Combination of the Swiss agrarian sector model SILAS-dyn with the life cycle assessment tool SALCA

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Paper prepared for presentation at the 107th EAAE Seminar *"Modelling of Agricultural and Rural Development Policies"*. Seville, Spain, January 29th -February 1st, 2008

Abstract

The agricultural sector model SILAS-dyn has been used by Agroscope ART for 10 years for the political advisory of the Swiss agricultural administration. To evaluate the environmental effects of different policy scenarios, a LCA module has been developed, connecting a hierarchical linkage to an existing LCA calculating tool. This lowers the formulation input and simplifies the adaptation of updated environmental models. The results of four scenarios show, through the example of energy use as an environmental impact, that indirect effects, such as energy use in the context of imported concentrates, can influence conclusions significantly. The scenario suggesting an increase of fertiliser prices does not change the results significantly, whereas higher energy prices increase the pressure upon energy-intensive activities.

Key words: Sector model, LP, Political advisory, LCA, Income

1. Introduction

Rather more than in its neighbouring countries, Swiss agriculture is characterized by high price and cost structures and a high degree of direct and indirect state support. State support of agriculture is justified on the grounds of its non-profit-making achievements, which are defined in the Swiss Federal Constitution (SR, 1999: Article 104): secure sustenance of the population, decentralized settlement of the country, conservation of natural resources and upkeep of the cultural landscape. Multifunctionality is a significant element of the concept of sustainable agriculture, in which the economic, ecological and social dimensions are simultaneously considered (BLW, 2005).

The decisions in Swiss agricultural policy, such as the design of support programmes or the amount of direct payments, are to some extent based on calculations using the sector model SILAS-dyn, developed by Agroscope ART (Mack and Mann, 2008). This model has been used for 10 years to forecast the effects of different policy scenarios on agricultural outputs, sector income and agrarian budget. In order to meet future needs, further developments of the model are taking place: A market module to consider the effects of liberalising agricultural markets has been developed (Ferjani, 2008), a transformation into a multi-agent model is planned to answer the increasing questions concerning agrarian structure, and since environmental topics have become more important again, a further module has been developed to evaluate the environmental effects of different policy scenarios. This latter module is presented in this contribution.

The main goal of this ecological module is the extension of the basis for political advisory services. The module evaluates the environmental impacts due to planned political measures and to the development of the economic conditions. Furthermore, the module can be used for many other studies in which both economical and ecological subjects are of interest.

Many other decision support models consider environmental impacts (e.g. Cretegny 2002, Andersen et al. 2004, Lehtonen et al. 2005). However, most models only examine individual emissions or indicators, and they only consider agricultural production processes. For political purposes, this could be of interest if the goal is to reduce a specific emission arising within a production sector or a country. But such a consideration might lead to a bias in favour of scenarios in which the environmental impacts are switched to other environmental ranges, to up- or downstream sectors or to foreign countries. For example, importing animal feed decreases the emissions of self-cultivation, but increases emissions abroad. Therefore, from an ecological point of view, also indirect effects should be considered.

One of the most accepted methods that take into account such interactions between several ecological effects and several stages of the production chain is the method of life cycle assessment (LCA). LCA considers most of the important environmental effects, which are caused directly or indirectly by a product or a process ("cradle-to-grave"). A disadvantage of LCA is the high data requirement. At Agroscope ART however, an extensive environmental inventory data base is available (SALCA: Swiss Agriculture Life Cycle Assessment database; Nemecek et al., 2004). This was established in collaboration with other institutions, and expanded with specific models for direct agricultural emissions. The agricultural processes and all upstream processes are included in the system, but for the time being not the downstream sectors like food processing, distribution and consumption.

2. Model SILAS-dyn

The research station Agroscope Reckenholz-Tänikon (ART) has been developing the dynamic sectoral information and forecasting system of Swiss agriculture (SILAS-dyn) since 1996 (Mack and Flury, 2006; Mack and Mann, 2008). The model is used as a decision support system in connection with budget fund planning for Switzerland’s agricultural sector. The system is also used to analyse the effects of new agricultural policy measures on regional and sectoral production, factor input in agriculture and income. These terms of reference form the background for the aims pursued with further development of the system: the model is expected to forecast production and income ratios as realistically as possible over a short to medium-term period of five to ten years. In addition, the system should be ready to provide information and perform calculations at any time and it should have an up-to-date database.

