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Sustainable biofuel production in Argentina

A spatially-explicit exploration on the future availability and use of land for large-scale biofuel production

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Summary

The present study aims to determine the availability of land and potential for sustainable large-scale production from soybeans and switchgrass in Argentina up to 2030. A land-use modeling framework combining an empirical approach based on statistical analysis with a theoretical approach based on economic theory was found to be the most appropriate method to explore the dynamics and future developments of the land-use system in Argentina. The future demand for food crops and animal products was determined based on the projected developments in population, diet, level of affluence, self-sufficiency ratio and exports. The most important agricultural production systems at national scale were identified, as well as the driving forces determining their geographical distribution and extension. According to this characterization, the future provision of food commodities by the land-use system was simulated through land-use modelling in order to determine the availability of land and the resulting potential for biofuel crop cultivation that does not compete for land with food production. The empirical approach explored the dynamic features of the land-use system in providing the demanded food commodities, while the theoretical approach aimed to reproduce the decision-making processes of farmers and their willingness to grow biofuel crops on the available surplus land.

Two scenarios were considered, a Business-As-Usual (BAU) scenario, in which the provision of food commodities takes place without major changes in policies, technology adoption and managerial practices, and a Progressive and Sustainable (PS) scenario implying a higher rate of technological change which results in more advanced and productive agricultural practices, achieving larger yield increases in agricultural production and intensification of livestock production through an increase in feed conversion efficiency and change in feed composition.

According to BAU scenario, it was found that under current conditions no surplus land for dedicated biofuel production is expected to become available. Nevertheless, large production of soy-based biodiesel is already taking place in Argentina, mostly as a by-product of bean crushing for soymeal production. Therefore, a potential of 80.6 PJ of soy-based biodiesel production from the existing soy complex could be expected by 2030. The increase in exports and domestic demand resulting from population growth and diet change, combined with the low rate of technology adoption in the livestock sector determine that land for agriculture and livestock production keeps expanding. Livestock displacement due to agriculture expansion may to some extent be accountable for large deforestation in the northern regions of the country. Therefore, some doubts can be raised on the future sustainability of soy-based biodiesel production in terms of indirect land-use changes, according to current development trends.

In PS scenario, a higher rate of technology adoption implies that less land would be required for crop and livestock production. Therefore 32.6 Mha could become available for dedicated biofuel production by 2030 without endangering food security and nature conservation. Land previously used as pastures for livestock grazing appeared to account for the large majority of surplus land. Thus, the availability of land will depend to a larger extent on the technological developments and intensification of livestock production.

However, cultivation of the considered biofuel crops appeared to be economically attractive only in a portion of this area: 4.3 Mha for soybeans and 18.6 Mha for

switchgrass. Considering the local specific yields, $16.1*10^6$ odt soybeans and $70.0*10^6$ odt switchgrass could be produced on the surplus land where biofuel crops showed a positive economic performance, which after conversion to biofuel could lead to a potential of 114.1 PJ for soy biodiesel and 596.3 PJ for switchgrass bioethanol by 2030. Furthermore, due to the increase on the demand for soymeal resulting from larger use of food crops in the feed composition of livestock production, an additional production of soybeans could be expected ($8.51*10^6$ odt). The by-product oil resulting from soybean crushing for this additional soymeal production could be then dedicatedly converted to biodiesel, thus providing an additional potential of 59.6 PJ. Therefore, a total potential of 254.4 PJ for soy-based biodiesel production could become available by 2030 according to PS scenario. However, these results are based in long-term projections that are fraught by a large degree of uncertainty, particularly in terms of future commodity market prices. Therefore, they should be interpreted as a projection according to current trends rather than a deterministic prediction.

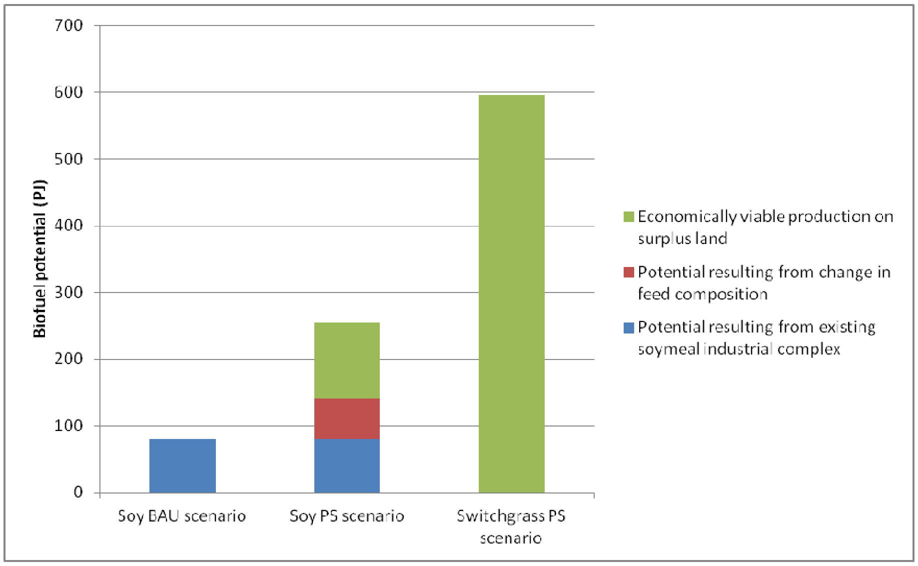

Figure 1: Biofuel production potential in 2030

The region of southwest Buenos Aires and La Pampa provinces appeared to be the area where land is most likely to become available, even when taking into account uncertainties in food demand, technology improvement and proximate driving forces. It also appeared to be particularly promising for switchgrass cultivation. Due to low local suitability for conventional crops, a high-yielding perennial crop such as switchgrass could become an attractive alternative for farmers in this region. This finding is line with previous research on biofuel potential in Argentina (van Dam et al., 2009a). However, large uncertainties still remain regarding the use of this crop for biofuel production, particularly in respect to its cultivation management, attainable yields, commercialization prices and availability of land, as well as conversion efficiency of feedstock to biofuel. Therefore, the deployment of large-scale sustainable biofuel potential will require a sound and integrative long-term strategy, including the promotion of technology and knowledge transfer programs of switchgrass cultivation farmers in this region, the promotion of market development initiatives, as well as the provision of stable policy frameworks to promote efficiency improvement in livestock production, to allow that land becomes available for biofuel production without endangering food security and biodiversity.

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1. Introduction

1.1. Background

The existing world energy system heavily relies on the use of fossil resources such as crude oil, natural gas and coal. However, regional and global phenomena such as water acidification and climate change have been raising increasing concerns on the environmental consequences of large-scale use of fossil fuels. Moreover, energy security issues such as dependence on energy supplies from politically unstable regions and depletion of finite fossil energy resources have been contributing to the need to develop alternative options. Therefore, a transformation of the energy sector is expected, as energy-efficient and renewable energy technologies start emerging and are gradually adopted.

Liquid and gaseous biofuels have been increasingly integrated into the fuel supply systems for transport in a large number of countries (IPCC, 2011). Besides the benefits of reducing CO_2 emissions, biofuels produced within a country provide energy security, since less petroleum needs to be imported and there is more immunity against political disturbances affecting oil supplies. Moreover, they can bring economic development to the rural areas, by coupling energy and agricultural policies.

In fact, the use of bioenergy resources has received much attention by policymakers in recent years. For instance, both EU Directive on Renewable Energy (EC, 2009) and US Energy Independence and Security Act of 2007 (DoE, 2007) state the key role that biofuels are expected to play in a close future on the substitution of fossil fuels in the transportation sector. In many other countries, governmental measures have also been introduced to promote the production and use of biofuels, mainly in the form of mandatory blending targets and tax reductions/exemptions (IEA, 2010).

However, large uncertainties on the social and environmental footprint of biofuels still exist. Increasing competition for land has been recently observed, arising from growing and changing demand for food, combined with increasing global demand for transport energy, under conditions of declining petrochemical resources and the need to reduce greenhouse gas emissions (Harvey and Pilgrim, 2011). Land competition may result in several undesired impacts: food insecurity due to increased food prices (Banse et al. 2008), particularly in developing countries (RFA, 2008); accelerated deforestation (Eickhout et al. 2008a) and decline in biodiversity (Van Oorschot et al., 2010); and indirect land-use changes (Bowyer, 2010). Thus, the extent to which sustainable biofuels will penetrate local, national and global energy markets will largely depend on the availability and management of land.

1.2. Problem definition

Climate change, fuel prices volatility, food insecurity and global economic turmoil have urged policymakers, academics and industries to find sustainable solutions in the area of biofuels. As a result, a rapid expansion of global biofuels production and markets is expected in following years. Previous studies (e.g. Hoogwijk et al, 2005, Smeets et al. 2007) have shown that there is a considerable potential for biomass production for energy purposes distributed across a number of key regions in the world, with South America accounting for a large bulk of this potential. While Brazil is nowadays recognized as the most cost-competitive bioethanol producer in the world due to the implementation of consistent and integrated biofuel programs since the 1970s, Argentina has emerged in recent years as a key player in the biodiesel market (Sorda et al., 2010; OECD/FAO, 2009). This is a consequence of governmental market-creating initiatives from 2007 on, which have resulted in an investment boom since then (Matthews and Goldsztein, 2009).

Due to favourable climate and soil conditions, low land and labour costs and high quality existing infrastructure and human resources, Argentina is regarded as an economically attractive country for biofuel production (Franke et al., 2009). Soybeans are by far the main feedstock for biodiesel production in Argentina (Van Dam et al, 2009a). In fact, an increment output of soy-based biodiesel higher than 400% has been recorded between 2007 and 2008 (ACER, 2009). Argentina is currently the world's number one biodiesel exporter: total production is expected to reach 2.9 billion litres in 2011, while exports are projected to account for almost 60% of this output, mainly for the US and EU markets (Joseph, 2010).

Van Dam et al. (2009a) assessed the future potential and economic feasibility for large-scale bioenergy production from soybean and switchgrass in a region in Argentina, as well as its environmental and socio-economic impacts (Van Dam et al., 2009b). In the same line, Wicke et al. (2009) have determined through input-output analysis the macroeconomic impacts in terms of gross domestic product (GDP), trade balance and employment of biofuel large-scale production at national level. Despite of providing valuable information and insights, these studies used statistical averages for physical parameters such as crop yields and water availability. However, those can vary considerably and depend strongly on the spatial location. Therefore, it would have been preferable if these assessments had been performed in a spatially explicit manner. That would allow calculating the potential more accurately taking into account the landscape heterogeneity and spatial features, as well as explicitly identifying the locations which hold higher potentials.

More recently, Van Rossum (2011) performed a spatially-explicit assessment of the future biofuel potential in Argentina, taking into account possible developments in population, technology efficiency and diet. Allocation rules based on spatial constraints were implemented, however without providing any empirical fitting or consistent theoretical framework to explain the assumptions underlying the allocation procedure.

This implies that land-use dynamics and decision-making processes were not thoroughly taken into account in previous studies. Land systems are often complex, showing features such as feedback loops, path-dependency, neighbouring effects, resilience and stability (Verburg et al. 2002). Hence, an approach fully accounting for the land system features and land-use decision-making processes is required to provide a more realistic assessment of possible future developments and better inform policy-makers on the use and management of land resources.

1.3. Objectives

The main goal of this research is to perform a spatially-explicit assessment of the availability of land and the resulting potential for sustainable biofuel production in Argentina, taking into account the features of the land system and decision-making processes while exploring possible future developments.

The availability of land for biofuel production and resulting spatial distribution will be explored through land-use modelling. Land-use models are capable of simulating the major socio-economic and biophysical driving forces of land use change, allowing to explore future developments in the land-use system, while taking into account its dynamic features (Verburg et al., 2006). Furthermore, they allow exploring scenarios on the functioning of the system, through the visualization of alternative land-use configurations that may result from policy decisions or developments on society (Alcamo et al, 2006).

A dynamic land-use model will be developed to determine and allocate the land available for various agricultural land-uses, including crops used as feedstock for biofuel. Based on the simulation results, the potential for biofuel production will be determined according to land availability, its spatial distribution and spatially-specific yields. The potential for first and second generation biofuels will be distinguished. Regarding first generation crops, soybean production will be used as a study case, as it is regarded as the most promising crop for bioenergy production in Argentina (Van Dam et al., 2009a). On the other hand, switchgrass will be chosen to assess the potential for second generation crops. Switchgrass has been studied as a potentially attractive bioenergy crop in Argentina (van Dam et al., 2009a). Therefore, it will be taken into consideration as a 2nd generation biofuel alternative.

1.4. Research question

The main research question of this study is:

"What is the future potential and spatial distribution for sustainable biofuel production from soy and switchgrass in Argentina up to 2030, taking into account the land system dynamic features and decision-making processes?"

To answer the main question, the following sub-questions must be addressed:

- *What land-use modelling approaches are more appropriate to describe and simulate the agricultural land-use system in Argentina at the national level?*

- *What are the main crop and livestock production systems in Argentina?*

- *What biophysical and socio-economic drivers determine the land demand and suitability for crop and livestock production in Argentina?*

- *How much land could become available for biofuel crops taking into account the demand for crops and feed? What is the spatial distribution?*

- *What is the economic performance of cultivating biofuel crops in the available surplus land?*

- *What is the future biofuel production potential for 1st and 2nd generation biofuels in Argentina?*

1.5. System boundaries

This research will look at the availability of land and resulting potential for sustainable biofuel production within Argentina. Two main stages can be identified on the production of biomass-based fuels: agricultural stage, in which the vegetable resource is produced; and the industrial stage, in which the vegetable resource is converted into an energy resource. The focus of this research is on the agricultural stage. Similarly to previous studies (Smeets et al., 2007; de Wit and Faaij, 2008; Van der Hilst and Faaij,

2011) sustainable biofuel potential will be defined as the potential that does not hamper food security and biodiversity conservation.

The cultivation of vegetable feedstock and resulting potential for biofuel production will depend on the availability of land that is not required for food crops, livestock production and nature conservation in Argentina. However, soybean production must be addressed in a specific way, since it is not a traditional dedicated energy crop but rather a food/feed crop from which only a by-product (19% dry weight) is used for energy purposes (INTA, 2010a). This implies that the demand for other soy products also has to be explicitly taken into account.

A land-use model will be applied to explore future developments in the land-use system and decision-making processes of farmers in Argentina. Both demand and allocation of food production will depend on several biophysical and socio-economic drivers. A scenario approach will be used to explore different trends in the development of these drivers, being considered a timeframe up to 2030.

2. Argentina case study

2.1. Country description of Argentina

Argentina is a country located in the extreme south of America between the Andes mountain range in the west and the Atlantic Ocean in the east. Its total area amounts to 273 million hectares, divided into 23 provinces and one autonomous city, the federal capital Buenos Aires. Five main regions can be distinguished, each with distinct geographic and economic features: Northwest (NOA), Northeast (NEA), Región Centro or Pampeana, Cuyo, and Patagonia (FAO, 2001). Historically, agriculture and livestock production have constituted the pillar of Argentinean economy (World Bank, 2006; INTA, 2011a). The recent developments within these sectors will be discussed in section 2.1.1. A special focus will be given to soy production (section 2.1.2), which has become the dominant agricultural crop in Argentina. The soy production chain is also intrinsically related to biofuel production, which has shown a dramatic increase in the last five years. In section 2.1.3, the main developments in the biofuel sector will be discussed, including not only biofuels from conventional crops but also future prospects of second generation biofuels.

2.1.1. Agriculture and livestock production

Due to the existence of a large area with deep soils, temperate climate, favourable levels of precipitation and good accessibility to ports, Argentina has privileged advantages for agricultural productivity and exportation (INTA, 2010a). Traditionally, two different types of production system have been identified to describe the Argentinean agricultural sector: pampean and regional production (INTA, 2011a). The first relates to the agriculture systems in Region Pampeana, essentially comprising grains, oilseed crops and cattle-raising to produce beef and dairy products. Pampean production is characterized by intensive use of equipment and management, while being land- and labor-extensive. In opposition, regional production is less intensive in management and capital and more in terms of land and labor, comprising several different regions and products: fruits and sheep raising in Patagonia; grapes and other fruits in Cuyo provinces; tobacco leaf, sugar cane, and citrus in NOA; and cotton, tea and maté herb in NEA (FAO, 2001). Since most of regional agricultural products are grown from perennial crops, they seem to be less responsive to short-run demand in comparison to pampean production, which is essentially driven by international markets of annual crops (Reca

2006). However, this dichotomic categorization has been gradually falling into disuse due to the rapid expansion of soybean crops and livestock displacement from Region Pampeana to the northwest and northeast regions during the last decades (INTA, 2011a).

