the United Nations Framework Convention on Climate Change (UNFCCC) which entered into force in 1994. It "should be achieved within a time-frame sufficient to allow ecosystems to adapt naturally to climate change, to ensure that food production is not threatened and to enable economic development to proceed in a sustainable manner." However, the UNFCCC does not include quantitative goals or legally binding commitments for countries to reducing or at least limiting their anthropogenic greenhouse gas (GHG) emissions. These are set in the Kyoto Protocol of 1997, which entered into force in February 2005 and defines the frame of reference of current climate policy for its signatories. It constitutes an important first step towards achieving the long-term goal of stabilizing GHG concentrations at a level which shall avoid dangerous climatic change. Accordingly, more stringent emission reduction targets must be agreed in the negotiations for the second commitment period and a new international framework that needs to be in place when the Kyoto Protocol expires in 2012. On national level, this involves the need of revising current legislation and reconsidering climate policy measures and instruments. Amongst others, this brings in the question about how much agriculture - and particularly livestock-based production - should contribute to meeting a country's climate policy targets. From an economic perspective, this calls for an integrated assessment of mitigation options and comparison of marginal abatement costs across different sectors. Indeed, economic efficiency requires marginal costs of mitigation being equalized across the different measures to either reduce GHG emissions at their source or to sequester carbon in soils and biomass, respectively. The equalization of marginal mitigation costs must be achieved both within agriculture and in the economy as a whole.

In this article, we utilize a meta-analytical approach that puts together the results of two different, but complementary studies that provide information about marginal greenhouse gas mitigation costs. The aim is to present a conceptual framework for integrated climate policy appraisal and, in particular, to address the question about how much the agricultural sector should contribute to reaching climate policy targets in a small country like Switzerland. For illustrative purposes, we use the results of existing studies by Bahn and Frei (2000), who studied policy options of mitigating energy-based CO_2 emissions in Switzerland for the year 2010, and Hediger et al. (2004), who assessed marginal costs of GHG reduction in the agricultural production sector with the same time horizon. This allows us to calculate, for different policy and price scenarios, economically optimal levels of GHG mitigation for Swiss agriculture and to assess the economic value of agriculture's contribution to climate policy in Switzerland since 1990 and the expected emission reductions until 2010. To this end, the paper is organized as follows.

In Section 2, we briefly review the state of the art in the economics of agricultural GHG mitigation. Section 3 gives an outline of the Swiss climate policy framework and relevant options of GHG mitigation in the agricultural sector. Section 4 portrays our methodological approach, and Section 5 gives a selection of base-run modeling results for the period 2000 to 2010. Building on this background and using a meta-analytical framework, Section 6 is devoted to the assessment of the economic value of agriculture's contribution to climate policy within the first commitment period of the Kyoto Protocol. Finally, Section 7 concludes with an outlook on considerations about agriculture's prospective role in post-Kyoto climate policy.

2. On the economics of agricultural GHG mitigation - a brief review

In the Kyoto Protocol of 1997 industrialized countries committed themselves to reducing their emissions of the six GHGs carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulphur hexafluoride (SF_6) by specified amounts below the reference level of 1990 until the first commitment period 2008 - 2012. To comply with these targets, countries must not only reduce energy-intensive activities and invest in clean technologies through adequate policy measures in their countries. They can also make use of international measures through means of joint implementation, clean development mechanisms and emissions trading. Moreover, countries can use biological sinks in vegetation and agricultural soils to remove CO_2 from the atmosphere. By various commentators, the latter is propagated as a prospective way of CO_2 mitigation and as an interesting new option for income support in agriculture, through either receiving government subsidies or participation in a carbon trading scheme (Sandor and Skees, 1999; Marland et al., 2001; Lal, 2004).

In the economics literature of the 1990s carbon sequestration has primarily been addressed with regard to forestry measures and afforestation on agricultural land, while carbon sequestration in agricultural soils only gained attention in recent years (cf. Antle and McCarl, 2002). Based on integrated assessments using biophysical simulation and econometric process models, Pautsch et al. (2001) and Antle et al. (2001, 2003) investigated specific options of soil carbon sequestration in Iowa and Montana, and compared the cost-effectiveness of different policy schemes that would encourage farmers to adopt targeted sequestration techniques on their land. The estimated costs indicate that, at least in Montana, carbon sequestration in agricultural soils would be competitive with measures to reduce GHG emissions in other sectors.

Antle et al. (2001) report marginal costs of C sequestration by converting cropland to permanent grassland (PG) in the range of 50 US$/t C to over 500 US$/t C, and for the alternative case of conversion to continuous cropping without set aside (CC) marginal costs in a range of 12 to 140 US$/t C. The main reason for this difference may be a consequence of fundamental differences in the two policy scenarios, rather than due to an effective difference in marginal costs of sequestration. Under the PG policy scenario, a fixed annual per hectare payment is given to producers for C sequestration, under the premise that all cropland and pasture land is eligible. In contrast, under the CC scenario, farmers are paid on a per hectare basis only for fields switched to continuous cropping. This has a similar effect as the distinction between payments to all adopters and new adopters only in the study of Pautsch et al. (2001).

A different approach with respect to methodology and research question has been used by McCarl and Schneider (2000, 2001). They analyzed various options for reducing GHGs in US agriculture by introducing alternative carbon prices in the Agricultural Sector and Mitigation of Greenhouse Gas (ASMGHG) model (Schneider, 2000), and conclude that, from an economic perspective, the contribution of C sequestration in agricultural soils exceeds that of reducing agricultural methane and nitrous oxide emissions. This means that for a given carbon price (marginal cost) the economic potential of GHG reductions by C sequestration is higher than the potential of reducing agricultural GHG emissions. But, McCarl and Schneider also emphasize the existence of more cost-effective measures for elevated carbon prices above 100 US$/t C-equivalent. These measures include C sequestration through afforestation on agricultural land and the use of bio-fuels as CO_2-neutral energy source (Schneider and McCarl, 2003).

These findings go in line with the results of De Cara and Jayet (2000) for French agriculture that is based on an analysis with a set of farm-unit linear programming models. They show that afforestation on set-aside land would be the cost-effective solution for curtailing net GHG emissions. In contrast, Lehtonen et al. (2006) conclude that significant GHG reductions can be reached with little decrease in national agricultural incomes, by restricting the cultivation of peatland in Northern Finland. They apply the dynamic regional sector model of the Finnish agriculture DREMFIA to simulate agricultural production and markets for the period 1995 to 2020.

Using the recursive dynamic linear optimization model S_INTAGRAL, Hediger et al. (2004) found much lower economic potential for soil carbon sequestration in Swiss agriculture and rather high cost of GHG mitigation from agricultural land use and livestock production. The deviation in results from the above studies is explained by the subsequent facts:

(a) the share and area of cultivated peatland is much smaller in Switzerland than in Finland;
(b) due to lack of adequate data, Hediger et al. (2004) did not consider the restoration of cultivated peatland despite the relatively high physical potential estimated by Leifeld et al. (2003);
(c) caused by the agricultural policy reform since the early 1990s, Swiss agriculture has already reduced its GHG emissions (mainly methane and nitrous oxide) by about 10 % between 1990 and 2000, whereas total GHG emissions in Switzerland are still around the reference level of 1990 (BAFU, 2006);
(d) the existence of a highly integrated agricultural production system with strong links between livestock and land use that has been historically developed and causes relatively high cost of agricultural GHG mitigation in Switzerland.