SILAS-dyn is a regionally differentiated process analysis model. These model approaches are characterised by modelling what are called “regional farms”, modelling all the interconnections in production, input and production factor creation and use and delimiting the sector according to the concept of agricultural accounting. The SILAS-dyn model bases the regional farms on eight agricultural areas defined by increasingly difficult production and living conditions. These areas form the basis for a number of agricultural policy measures. This enables very accurate modelling of the Swiss direct payments system, which is characterised by regionally graduated direct payment approaches and contribution restrictions. Furthermore, the relatively homogeneous production potential of individual areas can be very realistically represented in the model, as most of the statistical data is available at this regional level. As part of data preparation, a consistency check is carried out on all the regional coefficients against values from statistics for the sector.

A plant production module in SILAS-dyn comprises all the principal types of arable and grassland activities in Swiss agriculture, divided into different levels of intensity (Figure 1). These activities are in competition for scant resources. A fertiliser module enables, firstly, modelling of all the requirements to be met by farms in terms of a correct nutrient balance in order to obtain direct payments. Secondly, the use of standard fertilisers according to requirements is modelled and sectoral commercial fertiliser consumption is estimated. A feed ration module ensures model calculation of lowest cost rations for all livestock according to requirements and sectoral extrapolation of commercial feed consumption and the cost. A labour module optimises the use of hired labour as a function of specific regional working time requirements and available family labour. By means of a recursive dynamic approach, building and machinery investments are considered and transferred to the next model year.