Agricultural productivity in Argentina has steadily increased during the last decades. In the period 1990-2010, the production of grain crops and soy increased by 167%, with five main factors accounting for this strong acceleration in the rate of growth (World Bank, 2006; Lence, 2010):

- introduction of important economic policy reforms which favoured agricultural production, such as reductions of tariffs for fertilizers, herbicides, pesticides, machinery and irrigation equipment; elimination of export taxes and deregulation of economic activities; elimination of distorting taxes in fuels, commercial and financial transactions; and removal of inefficiencies and monopoly profits in the freight transportation sector;

- intensification of land use in Region Pampeana derived from shortening rotations, more use of fertilizers and adoption of modern and efficient farm machinery resulting from the removal of trade barriers;

- strong rise in yields per hectare resulting from the introduction of genetically-modified organisms (GMOs), namely gliphosate-resistant hybrids;

- adoption of technologies such precision agriculture and specially no-tillage planting technique, which consists of planting crops in soil without previous tillage, by opening only a slot in the soil with the smallest dimensions for the desired seeds. It has proved to allowing to cultivate in less suitable soils, decreasing soil degradation, improving the retention of soil moisture and allow for improved and cost-effective weed control (when used in combination with glysophate-resistant GMO seeds). Furthermore, despite of requiring more specialized and costly machinery, no-tillage technology requires less machinery than conventional techniques, since eliminates the need to till the soil and perform other farming operations, thus reducing fuel consumption and total costs;

- expansion of the crop frontier to the NOA and NEA regions, following the adoption of the aforementioned technologies;

- introduction of new forms of farm organization in agricultural production such as planting pools, where investors are joined together to finance agricultural production, renting extensive areas of farmland and thus exploiting economies of scale. Furthermore, the use of land is decided by highly specialized management, with the incorporation of advanced technology and use of risk management tools. This form of organization has also allowed to secure adequate financing by capturing funds from short- and long-term investors outside agriculture and even foreign investors.

The increase in arable farming can be mostly explained by the dramatic increase in soy cultivation (Lence, 2010), especially from 1996 onwards, coinciding with the period of higher rate of technology adoption through the combined use of GMO seeds with gliphosate and implementation of no-till cultivation (INTA, 2011b).

On the other hand, cattle livestock production is relatively stagnated, having grown only by 50% during the same period, due to lower rates of technological improvements. In fact, much of the sector operates at medium and low technology levels, being the output gap between productivity levels in cattle production much higher than in crop cultivation. Thus, there is a high potential to increase beef production, either in Region Pampeana as in other regions (World Bank, 2006).

Argentina has various agro-ecological livestock regions differing in their potential of production and quality of forage. Different livestock activities are distributed over the country: subsistence producers are located in North-Western Patagonia and Andean steppes; sheep are most important in Patagonia; cattle ranches and dairying are mostly associated to the periphery of Region Pampeana (Garbulsky and Deregibus, 2006).

Until recently, it was usual to find mixed animal and crop production in Region Pampeana, in order to maintain soil fertility. However, the dramatic increase in the profitability of grains and soy crops during the last decades, combined with the implementation of no-tillage techniques, has lead to the elimination of pastures in order to allow more land to be used for crop plantation, resulting in the displacement of livestock production towards more marginal land (Sturzenegger and Salazni, 2007). As a result, Argentinean producers are becoming more specialized either as farmers or as ranchers and an increasing trend for cattle-raising in feedlots has been observed in recent decades (Alerovich et al., 2011).

Furthermore, a long-term trend of low meat prices combined with a historic drought event forcing many breeding operators to liquidate their herd has lead to a dramatic decrease in total inventories in recent years, from 58.5 million heads in 2006 to 48.9 million in 2010 (Arelovich et al., 2011). Additionally, the perception of greater risks associated with cattle production (e.g. the foot and mouth disease outbreak in 2001), the effect of unstable macroeconomic conditions and high interest rates that particularly affect beef production (due to the longer term nature of its economic payoff) have resulted in farmers increasingly going for soy production, since this is the product that appears to provide more security (INTA, 2011). However, due to the increase in prices resulting from a lower supply and stable domestic demand, livestock production is expected to become more attractive and consequently total herd stocks are likely to increase in forthcoming years (Garre, 2011).

Milk production currently accounts for 6% of the total cattle herd. The majority of the dairy farms are small and medium size, with 42% of the units performing with very low productivity (UNDP, 2010). On the other hand, 17% of the milk cow population operates in large size farms, accounting for 38% of the total milk production. Therefore, despite the considerable increase in productivity in recent decades, the technology gap in the Argentinean dairy farming sector remains substantial (Lence, 2010).

Concurrently, poultry meat production has grown steadily, increasing 25-fold since 1961 (Lence, 2010). This is line with the on-going "livestock revolution" global trend, in which a gradual substitution from more extensive, land-based ruminant husbandry to more intensive, short-cycle monogastric modes of production can be observed (FAO, 2007). Pig meat production also increased during the same period, but at a much lower rate (Lence, 2010). Important technology gaps have been identified in this sector, especially regarding sanitation measures and breed quality in small producers (UNDP, 2010b; van Horne 2010).

Argentina's economy is strongly directed toward commodity exports and the agricultural sector is no exception. Argentina is one of the main world exporters in a large number of food commodities, with agricultural and livestock sectors representing 10% of GDP and accounting for 45% of total exports (INTA, 2011). The six main primary outputs of Argentine agriculture are soybean, meat, raw milk, corn, wheat, and sunflower, representing altogether 73% of the total value of agriculture production (Sturzenegger and Salazni, 2007).

Exports of agricultural commodities are heavily taxed, which has allowed for a considerable flow of fiscal revenue for public investment. Furthermore, exports of commodities with high domestic consumption rates such as wheat for bread and beef have been also restricted or sometimes even banned in order to keep domestic prices low in respect to international markets. The lack of a stable agricultural policy framework and excessive taxing is regarded as an obstacle for investment in the agricultural sector (World Bank, 2006) and has lead to severe turmoil among producers and government in recent years (Lence, 2010).

A variety of organisations exist in the country supporting farmers through R&D, networking, training and dissemination programmes (Tomei and Upham, 2009), such as the National Institute of Agricultural Technology (Instituto Nacional de Tecnologıa Agropecuaria, INTA), the Association of Regional Consortia for Agricultural Experimentation (Consorcios Regionales de Experimentacion Agricola, CREA) and the Association of No-Till Producers(AAPRESID). On the other hand, the contribution of the agricultural sector to the economy it is not limited by its direct output and employment. In fact, besides of landowners, contractors and planting pools, a number of additional players provide services and have a key role in the agricultural sector (INTA, 2011):

- providers of agricultural inputs, such as highly specialized national and international firms of (genetically modified) seed hybrids, agricultural equipment, fertilizers and agrochemicals;

- intermediaries that manage storage, handling, drying, commercialization and transportation;

- light processors of primary production, including slaughterhouses and refrigeration plants for producing beef, crushing mills for processing soybean and sunflower grains, and dairy plants for processing milk;

- commercial distributors, that deliver beef, dairy products, products derived from the processing of wheat, and vegetable oils to consumers through channels of distribution.

2.1.2. Soy production chain

An unprecedented growth has been observed in soybean production since the early 70s, with soy planting area increasing from 37.000 to 17 million hectares. These developments are even more striking when comparing the amount of hectares destined to the cultivation of soy, wheat and corn: the land ratio soy/soy+wheat+corn is currently near 70%, when in the 80’s it was around 15% (INTA,2010). Nevertheless, soy production expansion has been even higher than the increase of land area destined for that production, as a result of introducing GMO glyphosate-resistant soybean seeds in combination with advanced no-tillage technology.

The soybean chain is nowadays a crucial sector in the Argentinean economy, being responsible for 25 % of currency income of the country and accounting for 31% of the internal agroindustrial product. The efficiency of soybean production in Argentina has been spurred by the implementation of differential export taxes (DETs) between soybeans and its products. DETs are a system of taxes on exports in which the export tax rates are reduced as the product moves along the processing chain. As such, exports of soybeans are taxed at the highest rate (35%), while exports of soybean oil and soybean meal are taxed at a lower tax (32%), thus increasing the competitiveness of exporting soybean meal and oil, by reducing the internal price of soybeans (INTA, 2011). As a result, farmers have been forced to become more efficient on the one hand; on the other hand, the crushing industry has benefited from the lower soybean prices and although Argentina is only the world's third largest producer of soybeans, it has now a greater crushing capacity than either U.S. or Brazil (LMC, 2010).

As a matter of fact, Argentina is currently the world's largest exporter of soybean meal and oil, with a market share of 51% and 58% respectively (INTA, 2011; Hilbert, 2011b). In contrast with the U.S. and Brazil, only a very small percentage of soybean products are consumed domestically in Argentina (Xia et al., 2009). Despite a growing poultry and swine industry, Argentina's soybean meal domestic use still accounts for less than 5% of total soybean meal production. Similarly, the majority of soybean oil is exported as domestic consumers tend to prefer sunflower oil.

2.1.3. Biofuel production

In 2006, a new law on the promotion of biofuels was approved in Argentina (Ley 26.093/2006), involving a regulatory and promotion regime for the sustainable production and consumption of biofuels. The law and its regulations consider the market as divided into three clearly separated segments:

- self-consumption, directed to farmers looking to produce biofuels for their own consumption, which is in itself a significant market given the size of the Argentinean agricultural sector,
- internal demand
- export markets.

Although initially the biofuel production was exclusively export oriented, the national Biofuels law established a 5% blending mandate in 2010 for gasoline with anhydrous bioethanol and diesel with biodiesel, thus targeting the internal market. In the meantime, this has already moved to 7% and government has plans to go further to 10% in general and 20% for agriculture (INTA, 2010a).

The framework focuses primarily on conventional biofuels, namely sugarcane-based bioethanol and soy-based biodiesel, as Argentina has already available a well-developed vegetable oil industry and a growing ethanol industry based on sugarcane. Production in 2011 is projected at 2.9 billion litres of biodiesel and 280 million litres of bioethanol (Joseph, 2010). Soybean biodiesel is regarded as the most important biofuel option in Argentina due to two main reasons: diesel is currently the main transportation fuel in Argentina, thus making soybean biodiesel a suitable option for the internal market to reduce diesel imports and supply vulnerability; and the existence of a robust industrial park for vegetable oil production, since soy-based biodiesel is produced through the transesterification of soybean oil. In fact, most local crushers see the production of biodiesel as an opportunity for diversifying products and markets (Joseph, 2010).

However, only 2.6% of the total soybean oil production is currently being transformed into soy biodiesel, indicating the low weight of soy biodiesel in the current soy complex. The actual production capacity of soy biodiesel in Argentina is close to 2.5 million tons a year, which implies that only 4.9% of total soybean oil production could be converted into soy biodiesel. Moreover, in 2010 biodiesel exports accounted for only 6% of the total soy products exports. It could be concluded that the existing soy production complex is actually pushing the soy biodiesel production and not the other way round, thus defying the common assumption that alternative energies based on food commodities are the determinants for both food production and price growth (INTA, 2011; Hilbert, 2011b).

Argentina has rapidly become the world leader in biodiesel exports. Exports levels are projected to amount to 1.7 billion litres in 2011. The export market is highly concentrated, with only 3 countries accountting for 90% of Argentina's biodiesel exports, namely U.S. (39,5%), the Netherlands (32.7%) and Spain (17.3%) (Joseph, 2010). Given the recentness of the market, it strongly needs public policies in order to continue developing. In Argentina, the major incentive is provided by a lower DET compared to the other soy products: soy biodiesel is taxed at 17.5%, after reimbursements and adjustments, being the lowest DET in the soy production chain (INTA, 2011).

Even though current policy does not specifically address 2nd generation or advanced biofuels, some official programs are already researching these types of feedstocks and technology (INTA, 2008a). Switchgrass is one of the crops that has been considered as an alternative feedstock for biofuel production. Switchgrass is a perennial C4 grass which has been used primarily for production of fodder for livestock but its potential for biofuel production has been largely ignored in Argentina (INTA, 2011). Potentially high yields and high content of lignin and cellulose makes switchgrass an appealing alternative for biofuel production. Switchgrass biomass potential in Argentina has been previously assessed within a range between 99 x 10^6 (1.9 EJ) and 243 x 10^6 dry-matter tonnes (4.5 EJ) per year (Van Dam et al., 2009a), though this assessment was not performed in a spatially-explicit way.

2.2. Study area

2.2.1. System boundaries

Argentina is a very extensive country, extending for 3.700 km North to South. 6 large eco-regions can be identified (INTA, 2006), namely Region Norandina, Chaco, Mesoptamia, Cuyo, Region Pampeana and Patagonia, each one accounting for completely distinct climates, topographic and landscape features. A number of diverse landscapes and biomes can be found, namely rainforests, temperate forests, savannah, croplands, flooding grasslands, scrublands and steeps (Garbulsky and Deregibus, 2006). Consequently, agricultural production systems are extremely varied along the country. In fact, more than 100 homogeneous agroeconomic zones (HAZ) have been identified according to their environmental characteristics and socio-economic aspects (INTA, 2009a). Thus, it would be very complex and time-consuming to design and calibrate a land-use model capable of providing meaningful results while characterizing and accounting for all regional specificities (Morris and Hilbert, 2011).

Therefore, the study area that is assigned for dynamic simulation of food production allocation was confined to the eco-regions of Region Pampeana and Chaco, which comprise the provinces of Buenos Aires, Santa Fe, Cordoba, Chaco, Formosa, Santiago del Estero and partially include the provinces of Entre Rios, Salta, Tucuman, Catamarca and La Rioja (Figure 1). These two eco-regions account for more than 90% of the total production and total area required to produce food commodities, 80% of total cattle heads and almost 100% of total milk production in Argentina (INDEC, 2011; SIIA, 2011). These are also the regions where the processes of agricultural expansion and displacement of livestock production have been more pronounced (World Bank, 2006). Limiting the simulation area to these eco-regions will allow on the one hand to focus in the most relevant production systems in terms of land demand and on the other hand, to avoid computing issues resulting from dealing with large datasets.

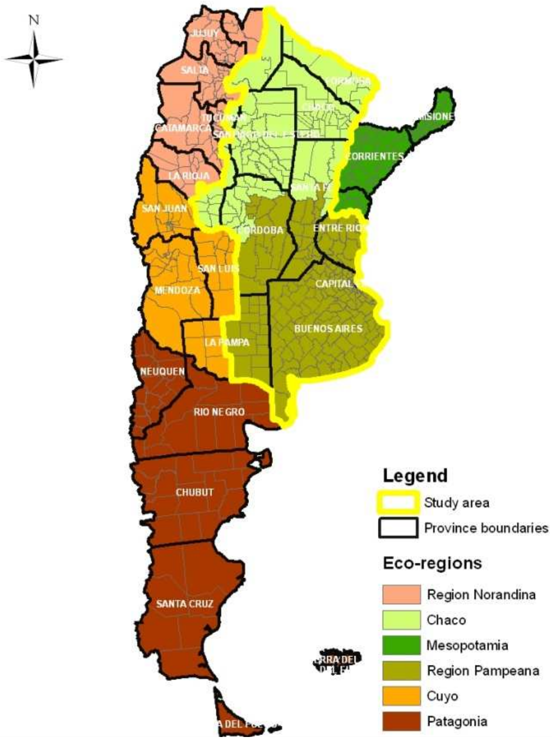

Figure 2: Eco-regions in Argentina and study area for dynamic modelling

2.2.2. Characterization of agricultural land-use within the study area

The study area is essentially characterized by rural production systems with intensive use of equipment and management and extensive use of land, essentially comprising oilseeds, grain crops and cattle-raising to produce beef and dairy products. Land-intensive activities such as horticulture, floriculture and fruit production are also important in economic terms. However, their use of land is virtually insignificant when compared with land-extensive activities and they are mostly concentrated in relatively small areas next to the main urban centres and transportation hubs, such as the cities of Buenos Aires, Cordoba, Santa Fe and Rosario and along the Uruguay river coast in Entre-Rios province (INTA, 2009a; INTA, 2009b; INTA, 2009c; INTA 2009d). Henceforth, the present study will solely focus in the future developments of activities with extensive use of land, in particular livestock production for beef and milk production and cultivation of soy, corn, wheat and sunflower. These activities represented altogether 77% of the total value in exports of agriculture production in Argentina during 2005-2007 (Lence, 2010). Furthermore, the cultivation of soy, corn, wheat and sunflower accounts for roughly 86% of the total area used for land extensive agriculture in the study area (INDEC/SIIA, 2011). A more in-depth analysis of the spatial patterns of agricultural and livestock production within the study area can be found in Appendix A – Section 8.

While agricultural expansion in Region Pampeana came at the expense of perennial forage crops, in Chaco eco-region it occurred mainly by replacement of native forests (Volante et al., 2005). Chaco eco-region region makes part of Gran Chaco, a large semi-arid ecosystem spreading over a number of countries in South America and composed by a combination of xerophytic vegetation, savannas and woodlands. A continuous process of deforestation has been observed in recent decades in Chaco eco-region, due to the displacement of livestock production from Region Pampeana and expansion of the agricultural frontier. Unlike other regions in the world, deforestation in Chaco eco-region appears thus to be driven not to by internal population growth or higher level of consumption but rather by external demands and resulting transition from a subsistence economy to a commercial one (Zak et al., 2008).

These processes have been more pronounced in the eastern part of the eco-region, where high livestock density along Parana river and high agricultural intensity in the southwest of Chaco and east of Santiago del Estero provinces can be observed (LART/FAUBA, 2004). However, western provinces are also catching up with this trend, specially in Burruyacu plain in Tucuman province (Boix and Zinck, 2008) and particularly in Salta province, which has shown a rapid increase both in soy monoculture and commercial livestock during the last decade, threatening native forests and the livelihoods of indigenous populations and small-scale farmers (Volante et al., 2011; Seghezzo et al., 2011).

