AN INTEGRATED SUSTAINABILITY ASSESSMENT OF THE SWEDISH SUGAR PRODUCTION SYSTEM FROM A LIFE-CYCLE PERSPECTIVE: 2003-2015

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ABSTRACT

The article presents a sustainability assessment of the beet-to-sugar production system in Sweden from 2003 until 2015. It focuses on the life-cycle phases of beet growing, beet transport and sugar processing. Based on the Swedish sustainable development strategy, eight indicators in environmental and socio-economic domains based significantly on EU price and production quota changes are assessed. The study also appraises the autumn wheat-to-flour production system as an alternative scenario to provide a better understanding of the overall impacts on the region of the effects of the EU price and quota changes. The method used is a system analysis (simulation) model developed with the software STELLA 9.1. The study is a part of a broader regional sustainability assessment that focuses on the sugar sector in Sweden. Model results of the combined sugar and flour systems show general declines in agricultural landscape diversity and revenues earned in the region with only slight decreases in the number of full-time jobs in the region. Results also reveal decreases in the amount of nutrient runoff, fossil fuel energy use, greenhouse gas releases and field chemical use, with more substantial decreases in biodiversity via the suspension of organic beet growing in the region.

KEY WORDS

sustainability assessment; sugar; Sweden; life-cycle perspective; STELLA software

CLASSIFICATION

JEL: C31, C32, O18, Q13, Q15, Q18, Q41, Q47

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INTRODUCTION

Concerns have been raised in recent decades regarding the sustainability of the European beet sugar production systems e.g. [1-4]. The discussion has not only focused on the regional environmental impacts from the sugar production chains, but it has also centred on the impacts – significantly economic – caused by European sugar policies on sugar production systems in- and outside of Europe. At the same time as these concerns have been lodged, sugar beet growing in European Union (EU) member countries in past decades has also grown to represent an economically integral part of European agriculture – propelling the EU in the recent past to the position of the second largest exporter of sugar in the world. The situation changed, however, in 2002 when the cane sugar-producing countries of Brazil, Australia, and later Thailand, sought consultations with the World Trade Organisation (WTO), alleging the EU's violation of its obligations for sugar under the WTO Uruguay Round Agricultural Agreement [5]. The three countries claimed that EU exports, and re-exports of imported sugar, should be considered as subsidized exports – creating a situation where the agreed upon quantity limit of 1,3 million tons of subsidized exports was being overshot by about 3 million tons annually e.g. [6]. To fend off retaliatory actions, subsequent reforms of the trade distorting system in the EU have been underway since the reform agreement by the EU Council of Ministers in November 2005 and formal reform adoption in February 2006 [7]. The EU sugar sector restructuring has meant step-wise cuts up until the year 2010 in both sugar and beet prices as well as individual member-country production quotas with the overall goal of removing six million tons of sugar from production. The proposed policy modifications have meant large cuts in EU intervention prices, or more specifically, a 36 % decrease in the price of sugar and a 39,5 % reduction in the beet price paid to farmers [8].

There have been a multitude of studies focusing on EU sugar policy changes e.g. [8-11]. The vast majority of these studies, however, have concentrated only on the economic implications of EU sugar policy changes brought about to create a more equitable global sugar trading market. But what have been impacts of the sugar production system on regional *sustainability* – that is, its impacts on a wider set of both socio-economic and ecological system (SES) parameters? Furthermore, what are the expected future regional effects on the wider set of sustainability based on the on-going EU sugar policy reform efforts along with forecasted sugar consumption trends?

With an emphasis on the EU reform measures the aim of this paper is to assess the significant impacts of the regional sugar production system in Sweden from 2003 to 2015. Based on Swedish sustainable development strategy (SDS) priorities, eight SES indicators from the sugar production system – focusing on the life-cycle production phases of beet growing and harvest, sugar beet transport and sugar processing are estimated. Furthermore because the decrease in sugar production, and hence beet growing, does not automatically correspond to a decrease in agricultural production in the region, the equivalent parameters for the alternative production scenario of autumn wheat growing for flour is assessed as one alternative for the land area previously devoted to beet growing. The goal is not to exhaustively assess each individual parameter, but it is to rather analyse the main contributors from each respective system for each production phase in order to gauge overall impacts from policy reforms. The objective is to estimate the wider indicator set, showing potential trade-offs between each indicator as well as provide a more realistic production scenario for the region given larger sugar policy changes.

The paper begins with the background to the Swedish sugar sector and the indicators selected. Through the use of a computer simulation model, it assesses the indicators for the Swedish beet-to-sugar production system based on EU sugar quota levels for Sweden. The paper then estimates the same indicators for the wheat-to-flour system, and combines the two to determine the aggregated impacts from the combination of both systems. The study is a part of a broader regional sustainability assessment focusing on the Swedish sugar sector. The model has been developed for analysing alternative production scenarios, which will be the focus of subsequent analyses, which will be focused on in subsequent papers.

METHODS AND MATERIALS

The method used was an integrated assessment model (IAM) using STELLA 9.1 software (see: http://www.iseesystems.com). STELLA is a stock and flow-based software where the practitioner can create and run simulations over time. Impacts for each of the eight indicators were calculated for each of the three sugar life-cycle production phases, weighted in a common unit (e.g. CO_2-equivalents) and then, where applicable, aggregated with other production phases. The autumn wheat-to-flour scenario included the same indicators, but included five production phases. Materials for the background comprised of academic literature on other sugar and flour systems and governmental reports focusing on Swedish sustainable development and environmental quality priorities. Materials for the model included statistical data for both the sugar and flour systems from a variety of sources – including government statistics, other sugar and flour system assessments as well as industry-specific data. The model relied on region- or industry-specific data when available.