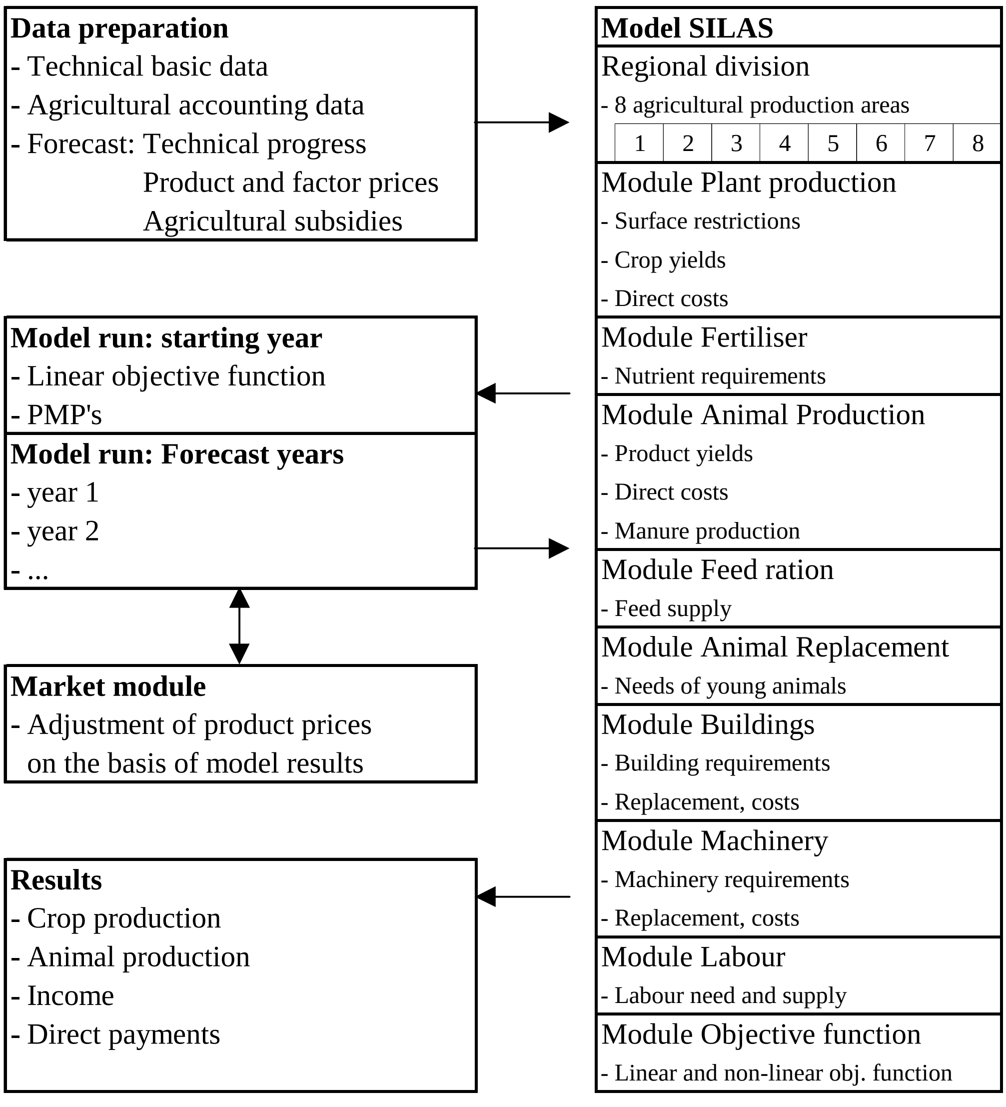

Figure 1. Structure of the model system SILAS-dyn

Parameters relating to the development of technical progress are forecast by trend extrapolation. Price developments of end products and factors are determined by consulting agricultural administrative experts. This procedure was adopted because pricing of the main Swiss products is to a great extent affected by market support and tariff policy measures. For some important end products, a market module that takes into account EU and world market prices as well as tariffs has been developed (Ferjani, 2008). Accounting equations at regional and sectoral level ensure domestic utilisation of all agricultural intermediate products. As Switzerland's agricultural sector is widely protected from the surrounding EU market, no trade relations for intermediate products with other countries are modelled.

The objective function optimises gross value for one year, added for all eight regions at the same time, thus ensuring optimum regional allocation of production. The method of Positive Mathematical Programming (PMP; Howitt, 1995) ensures that the model results for the starting year can be adjusted to the actual situation in the starting year. From an economic point of view, this non-linear element in the cost function takes account of increasing marginal costs as production expands.

To sum up, the SILAS modelling system may be described as follows:
- Process analysis approach
- Short to medium term forecasting horizon of five to ten years
- Consistency with agricultural accounting
- Regional subdivision of production into eight producing areas according to the regional farm concept
- Differentiated modelling of the Swiss agricultural direct payment system and the ecological requirements to qualify for direct payments
- Endogenous optimisation within the model of ration and outside labour input
- Simultaneous optimisation of all regional farms according to the Positive Mathematical Programming (PMP) method.

3. LCA method and data base SALCA

The LCA method is included in SILAS as a connectible sub-model. Four steps should be distinguished in the case of an LCA (ISO, 1997): Determination of the goal and scope definition, the inventory analysis, the impact assessment, and the interpretation.

The aim of the LCA included in the model SILAS-dyn is to calculate the environmental impacts for different scenarios of Swiss agriculture. Further processing, distribution and consumption of agricultural products are not taken into account. Hence, the system boundary is the "farm gate". There is no allocation of the impacts on the different products. An approximate allocation to main product groups (such as milk, meat, arable crops) is carried out. The results are related to general units like the whole Swiss agricultural surface or the amount of food energy produced.

The inventory analysis step includes the calculation of the environmentally relevant emissions of the system. A distinction can be drawn between direct and indirect emissions: Direct emissions arise directly on the farm, whilst indirect emissions stem from the provision or disposal of production factors such as seeds or machinery. In addition to emissions, the exhaustion of resources – especially of non renewable energy sources – is also taken into account. Methodologically, these are treated as indirect emissions. The data basis for the indirect emissions are the SALCA inventories (SALCA: Swiss Agriculture Life Cycle Assessment database; Nemecek et al., 2004). These inventories contain the average emissions involved in a product or a process, e.g. the emissions that occur during the manufacture of a machine, including all of the stages from the extraction of the raw materials to the transport of the machine to the point of sale. The general inventories (e.g. of diesel production) are taken from the Ecoinvent database (Frischknecht et al., 2004), complemented by self-calculated inventories for agricultural inputs (e.g. agricultural buildings). Calculation of the direct emissions is based on the models described in Gaillard et al. (2008). Table 1 contains all important emissions occurring in agricultural processes and their influencing factors in the used emission models. To calculate the indirect and direct emissions, all significant production factors and process conditions in the necessary classification have to be specified in the model SILAS-dyn (e.g. total weight of own machines for tillage).