3. Methodology

This section elaborates on the methodology that is implemented to achieve the research goals. The potential for sustainable biofuel production in Argentina will be determined through land-use modelling. Firstly, a literature review on land-use change science was performed (section 3.1), in order to identify the main features of land systems and conceptual issues regarding land-use change. This was followed by a literature review on land-use modelling (section 3.2), in which theoretical and methodological issues were discussed, including a description of existing spatially-explicit land-use modelling tools, their applicability, advantages and drawbacks. Based on this literature review, the most suitable land-use modelling approaches were chosen according to the research question, the characteristics of the study area and the availability of data, leading to the design of the modelling framework (section 3.3). Two methodological approaches were chosen, an empirical and a theoretical approach. The empirical approach aimed to study the dynamic features of the land-use system by extrapolating the current trends in a dynamic land-use model to determine the availability of land for biofuel crops. The theoretical approach consisted in an economic assessment that aimed to reproduce the human behavioural component in land management, and specifically the willingness of farmers to grow biofuel crops on the available surplus land.

The empirical approach was implemented by building and using a dynamic land-use model. Firstly, an existing model was adapted according to the characteristics of the land-use system in the study area (section 3.4). The resulting model was then calibrated (section 3.5): in the demand module, the future demand for food crops and grass was determined according to projections on the demand for vegetable and animal products; in the allocation module, the relation between land-use driving forces and the occurrence of land-use was quantified according to statistical analysis. This model allows identifying the area and spatial patterns of land where biofuel crops can be grown without competing for land with food production. Subsequently, the model was validated according to past observed land-use changes (section 3.6), in order assess the level of trust that could be put in the model outcomes.

An assessment of the economic performance of the production systems on the available surplus land was then performed (section 3.7) in order to identify the locations where biofuel crops could be more attractive than other alternatives and therefore farmers would be willing to grow them, from an economic point of view. Finally, the biofuel potential could be determined, according to the results obtained through the previous modelling steps (section 3.8). Different scenarios were designed in order to explore future developments in a number of key variables (section 3.9) and the effect of uncertainty in some these parameters was explored through uncertainty analysis (section 3.10).

The main methodological steps are summarized below in Figure 3. A complete overview of the data required to implement the present methodology and respective sources is available in Appendix F - Section 13.

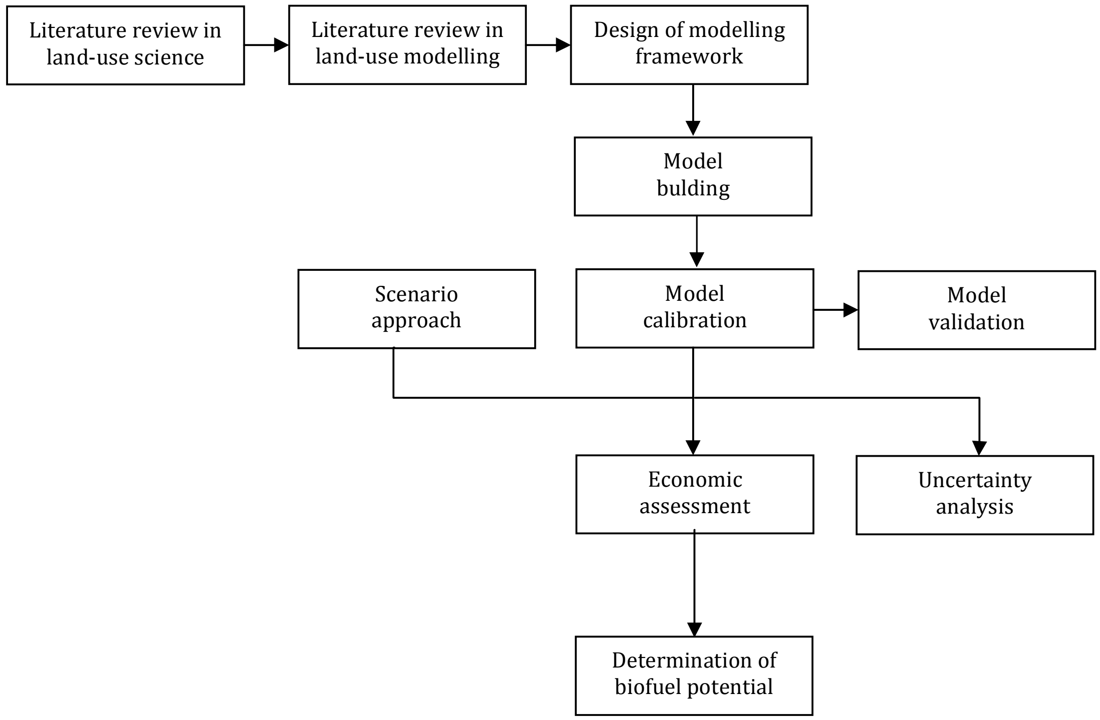

Figure 3: Main methodological steps

3.1. Literature review on land-use science

A literature review on land-use science was performed (Appendix B – Section 9) where the main features of land systems and conceptual issues regarding land-use change were discussed. Land-use systems can be interpreted as complex adaptive systems showing non-linear behaviour, dependency on initial conditions, path-dependency of system evolution, feedback loops, stability and resilience. Therefore land-use change cannot be explained as the equilibrium result of a set of driving forces at a certain moment in time (Verburg et al. 2006). Furthermore, developments in land-use do not occur independently at each individual location, but rather they affect and are affected by the conditions of neighbouring and distant locations (Verburg et al., 2004b). Land-use patterns result from complex interactions between numerous factors operating simultaneously at different spatial scales (Lambin et al, 2001). Furthermore, land-use change processes depend on their context, since driving forces will operate differently in distinct social and environmental backgrounds (Riebsame et al, 1994). Ultimately, land-use change can be conceptualized as being driven by responses to opportunities and constraints provided by the physical environment, socio-cultural context and technological capacity, in the pursuit of economic and socio-cultural welfare (Verburg et al, 2004b).

3.2. Literature review on land-use modelling

Since experiments in real land-use systems are hardly possible, land-use models can be used as learning tools to test hypothesis and formalize knowledge on understanding land-use systems (Verburg et al., 2006). A review on land-use modelling was performed (Appendix C - Section 10), where the main theoretical and methodological issues were discussed, including a description of existing spatially-explicit land-use modelling tools, their applicability, advantages and drawbacks. Due to the complexity of land-use systems, a monodisciplinary approach is often insufficient and thus land-use modelling is nowadays mostly regarded as a multidisciplinary exercise (Rindfuss et al., 2004). As a result, a large diversity of modelling approaches has evolved over the past years, with considerable differences in terms of background, starting point and range of applications (Koomen and Stillwell, 2007).

This review is summarized below in Table 1. Similarly to previous reviews on land-use modelling (e.g. Irwin and Geoghegan, 2001, Overmars et al. 2007) a broad distinction between empirical and theoretical models was made while reviewing current approaches. Empirical models are those which derive processes from patterns, for instance through rule-based algorithms or using statistical inference to find correlations between a set of explanatory variables and land-use patterns. On the other hand, theoretical models aim to explain the causal relationships between the human behavioural component and land-use change outcomes, namely through the incorporation of structured economic processes underlying land-use decisions. Thus, this classification allows distinguishing between inductive approaches that construct hypothesis about the relation between land-use and its explanatory factors through fitting of empirical data, from deductive approaches on which a structured theory is applied for a real case study.

Table 1: Land-use modeling approaches

Approach	*Empirical approaches*					*Theoretical approaches*	
	Rule-based	**Cellular automata**	**Multi-agent models**	**Microsimulation**	**Statistical models**	**Optimization models**	**Economic models**
Description	Aim to imitate processes that can be described by quantitative location-based rules.	The state of every individual cell is a result of the states of the neighbouring cells and its own in the previous time step. Deterministic or probabilistic transition rules give the degree and direction of interaction between cells.	The behaviour and interactions of in-homogeneous groups of actors is simulated based on information of socio-economic behaviour, Normally coupled with a CA model describing the natural system over which actors make decisions	Simulate the behaviour of all individual actors (e.g. persons, households, individual firms) that influence the land-use system, taking into account their individual characteristics and location.	Simulations are based on of the relations between the occurrence of competing land-use types and a set of explanatory variables that are considered to drive land-use, Quantification of the contribution of individual driving forces is performed through statistical techniques, e.g. logistic regression analysis.	Mathematical optimization techniques (e.g. linear integer programming) are applied to calculate the optimal land-use configuration, given a set of prior conditions, criteria and decisions variables.	Land-use patterns of competing land-use types are simulated by assuming that each cell will obtain the land-use yielding the highest net socio-economic benefits. Model calibration is performed through financial methods (e.g. NPV).
Scale and applicability	Applicable in all scale levels	Local to regional level, well suited to explore urban growth dynamics at the local level	Local to regional level, able to inform on policy-setting and decision-making processes on the use and management of land resources in small extent areas with simplified landscapes	Household/firm to local level, useful to explore spatial relationships and analyse spatial implications of economic development and policy changes at a more disaggregated level	Regional, national and continent level, well suited for modelling and exploring the effect of land-use policies in large extent areas	Well suited for industry/facility sitting at various levels	Applicable in all scale levels, well suited for modelling and exploring the effect of land-use policies
Unit of analysis	Pixel	Pixel	Plot or census tracks that match with agents of land-use	Plot or census tracks that match with individual actors	Pixel	Pixel	Pixel
Advantages	Models are flexible enough to simulate the consequences of spatial decisions according to different assumptions and as such they are useful as planning support tools	Provide good representation of actual existing urban forms	Explicitly address interactions among agents and their preferences; useful in organising knowledge from empirical studies and exploring theoretical aspects of particular systems	Land-use changes are modelled on the scale level in which choices are actually made, shifting from the traditional focus on aggregated sectors of the economy to individual decision-making units	Calibration relies in standardized and easily reproducible statistical methods which are available through regular statistics software packages.	Able to determine the optimal solution for different and even divergent objectives (e.g. profit maximization, reduction of CO_2 emissions)	Explain the causal relationships between the human behavioural component and land-use decisions according to a theoretical framework. Able to incorporate a large number of driving forces and discontinuities in the land system (e.g. new land-use types)
Disavantages	Calibration is performed according to expert knowledge, thus not always guaranteeing transparency and reproducibility	Lack of standardized methods to derive the transition rules. Parameter calibration is often complex, due to the use of many interacting coefficients. Incapable of fully exploring the driving forces of agricultural transitions.	Require large amounts of data. Calibration procedure is too complex and time-consuming. Validation methods are still lacking, thus not guaranteeing a comprehensive model able to provide realistic simulations.	Demand enormous amounts of detailed data on individuals and the characteristics of their spatial location. Unable to capture and integrate macroeconomic processes resulting from structural economic change and demographic developments.	May result in low degree of explanation due to the relative short-time period of analysis, variability over that time period and the inherent uncertainty with respect to the causality of the assumed relations.	Emphasis on the economic drivers, while using very coarse resolution for biophysical drivers. Somewhat neglects the importance of spatial variation of biophysical parameters.	Driving forces have to be translated into cash flows, often requiring expert knowledge, thus not always guaranteeing transparency.
Examples of existing tools	*PLUC* (Verstegen et al., 2012)	*MOLAND* (Petrov et al., 2009)	*LUDAS* (Le et al. 2008)	*UrbanSim* (Alberti and Waddell, 2000)	*CLUE* model family (e.g. Verburg et al., 2002)	*Bioenergy Sitting Model* (Tittman et al., 2010)	*Land Use Scanner* (Hilferink and Rietveld, 1999)

Despite the diversity of modelling approaches, it is possible to identify a common structure among them (Figure 4). Typically, a distinction is made between calculating the magnitude of change (demand module) and the allocation of change (allocation module), both determined by a set of factors assumed to influence and drive the land system (Verburg et al., 2006). Firstly, suitability maps are created based on the interpretation of these driving factors, indicating the aptitude of a location for each specific land-use type. According to these suitability maps, the determined amount of land-use change is then allocated according to an allocation algorithm. The resulting land-use map is then used as the starting point for the next time-step, and this operation is successively repeated until the limit of the timeframe is reached. The difference among approaches relies essentially on the selection of factors that are assumed to drive land-use (which in turn also depends on the level of analysis and extent of the study area), the method to translate them into a suitability map and the allocation algorithm.

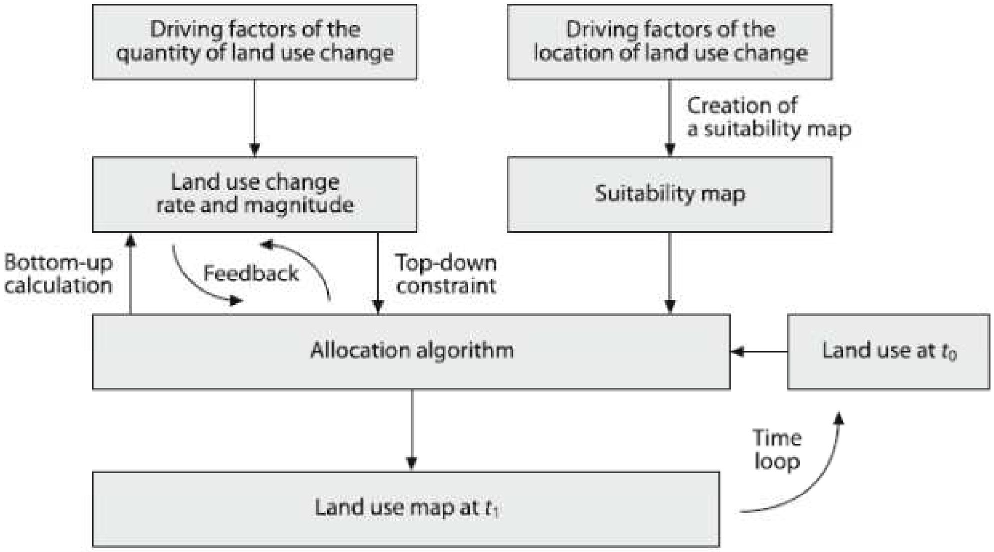

Figure 4: Model structure of spatially explicit land-use models (source: Verburg et al., 2006)

3.3. Designing the modelling framework

In the previous section, a number of land-use modelling approaches were reviewed. It can be concluded that both empirical and theoretical approaches have their advantages and drawbacks for different purposes (see Appendix C - section 10.3). Verburg et al. (2006) argues that in many cases it is more appropriate to use a range of different modelling approaches to study different aspects of the system, by combining the use of empirical and theoretical modelling approaches. Hence, two modelling approaches will be combined in the modelling framework implemented in the present study.

A discussion on the empirical and theoretical approaches that better suit the present research project is provided in Appendix D (Section 11). Two approaches were selected according to the research question, the characteristics of the study area and the availability of data: (1) statistical analysis as an empirical approach; (2) economic bid-rent theory as a theoretical approach.

The two approaches were then combined as follows. Firstly, the future developments of agricultural production were explored through an empirical approach according to statistical analysis, by extrapolating the current trends of land-use patterns. The demand for food products was assumed to be the main driver for the occurrence of land-use change, which in turn is driven by the development of underlying socio-economic factors. The following key factors are considered:

- Population and income growth, which determine the level of food consumption and diet composition;
- Self-sufficiency ratio (SSR) and exports level;
- Feed/food/fuel crops production efficiency, taking into account technology development such as no till seeding, biotechnology and precision agriculture, which determine the land demand for crops production;
- Animal production-feed composition and feed conversion efficiency, which determine the demand for feed crops and land demand for grazing areas;
- Nature conservation.

On the other hand, proximate factors such as infrastructure, proximity to markets and local biophysical characteristics were considered to be the main drivers for land-use change allocation. According to this approach, the spatial distribution of land required to supply the domestic and international demand for food crops (including soy used for food and feed purposes) and livestock production was dynamically simulated. The model output allows identifying the amount and the spatial distribution of surplus land that it is not required for food production and consequently where dedicated biofuel crops could be cultivated without endangering food security. A comparable approach has been applied in previous country-level assessments on biofuel potential (e.g. van der Hilst and Faaij, 2011). Taking the current land-use as a starting point, this modelling approach provides a dynamic simulation of land-use patterns, reproducing the dynamic features of the land-use system and spatially-explicit allocation of different agricultural uses. Therefore, it is expected to reproduce the functioning and future evolution of the agricultural production systems in Argentina, where a developed agricultural sector currently exists.

Then, a theoretical land-use modelling approach based on bid rent theory was applied to perform a spatially-explicit assessment on the economic viability of cultivating biofuel crops on the available surplus land that is not required to fulfil the expected demand for food. Accordingly, the potential for biofuel production was determined by identifying the locations where the cultivation of energy crops has a better economic performance than the other considered agricultural production systems. The theoretical approach aims to reproduce the human behavioural component in land management decisions, specifically the decision-making processes of farmers to grow biofuel crops on the available surplus land, while taking into account the profitability of other alternative land-uses.

The modelling framework is summarized in Figure 5. By combining two different types of modelling approach, such a framework allows to study complementary aspects of the land-use system, providing a more direct linkage between processes and patterns, which can then inform policy-setting and decision-making processes on the use and management of land resources.