Numerous studies - in particular from the USA and Canada - reveal that the economic potentials of C sequestration in agriculture and forestry are significantly smaller than biophysical potentials, and that carbon sequestration can only provide a limited contribution to achieving national Kyoto targets. Moreover, the economic assessment of GHG mitigation costs and potentials cannot be restricted to soil carbon sequestration. Rather, it must consider the various sources of agricultural GHG emissions and the related costs of mitigation through changes of land and livestock management. McCarl and Schneider (2001) observed that interdependencies of crop and livestock management affect the costs and potential for agricultural GHG emission mitigation in different ways. Accordingly, agriculture must be seen as a complex system with various interrelated nutrient cycles (nitrogen and carbon) that exhibit their own internal dynamics (Hediger, 2006). It is the resulting production structure (size and composition of livestock population and land use patterns) and the intensity of cultivation (especially the manure and fertilizer application rates) that, according to scientific studies and IPCC guidelines, determine agricultural emissions of methane and nitrous oxide.

From a methodological point of view, the various studies illustrate the relevance of an integrated modeling approach for the economic analysis of agricultural GHG-reductions. Such an approach particularly allows for consideration of synergies and trade-offs among separate measures in a systematic way, even if interdependencies are not always obvious.[1]

All in all, it is essential to consider the above insights for the development of further economic analyses that aim at evaluating alternative measures and potentials of GHG mitigation through emissions abatement and carbon sequestration in agricultural production systems. Finally, from an economic perspective, any assessment of agricultural

[1] It is increasingly acknowledged in the literature that the evaluation of agricultural and environmental policy measures asks for an integrating perspective across different disciplines (Antle and Capalbo, 2001; Braat and van Lierop, 1987; Hediger, 1999; Jakeman and Letcher, 2003; Morgan and Dowlatabadi, 1996). In particular, if complex systems and their interactions are considered, an integrated assessment approach is needed (Janssen, 1998; McCarl and Schneider, 2001; Schneider and Lane, 2005). According to Barker (2001, 2003) such approaches are required to incorporate scientific knowledge in different areas, to manage the huge amounts of data needed for modeling, to maintain consistency in definitions and identities at different levels of aggregation and to allow for easy and reproducible computation of solutions based on different sets of assumptions. Furthermore, Spedding (1987) emphasises that improvements for the agricultural system have to be sought for the system as a whole and cannot be achieved by changes in one component, and not without regard to the rest of the system. This is particularly relevant when a problem involves economic and environmental aspects of circular nutrient flows, such as the interconnection of forage and manure production and use that is central for the assessment of GHG mitigation options in agriculture.

GHG mitigation options must include a comparison with marginal GHG abatement costs in other sectors. Indeed, different measures in reducing GHG emissions and their cost-effectiveness in achieving national Kyoto targets can only be evaluated by comparing marginal abatement costs across the various sectors. To this end, we employ a meta-analysis that puts together the results from different sectoral studies.

3. Swiss climate policy and national options for agricultural GHG reduction

With the ratification of the Kyoto Protocol, Switzerland committed itself to reducing its GHG emissions by 8 % below the reference level of 1990 until the first commitment period (2008-2012). This goal is reflected in the national CO_2 Law (1999), which only prescribes a reduction of energy-based CO_2 emissions until 2010 by 10 % below the level of 1990, but does not address agricultural GHG emissions. In this legal framework, subsidiary targets are set for combustibles that shall be reduced until 2010 by 15 % and transport fuels (not including aviation fuel for international flights) by 8 % below their 1990 levels. These reductions shall primarily be achieved by means of energy, transport, environmental and fiscal policy, and, most importantly, by voluntary measures in the manufacturing and service industries. If the reduction target cannot be accomplished by these measures the CO_2 Law prescribes the introduction of a CO_2 tax on fossil fuels.

The current situation shows that the measures hitherto are not sufficient to meet the national reduction goal. Emissions from combustible fuels decreased by about 6 % from 1990 until 2005, whereas emissions from transport fuels increased by 9 % over the same period (BAFU, 2006). As a consequence, the Swiss Parliament approved in March 2007 the concept of a CO_2 tax on combustibles that is implemented in 2008 and shall increase in three steps from initially 12 CHF/t CO_2 to 36 CHF/t CO_2 in 2010. This constitutes an additional instrument besides the so-called "climate cent", which has been established in 2005 as a voluntary measure by the Swiss industry with a charge levied on all imports of petrol and diesel at a rate of 1.5 cents per litre. The estimated receipts of about 100 million CHF per annum shall be invested in GHG reduction projects in Switzerland and abroad. This instrument must prove its effectiveness until the end of 2007. Otherwise the Federal Council may also introduce a CO_2 tax on petrol.

In contrast, Swiss agriculture has already provided a contribution of 14 % to the national Kyoto target, even though there is no explicit commitment, neither in the Kyoto protocol nor in the CO_2 Law. The entire sector causes about 12 % of the national GHG emissions. It is the major emitter of methane with 67 % and nitrous oxide with 72 %, but only contributes 1.7 % of the national CO_2 emissions (BUWAL, 2004). Since 1990, Swiss agriculture has reduced its methane and nitrous oxide emissions by more than 10 %, as a result of reforms in agricultural policy that particularly forced livestock reduction and improved fertilizer management. Beyond that, further reductions of agricultural GHG emissions are expected until 2010 by continuing the current agricultural policy (Bundesrat, 2002).

Given the magnitude of methane and nitrous oxide as the major sources of agricultural GHG emissions, the most obvious GHG mitigation options are directly linked with a reduction of these emissions and thus with the farmers' interrelated decisions on livestock, manure and land use management. This accounts for the fact that, methane emissions are mainly caused by enteric fermentation of ruminants (mainly milk cows) and manure management, whereas nitrous oxide is due to manure management, fertilizer application and land use patterns. These emissions are reported on an annual basis in the national GHG inventory (cf. SAEFL, 2004), which is compiled in accordance with the requirements of the Climate Convention (UNFCCC, 2000, 2003). They are calculated according to methodological guidelines recommended by the IPCC (1997) and under consideration of specific conditions in Switzerland. The latter are documented in special reports on methane and nitrous oxide emissions from Swiss agriculture (Minonzio et al., 1998; Schmid et al., 2000).

Another option of GHG mitigation in agriculture is the sequestration of carbon in soils and biomass. Yet, carbon sinks have hitherto only been considered in the GHG inventory as far as they are due to GHG removals (biomass accumulation) by land-use change and forestry. Carbon stocks in agricultural soils have not yet been included, due to the lack of internationally approved reporting guidelines. These are described in the *Good Practice Guidance* of the IPCC (2003) and have been approved by the Conference of Parties of the UNFCCC for preparing annual inventories due in 2005 and beyond (UNFCCC, 2004: 31).

A first assessment of carbon stocks and sequestration potentials in agricultural soils in Switzerland is provided by Leifeld et al. (2003). This constitutes a scientifically based prerequisite for the assessment of carbon sinks in Swiss agriculture. Together with previous studies on methane and nitrous oxide emissions in Swiss agriculture (Minonzio et al., 1998; Schmid et al., 2000) and a state-of-the-art review by Fischlin et al. (2003) on carbon sequestration options in agriculture and forestry, it establishes a valuable basis for an economic appraisal of measures to reduce GHG emissions and to enhance soil carbon stocks by Swiss agriculture. Leifeld et al. (2003) show that the most important options of soil C sequestration in Switzerland are the adoption of no-till farming or the conversion of cropland to permanent pasture, and the restoration of the rather small area with organic soils (see also Hediger, 2004, 2006).[2]

Altogether, scientific studies indicate that the realization of sequestration potentials in Swiss agriculture would require fundamental changes of agricultural structures, while expected sequestration potentials in agricultural soils are relatively small compared to those in forests. Furthermore, the existence of systemic interdependencies of land use and animal production through the forage-and-manure cycle indicates, that an integrated approach is required for the economic appraisal of carbon sequestration options in agriculture. It will imply simultaneous consideration of all agricultural GHG emissions (CO_2, CH_4 and N_2O) as well as assumptions about the development of economic conditions and the agricultural policy framework. Apparently, this implies an allocation problem of finding the optimal (i.e., cost-minimizing) mix of mitigation measures.