Table 1. Important direct emissions in agriculture

Emission	Area	Determining factors
Ammoniak NH_3 (Menzi et al., 1997)	Housing	Quantity of N excreted (dependent for its part on animal species and number of animals, animal performance, feed), housing system, grazing time
	Animal-manure storage	Type and quantity of animal manure, storage system (open/closed)
	Animal-manure spreading	Type and quantity of animal manure, dilution of liquid manure, region and climate, season (month), quantity produced per area unit, special measures (e.g. production technique, consideration of weather conditions)
	Grazing	Quantity of N excreted, grazing time
	Chemical N-fertilisers	Type and quantity of chemical fertilizer
Nitrate NO_3 (Richner et al., 2006)	NO_3-generation in soil	Month, number of animals per surface, type of soil, soil cultivation measures, crop type (absorption of NO3)
	N-fertilisation	quantity of N-fertilisation, month, crop type, soil thickness
	Grazing	Quantity of N excreted, duration of grazing, Proportion Verhältnis dung : urine, season
Methane CH_4 (Minonzio et al., 1998)	Digestion	Quantity of feed uptake (dry matter), Percentage of roughage, animal type, animal weight
	Animal-manure storage	Quantity of feed uptake (dry matter), animal type, manure type (percentage of liquid manure)
Nitrous oxide N_2O (Schmid et al., 2000)	Animal-manure storage	Type and quantity of animal manure
	Animal-manure spreading	Type and quantity of animal manure and fertiliser, N-fixation, N-harvest residues
	Grazing	Quantity of N excreted, duration of grazing
Nitric oxides NOx (Grub, 1996)		Quantity of N_2O-emissions
Phosphate PO_4 (Prashun, 2006)	Leaching	Crop type, risk category, quantity of animal manure, P-supply category, drainage
	Avulsion	Crop type, risk category, P-fertilisation, gradient, type and length of slope, in- and outflow of water, distance to outflow
	Erosion	Erosion (dependent for its part on precipitation, soil type, gradient, length of slope, canopy), P-supply category, distance to outflow
Pesticides		crop type (connected with pesticide requirements per crop type)
Heavy metals (Freiermuth, 2006)		Purchase of fertilisers and feed
Combustion emissions CO2, CO, NOx, HC, .. (Rinaldi et al., 2005)		Use of diesel, tractor power and operating grade

The impact assessment step determines the effects of the emissions calculated in the inventory analysis on specific environmental impacts: for example, all emissions influencing the greenhouse-gas potential are converted into CO_2 equivalents and added up. Taken into account are the classic LCA impact categories (Gaillard et al., 2008; Table 2). The fourth and final step of the LCA – interpretation of the results and deducing of conclusions and recommendations – is to be carried out in each case following model calculations.

Table 2. Important environmental impacts

Environmental impact	**Unit**	**Determining emissions**	**Determining factors or processes in agriculture**
Energy use Use of non renewable energy carriers	MJ-Eq.	Crude oil, uranium, natural gas	Fuel, electricity, buildings
Greenhouse effect Change of the atmosphere by greenhouse gases	kg CO2-Eq.	Carbon dioxide, methane, nitrous oxide	Direct emissions (livestock), buildings, fuel, electricity
Ozone formation Formation of near-surface ozone ("summer smog")	g C2H4-Eq.	Nitrogen oxides, methane, hydrocarbons	Fuel, buildings
Eutrophication Nutrient entry in soil and water	kg N-Eq.	Ammonia, nitrate, nitrogen oxides, phosphates	Direct emissions (agricult. surface, livestock), feed
Acidification Acid entry in soil and water ("acid rain")	kg SO2-Eq.	Ammonia, nitrogen oxides, sulfur oxides	Direct emissions (agricult. surface, livestock)
Terrestrial ecotoxicity Damage of organisms in soil	m3 soil-Eq.	Zinc, copper	Feed, P-fertiliser
Aquatic ecotoxicity Damage of organisms in waters	m3 water-Eq.	Mercury, copper, cadmium, fungicides	Feed, buildings, machinery, P-fertiliser
Human toxicity Human health damage (through air or water)	kg 1,4 DCB-Eq.	Lead, cadmium, mercury	Machinery, buildings, feed, electricity

4. Linkage between SILAS-dyn and SALCA

Different possibilities exist for the connection of the economic sector model with the environmental module. In a previous project on farm level, an integration of the calculating steps of the LCA into the basis model was elaborated (Möhring and Zimmermann, 2005), which required great effort for the correct formulation of the partially unlinear emission formulae and data transfer, resulting in increased computation times. For most model applications of the sector model, the environmental effects are not considered directly during the optimization process, but they are calculated as consequences of certain scenarios. Therefore, their formulation was not carried out within the optimization model, but through a hierarchical linkage to an existing LCA calculating tool (Figure 2).