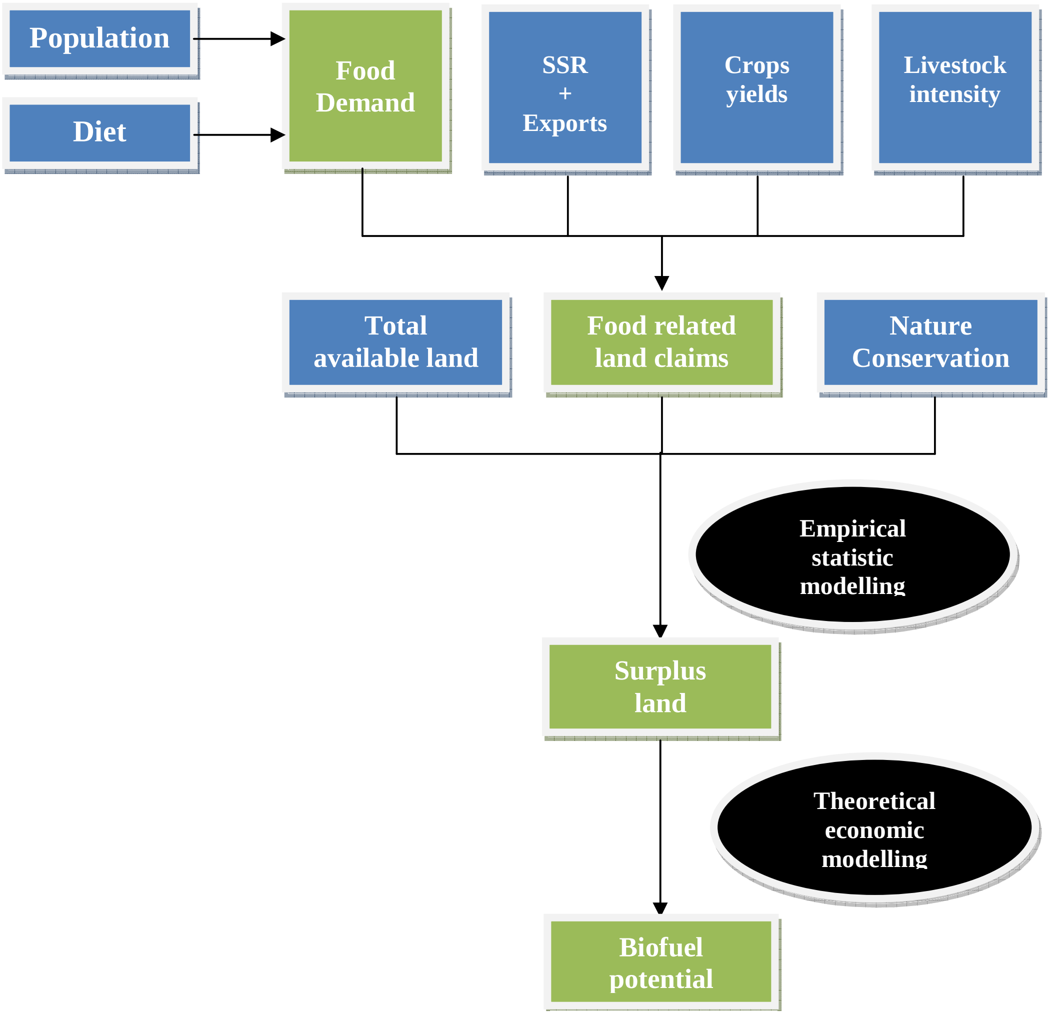

Figure 5: Modelling framework

3.4. Model building

The empirical model was built and operated in PCRaster Land Use Change (PLUC) model. The PCRaster Python is a construction framework that offers a combined interface for geospatial analysis, spatio-temporal modelling and a Monte Carlo analysis framework able to produce stochastic maps (Karssenberg et al. 2010, Verstegen et al., 2012), thus integrating simulation, uncertainty analysis and visualization. A model previously created for a similar case study in Mozambique (Van der Hilst and Faaij, 2011) was adapted to fit the Argentinean land-use system. A more detailed account on this model can be found elsewhere (Verstegen, 2011; Verstegen et al., 2012). The features of the model can be found in Appendix E (Section 12), namely unit of analysis, spatial scale, temporal scale, neighbourhood interactions, land-use conversion elasticity and feedback mechanisms, land-use driving forces and land-use typology.

Land-use systems are usually represented through maps using a typology based on general land-use types (e.g. urban areas, cropland, grassland, pastures, forests, mosaics of land-uses, etc). However, Argentina is a very large country with quite significant regional differences in terms of agricultural production. Therefore, a land-use typology was specifically designed for this study case. Special attention was given to the main land management practices in this sector, namely to the most relevant crop rotation schemes and livestock production systems currently existing in the study area. Two main criteria were used to define land-use types: production orientation (i.e. whether production system is oriented to agriculture, mixed rotations or livestock production) and the share of each crop and livestock in the rotation scheme of each production system. A detailed account on the method to derive the land-use typology of agricultural land-uses and their spatial distribution is available in Appendix E – Section 12.6. Five main types of production systems were identified: two mixed production systems, involving the rotation between livestock production and annual crops; two pure agriculture systems, involving rotation among annual crops; livestock production systems, in which only activities related to extensive livestock production are conducted.

In the final land-use typology, land-use types were distinguished as dynamic and static/passive land-use types. Dynamic land-use types are those which land claims will be assumed to change in time and thus are comprised by the aforementioned agricultural land-use types. Their demand will be determined according the demand for food and their future developments will be explored according to a scenario approach. Static land-use types have no demand assigned and thus are assumed to not change, unless a substitution by a dynamic land-use type is allowed, being in that case considered as passive (Table 2).

Table 2: Final land-use typology

Dynamic land-use types

- Mixed rotation 1
- Mixed rotation 2
- Agricultural rotation 3
- Agricultural rotation 4
- Livestock production

Passive land-use types

- Forest
- Sparse vegetation
- Mosaic forest/shrubland

Statitic land-use types

- Bare areas
- Water bodies
- Permanent snow and ice
- Urban areas
- (Semi-)Permanently flooded vegetation

Bare areas, water bodies, permanent snow and ice and (semi)permanently flooded areas are not allowed to be converted and consequently they will be regarded as static land-use types. Even though urban areas are expected to expand in the future due to population growth, the development of new urban areas is often relatively low when comparing to the total area of the country (e.g. Diogo and Koomen, 2010; Koomen et al., 2010). This does not mean that development of new urban areas is irrelevant for the land-use system. In fact, important urban-rural linkages occur in peri-urban areas, leading to ecosystem fragmentation and claim of croplands for rural housing (Lambin et al., 2001). However, considering the extension of the study area and purpose of the research, these effects can be considered negligible. Thus, the location and demand for urban areas was be assumed to be static and do not change during the simulation period.

It was required to reclassify the base land-use map used as starting point for simulation. A map depicting the regions where each type of production system is dominant was prepared (see Appendix E – Section 12.6.1). This map was then overlapped with the land-use map originally using a more general land-use typology (see Appendix F - Section 13.2.1 for an account on the original land-use map and further processing). The overlapping process proceeded as follows: the intersection of a cell assigned with a regional rotation scheme with a cell assigned with a general agricultural land-use type resulted in a cell assigned with a particular rotation scheme, defining its production orientation and the share of each crop/livestock on the rotation. The possible combinations of dominant regional rotation schemes and general land-use types, and resulting reclassification are summarized in Table 3.

Table 3: Possible combinations of regional rotation schemes and general land-use types and resulting rotation scheme land-use type

Rotation scheme region	*Original land-use type*	*Resulting land-use type*
Region 1	- Cropland - Mosaic cropland/grassland	Mixed rotation 1
Region 2	- Cropland - Mosaic cropland/grassland	Mixed rotation 2
Region 3	- Cropland	Agricultural rotation 3
Region 4	- Cropland	Agricultural rotation 4
Region 1, 2, 3 and 4	- Grassland/shrubland	Livestock production
Region 3 and 4	- Mosaic cropland/grassland	Livestock production

3.5. Model calibration

Calibration is the process of creating a model such that it is consistent with the data used to create it (Verburg et al, 2006). This implies quantifying the model parameters in order to fit specific regions and scenarios. The model is constituted by two distinct modules: a non-spatial demand module that determines the area change for all land-use types at the aggregate level, and an allocation module that translates these demands into spatially-explicit land-use changes. Firstly, the calibration of the demand module will be discussed, followed by an account on the calibration of the allocation module. A detailed account on the factors assumed to drive land-use change is provided in Appendix E – Section 12.7. The input data sources for the demand and allocation modules are presented in Appendix F – Section 13.

3.5.1. Demand module

The focus of this research lies on modelling the provision of different goods from agricultural and livestock production land-uses. The demand for each food commodity is calculated as follows:

$$D_c = \left[SSR_c * Pop * Food_{c,cap} + Proc_c + Feed_c + Exp_c\right] * [1 + \%S_c] * [1 + \%W_c]$$

where D_c is the demand for commodity c, SSR_c is the self-sufficiency ratio regarding that commodity, Pop is the country population, $Food_{c,cap}$ is the commodity consumption per capita, $Proc_c$ is the amount of commodity that is processed, $Feed_c$ is the amount of commodity that is used as feed for livestock production, $\%S_c$ is a seed factor related to the amount of commodity that is used for seeding or reproduction in respect to total demand, and $\%W_c$ is a waste factor related to the commodity losses occurring during processing, storage and transportation in respect to total production.

The demand for vegetal and animal products is analyzed separately. Firstly the demand for food crops resulting from domestic consumption and exports of vegetable products is calculated. Four main food crops will be considered: soy, sunflower, wheat and corn. The demand for food crops for feed purposes is then determined according to the demand for animal products. Finally, the demand for feed is added up to the demand for vegetal products, which gives the total demand for food crops, after correcting with seed and waste factors.

The following animal products will be considered: cattle meat, poultry meat, pig meat, bovine milk and eggs. The demand for animal products will determine the demand for feed from pastures and food crops used for feed purposes. The amount of land needed for the production of animal products will then depend on the efficiency of production, which is largely determined by the type production system. Two types of animal production systems will be considered: 1) pastoral systems, in which feed to animals comes mostly from grazing on rangelands and pastures; 2) intensive landless systems, which rely on a mix of concentrates, food crops and grass for feed. Each system will account for a share on the production of animal products, according to the assumed level advancement of technology.

The demand for animal products produced in landless and pastoral systems is translated into demand for food crops as follows:

$$Feed_{c,x} = (\%LL_x * \%FC_{LL,c} * Fce_{LL} + \%P_x * \%FC_{P,c} * Fce_P\ ) * D_x$$

where $Feed_c$ is the amount of food crop c that is used as feed for livestock in order to produce animal product x, $\%LL$ is the share of animal product x that is produced in landless systems, $\%FC_{LL,c}$ is the share of food crop c on the feed composition of landless systems, Fce_{LL} is the feed conversion efficiency in landless systems, $\%P_x$ is the share of animal product x that is produced in pastoral systems, $\%FC_{P,c}$ is the share of food crop c on the feed composition of pastoral systems, Fce_P is the feed conversion efficiency in pastoral systems, D_x is the demand for animal product x and $\%OT_x$ is the off-take rate (in the case of meat production.

The demand for animal products produced in pastoral systems is translated into demand for grass as follows:

$$Grass_x = (\%LL_x * \%Grass_{LL,x} * Fce_{LL} +\ \%P_x * \%Grass_{P,x} * Fce_P) * D_x$$

where $Grass_x$ is the amount of grass c that is used as feed for livestock in order to produce animal product x, $\%Grass_{LL,x}$ is the share of grass c on the feed composition of landless systems and $\%Grass_{P,x}$ is the share of grass on the feed composition of pastoral systems.

3.5.2. Allocation module - Empirical approach

The allocation module of the empirical modelling approach was calibrated according to statistical analysis. Logistic regression is the most commonly used method to calibrate land-use models based on statistical analysis (Verburg et al. 2004c; Koomen and Stillwell, 2007). Logistic regression is a multivariate generalized linear model that allows one to predict a discrete outcome from a set of explanatory variables. Because land-use change is usually represented as a discrete change from one land-use type to other, logistic regression is deemed as an appropriate statistical model to analyse these phenomena (Millington et al, 2007).

When applying logistic regression analysis to land-use modelling, the dependent variable, i.e. land-use, is categorical, with each category referring to one of the simulated land-use types. Logistic regression analysis is used to determine the local suitability of each land-use type, by quantifying the relation between the occurrence of land-use types and sets of explanatory variables that are considered to drive land-use allocation (Verburg et al., 2008; Koomen et al., 2010). The model transforms the dependent variable into a logit variable by estimating the odds of a land-use type occurring in a certain cell in relation to a reference class and then calculates the regression coefficients through maximum likelihood (Lesschen et al, 2005):

$$S_{c,i} = \ln\left[\frac{P_{c,i}}{P_{c,ref\ class}}\right] = b_{0,i} + \ b_{1,i}X_{1,c} + b_{2,i}X_{2,c} + \cdots + b_{n,i}X_{n,c}$$

where $S_{c,i}$ is the local suitability of land-use type i in cell c, $P_{c,i}$ is the probability of cell c being used for land-use type i, $P_{c,ref\,class}$ is the probability of cell c being used for the land-use type considered as a reference category (usually the land-use type that is more prevalent and has a homogeneous distribution along the study area), X_1 to X_n are independent explanatory variables (that is, the proximate factors assumed to drive land-use), b_0 is a constant (the intercept) and b_1 to b_n are the logistic regression coefficients which indicate the direction and intensity of each explanatory variable on explaining the occurrence of land-use type i.

Maps depicting land-use and factors assumed to drive the land system in the study area were overlaid and sampled using ArcGIS software package. The resulting observations were subsequently exported to SPSS, a statistics software package, in which the logistic regression analysis was performed. Then, the regression coefficients were determined through binomial logistic regression analysis and used to calibrate the model, according to which the allocation of the dynamic land-use types is simulated.

Logistic regression analysis also allows to identify which driving forces appear to be more relevant in explaining the land-use system, by determining a Wald statistic for each driving force on each land-use type: the higher the value of the Wald statistic, the higher the explanatory power of the driving force to explain the occurrence of that land-use type. Similarly to simple linear regression, a pseudo R^2 statistic is also provided in order to summarize the fitness of the model.

Prior to the analysis, the explanatory variables were normalized as follows:

$$\mathrm{X}_{norm} = \frac{X - X_{min}}{X_{max} - X_{min}}$$

where X_{norm} is the normalized value of the explanatory variable, X is its original value and X_{max} and X_{min} are its maximum and minimum values, respectively.

Land-use systems tend to show spatial autocorrelation. Despite of addressing explicitly this issue by including neighbourhood characteristics as an explanatory factor (see section 12.3), the occurrence of spatial autocorrelation can nevertheless generate inconsistent statistics estimates (Bell and Bockstael, 2000; Irwin and Geoghegan, 2001). Therefore, this issue was further minimised by using a sample of 10% of the total study area of randomly distributed observations while performing the statistical analysis, instead of using the whole dataset. This method has been successfully implemented in previous calibration efforts based on regression analysis (e.g. Verburg et al., 2004b).

3.6. Model validation

Validation consists in the process of measuring the agreement between the model simulation and independent data (Verburg et al., 2006). Hence, validation aims to inform the modeller about the level of trust one should put in the model, as well as about the need to improve it. A common procedure to perform model validation is to use historical land-use data as the starting point for simulation and verify whether the model is able to reproduce current land-use patterns. To evaluate the model performance in terms of agreement between observed and predicted land-use change, statistical measures based in 3-map pixel-by-pixel comparisons have been proposed by Pontius et al (2008):

- Figure of merit, which can range from 0%, meaning no overlap between observed and predicted change, to 100%, meaning perfect overlap between observed and predicted change, i.e., a perfectly accurate prediction.

$$\text{Figure of merit} = B/(A+B+C+D)$$

where:
A - area of error due to observed change predicted as persistence
B - area of correct due to observed change predicted as change
C - area of error due to observed change predicted as wrong gaining category
D - area of error due to observed persistence predicted as change.

- Producer's accuracy, which is the proportion of pixels that the model predicts accurately as change, given that the reference maps indicate observed change:

$$\text{Producer's Accuracy} = B/(A+B+C)$$

- User's accuracy which is the proportion of pixels that the model predicts accurately as change, given that the model predicts the occurrence of change:

$$\text{User's Accuracy} = B/(B+C+D)$$

However, these indicators only assess the ability of the model to correctly predict land use change. Therefore, an indicator measuring the ability to correctly predict persistence will be also determined (Diogo and Koomen, 2011):

$$\text{Well predicted persistence} = E/(D+E)$$

where E is the area of correct due to observed persistence correctly predicted as persistence.

Finally, the overall performance of the model will be assessed according to the following indicator (Diogo and Koomen, 2011):

$$\text{Model performance} = (B+E)/(A+B+C+D+E)$$

Only dynamic land-use classes will be evaluated while performing the model validation.

3.7. Economic assessment of biofuel crops cultivation on surplus land

The economic performance of biofuel crops on the surplus land was assessed according to bid rent theory, which assumes that economic agents make decisions on the land-use system by selecting the land-use type that provides the higher revenue at a certain location (see sections 10.2 and 11.2). In fact, while making land allocation decisions, farmers account for expected profitability to choose among different crops (Lorda, 2011; Garre, 2011). The net present value (NPV) is a standard method to appraise long-term projects, by measuring discounted time series of expected cash flows. When applying this method to land-use decision-making, NPV is determined in the following way:

$$NPV_{c,i} = \sum_{y=0}^{n} \frac{B_{c,i,y} - C_{c,i,y}}{(1+r)^{y}}$$

where $NPV_{c,i}$ is the net present value derived from land-use i in land parcel c in year 0, $B_{c,i,y}$ and $C_{c,i,y}$ are respectively the benefits and costs of land-use i in land parcel c in year y, r is the discount rate and n is the lifetime of the project. Thus, the NPV that a farmer can expect by producing a certain crop/livestock in a land parcel depends on the specific costs to produce that crop/livestock and on the attainable productivity, which in turn are directly related to the location and properties of that land parcel.