BACKGROUND

SWEDISH SUGAR PRODUCTION

The beet-to-sugar production system in Sweden is similar to production systems in many other EU countries. It has been subject to continual economic rationalization pressures – particularly since WWII [12]. In 2003, the two remaining processing facilities in Sweden produced roughly 417 000 tons of sugar originating from 50 000 ha of beet growing area; roughly 85 % of the beets are grown in the region of Scania at the southern tip of the country [13]. In Sweden, beet growing has represented one key part of a larger multi-year crop rotation system. Due to pest and plant disease problems, beets can at most be only grown on the same plot of land every fourth year.

The Swedish sugar production system is controlled by a complex set of both preferential and restrictive trading rules of the EU Common Agricultural Policy (CAP), which has effectively protected the European agricultural market system from outside competition. But due to on-going internal and external reform pressures, more substantial reforms of the CAP have taken place in recent decades. Situated within the CAP system is the Common Market Organization (CMO) for sugar. The sugar CMO is the specific rules and regulations governing the sugar system in the EU. Also called the *sugar regime*, the CMO for sugar has, until recently, managed to exempt itself from any of the broader CAP policy changes. The sugar CMO is made up of three main elements: guaranteed prices, import protection and export subsidies [14]. These building blocks ensure the domestic preservation of the system through holding out outside sugar penetration into the EU except in cases where special import arrangements have been made with formal colonies in Africa, the Caribbean and Pacific Island (ACP) countries plus India, or special agreements with a group of least developed countries through accords such as the Everything but Arms (EBA) agreement. The result of the different measures has been an EU price for sugar that has been as much as three-times the world market price for sugar.

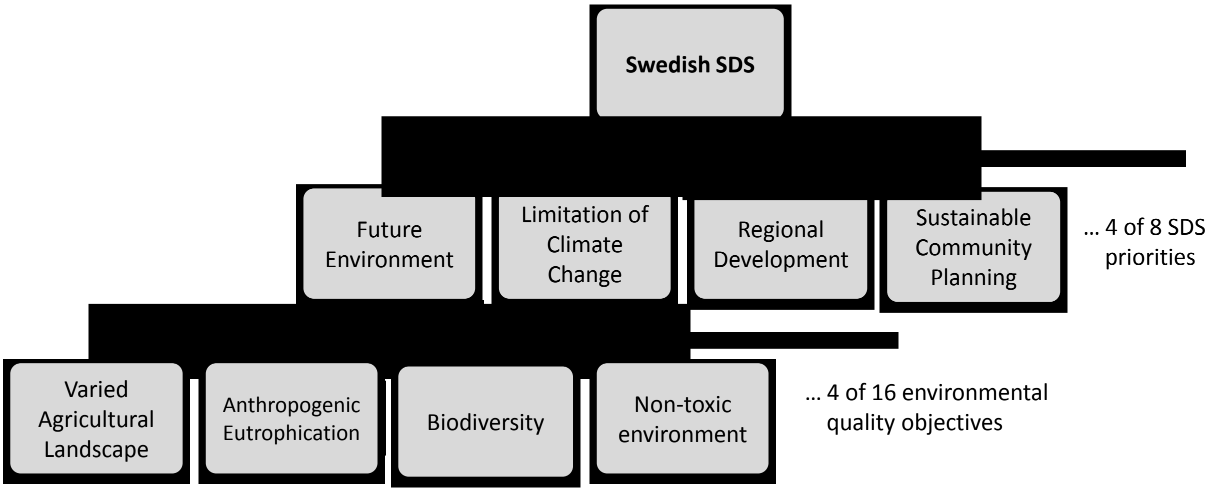

Figure 1. Swedish priority areas used in the study. The centre row describes the SDS priority area whereas the bottom row is the Environmental Quality Objectives.

INDICATOR BASIS

Assessment indicators are based on the Swedish SDS [15, 16] and the 16 Swedish environmental quality objectives (EQOs) [17], which are a part of the sustainable development strategy. Both the SDS and EQO were selected because they are used commonly as the priorities at the national level as well as at regional and local levels. The Swedish SDS consists of eight SDS core areas. Four of the eight broad priority areas were chosen because of their direct relevance to the sugar sector: *the future environment, limitation of climate change, regional development* and *community planning* (Figure 1, centre row). The 16 EQOs were established in the late-1990s and have been incorporated as sub-priorities of the SDS priority area of future environment (Figure 1, bottom row). They include a broad collection of environment-focused goals, many of which have direct relevance to agriculture and agro-industrial production systems. The four EQO areas chosen for this study are *a varied agricultural landscape, anthropogenic eutrophication, a rich diversity of plant and animal life* and *non-toxic environment* [17]. Table 1 displays the SDS parameters, the relevant environmental quality objective or the SDS sub-priority and the specific indicator calculated in the model. Hectares of sugar beet growing in the region were chosen to represent the goal of the varied agricultural landscape. Because of the fertile soils and Sweden's most favourable climatic conditions where beet growing is carried out, there is not a threat that a significant

Table 1. Table showing Swedish sustainable development strategy parameters, specific environmental quality objective or SDS sub-priority and the representative indicator measured in this study.