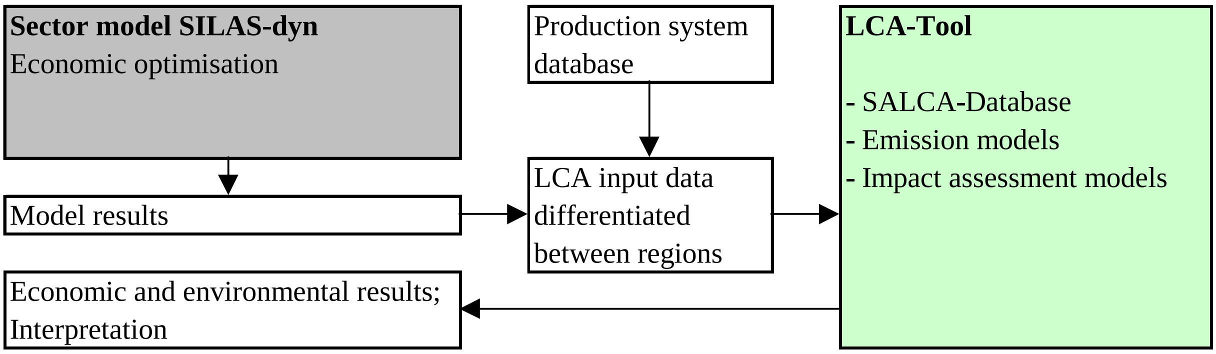

Figure 2. Linkage between SILAS-dyn and LCA/SALCA

In addition to the lower formulation input, this simplifies also the updating and extension of the environmental data and emission models. Nevertheless, all production data which is necessary for the calculation of the LCA had to be formulated within the model or at least generally defined. Normally, the objective function of the economic model SILAS-dyn maximises the sector income. The production data of the model solution is integrated into the LCA tool by means of an interface. Some production data that is not defined in SILAS-dyn in detail (e.g. the used pesticide products for a specific crop) is taken from a production system database in which crop and animal activities were defined using characteristic process parameters for Swiss agriculture. Subsequently, the computed ecological balance arrives back in the basis model for the evaluation of the entire results.

6. Model calculation for different agricultural policy scenarios

6.1. Definition of scenarios

In this paper the economic and ecological effects of four scenarios are shown (Table 3). The *Reference* scenario contains the developments in product and factor prices predicted by the agricultural administration. These assume a further decrease in product prices until 2015, but only slightly changed factor prices. Reductions of market support are partly compensated by increasing direct payments.

Table 3. Prices and direct payments of the scenarios (2007 = 100%)

Scenario		**Ref** Reference	**Ene** Energy	**Fer** Fertiliser	**FTr** Free trade
		Small reduction of market support	In addition to Reference:	In addition to Reference:	Large reduction of market support
		Transferral to direct payments	Increase of energy prices	Increase of fertiliser prices	Transferral to direct payments
Product prices	Milk	82%	82%	82%	67%
	Beef	97%	97%	97%	56%
	Pork	97%	97%	97%	49%
	Wheat	92%	92%	92%	35%
	Maize	90%	90%	90%	51%
	Potatoes	88%	88%	88%	53%
Middle product price development		**91%**	**91%**	**91%**	**65%**
Factor prices	Seeds	96%	96%	96%	89%
	Nitrogen mineral fertiliser	100%	**111%**	**191%**	100%
	Energy	103%	**170%**	103%	103%
	Feed	92%	92%	92%	49%
	Machinery	102%	102%	102%	102%
Middle factor price development		**98%**	**105%**	**98%**	**82%**
Direct payments	Surface contribution	96%	96%	96%	96%
	Extensive meadows	100%	100%	100%	75%
	Contribution to milk cows	300%	300%	300%	350%
	Animal-fair housing	100%	100%	100%	100%
Middle direct paym. development		**115%**	**115%**	**115%**	**115%**

The *Energy* scenario examines what effect significantly increased energy prices would have. The prices of fuel and electricity are gradually increased by 70 %. It is supposed that higher energy prices would cause price rises in the energy-intensive N-fertiliser production, the other assumptions remain the same as in the *Reference* scenario. In the *Fertiliser* scenario, a taxation on mineral fertiliser is assumed, the other assumptions remain, however, the same. The *Free trade* scenario assumes a liberalisation of the Swiss agricultural markets. Because of this, the product prices would decrease significantly by 2015, whereas the factor prices, with the exception of feed, would only slightly decrease. The direct payments would remain more or less unchanged.