[2] Notice that induced N_2O emissions in case of C sequestration in mineral soils has not been quantified by Leifeld et al. (2003), and can therefore not be considered in our analysis. Moreover, existing data on land use management are not sufficient to include the restoration of organic soils in the economic assessment.

4. Methodology

On the Swiss national level, the medium-term target for reducing GHG emissions is determined by the commitment in the Kyoto protocol. In the sense of an efficient use of scarce resources, this target should be achieved at the least cost for the Swiss economy within the time frame of the first commitment period (2008-2012). Building on this background, the potential contribution of Swiss agriculture shall be analyzed with regard to the achievement of the national Kyoto target in a cost-effective way. The institutional framework for this analysis is given by:

1. the Kyoto target which, as mentioned above, is translated in the Swiss CO_2 Law into a 10 % reduction of energy-based CO_2-emissions until the year 2010, and
2. the fact that, so far, there is no commitment for agriculture to reduce its emissions of methane and nitrous oxide within the legal frame of Swiss climate policy.[3]

Thus, under the current legislation, property rights are arranged in such a way that the „energy consumption sector“ (ECS), which consists of manufacturing and service industries, private households and transport, is legally obligated to reduce its emissions, whereas agriculture is free of any obligation to reduce its GHG emissions. However, this does not imply that it would be economically reasonable for agriculture not to reduce its emissions. Rather, from an economic point of view, each sector should contribute to achieve the Kyoto target in a cost-effective manner. In other words, agriculture should reduce its GHG emissions and provide carbon sinks as long as it can be realized at lower marginal cost than GHG abatement in the ECS. Apparently, this calls for an economic analysis which allows us to calculate and compare marginal abatement costs for different options of GHG mitigation in agriculture and the ECS. Theoretically, this could be calculated within the framework of one single model that includes all relevant activities and mitigation options.

[3] This could change in the second commitment period, if the Swiss parliament should decide to also include specific reduction targets for methane and nitrous oxide emissions that mainly stem from agriculture. However, this would not change the analytical approach that searches to equalize marginal abatement costs across sectors and mitigation measures.

Yet, to keep a model as simple as possible and as comprehensive as necessary, we use a meta-analytical approach that combines estimates of sectoral mitigation costs from different studies, such as described below. Given the complexity of the agricultural production system, this must allow for consideration of synergies and trade-offs among separate measures in a systematic way, even if interdependencies are not always obvious. Moreover, the prevailing institutional arrangements and policy framework must also be taken into account in both the modeling and the economic meta-analysis.

Building on a study that evaluates GHG abatement and carbon sequestration options from an economic perspective (Hediger et al., 2004), we use a *three-stage procedure* for the monetary assessment of Swiss agriculture's contribution to meeting the national Kyoto target. Applying the recursive dynamic optimization model S_INTAGRAL (Swiss INTegrated AGRicultural ALlocation model), we first assessed the expected development of agricultural GHG emissions and income for the period 2000 to 2010 for two price scenarios. With the same model, we then calculated the marginal cost of reducing GHG emissions in Swiss agriculture in the target year 2010. However, on this basis, one cannot conclude whether and to which extent agriculture should reduce its GHG emissions. Rather, the marginal abatement costs in other sectors must also be considered.

To this end, we also use results of a study by Bahn and Frei (2000) who investigated different strategies to reduce energy-based CO_2 emissions in the framework of a computable general equilibrium (CGE) model of the Swiss economy and its interaction with the energy system. In particular, they estimated for a unilateral and a multilateral strategy the specific carbon tax that would have been required to realise by 2010 a 10 % cut in CO_2 emissions below the 1990 base level. Using this information, we approximate the marginal abatement cost function for the ECS and compare in a *meta-analysis* the results for the agricultural sector with those for the ECS. On this basis, we assess the optimal levels of GHG abatement for the ECS and the agricultural production sector. Moreover, we calculate the total GHG abatement cost for the ECS and the cost reductions it can benefit, under the Kyoto protocol, due to agricultural GHG mitigations. These are the benefits to the national economy, as the agricultural contribution lowers the remaining abatement efforts required from the ECS and thus the total GHG mitigation cost of the economy, such as illustrated in Figure 3, below.

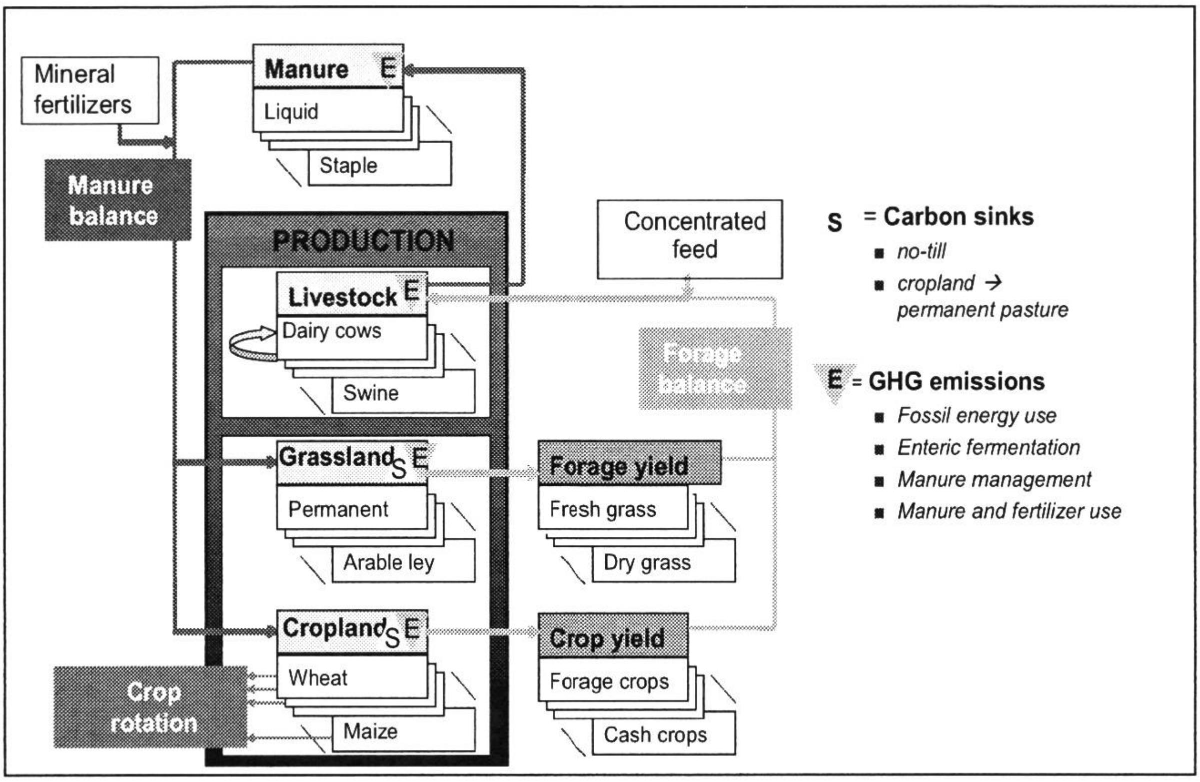
4.1 The model S_INTAGRAL[4]

S_INTAGRAL is a recursive-dynamic linear optimization model which maximizes the aggregate annual income (labor 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 and dynamic adjustment processes of the system. It provides an analytical tool for economic appraisals of GHG abatement strategies in the agricultural sector for different price and policy scenarios, and, in particular, to assess marginal GHG abatement costs at different points in time and for different scenarios.