SDS parameter	Environ. quality objective/ SDS sub-priority	Specific indicator
The future environment	Varied agric. landscape	Beet area planted (ha/yr)
The future environment	Zero eutrophication	N & P leaching (t PO_4 eq/yr)
The future environment	Rich plant/animal diversity	Eco-beet growing (ha/yr)
The future environment	Non-toxic environment	Herb. & pest. use (t/yr)
Limitation climate change	Reduced climate impact	GHG release (t CO2 eq./yr)
Regional dev. & conditions	Regional development	Full-time jobs (jobs/yr)
Regional dev. & conditions	Regional development	Revenues (thousands €/yr)
Sustain. comm. planning	Sustain. energy & transport	Fossil fuel use (GJ/yr)

share of the growing areas will disappear, except to peri-urban expansion processes. The agricultural landscape can however become less diverse with a decrease in the amount of beet growing in the region – a region dominated by cereals production. The second parameter that has presented challenges in recent decades is anthropogenic eutrophication of water bodies in and around southern Sweden. The challenge has led the goal of zero human-induced eutrophication, where agriculture is responsible for 49 % of nitrogen leaching and 45 % of phosphorus leaching to water in Sweden [18]. The most recent EQO is a rich diversity in plant and animal life. The indicator of organic beet growing (ha) was selected to represent a cropping system that allows a richer diversity in plant and animal life in and around beet growing areas through the absence of field chemical use (i.e. insecticides, herbicides, pesticides), synthetic fertilizers, etc. The final EQO-based parameter is the indicator of total pesticide, herbicide and insecticide usage. It was selected to represent the objective of a non-toxic environment, with the goal of eliminating man-made or natural compounds that represent a threat to human health or biological diversity. The main greenhouse gas (GHG) releases from the three life-cycle phases were calculated to represent Sweden's second SDS goal of a limitation of climate change and the overarching goal of a decrease in GHG emissions of four percent below 1999 levels by 2008-2012 [16]. The gases included in the analysis were CO_2, CH_4 and N_2O.

Parameters that were included directly in the SDS were the area of regional development that place priorities on the socio-economic development. For this category two indicators were used: the number of full-time jobs (in year-round-equivalents) in the respective production phases, and the gross revenues generated for sugar beets and sugar production as indicator for the sugar system and the gross revenue from the sale of wheat and the production of flour for the alternative production chain. Finally, fossil fuel usage was used as the indicator for the core area of sustainable community planning in the sub-priorities of energy and transport systems and infrastructure to represent national ambitions to reduce fossil fuel use.

Table 2. Prices and production quotas used in the simulation model [13, 18, 25].

Year	2003	2004	2005	2006	2007	2008	2009	2010-15
Beet price (€/t)	46,7	46,7	46,7	32,9	29,0	27,0	25,5	25,5
Sugar price (€/t)[2]	632	632	632	631	631	541	404	404-450[2]
Quota (000 t)	417	405	406	372	354	327	403	328[3]
Wheat price (€/t)	90	93	100	113	150	274	153	121-140[2]
Flour price (€/t)	318	318	318	318	344	466	397	395-390[2]

[1]Prices denote white sugar.
[2]Represents a step-wise increase (or decrease) in prices.
[3]Quantity signifies the national production quota plus an over production of 15 %.

MODEL AND ASSUMPTIONS

QUOTA SYSTEM AND GENERAL ASSUMPTIONS

The unit of analysis (functional unit) for the study is 50 000 ha of arable land in southern Sweden corresponding to the initial area used to produce the annual production of sugar (raw and white) for 2003, a representative production year prior to the sugar sector policy reforms. The model used actual Swedish production amounts for 2003 to 2009 and the proposed EU-CMO Swedish reform quota amounts for 2010-2015. The Swedish portion of the EU sugar quota from 2011 to 2015 was assumed to be the same as 2010 amounts based on present production quantity agreements. By-product production (e.g. molasses, beet pulp, animal feeds) and their corresponding revenues were also included in the calculations. Actual by-product commodity prices were taken from multiple Swedish Statistical Yearbooks e.g. [13, 18]. Future price developments for these commodities were assumed to stabilize somewhat above 1997-2006 averages as specified in the OECD-FAO World Agricultural Outlook 2009 [25]. The sugar consumption life-cycle phase was not included in the model because of the multiple distributional paths sugar takes after being processed, e.g., food industry, beverage industry, confectionary industry, retail sales, further refining. A summary of beet, sugar, wheat and flour prices and quotas can be found in Table 2. The model was divided into a number of subparts (e.g. beet and sugar production, processing energy use, transport emissions, etc.), which used the parameter-specific input data from Tables 2-6. Special aggregation subsections were then created to weigh and compute aggregated quantities for each indicator area over time.

BEET GROWING AND HARVESTING

Basic assumptions for sugar beet growing are presented in Table 3. Average beet yields were based on real data from 2003 until 2009. The average yields fluctuate significantly annually due to such factors as precipitation and temperature. For the model created, average beet yields from 2010 were assumed to increase by roughly 1 t/(ha × yr) until 2015. Nitrogen and phosphorous leaching is a complex processes with many factors involved such as soil properties, water transport fertilization, and soil management. The model used average leaching amounts from studies in South Sweden on the types of soils most common to beet growing [23, 26]. N_2O releases from field were calculated as percentage of nitrogen applied. Economic calculations included only the costs paid to growers for the agricultural commodities or the revenues generated by sugar and flour producers. The purchase of extra quota amounts or the sale of a percentage of annual sugar production, likewise any additional profit-sharing agreement amounts between the beet grower and sugar processor, were not included in the model. Furthermore, neither one-time CMO sugar restructuring pay-outs nor general EU agricultural support pay-outs were included. All prices are in given in Euros (€) and were denoted as real prices. An exchange rate of 9,3 SEK per € 1 was used when data was acquired in Swedish Crowns. Because beet growing is part of a crop rotation system, the number of growers cannot be attributed to only beet growing. The number of growers was determined by dividing the average amount of beet hectares per grower divided by average farm size in Southern Sweden and then multiplied by the total number of growers.