6.2. Results

The annual reactions of Swiss agriculture to the changed conditions were estimated with the model SILAS-dyn. Table 4 shows surfaces and livestock, amounts of production and the sectoral success for the final year 2015. In the first three scenarios, livestock slightly decreases, whereby the higher energy prices of the *Energy* scenario effect a slightly higher decrease especially of pigs and poultry. The higher fertiliser prices of the third scenario lead to a slightly smaller decrease of livestock, this to the detriment of arable activities. In the *Free trade* scenario, above all, dairy cow livestock rise despite strongly decreasing milk prices. The main reason for this are the even stronger price cuts of arable products as well as the slightly higher direct payments for dairy cows. The changes in production quantities (e.g. milk production) are more significant than the increased number of livestock. This is due to technical progress. The food energy produced thereby also increases especially in the area of milk production. The sectoral production revenues decreases due to falling product prices in all scenarios, most clearly in the *Free trade* scenario. The sectoral income also decreases because of this in all scenarios, despite higher direct payments and slightly lower production costs. In the *Free trade* scenario, income drops by around a quarter.

Because the emission models of direct emissions are currently being revised, only the results for the environmental impact *energy use* as well as various environmental indicators are shown in this paper. Table 5 shows the development of these parameters for the year 2015. Total energy use varies only a little in the first three scenarios, while it increases slightly in the *Free trade* scenario. This is the case, although the use of energy carriers decreases in all scenarios. This decrease is compensated by higher concentrates imports, in the first three scenarios also by a larger domestic production of concentrates accordingly increasing energy use for processing and drying. The increased need for concentrates is, among other reasons, caused by the higher milk production per cow, which leads to ration changes with a lower roughage proportion. The environmental indicator nutrient balance shows a slight fall in mineral fertiliser use in the *Fertiliser* scenario. Despite the high fertiliser price increase, this fall is not larger because fertiliser costs form a low proportion of the total costs. An even larger reduction of mineral fertiliser use is shown in the *Free trade* scenario, because of decreasing crop production and rising manure production from livestock. The development of pesticide use is similar to the development of arable activities.

Table 4. Economical results of the scenarios (2007 = 100%)

		Ref 2007 (100%)	**Ref 2015**	**Ene 2015**	**Fer 2015**	**FTr 2015**
Agricultural surface	**km^2**	**10642**	**100%**	**100%**	**100%**	**100%**
Open arable surface	**km^2**	**2581**	**101%**	**99%**	**96%**	**84%**
Corn	km^2	1518	107%	106%	102%	90%
Maize silage	km^2	347	107%	105%	108%	108%
Grassland	**km^2**	**7699**	**100%**	**100%**	**101%**	**106%**
Livestock	**1000 LU**	**1232**	**97%**	**95%**	**98%**	**102%**
Dairy cows	1000 LU	546	99%	97%	100%	116%
Beef cattle	1000 LU	81	84%	83%	85%	85%
Pigs	1000 LU	177	96%	93%	99%	80%
Poultry	1000 LU	36	87%	84%	91%	94%
Production						
Corn	1000 t	989	113%	112%	107%	95%
Milk	1000 t	3772	107%	106%	108%	124%
Beef	1000 t	134	98%	97%	98%	104%
Pork	1000 t	200	98%	95%	101%	81%
Poultry	1000 t	49	82%	78%	85%	70%
Eggs	Mio.	553	91%	88%	95%	115%
Revenue	**Mia. SFr.**	**7582**	**93%**	**91%**	**93%**	**73%**
Crop activities	Mia. SFr.	2237	89%	88%	87%	47%
Animal activities	Mia. SFr.	4446	93%	91%	94%	81%
Other revenues	Mia. SFr.	898	100%	100%	100%	100%
Direct payments	**Mia. SFr.**	**2475**	**113%**	**112%**	**113%**	**118%**
Costs	**Mia. SFr.**	**7572**	**99%**	**101%**	**101%**	**88%**
Energy costs	Mia. SFr.	384	95%	154%	94%	88%
Fertiliser costs	Mia. SFr.	110	96%	100%	164%	70%
Feed (concentrates)	Mia. SFr.	1374	111%	109%	115%	76%
Salaries	Mia. SFr.	823	100%	100%	104%	84%
Income	**Mia. SFr.**	**2484**	**94%**	**83%**	**90%**	**73%**