Since the GHG inventory constitutes the official reference for evaluating national policy achievements, we based the model on the same methodology as the GHG inventory and used the latter as benchmark for the validation. In other words, all factors that determine agricultural GHG emissions and carbon sequestration are considered in the model, and therefore determine the structure of the economic allocation model that has been particularly developed for the purpose of analyzing agricultural GHG emissions and carbon sequestration from an economic perspective. Options considered in the model are no till (direct drilling) and the conversion of cropland into permanent grassland. These constitute, according to Leifeld et al. (2003), the two alternatives for soil carbon sequestration in mineral soils. In contrast, the renaturation and extensification of cultivated organic soils is not included in the model, due to lack of spatially differentiated data that would be required to investigate this option.

Moreover, S_INTAGRAL includes the most important activities of Swiss agriculture with regard to revenue, land use, livestock population and GHG emissions. It is divided into three major production zones (plains, hills and mountain area) and is based on the three production modules "livestock", "grassland" and "cropland". As stylized in Figure 1, these modules are integrated through balances between production and use of forage (grass and crop forage) and livestock manure. The latter must be applied within the zone of origin, while forage exchange between regions is allowed in the model, but implies transportation costs.

[4] A detailed description and validation of the model are available from the authors.



[adapted from Hediger et al. (2004)]

Fig 1. The structure of the model S_INTAGRAL.

The model also includes constraints for crop rotations that are compatible with the legal requirements for receiving direct payments, as well as with recommendations for minimum nutrient inputs for different levels of intensity in crop and forage production. Furthermore, a characteristic feature of our linear programming model is the consideration of different technology options of mechanization (different types of machinery) and livestock management (different types and sizes of stables, manure management systems, and different shares of grazing time and concentrated feed), as well as different options for forage production (grazing, fresh grass, dry grass, silage, forage crops) and final products (cash crops and animal products) that are sold on the market. In the numerical solution, the model determines the conditionally optimal use of these options together with the optimal allocation of the land (cropland, grassland, crop rotation, as well as the intensity of cultivation and the option of land retirement) and the optimal development of livestock populations and animal holding systems.

Given the fact, that Switzerland is a small open economy with an agricultural sector that is in transition from border protection to market liberalisation, producer prices are assumed exogenous. This may be criticised from a general equilibrium perspective. However, despite of its analytical and theoretical strengths, the latter also suffers from stylised assumptions - such as perfect competition, single-output sectors, vertical integration of production, *et cetera* - that cannot be maintained in many situations.[5] Agricultural and food markets, for instance, are not fully integrated as assumed in the standard Walrasian framework. Rather, they are characterised by large retailers and manufacturers who exercise market power, which leads to distortions between producer and consumer prices, and distortions in the price transmission from consumers to producers and vice versa. In other words, changes on the consumer markets do not, in general, result in immediate changes of producer prices, but may rather affect future prices and expectations.

Accordingly, producer prices are taken exogenous in the agricultural production model S_INTAGRAL, but with a differentiation between domestic and foreign prices. That is, Swiss farmers can sell their products on the domestic market at a more or less fixed price within bounds of the established market capacities, while a decrease in domestic supply may not lead to higher producer prices but rather to more imports. In contrast, excess products can only be sold on the much larger European market, where (for most products) a lower price level applies that cannot be influenced by Swiss producers. Together with constraints that reflect observed absorption capacities of domestic markets, this differentiation between domestic and foreign price levels eliminates the overshooting of single activities.[6]

The recursive-dynamic connection of consecutive production years is another characteristic element which helps to avoid the extreme behavior ("bang-bang" or "flip-flop") that is typical for linear programming models. It allows us, at the same time, to take existing structures and costs of structural changes into account and to conditionally forecast the development of the agricultural production system with sequential calibration to the structural variables (livestock population, stable capacities,

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[5] See also McKenzie (1998).

[6] Notice that only producer prices, but no consumer prices are considered in S_INTAGRAL.

and machinery stock) of the previous year. Altogether, these issues are important for assessing the mitigation cost and evaluating the different options of GHG reduction in a realistic way. Flexibility is built in through a procedure of depreciation of existing capacities and investments in new ones, which can result in a gradual shift from original activities to an increase in other ones (structural change). Livestock populations are dealt with in a similar way, whereas dynamic considerations are formalized and translated into adequate constraints (cf. Hediger, 2006) to eliminate extreme and unrealistic changes. Due to this recursive dynamic formulation, our model is more robust against exogenous shocks and comes closer to reality than an aggregation of farm-level optimization models would.

The basis for the economic evaluation of agricultural measures is provided by a recursively related set of model runs for the time period 2000 to 2010. Starting from the results of these base runs, we can impose and gradually tighten a constraint on net GHG emissions (emissions minus sequestration rates) in our model. As a consequence, the solution space is increasingly confined and the value of the objective function (the total agricultural income) decreases with the GHG constraint. The loss of income (the difference to the income without GHG constraint) represents the total cost of GHG mitigation at a given (predetermined) level of GHG reduction. These model-based results can then be used to assess mitigation cost functions for Swiss agriculture and to get estimates of the marginal abatement costs by differentiation of the total cost functions with respect to the level of additional GHG mitigation.

4.2 Data[7]

The calibration of the model is based on statistical data for the year 1999 and validated over the period 2000 to 2002 under consideration of agricultural statistics[8] and the national GHG inventory[9]. Carbon and nitrogen flows are formalized and parameterized on the basis of scientific studies and synthesis reports (Minonzio et al., 1998; Schmid et al.,

[7] Further details are available from the authors.

[8] www.agr.bfs.admin.ch

[9] www.bafu.admin.ch/climatereporting/index.html?lang=en

2000; Leifeld et al., 2003; Hediger, 2004) for Switzerland as well as on international guidelines (IPCC, 1997) for the preparation of national GHG inventories. The corresponding equations allow us to determine the feed energy requirement and manure production of animals, to assess related GHG emissions from various sources and to evaluate different options of emissions control and soil carbon sequestration.

For simplicity we only consider to two different scenario settings in our analysis: (a) the unilateral case of climate policy with continued border protection for agriculture and related price development; and (b) the multilateral case with international cooperation in climate policy, opening of agricultural markets and adequate prices. For the time period 2000 to 2005 only one agricultural price scenario ("base-scenario") is used, whereas for the period 2005-2010 a "Swiss price scenario" (scenario "CH") and an "EU price scenario" (scenario "EU") are distinguished. In the official "Swiss price scenario" of the Federal Office of Agriculture producer prices are expected to decline in a range between 10 and 30 % for most of the crop and livestock products between 2005 and 2010. In contrast, in the "EU price scenario" a continuous decline and approximation of the EU price level until 2010 is assumed for both agricultural outputs and tradable inputs. This implies a decline of 20-40 % for livestock and 60-70 % for crop products between 2005 and 2010. Thus, future producer prices are considerably lower in this alternative scenario than in the official one, while the prices for domestic inputs may decline less rapidly due to institutional capture and market imperfections. Table 1 illustrates the reference prices in 2000 and scenario assumptions for selected products in the years 2005 and 2010.