Table 3. Basic beet growing model assumptions.

Area	Assumption	Source
Initial beet area (ha)	50000	[13]
Beet yield (tons/ha)	49,5	[13]
Ave. farm holding size (ha)	49,6	[13]
Ave. beet growing area (ha)	13,2	[12]
Growing energy use (MJ/ha)	21800	[19]
Beet N use (kg/ha)	115	[20]
Field treated N (%)	100	[13]
N in PO_4-eqivilents	0,42	[21]
P use (Sw. Class III) (kg/ha)	25	[22]
Field treated P (%)	79	[13]
P205 in PO_4 equivalents	3,06	[21]
N field runoff (kg/ha)	19	[23]
N_2O releases field (% N)	3	[17]
N_2O in CO_2 equiv.	310	[24]
Total field chem. Use (kg/ha)	2,64	[18]
Beet area treated with chem. (%)	95	[18]

BEET TRANSPORT

Basic sugar beet transport (to processing facility) assumptions are shown in Table 4. Additional details on the Swedish sugar beet transport system can be found in [27]. All transport was assumed to be done by lorry; in reality a certain small percentage of beets are transported via tractor. All trucks were assumed to be fully loaded (36 t). Fuel type was assumed to be conventional diesel (MK1). The fuel use rate used was an average of the loaded rate to the facility and the empty load rate back to the field; the rate was based on actual industry data [*Personal communication with beet transport representative,* 2006]. The vehicle types were assumed to be a combination of Euro 2 and Euro 3 trucks. The number of full-time jobs in beet transport was determined through transport industry data.

Table 4. Model assumptions for sugar beet transport.

Area	Assumption	Source
Distance to facility (km)	50	[13]
Lorry fuel use rate (l/km)	0,52	Personal communication
CO_2 release rate (kg/l diesel)	2,6	[28]
Beet payload weight (t)	36	Personal communication
Diesel energy content (MJ/l)	40,9	[29]

SUGAR PROCESSING

Sugar processing assumptions are provided in Table 5. There were two processing facilities remaining in Sweden up until the closure of facility 2 in 2006. Facility 1 was responsible for roughly 62,5 % of total sugar production; facility 2 produced the final 37,5 % [30, 31]. Facility 1is significantly fuelled by natural gas; facility 2 was operated mainly by fuel oil. The processing facility produces two types of sugar: white and raw sugar. Each has a different price determined by the sugar CMO. In 2007 60 % of facility one's production was white sugar; the other 40 % produced was raw sugar (*Personal communication with sugar industry representative* 2008). Sugar prices were assumed to decline gradually from € 631/ton for white sugar in 2006 to € 404/t for processing year 2009. Prices for raw sugar were € 497/t in 2006, declining to € 335/t for 2009 [7]. Based on the OECD-FAO predictions, prices for both commodities were assumed to rise slightly in the period 2010-2015 due to increasing global demand for sugar and biofuels [25]. Sugar processing jobs were calculated as the number of full-time year-round employees of each respective facility. Seasonal workers were determined

Table 5. Model assumptions for sugar processing.

Area	Assumption	Source
Facility 1 processing (%)	62,5	[30]
Facility 2 processing (%)	37,5	[31]
Average sugar in beet (%)	17	[13]
Facility 1 N release (kg/t sugar)	0,144	[30]
Facility 1 P release (kg/t sugar)	0,002	[30]
Facility 2 N release (kg/t sugar)	0,117	[31]
Facility 2 P release (kg/t sugar)	0,002	[31]
Nat. gas use Fac. 1 (MWh/t sugar)	0,12	[30]
Fuel oil use Facility 2 (t/t sugar)	0,12	[31]
CO_2 nat. gas release (kg/kWh)	0,21	[24]
CO_2 fuel oil release rate (kg/l)	3,16	[31]
White sugar pro'd (% of total)	60	Personal communication
Jobs facility 1 (jobs/t sugar)	0,0007	[32]
Jobs facility 2 (jobs/t sugar)	0,0011	[32]

by dividing the number of workers divided by the length of the sugar processing season.

WHEAT-TO-FLOUR SYSTEM

Basic wheat-to-flour system assumptions can be viewed in Table 6. The flour production chain was used because it represents a likely alternative to sugar beet growing in the region – especially with recent commodity price increases for wheat. The wheat yield in the model was assumed to be 8 t/ha, which compares to a Swedish statistical average of 7,93 t/ha for the region [13]. The wheat was assumed to have 15 % wet weight content [20]. The wheat system was assumed to have a catch crop planted after harvest, which has been estimated to reduce nitrogen leaching by an additional 30 % [23]. Energy and fuel use and emissions for the catch crop were included in the calculations.

Table 6. Assumptions for the wheat-to-flour production system.