In order to compare the environmental impacts of various scenarios, they must be applied to a functional unit. Figure 3 shows the relationship between environmental impact energy use and food energy produced. Although, particularly in the *Free trade* scenario, use of energy carriers decreases, the total energy use, under consideration of indirect energy, especially concentrate imports, rises. The shift from arable to animal production worsens thereby, as expected, the energy balance. In the first three scenarios, however, an improvement in balance is shown, which is mainly due to technical progress. When energy use is regarded in terms of value creation or income, as in the concept of the environment-efficiency-indicator (DIW, 2006; Kränzlein, 2008), a significant decline results in the indicator. This is mainly due to falling product prices (Figure 4).

Table 5. Ecological results of the scenarios (2007 = 100%)

		Ref 2007	Ref 2015	Ene 2015	Fer 2015	FTr 2015
Total energy use	**TJ**	**38243**	**101%**	**98%**	**99%**	**104%**
Fuel	TJ	8992	90%	89%	88%	73%
Electricity	TJ	4963	96%	93%	97%	93%
Buildings, machinery	TJ	10220	96%	94%	95%	97%
Seeds, pesticides	TJ	517	94%	92%	90%	67%
Fertiliser	TJ	2378	111%	93%	54%	90%
Feed (concentrates)*	TJ	10608	118%	115%	122%	149%
Other factors	TJ	566	98%	97%	97%	91%
Food energy produced	**TJ**	**25597**	**105%**	**104%**	**104%**	**99%**
Arable products	TJ	12322	100%	99%	95%	76%
Animal products	TJ	13274	110%	108%	111%	120%
Concentrates imports	**1000 t**	**850**	**103%**	**99%**	**113%**	**148%**
Corn	1000 t	563	98%	94%	111%	154%
Oil seeds	1000 t	288	112%	110%	118%	136%
Concentrates production	**1000 t**	**730**	**109%**	**108%**	**103%**	**94%**
Animal stock per ha	**LU/ha**	**1**	**98%**	**97%**	**100%**	**104%**
N-fertiliser use	**t N**	**40763**	**95%**	**93%**	**89%**	**76%**
N-fertiliser per surface	kg N/ha	38	95%	93%	89%	76%
P-fertiliser use	**t P_2O_5**	**14477**	**101%**	**99%**	**88%**	**72%**
P-fertiliser per surface	kg P_2O_5/ha	14	101%	99%	88%	72%
Pesticide use	**%**	**100%**	**93%**	**92%**	**90%**	**69%**
Ecolog. comp. surfaces	**km^2**	**1370**	**104%**	**110%**	**112%**	**108%**
Organic surface	**km^2**	**1100**	**97%**	**98%**	**82%**	**94%**