Tab. 1: Reference levels and scenarios of producer prices for selected products and years

Products:	Units	Year and scenario 2000 base	2005 base	2010 "CH"	2010 "EU"
winter wheat	CHF/ton	750	547	445	179
winter barley	CHF/ton	470	421	359	154
rape	CHF/ton	750	768	625	420
sugar beets	CHF/ton	112	110	90	102
potatoes	CHF/ton	440	341	304	173
milk	CHF/kg	0.77	0.67	0.56	0.47
calf	CHF/kg	11.30	11.31	10.41	7.36
beef	CHF/kg	7.30	6.21	5.72	4.15
"Natura Beef"	CHF/kg	9.65	9.26	8.52	8.23
fattening pigs	CHF/kg	4.80	4.18	3.72	2.11
lamb	CHF/kg	8.88	8.70	8.25	6.20
milk cows	CHF/kg	3.60	3.42	2.84	3.01

In all scenarios, EU prices are assumed for excess production that cannot be absorbed by the domestic market and therefore must be exported at a lower price.

4.3 A CGE analysis of curbing energy-related CO_2 emissions in Switzerland

To investigate different strategies to reduce Swiss CO_2 emissions, Bahn and Frei (2000) implemented the applied general equilibrium model GEM-E3 to the case of Switzerland. It provides details on the macro-economy and its interaction with the environment and the energy system.

GEM-E3 is a recursive-dynamic model that contains of one economic and one environmental module. The model considers four economic agents (producers, one representative household, government and foreign sector), 13 consumption categories, and 18 production sectors using capital and labour as the two primary production factors. Thus, land is not considered in GEM-E3 Switzerland, and agriculture is highly aggregated (one single production sector), which dos not allow for calculating agricultural GHG emissions according to the requirements of the national GHG inventory (IPCC guidelines). However, GEM-E3 has been designed and implemented to conduct policy analysis in the economy-energy-environment sphere, rather than to investigate greenhouse gas mitigation options in agriculture. Accordingly, the model distinguishes among electricity, natural gas and crude oil or oil products as the primary energy resources. The related CO_2 emissions are computed in linear relation to the use of fossil fuels (using fixed emission factors according to the specific carbon contents) within the environmental module.[10] The time period considered for calculations was from 1990 (base year) forward to the year 2010 in steps of 5 years.

Within the frame of GEM-E3 Switzerland, Bahn and Frei (2000) investigated two strategies that are either based on a national carbon tax (the unilateral case, or what they call "the 'tax only' strategy"), or the combination of a carbon tax with the buying of CO_2 emission permits on the international market (the multilateral case, or "permits & tax" strategy). For both strategies, they further considered a low and high growth variant, reflecting the assumption about technical progress and economic growth in the rest of the world. In their analysis, they particularly calculated the CO_2 taxes that would be required to satisfy the 10 % reduction target of the CO_2 law until 2010. In equilibrium, these imputed prices correspond to the marginal CO_2 abatement costs under the different scenarios. These results are subsequently used to approximate the marginal abatement cost curve for the ECS and to compare in a meta-analytical framework the marginal CO_2 abatement costs of the ECS and the agricultural production sector.

4.4 Meta-analysis

Meta-analysis is a research method to synthesise previously obtained research results. It is usually seen as a statistical approach towards reviewing and summarising the literature (Florax et al., 2002). However, in more general terms, meta-analysis is referred to summarising, com-

[10] The economic and environmental databases have been developed on the basis of an existing Social Accounting Matrix and official statistics (see Bahn and Frei, 2000, for details).

paring, averaging, evaluating and apprehending common elements in other studies. In this regard, van den Bergh and Button (1997) emphasise that meta-analysis - or, more adequately, a meta-analytical framework and the use of meta-analytical tools and techniques - can help to improve our understanding of environmental economic analysis. In this sense, we apply in the subsequent section a meta-analytical approach to compare the marginal GHG mitigation costs across different sectors and gases, and to assess the economic value of Swiss agriculture's contribution to the national Kyoto target. The advantage of this approach is the integration of results from complementary studies in an economic meta-analysis at the interface of the respective studies, using information that cannot be transmitted within the frame of the respective models due to restricted research questions and simplifying assumptions. The key issue here is the comparison of marginal GHG abatement costs that have been calculated in different sector-specific models for the energy and agricultural sector, respectively.

5. Base results for the period 2000-2010

The results of the base runs with the agricultural allocation model S_INTAGRAL reveal the expected decline of agricultural income under the current agricultural policy regime and for a decline of producer prices to the EU level (cf. Figure 2). Furthermore, the decline of agricultural GHG emissions until 2010 is, as illustrated in Table 2, quite similar for both price scenarios. This indicates that Swiss agriculture can be expected to further reduce its GHG emissions in about the same range of magnitude as between 1990 and 2000, even without specific climate policy incentives. Moreover, the results show, in contrast to those from the USA and Finland, that cost-effective measures to reduce GHGs in Switzerland will be mainly achieved by means of emission reductions, rather than carbon sequestration in agricultural soils.[11]

[11] Reasons that explain these differences are given in Section 2.

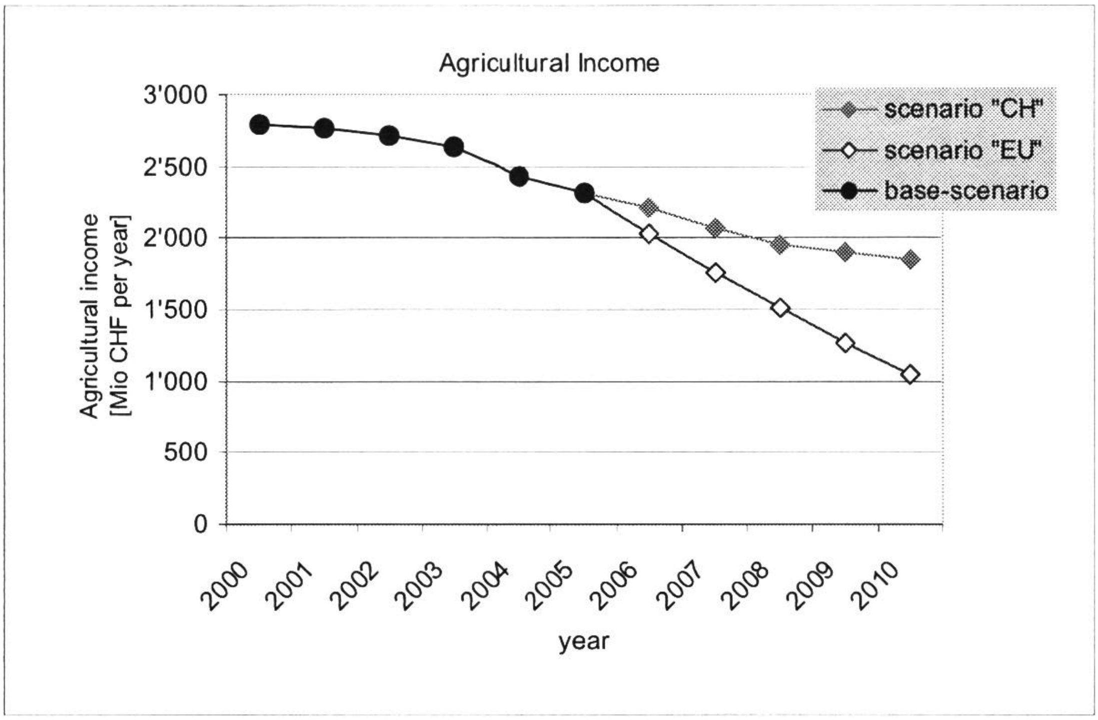

Fig. 2: Changes in agricultural income 2000-2010 according to calculations with S_INTAGRAL.