Area	Assumption	Source
Wheat yield (t/ha)	8	[20]
Growing energy use (MJ/ha)	16800	[34]
Wheat N use (kg/ha)	165	[20]
Wheat N runoff rate (kg/ha)	16	[35]
Wheat P use (kg/ha)	24	[22]
Wheat P runoff rate (%)	0,31	[26]
Wheat field chem. use (kg/ha)	0,61	[18]
Wheat payload (t)	11	[20]
Distance to silo (km)	10	Own estimation
Tractor diesel consumption (l/hr)	8	[18]
Lorry payload weight (t)	37	[39]
Distance to mill (km)	40	Own estimation
Wheat transport (h/load)	3	Personal communication
Energy use drying (kWh/t)	43,4	[36]
Wheat to flour ratio	1,28	[37]
Processing natural gas (m^3/t)	1,14	[38,39]
Flour energy use (MJ/kg flour)	1,05	[33]

Wheat transport between field and dryer/grain storage facility was assumed to be carried out by the grower with a 75 kW four-wheel-drive four cylinder turbo diesel tractor pulling a trailer with an 11 ton wheat net payload; the one-way distance was assumed to be 10 km with a tractor using conventional diesel fuel (MK1) with a consumption rate of 8 l/h [23]. All wheat was assumed to be transported via lorry to the flour mill [*Personal communication with flour industry representative,* 2008]. The average single way distance was assumed to be 40 km, which represents the actual distance from a silo in the centre of the region to the mill in central Malmö. Since net payloads are similar, fuel use rates were assumed to be the same as beet transport. Flour production energy use was taken as an average of two industrial sized mills operating in Sweden [33]. Wheat prices were obtained from the online Swedish agricultural news, *ATL* (http://atl.nu/marknad), and based on Swedish prices at the start of each year. Conversions were then made to €/t. Flour prices were obtained from industry sources in SEK/kg and converted to €/t. Price developments for both wheat and flour were assumed to stabilize at a rate below the 2008 price peak but higher than the 1997-2006 average based on the World Agriculture Outlook [25] prognoses.

RESULTS AND DISCUSSION

Figures 2-4 illustrate the results until 2015 for each of the eight indicators. The three lines depict the beet-to-sugar system, the wheat-to-flour system and aggregate results for the combined systems. Results show that there will be general impact decreases in many of the environment-focused indicators. Whereas there will be general decreases in the two socio-economic indicators due to the decreases in annual sugar production quantities.

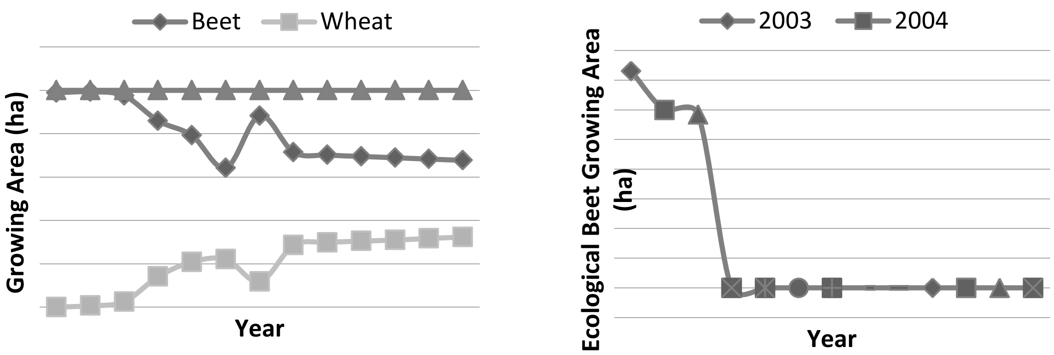

Figure 2. Land use model results for conventional beet growing and ecological beet growing. Results show the gradual decline in a varied agricultural landscape through conventional beet growing due to EU quota changes and general technology improvements. Results also depict a decrease in plant and animal diversity because of the of closing of ecological beet production.

MODEL RESULTS

Land use

Figure 2 shows the two land use indicators under the Swedish SDS parameters of future environment. Simulation results (Figure 2 top) show a decrease in the goal of varied agricultural landscape with the sugar policy change in conjunction with the land being devoted to the flour production. The upper horizontal line denotes the 50,000 ha reference growing area. Due to the quota changes the figure illustrates the almost continuous decline in growing area from the 50,000 ha to under 34,000 ha by 2015 – with the vast majority of the decreases taking place during the 2006-2010 quota reduction period. The modest reductions for the final five years were largely due to technology-driven beet yield increases. The difference between the two lines is made up by the increasing amounts of growing area devoted to autumn wheat growing. The overall result is a less-varied agricultural landscape due to the increase in cereals growing area in the region. It is acknowledged that in reality a larger diversity of crop types would be planted (e.g. rapeseed, peas, other cereals) based on such aspects as commodity prices and the individual grower's rotation system. Further development of the model to include a greater diversity of alternative production and/or cropping systems will be carried out in the future. It should also be noted that larger yield efficiencies or even environmental impact decreases could be realized through the introduction of genetically modified (GM) beet growing, which would give differing results. Bennett, Phipps and Strange (2006) for example have compared GM system with conventional beet growing systems in different locations in throughout the EU.

The starkest change comes with the results for the category of rich biodiversity for the region through the indicator of ecological beet growing (and sugar production). The lower graph in Figure 2 describes the sharp decline in eco-beet growing – from a high of 1462 ha in 2003 to zero in 2006. The reason for the decline was the closure of the facility 2 between production years 2005 and 2006 resulting in no organic beet growing contracts being issued or organic sugar being produced in Sweden beyond 2005. It is not expected that ecological beet growing for sugar production in Sweden will emerge again in coming decade due to adequate supplies from past regional production and due to the ability to import organic cane sugar from South America (*Personal Communication with sugar industry official,* 2008). The assessment also assumed that the organic beet growing was not replaced by organic wheat growing as with the conventional production system due to the overall minuscule amounts of organic wheat production taking place in the region, namely 500 ha of organic wheat growing versus roughly 85 000 ha of conventional wheat growing [18].