The costs related to crop production include four main categories of expenses: field operation costs (contractor, machinery, labour and diesel costs), input costs (seeds, fertilizers and pesticides), fixed costs (insurance, soil sample assessment, etc.), commercialization costs, drying and storing costs. Thus, the specific yearly costs per unit of area for a certain agricultural land-use type are calculated as:

$$\mathrm{C_{c,i}} = \mathrm{FOC_i} + \mathrm{IC_i} + \mathrm{Y_{c,p}} * (\mathrm{SC_p} + \mathrm{CC_p} + \mathrm{STC_p} * \mathrm{D_c})$$

where:
$C_{c,i,y}$ are the total costs resulting from land-use i in cell c in year y
$FOC_{i,y}$ are the field operation costs resulting from land-use i in year y
$IC_{i,y}$ are the input costs resulting from land-use i in year y
$FC_{i,y}$ are the fixed costs resulting from land-use i in cell c in year y
p is the product generated by land-use i
$Y_{c,p}$ is the yield of product p in cell c
$SC_{p,y}$ are the storing costs of product p in year y
$CC_{p,y}$ are commercialization costs of product p in year y
STC_p are the specific transportation costs of product p
D is the distance of cell c to the nearest market

The benefits of a certain land-use type are the revenues from selling the product. They are strongly related to local biophysical characteristics which determine the attainable yield and are calculated as follows:

$$\mathrm{B_{c,i}} = \mathrm{Y_{c,p}} * \mathrm{P_p}$$

where:
$B_{c,i,y}$ are the benefits derived from land-use i in cell c
p is the product generated by land-use i
$Y_{c,p}$ is the yield of product p in cell c
$P_{p,y}$ is the price of product p in year y

Maps depicting soil use capacity per crop are used to differentiate the benefits that can be derived for each land-use according to the location. A comparable methodology has been recently used in a spatially-explicit assessment on the potential of biofuel crops production in a region of the Netherlands by comparing the NPV of biofuel production with current agricultural crops and land-uses (Hilst et al., 2010).

According to bid rent theory, this method implies that farmers will choose to produce the crop/livestock from which the highest NPV can be derived in each land parcel. Thus the economic performance of biofuel crops on the surplus land will be assessed by comparing the NPV's of different uses in each land parcel. For any land parcel, if biofuel crop's NPV is higher than all other uses, it will be considered as potentially viable for biofuel crop production.

A discount rate of 9% for crop cultivation and 2.5% for livestock production will be assumed. The difference on the discount rates between these activities is explained by the risk inherent to them (Garre, 2011). Crop farming can generate higher profits in a shorter term, but is also more susceptible to changes in climate conditions and thus its profitability is more likely to fluctuate. On the other hand, livestock production represents a longer term investment but the risk to lose all capital is lower, since it would imply the death of all animals, which is not so likely to occur. The lifetime of the project will be assumed to be 20 years, which is the considered modelling timeframe for this study and it is line with previous assessments on economic performance of agricultural activities and perennial biofuel crops (van der Hilst et al., 2010; Kuhlman et al., forthcoming).

The costs and benefits for annual crops and livestock production will be directly derived from magazines specialized in agriculture production in Argentina (Margenes Agropecuarias, 2011; Agromercados, 2011 – see Appendix E – Section 0). No agricultural subsidies are currently provided to farmers in Argentina and export taxes for agricultural products are on average around 20% of the export value, in order to ensure local food supply and maintain domestic food prices low (van Dam et al., 2009a). Likewise, meat prices are regulated and decoupled from international market prices.

For switchgrass, field operations, harvest costs and input requirements will be derived from Smeets et al. (2009). A maximum yield of 10 ton/ha will be assumed (van Dam, 2009a). Since there is not an established market for switchgrass in Argentina yet (Hilbert, 2011), the selling price of switchgrass will be assumed to be the same as sorghum, which is a forage grass that it is also being considered as a promising option for biofuel feedstock in Argentina (INTA, 2008). The prices of inputs and operation costs will be derived from Margenes Agropecuarias (2011), assuming that the operations for switchgrass cultivation require the same machinery type, labour and fuel consumption as sorghum. Seed prices are derived from Van Dam et al. (2009).
Regarding transportation costs of oilseeds and grains, specific gasoil consumption will be assumed to be 0.037 L/km.ton for short distance transportation on dirt tracks and 0.019 L/km.ton for long distance transportation on paved roads (Donato, 2011). For cattle transportation, the specific gasoil consumption is 0.92 L/km.ton animal in dirt tracks and 0.19 L/km.ton animal in paved roads (Garre, 2011). The price of gasoil is assumed to be 1.07 US$/L, VAT included (Margenes Agropecuarias, 2011b).

3.8. Calculating the potential for biofuel production

The output of the simulations will consist in maps depicting the spatial distribution of land available for biofuel production. This will allow to determine the geographical potential, i.e. the amount of land that is available for biofuel production. However, yields can vary considerably according to the location. Therefore, to determine the technical potential it is required to calculate the actual levels of biofuel crop production. This can be determined through the following GIS algebraic calculation:

$$\mathrm{TCP} = \sum [\mathrm{A_c} * \mathrm{yield_c}]$$

where TCP is the yearly total crop production in Argentina, which is equal to the sum of the area of the grid cells c that were allocated with biofuel crops (A_c) multiplied by the yearly attainable yield of biofuel crops in each of those cells ($yield_c$). The technical potential for biofuel production can be finally calculated as follows:

$$\mathrm{TBP} = \mathrm{TCP} * \mathrm{EC} * \eta_{\mathrm{conv}}$$

where TBP is the annual total biofuel production, TCP is the annual total biofuel crop production, EC is the crop energy content and η_{conv} is the efficiency of converting feedstock crop into biofuel.

Two main steps are required for soy-based biodiesel production: (1) firstly, soybeans are crushed in crushing plants, from which 19.4% of the final output consists in raw vegetable oil; (2) then, the extracted oil is converted to fatty-acid methyl ester (FAME) biodiesel through a transesterification process, in which oil is blended with methanol and a catalyst (van Dam et al., 2009a; INTA, 2012). Argentina has a very efficient biodiesel industry, with conversion efficiency levels of 97.5% (INTA, 2012). The energy content (LHV) of biodiesel is assumed to be 37 GJ/ton (European Commission, 2009).

It should be noted that besides of the biofuel production from crop cultivation on surplus land, the potential for soy-based biodiesel also takes into account the soybean production resulting from the demand for soymeal, since biodiesel is produced as a by-product of soybean crushing (INTA, 2010a). The potential for biofuel resulting from this production chain is determined according to the demand for soymeal and soy oil, assuming that all soyoil that is produced during soymeal production and that is not required to supply soyoil demand can be further processed to biodiesel. Since FAO (2011) projections for 2030 do not specify the final use for soy, it is assumed that the current shares of the production chain are maintained (INTA, 2011c – see Figure 6). Furthermore, an increase in the use of soymeal in the feed composition for livestock production (see section 3.9.5) can also lead to an increase in the biofuel potential: since the demand for soyoil is already fulfilled, the vegetable oil resulting from bean crushing for the additional soymeal production can be used for dedicated conversion to biodiesel.

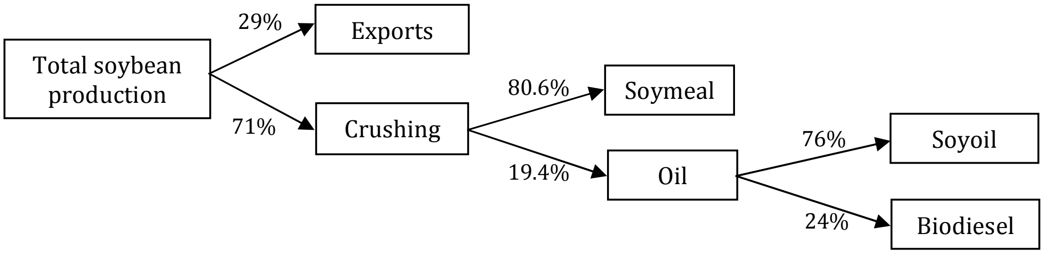

Figure 6: Product share in the current soy complex in Argentina

Switchgrass is converted to anhydrous ethanol through cellulose enzymatic hydrolysis and sugar fermentation. The crop energy content (LHV) is assumed to be 18 GJ/odt (Boehman et al., 2008) and the conversion efficiency of lignocellulose conversion to ethanol is assumed to be 47.3% by 2030 (Hamelinck and Faaij, 2006).

3.9. Scenario approach

The use of scenarios is a popular approach to identify policy alternatives and assess possible future developments of complex systems such as land-use systems (Verburg et al. 2006). Rather than predictions, they are an approach to help manage decisions based on the interpretation of qualitative descriptions of alternative futures translated into quantitative scenarios (Petrov et al., 2009). Since future development in land-use drivers is highly uncertain, a number of different scenarios will be designed in order to explore possible future alternatives.

Similarly to a previous spatially-explicit assessment of biofuel potential (Van der Hilst and Faaij, 2011) socio-economic drivers such as population, GDP and diet will not be subject to scenario variation, in order to allow for a more transparent comparison among scenarios. Though GDP and diet change over the simulated time frame, the rate of change is the same among scenarios. Consequently, food and feed demand will also be the same for all scenarios, but the allocation process and land claimed for food production may differ substantially according to the scenario. Firstly the indicators that remain unchanged will be discussed, followed by a description of the assumed scenarios.

3.9.1. Developments on population, level of affluence and diet

The population in Argentina increased from 32 to 40 million inhabitants between 2000 and 2010 (UNDP, 2010a). The annual growth rate has been decreasing along the years and is expected to continue slowing down. The medium variant of UNDP's *World Population Prospects: The 2010 Revision* will be considered, thus being expected a population of 46761 thousand inhabitants by 2030 (Figure 57).

The diet in Argentina is mainly composed by cereals (particularly, wheat flour), bovine meat, refined sugar, sunflower oils and cow-milk (Figure 58; FAO, 2010; FAOSTAT, 2011). Gross domestic product (GDP) per capita in Argentina increased sharply during the last two decades, almost doubling from 5,607 US$2000 in 1990 to 10,682 US$$_{2000}$ in 2010, except for a period of economic crisis between 1999 and 2002 . From 2003 on, an economic recovery has been observed, with GDP/capita increasing on average by 6,45% per year during this period. Daily food intake appears to roughly follow this pattern, with an increase from 2925 to 3272 kcal/capita/day between 1990 and 2000, followed by a decrease down to 2966 kcal/capita/day in 2002 during its economic recession. After that, food intake has fluctuated around 3000 kcal/capita/day, despite the significant increase on the affluence level. Therefore, it can be concluded that food intake has been to a certain extent influenced by the level of affluence, even though a linear correlation cannot be derived.

Not only food intake but also diet composition appears to depend on the level of affluence. Due to the economic crisis, besides of the drop in total food intake, a sharp decrease in the share of animal products on the food supply intake could also be observed, from 31.6% to 26.4% between 1999 and 2004 (Figure 59). Following economic recovery, a relative increase on animal product consumption up to 32.4% in 2007 can be noted. This variation appears to be mostly explained by changes on the consumption of milk and higher-value dairy products (Figure 60), which seem to be the most sensitive product to variations on the affluence level. Therefore, an increase in animal products can be expected resulting from the improvement of affluence level.

Total meat consumption per capita is remarkably high in Argentina (around 90 kg/capita/year), which is comparable to that of European Union (Van Horne et al., 2010). However, the contribution of each livestock species to supply meat demand has been changing in the last 20 years: the share of bovine meat has been slowly decreasing, while on the other hand consumption of pig and particularly poultry meat has been increasing, except during the economic crisis, when the opposite trend could be noticed (Figure 61). This might show that, in comparison to pig and poultry meat, bovine meat consumption is relatively inelastic in respect to price and purchasing power in Argentina (Rearte, 2007a) and consequently the absolute consumption per capita tends to remain stable.

Due to the economic growth observed in recent years, it could be expected by 2030 a level of affluence almost comparable to the one currently observed in developed countries. For instance, if annual economic growth maintained its current rate, GDP/capita in Argentina would reach around 37,000 $\text{US\$}_{2000}$ in 2030. However, growth rates are not likely to always remain as high as nowadays. Hence, a more conservative estimative will be considered. In line with the most recent FAO projections (FAO, 2011), GDP/capita will be assumed to reach 21,700 US$ in 2030, which will be followed by an increase on the daily caloric intake per capita up to 3207 kcal/cap/day.

The future patterns of food consumption of grains, oilseeds and animal products will be also expected to follow the trends projected in FAO (2011). Accordingly, annual consumption of meat per capita will be assumed to increase up to 104 kg/capita/year in 2030. Although bovine meat consumption per capita will remain stable in absolute terms, its share on total meat consumption is expected to decrease from 62% to 52%, due to the increase in poultry meat (from 29% to 37%) and pig meat consumption (from 7% to 9%). Egg consumption is expected to increase from 9 to 11 kg/capita/year, while milk consumption increases up to 210 kg/capita/year. The current and future level of affluence and dietary patterns are summarized below in Table 4.

Table 4: Current and future level of affluence, daily food intake and dietary patterns (Source: FAO, 2011)

			Food consumption (kg/cap/year)						
Year	*Level of affluence ($\text{US\$}_{2000}$/cap)*	*Daily caloric intake (kcal/cap/yr)*	*Wheat*	*Corn*	*Bovine meat*	*Poultry meat*	*Pig meat*	*Milk*	*Eggs*
2006	9400	2966	102.6	19.0	55.4	26.2	6.2	194.3	9.2
2030	21,700	3207	110.0	16.0	54.0	39.0	9.5	210.0	11.0

3.9.2. Self-sufficiency ratio, exports, processing, seeding and waste

Since Argentina is essentially a net exporter, self-sufficiency ratio will be equal to 1 (i.e. domestic demand is fully met by domestic supply) for all for food commodities but pig meat (FAO, 2011). Seeding and waste factors will be determined by calculating the ratios Seed/(Food+Proc+Feed+Exports) and Waste/(Food+Proc+Feed+Exports+Seed), repectively, as projected in FAO (2011).

Table 5: Current and future demand coefficients for food commodities in Argentina (Source: FAO, 2011)

Commodity	*Year*	*SSR*	*Processing (1000 tonnes)*	*Seed factor*	*Waste factor*	*Exports (1000 tonnes)*
Wheat	2006	1	12.9	4.0%	3.7%	10527.1
	2030	1	13	4.4%	3.5%	13518.1
Corn	2006	1	954	0.6%	2.1%	15476
	2030	1	954	0.6%	2.1%	22192
Bovine meat	2006	1	-	-	3.8%	602
	2030	1	-	-	3.8%	723
Pig meat	2006	0.88	-	-	-	0.8
	2030	0.82	-	-	-	-
Poultry meat	2006	1	-	-	-	132
	2030	1	-	-	-	82
Milk	2006	1	2.4	-	0.4%	2207
	2030	1	2	-	0.4%	4582
Eggs	2006	1	-	9.3%	5.3%	11
	2030	1	-	9.3%	5.3%	2

The available projections regarding future production of soy and sunflower are not distinguished in terms of domestic consumption, feed use and exports, but instead only data on total final production is available (Table 6).

Table 6: Current and future production of soy and sunflower in Argentina (Source: FAO, 2011)

	Crop Production (1000 ton/year)	
Year	*Soy*	*Sunflower*
2006	42103	3640
2030	69250	6171

3.9.3. Supply of food demand per type of production system

During the last decade, production systems of type 3 and 4 (purely agricultural with high share of soy in the rotation scheme) have accounted for most of total agricultural production and total cultivated area in Argentina. In regions with high biophysical suitability and proximity to the main markets, agriculture intensification has been observed, through the increase of soy in the rotation share and land renting to planting pools. In less suitable locations, as technology is gradually adopted by farmers and soy cultivation becomes profitable, farmers tend to gradually increase the share of soy in the rotation scheme and abandon the traditional practices of rotating agriculture with livestock production (Garre. 2011; Lorda, 2011). This trend will be assumed to continue during the considered timeframe. The annual rate of change on the share of each production system in total production observed during 2003-2011 (which according to Carballo (2011) can be considered a good reference, since it follows a period of relative economic stability) is assumed to be maintained until 2030. Table 7 summarizes the assumed share of each production system in supplying the demand for food crops by 2030.

Table 7: Future share on total production per type of production system

Production system	Average 2003-2011	*2030*
Mixed rotation 1	0.78%	0.5%
Mixed rotation 2	13.74%	7.5%
Agricultural rotation 3	39.65%	37%
Agricultural rotation 4	45.83%	55%

3.9.4. Nature conservation

During the last decade, deforestation rates in Argentina were relatively higher than Latin American and world averages (0.51% and 0.20% respectively), especially in Chaco region, where it has varied between 1.5% and 2.5% (Seghezzo et al., 2011). Since 2007, Argentine provinces have begun enacting land zoning policies regarding nature conservation under the Forest Law's land management provisions (Law No. 26331/2007). According to this law, provincial governments are responsible for laying out and enforcing three levels of protection (Hilbert, 2011b):

- forests of high conservation value which are to remain completely untouched;
- forests where sustainable exploitation is tolerable;
- forests that can be altered and where agricultural expansion is permissible.