Tab. 2: Changes of agricultural GHG emissions and C sequestration (kt CO_2eq/year)

year and scenario:	2000 base	2005 base	2010 "CH"	2010 "EU"
CO_2 emissions	132.6	124.2	121.9	117.8
CH_4 emissions	2572.7	2525.4	2220.9	2227.9
N_2O emissions	2016.8	1961.2	1828.8	1801.6
GHG emissions totally	4722.1	4610.8	4171.0	4147.3
Reduction of emissions compared to 2000	—	**111.3**	**551.1**	**574.8**
C sequestration	11.5	15.6	19.4	26.0
Total GHG reduction compared to 2000	—	**126.9**	**570.5**	**600.8**

As illustrated in Table 3, the results of our model-based calculations suggest that one could expect for both price scenarios a decline of GHG emissions until 2010 by about 12 % compared to the year 2000. This is apparently higher than the 3 to 4 % that are expected by the Federal Council (Bundesrat, 2002). This difference can, to a certain extent, be explained by the fact that Swiss agriculture is considered in the model as one single enterprise. It offers more flexibility to the overall system than individual farmers effectively will have in their decisions, given the existence of farm level constraints. Hence, the results of the model-based expectations for future GHG reductions under the current agricultural policy must be considered as over estimations. Thus, our results indicate an upper limit, while the reductions expected by the Federal Council represent a lower limit for the future development of GHG emissions under the current agricultural policy.

Tab. 3: Changes of expected GHG emissions compared to 2000 (in percent)

year and scenario:	2005 base	2010 "CH"	2010 "EU"
CO_2 emissions	- 6.4 %	- 8.1 %	- 11.1 %
CH_4 emissions	- 1.8 %	- 13.7 %	- 13.4 %
N_2O emissions	- 2.7 %	- 9.3 %	- 10.7 %
GHG emissions	**- 2.3 %**	**- 11.7 %**	**- 12.2 %**

The main reasons for the estimated decline in the emissions of all three GHGs are a further decrease of livestock populations and manure production until 2010, and the related effects on land management tending to more open cropland with a reduction in forage production and lower intensity of cultivation (see also Hediger et al., 2004, p. 66). This development is primarily due to the assumed development of agricultural prices. However, apart of the level of total agricultural income (cf. Figure 2), these results do not show significant differences in real variables (livestock populations and land allocation) between the two price scenarios. This also explains why there is no substantial difference in our projections of GHG emissions for the year 2010. The development of the real variables that determine agricultural GHG emissions is driven by relative prices (the allocation problem), rather than by the price level. On the contrary, the difference in the level and decline of agricultural income is directly explained by the differences in the absolute prices.

6. The economic value of agriculture's contribution to Swiss climate policy

As mentioned in Section 3, Switzerland committed itself in the Kyoto Protocol to reducing its GHG emissions until the commitment period by 8 % below the level of 1990. This corresponds to a reduction of 4.25 Mt CO_2eq/year. However, until 2002, total GHG emissions in Switzerland only marginally declined by 0.88 Mt CO_2eq/year (or 1.7 %) below the 1990 level (BUWAL, 2004; SAEFL, 2004). In contrast, Swiss agriculture reduced its GHG emissions over the same time interval by 0.6 Mt CO_2eq/year. This corresponds to 14 % of the Swiss reduction commitment according to the Kyoto protocol.

The economic value of this contribution to Swiss climate policy can only be determined from an efficiency point of view which reflects the above mentioned allocation problem of equalizing the marginal abatement costs across GHG mitigation measures and sectors. This value is optional, as it refers to reduced abatement costs for the ECS in the commitment period of the Kyoto protocol, and it is conditional to assumptions about the institutional framework. The latter can either be represented by a *unilateral policy*, which means all reductions must be realized in Switzerland, or a *multilateral policy*, which also includes reductions generated abroad through international emissions trading and investment in specific mitigation projects (joint implementation and clean development mechanism) that are principally permitted under the Kyoto protocol.

6.1 Value of previous GHG reductions in agriculture

The following considerations are based on assessments of implicit CO_2 prices for the energy consumption sector (ECS) as reported in a study by Bahn and Frei (2000) who used a computable general equilibrium (CGE) model of the entire Swiss economy, but without specific consideration of the agricultural production system. They calculated marginal costs for reducing energy-based CO_2 emissions by 5 % until 2005 and by 10 % until 2010. In the case of a unilateral policy the estimated CO_2 price for the year 2010 ranges between 83 and 103 CHF/t CO_2. In case of participation in a European emissions trading system, the estimated price is 42 CHF/t CO_2.

These results of Bahn and Frei determine the reference framework for our evaluation of GHG mitigation options in Swiss agriculture, which includes the assessment of the economically efficient levels of GHG reduction by agriculture and its conditional value to society. To this end, the marginal abatement costs of the energy consumption sector (ECS) and the agricultural sector must be compared. This is schematically illustrated in Figure 3, which shows in stylized form the marginal abatement costs of both sectors as increasing functions of the respective GHG mitigation efforts. The latter are represented with opposing orientation on the horizontal axis. On the one hand, it shows an increasing level of GHG reductions by the ECS from the left to the right. On the other hand, it uses the Kyoto target Q_0 as point of reference for the evaluation of GHG reductions by the agricultural sector. Even without any legal commitment, the latter contribute to fulfilling the national Kyoto target and thus reduce the need to curbing GHG emissions in the ECS. In Figure 3, the agricultural GHG reductions therefore point in the opposite direction than those in the ECS. The vertical axis refers to the marginal abatement cost for the ECS (MAC_E) and agriculture (MAC_A), respectively, as well as to the related CO_2 prices.