Environmental indicators

Figure 3 shows the three indicators under the SDS parameters of future environment and limitation of climate change. It shows that there will be overall decreases in GHG releases, nitrogen and phosphorus runoff (eutrophication) and field chemical use with the sugar policy changes in conjunction with the switch to the wheat-to-flour system. The top graph displays the results for greenhouse gas releases from each system and the aggregated amounts for both production systems for the SDS priority of limitation of climate change. There is a decrease in greenhouse gas releases in the beet production chain for Sweden from 282 000 t CO_2-equivalents in 2003 to just under 208 000 t by 2015. Furthermore, because the flour

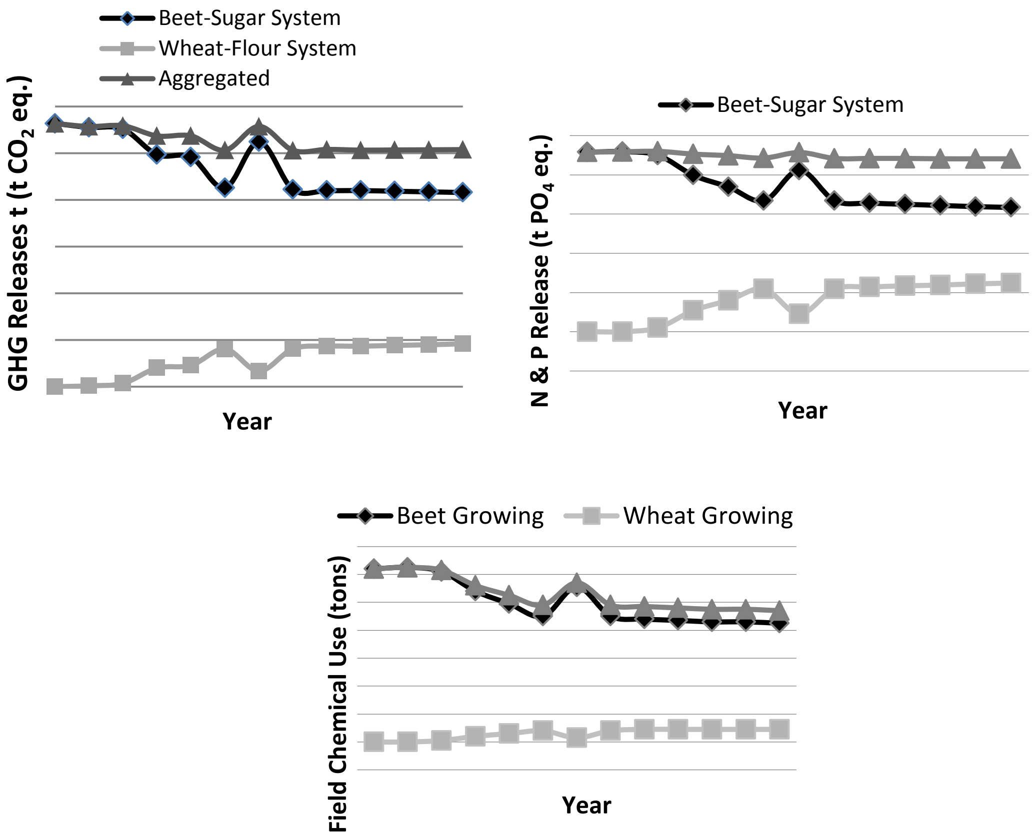

Figure 3. Model results for the three environmental indicators all showing similar patterns due to the beet quota decreases.

production system was less energy intensive in comparison with the sugar production system despite there being more life-cycle phases, there was an overall decrease with both systems from the 282 000 t at the beginning of the study to 253 000 t in the final assessment year – creating an almost 30 000 t CO_2-equivalent decrease by 2015.

Results are similar for the two main contributors to eutrophication, namely nitrogen and phosphorus runoff (centre graph). There is a substantial decrease in the amount of nitrogen and phosphorus leaching to waterways through the decreased sugar production from roughly 458 t PO_4 equivalents in 2003 to just over 317 t in 2015. With the inclusion of the flour production chain, results showed that there is also an overall slight decline in the quantity with the switch to the wheat system due to slightly lower nitrogen and phosphorus leaching rates of 17 t with the wheat growing system and a decrease in flour processing compared to sugar production, with a decrease from the 458 t PO_4 equivalents to 441 t with the combined systems. Despite the model results, it is also acknowledged that there could be an increase in runoff rates with the change-over to the autumn wheat system. The leaching rates used in the model were not based on the amount of macro nutrients applied to the field. The significant increase in the amount of N use with the wheat system, 165 kg/ha compared with 115 kg/ha for the beet growing system, could mean increased leaching from the wheat system. Additional analysis would need to be carried out calculating the nutrient balances of both systems and the effects of the catch-crop often planted after wheat harvest.

Field chemical use (bottom graph) decreases significantly for both beet growing and for the aggregated beet and wheat growing systems. With the decrease in beet growing in the region due to the policy changes, the beet growing system experiences an overall annual decrease from 124 t of insecticides, herbicides and fungicides to 85 t by 2015. Furthermore, due to the less intense use of chemicals for the autumn wheat system, aggregated chemical use for both systems also falls from the 124 t in 2003 to 94 t in 2015. It should be emphasized however that these are strict quantity decreases for field chemical use and say nothing about the overall toxicity on humans or impact on biodiversity from each of the specific field chemicals.