Following these criteria, all provincial governments elaborated a map depicting the existing forestry resources within each province and the levels of protection to be enforced in those areas. However, the maps in GIS format are not yet held by any central governmental institution but instead owned by each provincial government and as a result it was not possible to collect all of them. Thus, this zoning policy cannot be taken into account while designing future scenarios regarding nature conservation. Instead, it will be only assumed that agriculture and livestock production are not allowed to expand to protected nature areas.

3.9.5. Scenario-dependent variables

The scenarios will be designed following similar storylines as those presented in Van der Hilst and Faaij (2011). In that study, two main storylines were taken into account: a Business-As-Usual (BAU) scenario and a Progressive and Sustainable (PS) scenario. In the BAU scenario, bioenergy large-scale production is implemented without major changes in policies, technology adoption and managerial practices. The PS scenario involves a higher rate of technological change which results in more advanced and productive agricultural practices.

Following these storylines, the scenarios will be designed by varying 2 main components, in order to explore their joint impact on land availability:

- feed composition, productivity and technological change in livestock production;
- productivity and technological change in agriculture

<u>Livestock production</u>

Similarly to Bouwman et al. (2005), livestock production is assumed to take place either in pastoral systems, in which feed is mostly provided by grass, or in mixed/landless systems, in which livestock is produced in land intensive systems with a higher share of concentrates in feed composition. 3 main categories of feed are distinguished:

- grass, including hay and silage grass
- food crops and by-products, namely 50% soymeal and 50% sunflower cakes.
- crop residues and fodder crops, namely silage corn, which will be assumed to have a 30% harvest index (grain/rest of the plant) (Pordomingo, 2005; Vernet, 2005, Machado, 2007, Vacrezza et al., 2009).

- **Bovine meat production**

Special emphasis will be given to the level of technological advancement on livestock production. Despite of the importance of beef production sector, Argentina has been remarkably lagging behind the other main Latin American meat producer countries during the last decades, with only Uruguay performing poorer in terms of productivity growth (World Bank, 2006). Currently, this is the agricultural sector with the largest technological gap in Argentina. In some regions, large productivity gaps up to 120% between low and high technology cattle meat producers, showing not only that differences in agro-ecological conditions do not fully explain differences in productivity, but also that producers with distinct rates of technology adoption may co-exist within a given agroecological area (Lema, 2010). Thus, even though more advanced technology is already available in Argentina, its availability does not necessarily imply adoption and as result there is still much room for technological change in livestock production.

Traditionally, cattle-raising was performed solely in pastoral systems. However, the adoption of feedlots for beef production has been gradually introduced in Argentina since the 90s, due to a growing trend of pasture replacement by arable farming. Initially, feedlots were used seasonally as a way to address temporary drops in the supply of forage from natural pastures, but in the meantime, they have increasingly become year-round operations, with substantially more uniform and higher-capacity utilization rates (Lence, 2010). In addition to the decreasing availability of pastures, two market factors have also contributed to the implementation of feedlots. On the demand side, beef production in feedlots allows to produce meat on a constant basis with more uniform quality, thus fulfilling stricter requirements by domestic consumers (Vernet, 2005; Lence, 2010). On the supply side, a government reimbursement scheme to feedlots offering partial refunds for the costs of grains used for feed was instituted in early 2007, explaining the recent further surge in feedlot production. While 1.5 million of slaughtered cattle heads had been finished in feedlots in 2001, in 2007/08 this number amounted to 3.6 million (SENASA, 2008), reaching roughly 5 million heads in 2009, which represented 42% of total slaughtered heads in that year (Camara Argentina de Feedlots, 2009).

However, due to evidence of occurrence of false reporting on feedlot meat production and fraudulent attribution of refunds, this scheme was suspended altogether by the government in 2010 and nowadays no support is given to this activity (Carballo, 2011), As a result, the participation of feedlots in meat production has rapidly declined down to 3 million slaughtered heads in 2010/2011 (SENASA, 2011), which accounted for roughly 30% of total meat production (Carballo, 2011).

The profitability of meat production in feedlot is very sensitive to changes on grain prices, meat prices and cattle purchase and selling prices (Vernet, 2005; Pordomingo, 2005). Sudden changes in any of these variables occur quite frequently in Argentina and therefore technological improvements within this sector could only be expected if a stable policy setting with strong legislation is provided in order to reduce uncertainty and create favorable conditions for investment. In such a framework, it would possible to further develop and improve the use of mechanization and management tools such as feed formulation, improvement of breed genetics and feed conversion optimization (Arelovich et al., 2011).

Hence, two scenarios will be taken into account regarding the future development of meat production in feedlots. In the BAU scenario, no stable framework is provided by the government, resulting in a moderate increase of meat production in feedlots and feed conversion efficiency improvement. Meat production in feedlots will be assumed to have a share of 35% in total meat production by 2030, which represents an increase of only 5%. However, if a clear and stable governmental policy framework is designed, a steady increase on the productivity of this activity can be expected, since advanced technology is already available in Argentina. Therefore, in the PS scenario, feedlot meat production will be assumed to account for 60% of total meat production in 2030, which is according to Bouwman et al. (2005) the expected average for South America in 2030.

Regarding feed conversion efficiency, in BAU scenario the average values for South America will be considered, while in PS scenario it will be assumed that the current values for USA will be attained by 2030 in Argentina, due to improvements on feed formulation. It should be noted that even when fattening and termination stages occur in landless systems, breeding activities are still performed in pastoral systems (Lorda, 2011). Weaning normally occurs 6-7 months after birth, while fattening can take 12 to 24 months, depending on the breed type. Therefore, a large share of the feed composition for meat produced in feedlots is still provided to a great extent by grass and residues.

Low productivity in Argentina cattle production is not solely explained by low rate of intensification but also due to low productivity in pastoral systems themselves. In general, off-take rate in Argentinean pastoral systems has been maintained at a low rate, around 25% (Cap et al., 2010; UNDP, 2010b). However, increasing productivity cannot be achieved solely by increasing off-take rate, since that could lead to an unsustainable decrease of the herd stock. In fact, the low off-take rate in Argentina is to a great extent a consequence of low reproduction efficiency and low weaning rate due to deficient sanitation and poor management (Rearte, 2007b; Demarco, 2011). With better technology and management practices, these parameters could be improved in such a way that off-take rates could be ultimately increased in a sustainable manner (Demarco, 2011). Furthermore, carcass weight remains somewhat low when compared to that obtained in USA and Australia, showing that the full genetic potential of existing breeds may have not been fully explored yet (UNDP, 2010).

Thus in BAU scenario feed conversion will be assumed to increase very moderately, reaching the average value for South America according to Bouwman et al. (2005). In PS scenario, feed conversion efficiency will be assumed to achieve the same level as currently observed in Australia, which has comparable pastoral systems and has accomplish to sustainably increase off-take rates while increasing its total herd stock (Demarco, 2011).

In pastoral systems, animals spend most of the time grazing in rangelands and pastures, followed by a short period in which they are fed with corn silage, forage and feed concentrates (Bouwman et al., 2005, Rearte, 2007).

- **Dairy products**

Despite the existence of high-technology dairy farms in Argentina, the sector is still mainly composed by low productivity producers and therefore the technology gap is still large. The productivity in dairy farming can be improved by correctly managing the following factors (Lence, 2010): animal genetics and use of advanced milking machines technology, which improves milk yield per animal, management (e.g. fertilizing, rotating and better use of genetic materials for pastures), which improves feed conversion efficiency, and improving reproduction efficiency (e.g. through artificial insemination).

Due to the lack of clear government policies and extreme weather events, a high number of dairy farms closed due to bankruptcy between 2007 and 2009, while others decided to switch to other activities such as crop farming and husbandry (Revelli et al., 2011) or even quit activity and start renting their land to planting pools (Carballo, 2011). Therefore, an overall improvement in the sector's productivity can be expected even in the BAU scenario, due to the exit of less productive players which are not able to attain economic viability in such a competitive setting. However, the improvement of feed conversion efficiency will be larger in PS scenario, by assuming the existence of a solid policy framework allowing producers to have a clearer foresight of future developments to make their investments, and promoting technology adoption and better management practices through technology transfer programs. In this scenario, the share of mixed systems, their feed conversion efficiency and feed composition will be assumed to reach the levels currently observed in USA, according to Bouwman et al. (2005).

The feeding of dairy herds is mostly provided in mixed systems based on direct grazing and continuous supplementation (Revelli et al., 2010; Bouwman et al., 2005), with pastoral grass still accounting for a large share of the feed composition (Vacarezza et al., 2009). An increase on the share of feed concentrates can be expected as small producers exit the sector. However, it has been proven that a complete switch to confined landless systems is not necessarily more profitable, due to higher requirements in terms of labor and higher infrastructure and maintenance costs (INTA, 2010b).

- **Egg, poultry and pig meat production**

The level of technology advancement in the poultry meat sector is already relatively high, with high rates of technology adoption in farm automation, automatic feeders and improved shed ventilation and humidification (UNDP, 2010; van Horne, 2010). However, in the layer sector around 35%-40% of the total production is still done in small scale, obsolete stalls which are not able to maintain production throughout the year and mainly operate through informal channels of distribution (van Horne, 2010).

In the pig meat sector, the technological gap is still large and producer's profile is very heterogeneous. On the one hand, large producers are characterized by production systems with good management practices, advanced genetics, good sanitation and balanced feeding, while on the other hand small scale producers still operate in facilities with minimum health care plans, low levels of genetic improvement and no business management (UNDP, 2010; van Horne, 2010).

Therefore, there is a large potential for improvement in the egg layer and pig meat sectors. Feed conversion efficiency will be assumed to account for a larger increase in the PS scenario reaching the levels currently observed in USA according to Bouwman et al. (2005), reflecting governmental efforts in enforcing strong legislation and a policy framework promoting technology development in these sectors. Regarding, poultry meat production, no distinction will be made between BAU and PS scenario and productivity growth will be moderate, reflecting the current existence of a rather mature industry.

The production of eggs, poultry and pig meat will be assumed to take place only in landless systems. Even though almost 50% of pig production is performed in extensive open air systems combined with agriculture (van Horne, 2010), the use of land is much smaller than for extensive cattle production and therefore assuming that production occurs in landless systems is a good approximation in terms of land-use modelling. Feed will be assumed to be composed by feed crops and residues (Bouwman et al., 2005, Machado; 2007).

The scenario-dependent variables related to livestock production are summarized below in Table 8 and Table 9.

Table 8: Share in total production and feed conversion efficiency of pastoral and mixed/landless systems

System	Parameter	Year		Bovine meat	Dairy products	Eggs	Poultry meat	Pig meat
Pastoral systems	Share in total production	2009		70%	6.1%	-	-	-
		2030	BAU	65%	5.1%			
			PS	40%	4.0%			
	Feed conversion efficiency (kg feed/kg product)	2009		43.95	1.91			
		2030	BAU	41.39	1.89			
			PS	40.45	1.77			
Mixed/Landless systems	Share in total production	2009		30%	93.9%	100%	100%	100%
		2030	BAU	35%	94.9%			
			PS	60%	96.0%			
	Feed conversion efficiency (kg feed/kg product)	2009		33.7	1.15	3.94	3.42	6.55
		2030	BAU	32.0	1.12	3.65	3.42	6.44
			PS	29.4	0.93	3.11	3.11	6.22

Table 9: Feed composition of pastoral and mixed/landless systems

System	Feed composition	Year		Bovine meat	Dairy products	Eggs	Poultry meat	Pig meat
Pastoral systems	Feed crops	2009		1%	1%	-	-	-
		2030	BAU					
			PS					
	Residues	2009		9%	9%			
		2030	BAU					
			PS					
	Grass	2009		90%	90%			
		2030	BAU					
			PS					
Mixed/Landless systems	Feed crops	2009		2%	4%	59%	59%	60%
		2030	BAU	2%	4%	59%	75%	
			PS	22%	42%	75%	75%	
	Residues	2009		23%	36%	41%	41%	40%
		2030	BAU	23%	36%	41%	25%	
			PS	17%	18%	25%	25%	
	Grass	2009		75%	60%	-	-	-
		2030	BAU	75%	60%			
			PS	60%	40%			

Agriculture

The level of technology advancement in Argentinean agriculture is already quite high, being the productivity gap much lower than in the livestock sector (Lema, 2010). Use of GMO is common and widespread, with soy and corn accounting for 100% and 70% use of GMO seeds, respectively. No-tillage farming has also been increasingly adopted, accounting in 2007 for 75% and 83% of total soybean area planted as *soja de primera* and *soja de segunda*, respectively, 74% for corn, 72% for wheat and 45% for sunflower (Lence, 2010).

In BAU scenario, maximum attainable yields will be assumed to continue growing at the same average rate as observed in the last decades (see Appendix H – Section 15 for an analysis on past trends of yield growth rate per crop). In PS scenario, the average yield for state-of-art technology will be assumed to be the maximum attainable yield in 2030, according to the range of attainable yields while using state-of-art technology in the most suitable areas (*Margenes Agropecuarias*, 2011). It thus assumes that the rate of adoption of the best available technological packages and management practices by farmers in Argentina in 2030 is 100% for all crops.

Table 10: Future maximum attainable yields per crop

Crop	***Maximum attainable yield (ton/ha)***	
	BAU scenario	**PS scenario**
Sunflower	2.45	2.65
Corn	9.29	12.00
Soy	3.45	4.60
Wheat	3.69	5.50

Taking into account the share of each crop in each production region, it is possible to calculate the future maximum attainable yield for each production system. Statistics on maximum attainable yield per region were used to calibrate the base year. Local attainable yield will be then spatial-explicitly represented in the model through yield reduction maps depicting the biophysical suitability of each rotation scheme according to the crop suitability and the share of each crop in the rotation scheme.

3.10. Uncertainty analysis

Projections of population growth, diet change, exports and technological improvements in the agricultural sector can differ significantly (Bruinsma et al. 2003; UNDP, 2010a; FAO, 2011, MAGyP, 2011). Therefore, applying these data deterministically may imply that a large input error is ignored. Input errors can be taken into account within the PLUC modeling framework by calculating the forecast uncertainty, namely determining the probability, the relative error (standard deviation/mean) and the variance of each gridcell becoming available for biofuel production. A more detailed account on the model capababilites to perform uncertainty analysis is provided elsewhere (e.g. Verstegen, 2011; Verstegen et al., 2012).

The effect of uncertainty in three main input variables will be explored: demand, maximum attainable crops yields and feed conversion efficiency. The assumptions underlying the range of variation of these parameters are discussed below.

3.10.1. Demand

Lower boundary:
Consumption per capita will be assumed to remain at the lowest level recorded in the last 10 years. Exports will be assumed to remain at the same level as in the base year. Population growth will be assumed to develop according to UNDP (2010) low variant.

Upper boundary:

Consumption per capita of animal and vegetal products will be assumed to reach the current consumption levels in USA. Export levels will be assumed to have an average annual growth rate twice as high than assumed in FAO (2011), unless the growth rate is negative: in this case it will be assumed to remain at current levels. Population growth will be assumed to develop according to UNDP (2010) high variant. The range of demand variation is presented below in Table 11.

Table 11: Total demand for crops and grass in 2030

	Crops (ton)		Grass (ton)	
	BAU	PS	BAU	PS
Lower boundary	79,511,721	94,900,568	75,241,612	57,135,934
Standard calibration	123,016,528	143,981,370	99,028,007	73,403,937
Upper boundary	190,188,121	218,138,158	130,380,974	93,700,911

When comparing the estimates for the BAU scenario demand's upper boundary with the targets set by the Argentinean government for 2020 in the Agro-food Strategic Plan 2010-2020 (PEA 2010-2020 in Spanish), it can be seen that the obtained values are slightly lower that the governmental targets but they are still within the same range. However, poultry meat production holds a larger difference, since the Argentinean government has a very ambitious target for this sector in particular, envisioning a growth of 88% between 2010 and 2020.

Table 12: Comparison between estimated (upper boundary, BAU scenario) and government targets for production in 2020

Product	Estimated value for 2020 (ton)	Government targets for 2020 (ton)
Crops	155,834,623	157,500,000
Bovine meat	3,371,567	3,800,000
Poultry meat	1,860,470	3,000,000
Pig meat	586,712	822,000
Milk	15,373,306	18,540,000

3.10.2. Maximum Yield

The magazine *Margenes Agropecuarias* (2011) refers a high and a lower value for the maximum attainable yields when using state-of-art technology. The average value has been used to calibrate the maximum attainable yield for the PS Scenario. In the uncertainty analysis, maximum yields will be assumed to vary by the percentage difference between the average and extreme values. The same percentage variation will be applied to the BAU scenario. Grass yields will be assumed to vary according to the same percentage as food crops.

3.10.3. Feed conversion efficiency

Feed conversion efficiency will be assumed to vary by 12% for non-dairy cattle and by 5% for dairy cattle, which is line with the sensitivity analysis performed in Bouwman et al. (2005). For non-ruminant animal production, a 5% variation will be assumed.