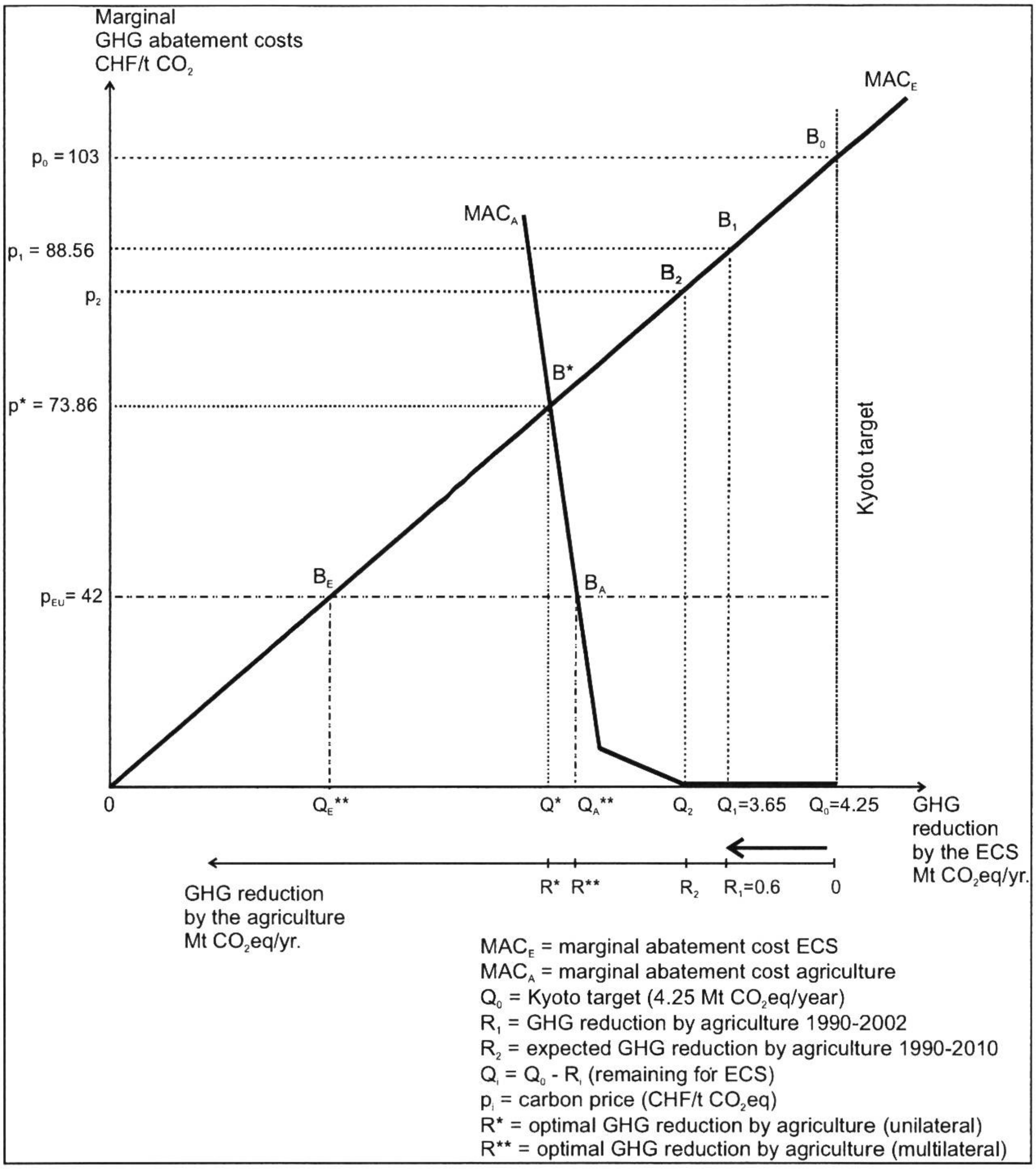

Fig. 3: Optimal allocation of GHG reductions in a two sector representation.

The reference point of our analysis is given by the national Kyoto target of reducing GHG emissions, which is equivalent to the 10 % reduction of CO_2 emissions that shall be achieved according to the CO_2 Law until 2010. The economic value of agriculture's contribution to fulfilling the Kyoto target is equal to the induced reduction in total abatement costs for the rest of the economy, which is represented here by the ECS.

Taking a linear approximation of the MAC_E curve,[12] using the upper value of 103 CHF/t CO_2 from Bahn and Frei (2000) and the Kyoto target Q_0 = 4.25 Mt CO_2eq/year, the total abatement costs for the ECS would be nearly 220 Mio CHF/year averaged over the commitment period 2008-2012. This calculation refers to the requirement of the CO_2 Law that the Kyoto target shall be achieved by reducing energy-based CO_2 emissions by 10 % until 2010.

Yet, the Kyoto protocol does, in contrast to the Swiss CO_2 Law, not only address CO_2 but also other anthropogenic GHG emissions. Correspondingly, agriculture's mitigation efforts can be accounted for in this framework, such that the remaining requirement to reducing emissions by the ECS declines by the respective amount. Taking into account the reduction of agricultural GHG emissions between 1990 and 2002 by 0.60 Mt CO_2eq/year (R_1 in Figure 3), the remaining commitment for the ECS reduces to $Q_1 = Q_0 - R_1$ = 3.65 Mt CO_2eq/year. In relation to this, the expected annual abatement cost for the ECS diminish by 57.1 Mio CHF, or 26 % of the original value. This corresponds to the area $Q_0B_0B_1Q_1$ in Figure 3, and quantifies the economic value of the agricultural GHG reduction between 1990 and 2002.

The resulting CO_2 price goes down from p_0 = 103 CHF/t CO_2eq to p_1 = 88.56 CHF/t CO_2eq (see also Table 4).

6.2 The value of further GHG reductions until 2010

6.2.1 The unilateral case

As presented in Section 5, further reductions of GHG emissions from agriculture can be expected if the current agricultural policy is continued and if price relations develop as assumed in official scenarios of the Swiss Federal Office for Agriculture and without specific climate policy measures and obligations imposed on agriculture. These reductions

[12] Since Bahn and Frei (2000) only provide the above mentioned estimates for a 10 % reduction in 2010, we do not have full information for the assessment of the MAC_E curve and therefore use a linear approximation, as represented in Figure 3. Given the theoretical convexity of the abatement cost function and additional estimates by Bahn and Frei for the year 2005, this approximation may represent a slight overestimation of the MAC_E curve.

(including carbon sequestration) are estimated between 0.12 and 0.50 Mt CO_2eq/year ($R_2 - R_1$) for the period 2002-2010. They further reduce the ECS's total abatement cost by about 10 to 40 Mio CHF/year (area $Q_1B_1B_2Q_2$ in Figure 3), which determines the economic value of additional GHG reductions by agriculture. Another effect, which is visualized in Figure 3, is the decline of the marginal costs for the ECS and of the related CO_2 price that would be in the range of 76 to 86 CHF/t CO_2eq (cf. rows C and D in Table 4).

All in all, previous and further GHG reductions that can be attributed to the current agricultural policy accumulate to an estimated economic value of about 67 to 99 Mio CHF/year in the commitment period of the Kyoto protocol. This value corresponds to 30 to 45 % of the originally calculated abatement costs for the ECS of 220 Mio CHF/year. This will be enabled by Swiss agriculture without having to bear effective GHG abatement costs. Indeed, losses of farmers' aggregate income that are caused by agricultural policy measures and changes in economic conditions (prices) cannot be attributed to climate policy, and must therefore not be considered as GHG mitigation costs. Nonetheless, they are relevant for addressing socio-economic aspects of both agricultural and climate policy.

Tab. 4: GHG reductions and economic value of agriculture's contribution until 2010 with a unilateral policy and Swiss price scenario

	GHG reduction by agriculture Mt CO_2eq/year	Remaining commitment for the ECS Mt CO_2eq/year	Equilibrium CO_2 price CHF/t CO_2eq	Abatement costs for the ECS Mio CHF/year	Value of agricultural contribution Mio CHF/year	Abatement costs agriculture Mio CHF/year
A	0	4.25	103.00	218.9	0	0
B	0.60	3.65	88.56	161.8	57.1	0
C	0.72	3.53	85.61	151.2	67.7	0
D	1.10	3.15	76.32	120.2	98.7	0
E	1.20	3.05	73.86	112.6	106.4	2.2-2.5

A = Kyoto target (commitment to reduce GHG emissions)
B = effective decline of agricultural GHG emissions 1990-2002
C = expected decline of agricultural GHG emissions 1990-2010 with a continuation of current agricultural policy (assumption: 3 % reduction compared to emissions in 2000; source: Bundesrat 2002)
D = expected decline of agricultural GHG emissions 1990-2010 with a continuation of current agricultural policy (model-based assessment with S_INTAGRAL, incl. C sequestration 2000-2010)
E = maximal reduction of agricultural GHG emissions in 2010 with additional incentives for GHG reduction (according to model-based assessments with *S_INTAGRAL*)

Additional GHG reductions might be expected from agriculture if targeted economic incentives would be introduced. In this case, an additional GHG reduction of 2.5 % in the year 2010 would be efficient, under the assumption of a unilateral policy and the Swiss price scenario. This is determined by the intersection of the MAC_E and MAC_A curves in Figure 3, and would result in an estimated CO_2 price of 73.86 CHF/t CO_2eq. The costs involved amount to 2.2-2.5 Mio CHF/year for the agricultural sector (cf. row E in Table 4, area $Q_2Q^*B^*$ in Figure 3). Compared to savings in abatement costs for the ECS of about 7.5 Mio CHF/year (difference between rows D and E in Table 4), it proves to be economically efficient to further reduce agricultural GHG emissions beyond the reference level in 2010 (row D in Table 4). However, it must also be considered that, due to transaction costs that are eventually incurred with the implementation of a system of policy measures and incentives to reduce agricultural emissions of methane and nitrous oxide and to sequester carbon in agricultural soils, the net benefit to society may be smaller than estimated or even negative.