Socio-economic indicators

Figure 4 shows simulation results for the remaining three (socio-economic) indicators under the SDS areas of regional development and sustainable community planning. There are significant negative changes in the SDS priority area of regional development. The values from both beets and each of the two types of sugar (i.e. raw and white) decrease not only because of the Swedish production quota decrease, but decreases are also due to on-going price decreases for both beets and sugar. The revenues in 2003 were determined to be € 243 million and € 153 million by 2015. However, it should be noted that decreases in aggregated revenues are prolonged because of the general rises in both wheat and flour prices between 2006 and 2008, but then decline sharply with the assumed price reductions between 2008 and 2010. Revenues then recover slightly and stabilize due to the assumed price increases after the 2010. Total revenues from the combined systems decrease from € 243 million to € 169 million at the end of the assessment period – with much of the revenues coming from the sharp 2007-08 price increases for wheat and flour.

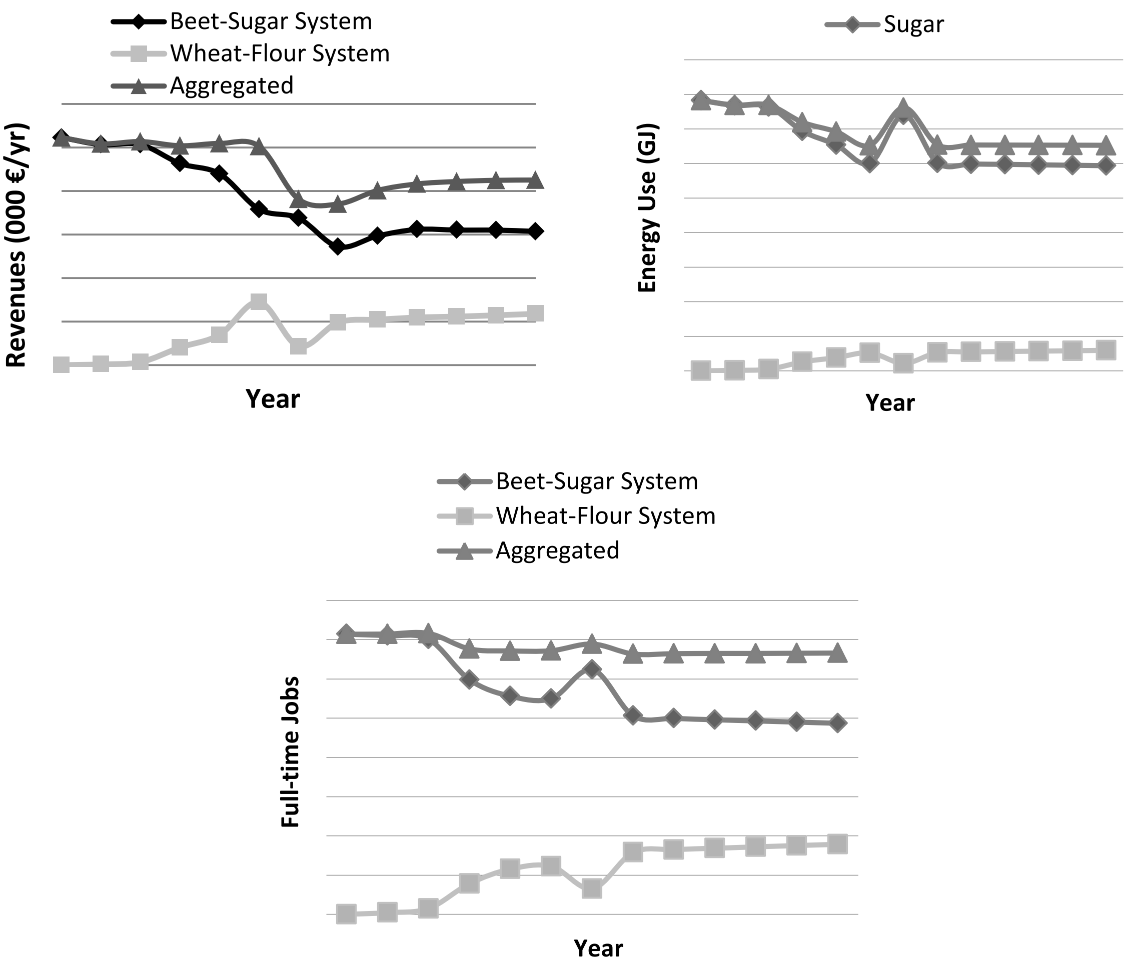

Figure 4. Model results for the three socio-economic indicators of production chain revenues, energy (fossil fuel) use and full-time jobs. The graphs show general decreases in all three aggregated indicators.

The centre graph in Figure 4 shows the results for the indicator for the goal of reduced fossil fuel use under the theme of sustainable community planning. As with numerous other indicators, there is an improvement (i.e. decreased use) with throughout the assessment period. The sugar production system shows the decrease of just below 4 million GJ of energy used in 2003 to an expected use of just under 3 million GJ by 2015. Aggregated results from both systems show an overall decrease to 3,26 million GJ. Due to modernization processes already carried out at sugar facility 1, the model assumed no efficiency gains or fuel type changes. But due to past rises in oil prices, it would be expected that additional fossil fuel use reduction measures would take place in both production systems throughout all life-cycle production phases.