3.10.4. Suitability factors

Due to computation errors, it was not possible to include all the suitability factors in the uncertainty analysis. Therefore, neighbour relationships and yield were selected for the uncertainty analysis, since these were the factors that shown to have a higher explanatory power in determining the suitability for land-use (see Section 4.2.2 on the results of the logistic regression analysis). These suitability factors were varied according to error models presented in Verstegen et al. (2012).

4. Results

4.1. Base year land-use map

After overlaying the production regions map with the GlobCover land-use map, a map explicitly depicting the spatial distribution of the identified production systems in Argentina was obtained (Figure 7).

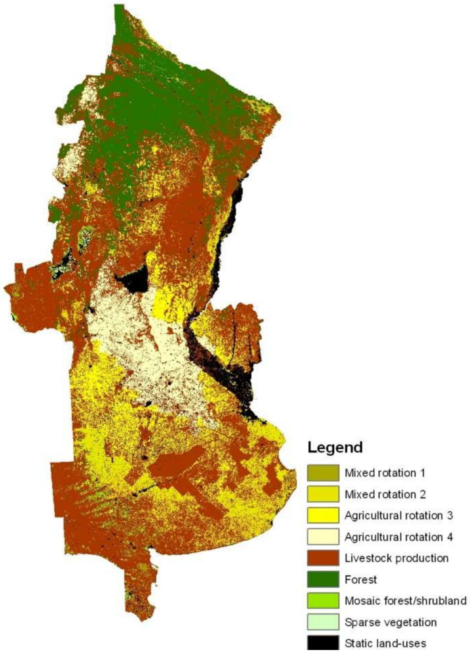

Figure 7: Base year land-use map

When comparing the obtained map with statistics on cultivated land and livestock production in 2009 (Table 13), it can be concluded that in general there is a fairly good approximation between the amount of land that is attributed to agriculture in each production region and the actual statistics on cultivated area. However, in mixed production systems, and in particular in region 1, the estimation of area dedicated to agriculture does not seem to match so well with the recorded statistics. This might be due to land classification issues, i.e. mixed rotation systems being identified as pastures within this region, or/and due to the aggregation process resulting from increasing the cell size, which may lead to underestimation of mixed systems and overestimation of pastures within this region. This issue should be taken into account while performing the model validation (section 4.3), since the model can be expected to allocate more land to the mixed rotation 1 land-use type than the area that is originally depicted in the base year land-use map.

Table 13: Comparison between statistics on cultivated land and number of cattle heads with related land accounts in the base land-use map

	Cultivated land			Livestock production		
Region	Statistics at department level (km^2)	According to land-use map (km^2)	Error	Land classified as pasture (km^2)	Statistics on bovines (nr. heads)	Bovine density (nr. heads/ha)
Region 1	4,105	2,605	-36.5%	88,614	17,38,767	0.20
Region 2	46,315	50,217	8.4%	171,370	11,991,046	0.70
Region 3	116,231	115,275	-0.8%	264,792	22,868,783	0.86
Region 4	105,109	103,789	-1.3%	85,151	6,334,232	0.74

Furthermore, the calculated cattle density is also comparable to the actual observed values in each region. For instance, Garre (2011) mentioned a bovine density of 0.7 heads per hectare as a typical value in areas located in production region 2. In semi-arid region 1 a lower density was obtained, which can be explained by a much lower carrying capacity of the pastures in this region. However, in reality bovine density in region 1 might be slightly higher than the estimated value, due to eventual misclassification of mixed production systems as pastures. Nevertheless, it is expected to be lower than in the other regions. In regions 3 and 4, the determined bovine density is slightly higher than in region 2, which can be explained by higher pasture suitability, better forage quality and more intensive land management.

4.2. Model calibration

4.2.1. Demand module

The demand module was calibrated for BAU and PS scenarios, according to the parameters configuration defined in section 3.9. For year 2009, statistics on crop production and livestock herd statistics were used to calibrate the demand. It was assumed that the study area accounts for 95% of the total national production of grains and oilseeds, and around 81% of the total national grazing livestock herd in 2009, which were the observed averages during the period 2003-2011. From 2010 on, it was assumed that any increase in the national crop and livestock production would take place within the study area (i.e., the production taking place in the regions outside the study area remains static).

It can be seen that the demand for food crops tends to grow in both scenarios (Figure 8), not only due to population growth and increasing exports but also as a result of the increase on the demand for animal products, and consequently on the demand for feed. Furthermore, the demand for food crops is slightly higher in the PS scenario, due to higher demand for feed from food crops (Figure 9) resulting from the shift of livestock production from pastoral to intensive landless systems and underlying changes in feed composition.

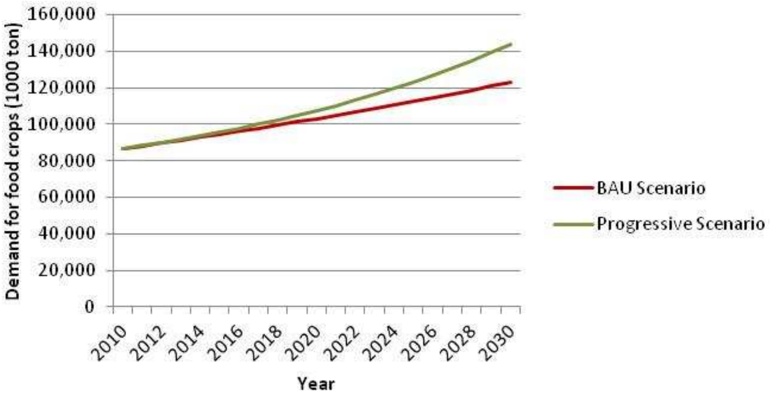

Figure 8: Demand for food crops

In BAU scenario, the overall feed demand tends to increase in time, following the increase on the demand for animal products. In the PS scenario, the overall feed demand is lower than in the BAU scenario, due to an increase on the feed conversion efficiency. Moreover, while in the BAU scenario feed demand for grass increases due to the increase of demand for animal products, in the PS scenario it tends to decrease, following the change in feed composition.

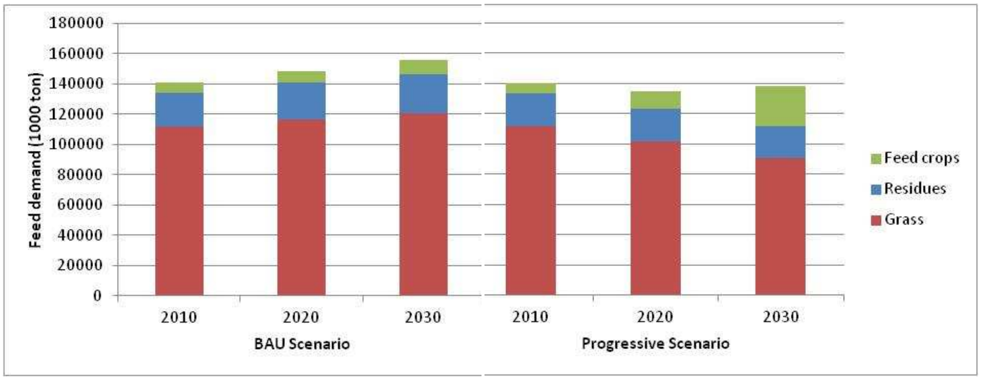

Figure 9: Feed demand

4.2.2. Allocation module – empirical approach

A statistical analysis was performed in order to calibrate the allocation module of the land-use model. Coefficients indicating the direction and intensity of explanatory variables were estimated according to the logistic regression model. A binomial regression analysis was performed for each dynamic land-use type, using land-use type "Forests" as the reference category, which is the most prevalent and homogeneously distributed non-dynamic land-use type in the study area. The forward selection method based on likelihood ratio was implemented, in which the stepwise selection of explanatory variables is based on the significance of the score statistic, and removal testing based on the probability of a likelihood-ratio statistic according to the maximum partial likelihood estimates. Not all explanatory variables were used to explain the occurrence of the production systems. Those that not appeared to be statistically significant or/and were strongly correlated with another explanatory variable were removed from the regression analysis. The results of the statistical analysis are summarized below in Table 14 (a full account on the results of the regression analyses can be found in Section 16 – Appendix I).

Table 14: Statistical analysis of land-use patterns in the study area

Explanatory variable	*Estimate*	*Mixed rotation 1*	*Mixed rotation 2*	*Agricultural rotation 3*	*Agricultural rotation 4*	*Livestock production*
Crops Suitability	**β**	-	0.851	2.063	1.322	-
	Wald	-	261.743	2038.655	352.414	-
Pastures suitability	**β**	-	-	-	-	-0.154
	Wald	-	-	-	-	94.698
Population density	**β**	-	-0.384	-	0.404	1.602
	Wald	-	12.540	-	4.144	555.656
Elevation	**β**	-	-	-	-	0.788
	Wald	-	-	-	-	116.113
Precipitation	**β**	-12.658	-	-	-	-
	Wald	182.697	-	-	-	-
Distance to markets	**β**	-10.016	-5.542	-5.545	-2.780	-5.388
	Wald	293.134	6779.731	3430.490	525.103	44024.337
Distance to urban areas	**β**	2.474	1.194	-0.337	0.906	0.404
	Wald	9.510	92.306	4.526	23.456	94.445
Distance to water	**β**	-	-1.896	1.096	-3.179	-
	Wald	-	238.382	192.087	201.885	-
Neighbourhood	**β**	61.527	12.947	16.934	19.237	6.707
	Wald	1037.894	30360.207	20019.067	16281.304	121116.181
Model Fitness	**Nagelkerke R^2**	0.966	0.934	0.958	0.976	0.779

It can be seen that the fitness of the model for mixed and agricultural rotations is quite strong, with R^2 being very close to 1. For livestock production systems, the fitness of the model is somewhat weaker, which can be explained by the fact that livestock production was considered as a single class without differentiating between livestock breeding systems, livestock fattening systems, milk production, etc, while in fact they may have different requirements. Furthermore, various agro-ecological livestock regions can be found in Argentina, differing in their potential of production and quality of forage (Garbulsky and Deregibus, 2006). However, even though the lower fitness, the obtained model for explaining livestock production can still be considered acceptable.

It can also be concluded that according to Wald statistics, neighbourhood relationships are the factors with the strongest explanatory power for all productions systems. This reflects the importance of positive spatial autocorrelation in explaining land-use patterns, due not only to the existence of biophysical gradients and clustering of landscape features but also economies of scale and spillover effects in agricultural production, which tends to cause an aggregation of similar production systems.

The results of the regression analysis for mixed rotation 1 and livestock production are remarkable because, unlikely all other production systems, they appear to be negatively correlated with precipitation and biophysical suitability, respectively. In the case of mixed rotation 1, crop suitability even appeared to be not statistically significant to explain the spatial distribution of this production system. This result can be explained by the fact that this production system tends to be located in arid regions with low aptitude for agriculture. In the case of livestock production, these results actually underpin the observed gradual marginalization of this type of production system to less productive regions, and in particular to areas were soy cultivation is not yet profitable under current adopted technology.

The determined β coefficients were then used to calibrate the allocation module of the model. In order to suit the original land-use model and the method (Verstegen, 2012), the coefficients were further normalized as folows

$$\beta_{i,norm} = \frac{X_i}{\sum_{\mathrm{k}} |\mathrm{X_k}|}$$

where $X_{i,norm}$ is the normalized value of the regression coefficient for explanatory suitability factor i, X_i is its original value, k are suitability factors considered in the analysis and $|\mathrm{X_k}|$ is the absolute value of regression coefficient for suitability factor k.

4.3. Model validation

The validation of the model was performed by simulating land-use in the period 2005-2009 and comparing the simulated land-use patterns and processes with the ones observed during the same period. Firstly, the observed land-use changes will be identified in section 4.3.1, followed by an assessment of the land-use patterns obtained through land-use modelling in section 4.3.2. Finally, the overall performance of the model will be evaluated in section 4.3.3.

4.3.1. Observed land-use change 2005-2009

Agricultural production in Argentina between 2005 and 2009 is mainly characterized by an overall steady increase in production during 2005-2008, followed by an extreme drought event in 2008/2009, the most severe in 100 years in Argentina (INTA, 2011a), which caused significant losses in cattle and crop production (Table 15).

Table 15: Production in Argentina 2005-2009

Production	*2005/06*	*2006/07*	*2007/08*	*2008/09*
Sunflower (ton)	3,759,736	3,497,732	4,650,365	2,483,437
Corn (ton)	14,445,538	21,755,364	22,016,926	13,121,380
Soy (ton)	40,537,363	47,482,786	46,238,087	30,993,379
Wheat (ton)	12,593,396	14,547,960	16,347,722	8,372,592
Livestock (heads)	58,293,600	58,722,100	57,583,100	54,429,911

However, this remarkable decrease in production does not necessarily imply that less land was used for agriculture, but essentially that attained yields were substantially lower. In fact, total area of pure agricultural systems remained fairly stable between 2005 and 2009 (Table 16). Furthermore, mixed rotation land-uses increased quite substantially during the same period. This seems to underpin the recent gradual introduction of agriculture in areas that traditionally were not attractive for crop cultivation. As a result, livestock had to be displaced to less productive areas, in which more area is required to produce the required amount of grass feed. Consequently, the amount of land dedicated to livestock production has increased, even though the total herd stock has decreased.

Table 16: Area per land-use and land-use changes (LUC) in the study area 2005-2009

Land-use type	*2005 (km^2)*	*2009 (km^2)*	*LUC 2005-2009 (km^2)*
Mixed rotation 1	1628	2605	977
Mixed rotation 2	82820	100434	17614
Agricultural rotation 3	115235	115275	40
Agricultural rotation 4	103723	103789	66
Livestock production	576627	582584	5957
Forest	199051	184649	-14402
Mosaic Forest/Shrubland	27823	19836	-7987
Sparse vegetation	4299	2775	-1524
Static land-use types	53523	52782	-741

Furthermore, nature areas have shown to be decreasing as a result of the expansion of the agricultural frontier and particularly land conversion for livestock production (Table 17).

Table 17: Land conversion of nature areas for agricultural production during 2005-2009 (km^2)

		2009				
		Mixed rotation 1	**Mixed rotation 2**	**Agricultural rotation 3**	**Agricultural rotation 4**	**Livestock production**
2005	**Forests**	9	2443	208	107	11456
	Mosaic forest/shrubland	330	2654	133	71	3909
	Sparse vegetation	0	6	0	0	124

4.3.2. Simulated land-use change 2005-2009

The demand module and maximum attainable yields were calibrated according to the recorded statistics on production and yields for each year during 2005-2009. Accordingly, land-use was simulated for this period, using 2005's land-use map as a starting point. The results regarding simulated land-use change in 2005-2009 are summarized in Table 18.

Table 18: Simulated land-use change (LUC) in the study area 2005-2009

Land-use type	*Observed land-use 2005 (km^2)*	*Simulated land–use 2009 (km$^{2)}$*	*Simulated LUC 2005-2009 (km^2)*	*Error between simulated and observed land-use area in 2009*
Mixed rotation 1	1628	7800	6172	199.42%
Mixed rotation 2	82820	100138	17318	-0.29%
Agricultural rotation 3	115235	115153	-82	-0.11%
Agricultural rotation 4	103723	103546	-177	-0.23%
Livestock production	576627	574033	-2594	-1.47%
Forest	199051	179679	-19372	-2.69%
Mosaic Forest/Shrubland	27823	23383	-4440	17.88%
Sparse vegetation	4299	4181	-118	50.67%
Static land-use types	53523	53523	0	1.40%
Available land[1]	-	3293	-	-

It can be seen that there is a high level of agreement between the observed and simulated land-use area in 2009 for mixed rotation 2, agricultural rotations and livestock production. However, mixed rotation 1 appears to be largely overestimated. This was already expected while comparing statistics on cultivated land area and the land accounts of 2009's land-use map (see section 4.1). Even so, the amount of land assigned by the model simulation is still larger than the recorded statistics. These differences might indicate that this production system is not properly characterized within the model. In fact, this production system is located in a semi-arid region in transition to an arid region, and consequently large biophysical gradients may be found in relatively short distances. Hence, the results regarding mixed rotation 1 should be interpreted with cautious. Production systems may actually be more heterogenic than previously assumed and as a result a land-use model at national level might be incapable of fully capturing the land-use dynamics of this particular region, being a local/regional model more adequate instead. However, this is not expected to have a considerable impact on the overall performance of the model, since this type of production system accounts for less than 2% of the total cultivated area.

Therefore, it can be concluded that in general the model is able to determine the amount of land required for agricultural production with a relatively good level of accuracy. Furthermore, the simulated land-use system appears to be quite stable and do not manifest very abrupt land-use changes, even when reproducing the occurrence of an external disturbance such as an extreme drought event (Figure 10). Thus, it can also be concluded that the model has the ability to reproduce the resilience and stability to short-term disturbances that characterize land-use systems.

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[1] [1]The model introduces a new land-use type, "Available land", which are those areas that were previously used for agricultural production but which are not required to fulfil the demand for a particular year and thus could be available for other uses.