* Including processing and drying of domestic concentrates production

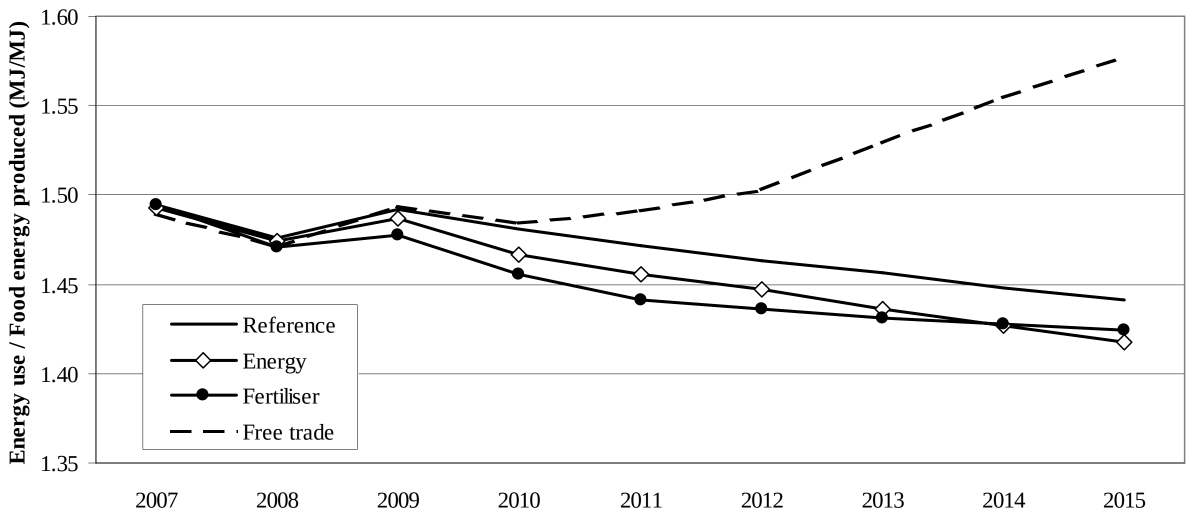

Figure 3. Energy balance: Energy use per MJ food energy produced (MJ/MJ)

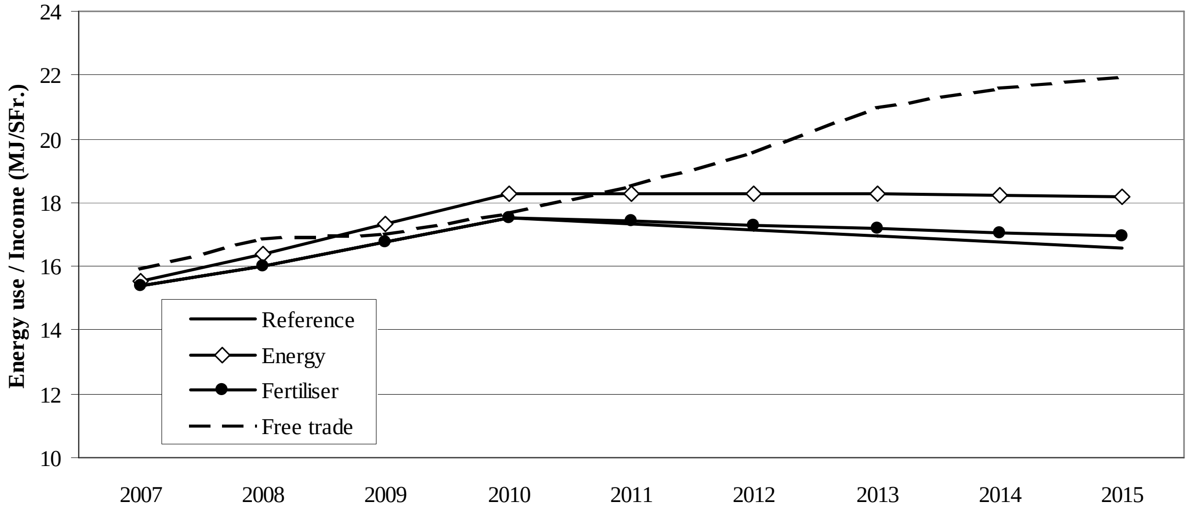

Figure 4. Environment-efficiency-indicator: Energy use per SFr. income (MJ/SFr.)

7. Conclusions

Environmental analysis often only considers direct effects or effects within one country. The results in this paper show that when the LCA method is applied and indirect environmental effects are considered, other outcomes can result. An emphasis on animal production instead of arable production leads, as expected, to a deterioration in the energy balance. Certainly, the Swiss roughage based livestock production seems more ecological than production with high concentrate use. A Swiss animal production which replaces foreign intensive animal production systems, could improve the total energy balance. A price increase of fuel leads to a decrease in energy-intensive production activities. Such effects are very slight in the case of a price increase of mineral fertiliser. A liberalisation of Swiss agriculture would have consequences, above all, in the economic area with an according significant decline on the environmental impacts related to sectoral income.

The linkage of an economic sector model with the LCA method has as its consequence a substantial improvement of the basis for political consulting in that the direct and indirect environmental effects of various scenarios can be demonstrated. By considering several environmental impacts, their interactions and possible conflicts of aims can be investigated. A further development of this environmental module is planned, which considers further impacts such as biodiversity and soil quality or even the third dimension of sustainability in the form of social indicators. A disadvantage of the type of hierarchical linkage used is the increased difficulty of applying methods of multi-objective optimization. Similar results can, however, be reached with the simulation of various scenarios. On the other hand, this type of linkage reduces the complexity of the model and is less labour intensive. It also facilitates the replacement of emission and environmental models with updated versions.

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