6.2.2 The multilateral case - participation in international emissions trading

With the participation of Switzerland in international emissions trading and thus in a multilateral policy, both GHG abatement costs for the ECS as well as the economic value of the agriculture's contribution will decline. Given the price p_{EU} = 42 CHF/t CO_2, assessed by Bahn and Frei (2000), the total cost for the Swiss economy to achieve the Kyoto commitment fall from 120 to 151 Mio CHF/year (cf. Table 4) into the range of 94 to 112 Mio CHF/year (cf. Table 5). This elucidates the social benefit of following a multilateral climate policy. In turn, the value of agriculture's contribution also decline from the range of 67 to 99 Mio CHF/year to the level of 30 to 48 Mio CHF/year in the base-line projections for the year 2010. This still corresponds to about 20 to 33 % of the ECS's total CO_2 abatement cost. However, the agricultural contribution that could be induced by specific economic incentives and under assumption of the EU price scenario will be almost negligible with only 5 kt CO_2eq/year.

Tab. 5: GHG reductions and economic value of agriculture's contribution until 2010 in the multilateral case with participation in international emissions trading and EU prices

	GHG reduction by agriculture Mt CO_2eq/year	Remaining commitment for the ECS Mt CO_2eq/year	CO_2 price (according to Bahn and Frei, 2000) CHF/ t CO_2eq	Total costs for the ECS (incl. certificates) Mio CHF/ year	Value of agricultural contribution Mio CHF/ year	Abatement costs agriculture Mio CHF/ year
A	0	4.25	42.00	142.1	0	0
B	0.53	3.72	42.00	119.8	22.3	0
C	0.72	3.53	42.00	112.0	30.2	0
D	1.13	3.12	42.00	94.6	47.5	0
E	1.14	3.11	42.00	94.4	47.8	0.1

For explanations about A to E, see Table 4

7. Summary and conclusion

Since 1990, Swiss agriculture has reduced its GHG emissions by 0.67 Mt CO_2eq, whereas methane and nitrous oxide as the most important gases decreased by about 10 %. This contribution corresponds to about 16 % of the national Kyoto commitment. It is primarily a consequence of changes in economic conditions and agricultural policy reform, but has not been induced by climate policy measures. Therefore, agricultural income losses cannot be attributed to climate policy (no effective abatement costs), even though agriculture has provided a valuable contribution on the way to achieving the national Kyoto target. Moreover, it cannot be concluded that Swiss agriculture has already fulfilled its commitment to reduce GHG emissions. Indeed, the Kyoto protocol does only specify national commitments for GHG reduction, but no sectoral targets.

Yet, the effort of each sector, such as agriculture, cannot solely be evaluated on the basis of quantities. Rather, it is necessary to consider different options and costs for reducing GHGs in different sectors. This can be realized by calculating and comparing marginal abatement costs across sectors, which also allows for the determination of an economically efficient allocation of mitigation efforts. From an economic point of view, this may require targeted incentives to agriculture, such as compensation payments according to the marginal abatement costs (CO_2 prices) that are reported in Tables 4 and 5 for additional GHG reductions. However, the establishment of an exclusively efficiency-oriented climate policy with targeted incentives to agriculture may also induce presumably high costs of monitoring and implementation.[13] Therefore and under consideration of the relatively small contribution that can be expected from such a policy in the short run (i.e., within the first commitment period of the Kyoto Protocol), we cannot recommend the introduction of additional incentives to induce Swiss agriculture to further reduce its GHG emissions beyond the expected level under the current

[13] These transaction costs are generally assumed to be higher than those for measures aimed at reducing CO_2 emissions from fossil fuels, where emission coefficients only depend on their carbon contents. In contrast, agricultural GHG emissions of methane and nitrous oxide are determined by numerous factors that are due to farmers' decisions (cf. IPCC, 1997).

agricultural policy. Nonetheless, we can attribute the base-level reductions as a result of the ongoing agricultural policy reform.

Under the given institutional situation and implicit assignment of property rights, the assessment of marginal abatement costs also provides the analytical framework for assessing the economic value of Swiss agriculture's contribution to achieving the national Kyoto target. In case of a unilateral policy, this value amounts to 67 to 107 Mio CHF/year for expected GHG reductions in the year 2010. It corresponds to about 30 to 50 % of the total abatement costs the Swiss economy would have to bear to unilaterally achieve the Kyoto target with a policy exclusively based on measures to reducing energy-related CO_2 emissions.

From an economic perspective, however, it would be efficient to participate in international emissions trading (multilateral climate policy). This would reduce, on the one hand, the total abatement cost of the energy consumption sector in the commitment period from about 220 Mio CHF/year to estimated 142 Mio CHF/year. On the other hand, the value of agriculture's overall contribution would also diminish to about 30 to 48 Mio CHF/year. This can be achieved without effective abatement costs for agriculture.

With targeted measures and economic incentives, agriculture could further reduce its emissions. In this case, farmers would have to bear effective abatement costs. This has been analyzed by means of incremental GHG constraints in our optimization model. The results show that cost-effective potentials for additional GHG reductions by agriculture exist, but that - at least within the first commitment period - they are rather small compared to the estimated base-level reductions. Moreover, the results indicate that soil carbon sequestration may only constitute a moderate option in the short term. This leads to the advice of renouncing targeted measures for additional GHG mitigation in agriculture under the current policy framework. However, an active policy might be adequate in the longer term, since future options may include the production of bio-fuels and the use of new technologies. These have not been included in the present analysis. Given the current structures and market conditions of regenerative energy sources, no significant contribution from the use of bio-fuels can be expected in Switzerland until the commitment period 2008-2012.

The fact that our results are partly different from those received in other countries, such as the USA and Finland, underlines the necessity of carefully designed analyses and policies that account for national circumstances. For instance, the relatively steep slope of the marginal GHG abatement curve for Swiss agriculture is primarily due to the historical development of a highly integrated agricultural production system with a nearly closed forage-manure cycle. Finally, from a methodological point of view, our analysis shows how the results from a highly detailed allocation model of the agricultural sector in a small open economy can be combined with those from an energy-allocation model of the overall economy by using the framework of a meta-analytical approach. This particularly allows us to integrate results from different models with different degrees of disaggregation, different levels of detail, and different simplifying assumptions. This is not only important for the ex-post evaluation presented in this article, but especially for the ex-ante appraisal and a well-informed design of future climate policies. Our approach particularly allows for careful evaluation and discussion of agriculture's role in future GHG mitigation strategies, while using information gained from carefully designed and targeted studies on GHG mitigation costs in different sectors.

On the basis of the present analysis and with updated estimations of marginal GHG mitigation costs for different sectors or domains, the answer about how much agriculture should contribute to climate policy can also be answered in a prospective manner for the upcoming decade. From a theoretical perspective, the answer is straightforward. Each sector should contribute to achieving a national GHG reduction target as long as its own marginal abatement costs are lower than those of other sectors. Thus, additional assessments about the marginal abatement costs in the different sectors are required before a final answer and policy recommendation can be drawn.

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