Finally, the results for the other socio-economic domain indicator of full-time employment positions in the SDS area of regional development are provided in the bottom graph. The figure shows that full-time employment position losses by roughly one-third in response to the Swedish production quota reductions. The most significant changes to the sugar system occurred with the closure of production facility 2 for the 2006 production season – decreasing from just over 1400 jobs to below 1200. The numbers of full-time jobs for the combined systems in 2015 were just over 1300, which represent roughly a ten percent decrease in the number of jobs over the total assessment period.

ASSESSMENT APPROACH

Results of the study generally show that there will be both positive and negative implications due to the sugar quota and price changes for Sweden. Much of the early concerns in response to the changes by regional industry officials, grower organisations, etc. predicted dire consequences for the industry and region. Viewed in isolation there were significant impacts in the forms of job and revenue losses for the region; conversely improvements were recognised with a majority of the environment-focused indicators due largely to the energy and resource intensity of the sugar production chain. The inclusion of the wheat-to-flour system in the model represented one relevant and established production chain to utilise the land areas no longer devoted to beet growing. In a regional perspective, the inclusion of the system for understanding overall impacts on sustainability, in some cases positive, in others negative. The study reveals that such changes, such as beet production quotas and prices, cannot be viewed in isolation, but rather from the perspective of a complex mix of systems interacting and reacting with each other.

The study used the wheat-to-flour production system as the alternative for the land no longer devoted to sugar beet growing and sugar production. It is acknowledged that in reality with the decrease in sugar production in the region, the beet growing area would be distributed amongst a variety of cropping, and ultimately, food, and now more commonly, energy production systems. Relevant systems for southern Sweden include oats, rye, peas, rapeseed, etc. Another alternative that is being experimented with in the region, with the potential for large implications on land use patterns in the region, is beet (and other crops) for biofuels production, and in particular biogas. If done incorrectly, adding such production systems has the potential to create land use pressures and environmental impacts; at the same time, investments in the production chains can stimulate new rural development and job growth in non-urban regions.

It is acknowledged that the IAM created for the assessing the two systems could have also been performed using alternative assessment approaches (e.g. Life Cycle Assessment [LCA], Environmental Impact Assessment) e.g. [40] (for a more detailed description of other assessment tools see e.g. [41]). The stock and flow model represented a flexible approach. The software allows for the flexibility in including both environmental and socio-economic parameters and the interaction and feedbacks between them into a single model. LCA software has only begun in recent years to include both domains.

Because of the flexibility of the software, it is envisioned that future model use and experimentation can be expanded in a number of possible directions. One obvious starting point is to forecast the impacts from different national sugar quotas (including no national production quota), changing sugar and beet prices, efficiency rates, average transport distances, etc. All of these areas have the ability to be altered over time in the model, making it an useful tool for expanding and testing different regional land use and production scenarios over longer time perspectives. Furthermore, the addition of new assessment parameters, or even new production chains, can be added into the existing model with relative ease. Despite the approach’s flexibility, a negative aspect is the time required for initially creating and verifying the IAM.

CONCLUSION

This article has assessed the sustainability of the Swedish sugar production system from 2003 until 2015 – with the intention of incorporating a wider assessment perspective. Based on the Swedish sustainable development strategy, the study focused on eight SES indicators. The article also used the autumn wheat-to-flour productions system as a scenario to gain the wider perception of impacts on the region than just the effects of the EU sugar production and price quota cuts. Results of both systems combined included declines in landscape diversity and revenues earned in the region with slight decreases in the number of full-time jobs. Results also showed improvements (i.e. decreases) in the amount of nutrient runoff, fossil fuel energy use, greenhouse gas releases and field chemical use. The largest changes came in the area of biodiversity, with the suspension of ecological beet growing in the region.

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INTEGRIRANA PROCJENA ODRŽIVOSTI ŠVEDSKE PROIZVODNJE ŠEĆERA SA STAJALIŠTA PERSPEKTIVE ŽIVOTNOG CIKLUSA 2003.-2015.

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SAŽETAK

Članak razmatra procjenu održivosti proizvodnje šećera iz šećerne repe u Švedskoj od 2003. god. do 2015. god. Fokusira se na faze životnog ciklusa rasta šećerne repe, njenog transporta i proizvodnje šećera. Na temelju strategije održivog razvoja Švedske, postavljeno je osam indikatora iz domene okoliša i socio-ekonomske domene koji su u znatnoj mjeri povezani s europskom cijenom i promjenama proizvodnih kvota. Članak uzima u obzir jesenski proizvodni ciklus brašna iz žita kao alternativu radi boljeg razumijevanja ukupnog utjecaja regije na europske cijene i proizvodne kvote. U članku se koristi simulacijski model sustavnosne analize razvijen pomoću programa Stella 9.1. Modeliranje je dio šire regionalne procjene održivosti koja se fokusira na proizvodnju šećera u Švedskoj. Rezultati modeliranja kombinirane proizvodnje šećera i brašna pokazuju općenito na smanjivanje raznolikosti agrikultura i smanjivanje zarada u regiji usporedo s neznatnim smanjenjem broja stalnih radnih mjesta u regiji. Rezultati također pokazuju smanjenje toka hranjivih tvari, uporabe fosilnih goriva, emisije stakleničkih plinova i uporabe kemikalija na poljima, kao i značajnije smanjenje bioraznolikosti zbog slabljenja organskog uzgoja šećerne repe u regiji.

KLJUČNE RIJEČI

procjena održivosti, šećer, Švedska, perspektiva životnog ciklusa, softver Stella