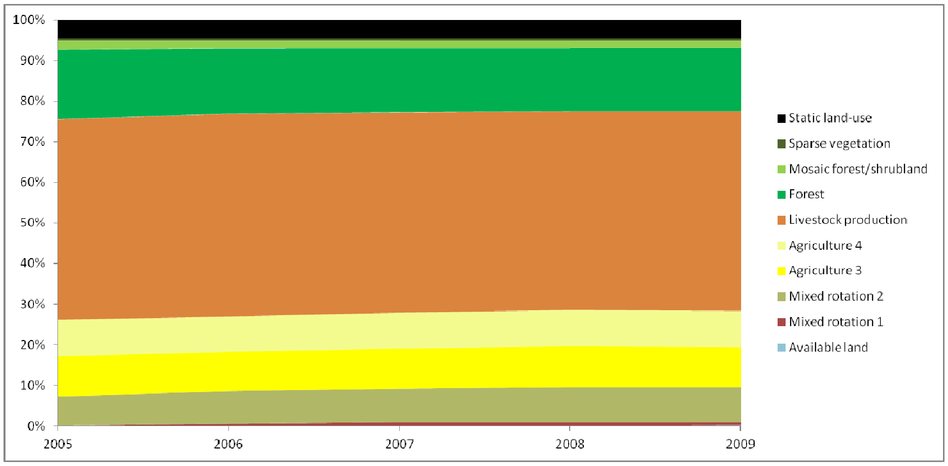

Figure 10: Simulated land-use between 2005 and 2009

However, deforestation appears to be slightly overestimated by the model and instead the simulated mosaic forest/shrubland and sparse vegetation areas decrease slower than observed. Forest areas account for higher productivity than the other nature areas and therefore the model may tend to allocate new agricultural/livestock production there, while in reality farmers may choose less productive areas giving priority to other unforeseen factors, such as proximity and lower conversion costs.

4.3.3. Model performance

Through a 3-map comparison, it was possible to determine a number of indicators assessing the model performance in simulating land-use patterns (Table 19). It can be concluded that model has a very good overall performance, with 90.9% of land-use correctly allocated. In particular, the model has a very good ability to correctly predict persistence of land-use (95%). On the other hand, the model does not perform so well in the allocation of land-use change, showing a very low level of concordance between observed and predicted land-use change in 2005-2009, with a figure of merit of 10%. However, the ability to allocate the actual observed land-use change is slightly higher, with a producer's accuracy of 19%. A similar value was obtained for the user's accuracy. In fact, the areas in which observed land-use change was predicted as persistence and observed persistence was predicted as land-use change are almost equal. On the other hand, the amount of observed change predicted as wrong gaining category is very low. This might imply that the model is allocating the correct land-use change in the wrong cells.

Table 19: Indicators of the model performance

Figure of merit	*Producer's accuracy*	*User's accuracy*	*Persistence well predicted*	*Model performance*
10.7%	18.8%	19.0%	95.4%	90.9%

It should be noted that this analysis is based on a pixel by pixel comparison and therefore it can be somewhat misleading in terms of assessing the ability to model land-use change. For example, the model might be allocating land with the correct land-use in the surroundings but not exactly on the correct cells, then leading to the conclusion that a cell has been assigned with a wrong land-use, while in fact the model producing a sensible land-use change pattern. Therefore, in order to perform a fairer evaluation of the model, the assessment of the model performance was repeated after increasing the cell size by a factor of 3 and 5 in order to explore this effect. As a matter of fact, all the indicators increase when the resolution is coarsed, particularly the indicators on land-use change, with the model achieving an overall performance of 95%. Therefore, it can be concluded that the model has a very good performance and even though land-use change is not perfectly allocated, the model is able of producing sensible land-use patterns of the (agricultural) land-use system (Figure 11).

Table 20: Indicators of the model performance after coarsing the map resolution

Aggregation Factor	***Figure of merit***	***Producer's accuracy***	***User's accuracy***	***Persistence well predicted***	***Model performance***
3	13.0%	20.0%	25.7%	97.6%	94.2%
5	19.1%	30.7%	32.4%	97.5%	94.8%

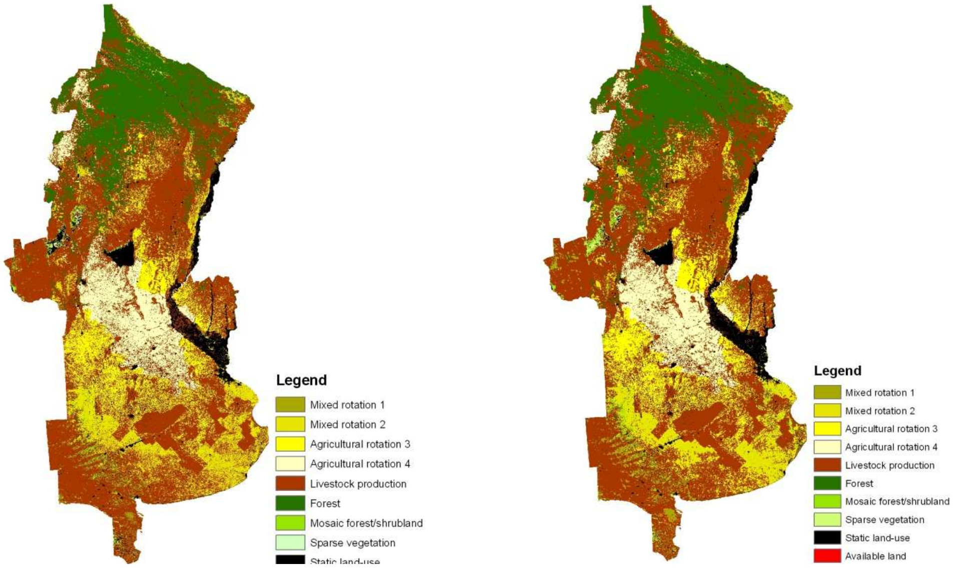

Figure 11: Observed (left) and simulated (simulated) land-use in 2009

4.4. Economic assessment of production systems

The yearly revenues and cost breakdown of annual crops and switchgrass for the most suitable locations while using cutting edge technology are shown in Figure 12 (excluding transportation costs). Corn appears to be the most profitable annual crop due to very high yields, but its cultivation also involves large capital invested in inputs. Due to high market prices, soy also holds high revenues, however without requiring such large investments. On the other hand, the economic performance of wheat is considerably lower due to to lower market prices, despite of involving lower production costs. The same applies for sunflower, which is the annual crop with the worst economic performance. Doublecropping soy cultivation performs better than sunflower despite being cultivated out of the optimal season, due to very low input and operation costs and high market prices. Under the assumed conditions, switchgrass appears to be the most attractive option from an economic perspective. High yields with relatively low fertilizer applications and resistance to pests and plant diseases result in very low input requirements and consequently explain the high net revenue. However, in the first year, the net revenue is negative, since it is necessary to establish the plantation (including acquiring the seeds, seeding and weed treatment) without obtaining any harvest in that year.

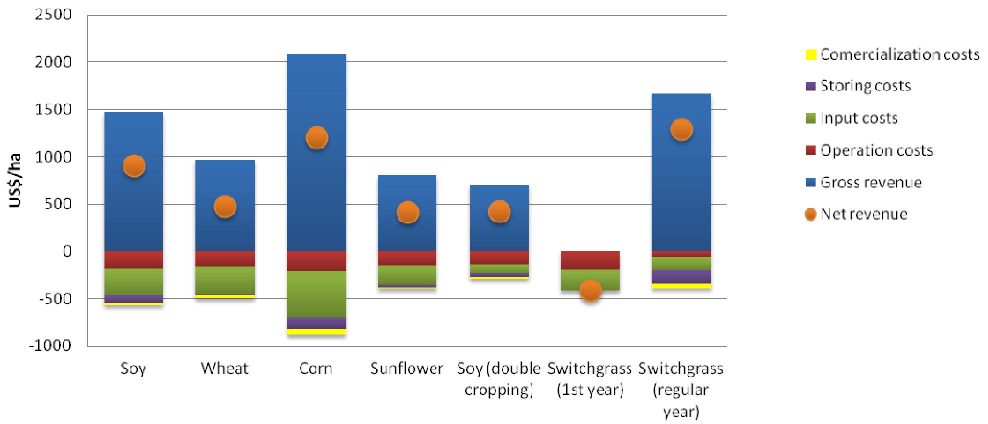

Figure 12: Breakdown of yearly costs for switchgrass and annual crops cultivation with the implementation of cutting edge technology in the most suitable locations (transportation costs are location-dependent and thus they are excluded for illustration purposes)

In Figure 13, it can be seen that lower revenue crops such as wheat and sunflower are only profitable in locations where the yield reduction is not higher than 50%. Soy, doublecropping soy and corn are still profitable in locations up to 65% yield reduction. Due to the large input requirements, corn net revenue decrease at a faster rate in relation to yield reduction than the other crops. On the other hand, switchgrass cultivation appears to be the most attractive crop in all locations, due to high yields and low operation and input requirements. In fact, this crop appears to be economically viable in locations with a yield reduction up to 85%. However, it should be kept in mind the uncertainty regarding the market price of this crop.

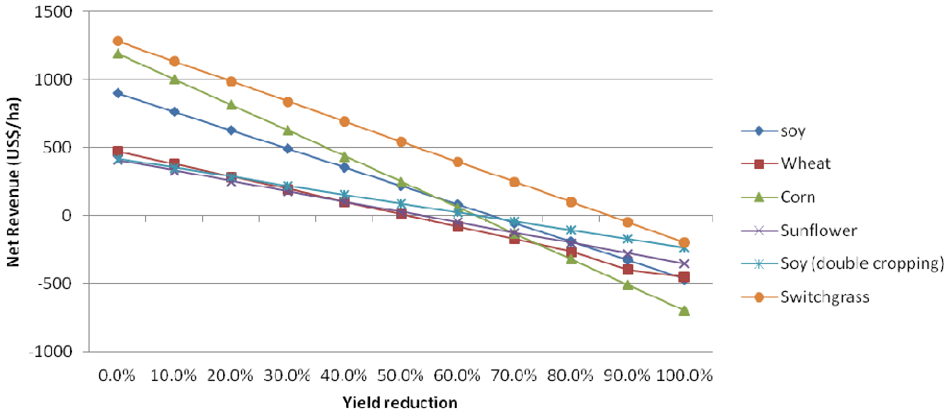

Figure 13: Net revenue for annual crops and switchgrass according to local biophysical suitability (transportation costs excluded)

In Figure 14, the revenue and cost breakdown for cattle livestock production is shown for different activities: wintering, breeding and complete cycle. These activities have completely distinct profiles. Livestock wintering holds much higher gross revenues but it also accounts for large costs resulting from the acquisition of calves, transactions costs and feed supplementation. Hence, net revenues do not differ that considerably from the other activities. Livestock breeding requires much less investment of capital but the net revenue is also lower. In complete cycle systems, breeding and wintering takes place within the same system and therefore there is no acquisition of calves involved. However, the wintering production in complete cycle systems is much smaller than in dedicated wintering systems and therefore gross revenues are not so high.

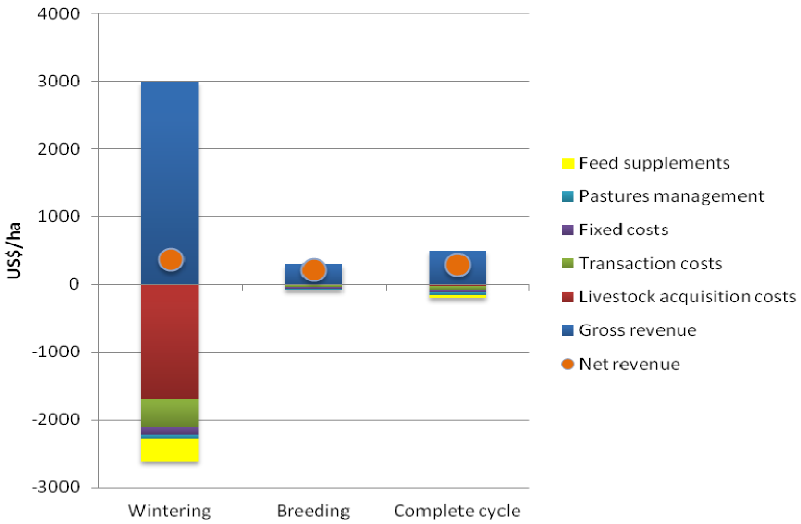

Figure 14: Breakdown of yearly costs for cattle livestock production in the most suitable locations (transportation costs excluded)

Compared to annual crops, livestock production is able to remain profitable in locations with much lower suitability (Figure 15). Particularly, breeding and complete cycle systems are still able to achieve a positive economic performance in locations with producticity reduction up to 90%. Wintering systems perform worse than breeding and complete cycle systems when productivity reduction is higher than 60% and become unprofitable when it is higher than 75%.

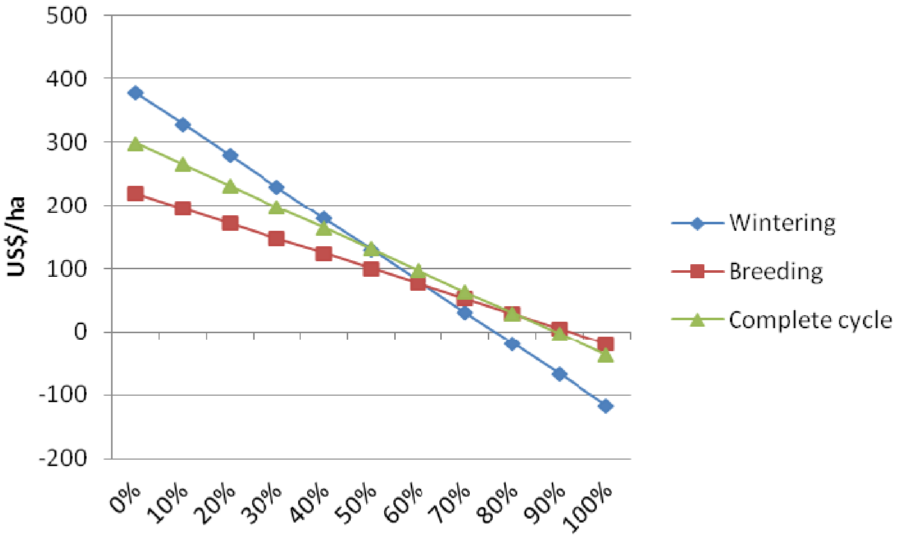

Figure 15: Net revenue of livestock production systems according to local biophysical suitability (transportation costs excluded)

Figure 16 depicts the revenues and cost breakdown for the considered mixed and agricultural production systems in the most suitable locations. Dedicated agricultural systems are much more profitable than mixed systems, since agriculture is more profitable than livestock production. However, the inclusion of livestock production in mixed systems allows them to remain profitable in areas with lower suitability. Agriculture 4 appears to be the most profitable system, due to the higher share in soy and corn.

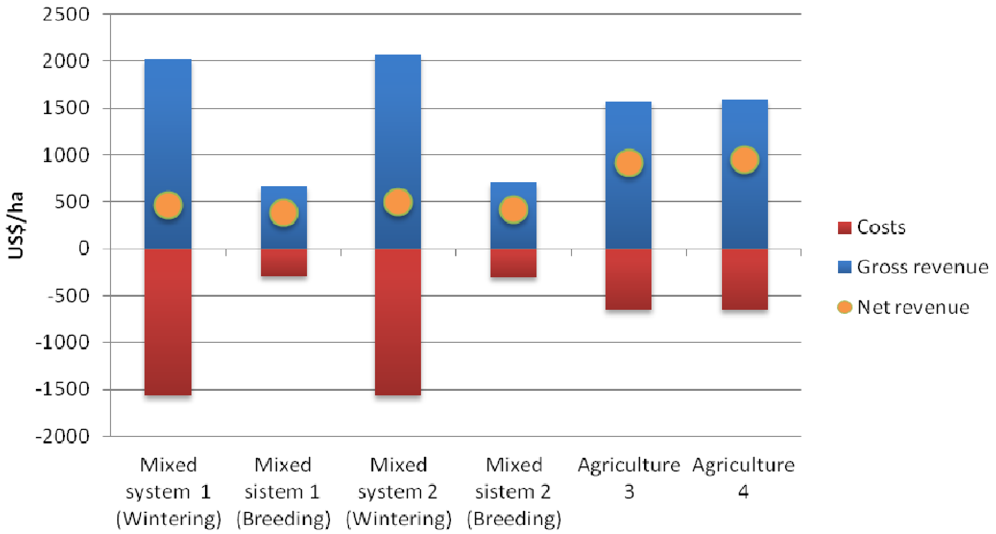

Figure 16: Cost breakdown per production system in the most suitable locations (transportation costs excluded)

4.5. Modelling results

The land requirements to meet the demand for food crops and grass were modelled in yearly timesteps up to 2030 for the BAU and the PS scenarios. In the following sub-sections, the modelling results are presented for each scenario, namely the development of land-use during the considered timeframe and the availability of land for biofuel production in 2030, followed by an assessment of the economic performance of biofuel crops on the available surplus land.

4.5.1. BAU scenario

The development of land-use according to the BAU scenario between 2010 and 2030 is depicted in Figure 17. Since the technological developments in livestock and crop production are modest, no surplus land becomes available for biofuel production. It can also be observed that the combined area of mixed and pure agricultural systems remains constant, while grazing areas for livestock production increase steadily at the expense of forest areas. Pastoral grazing areas seem to increase at a higher rate than mixed rotation systems decrease. Since new pastoral areas are not necessarily allocated in regions with lower suitability, it can be concluded that the expansion of pastoral areas for livestock production results then from a combined effect of livestock displacement from mixed production systems and increase on the demand for animal products. Hence, deforestation occurs due to both direct land-use change from expansion of livestock production and indirect land-use change from intensification of agriculture.

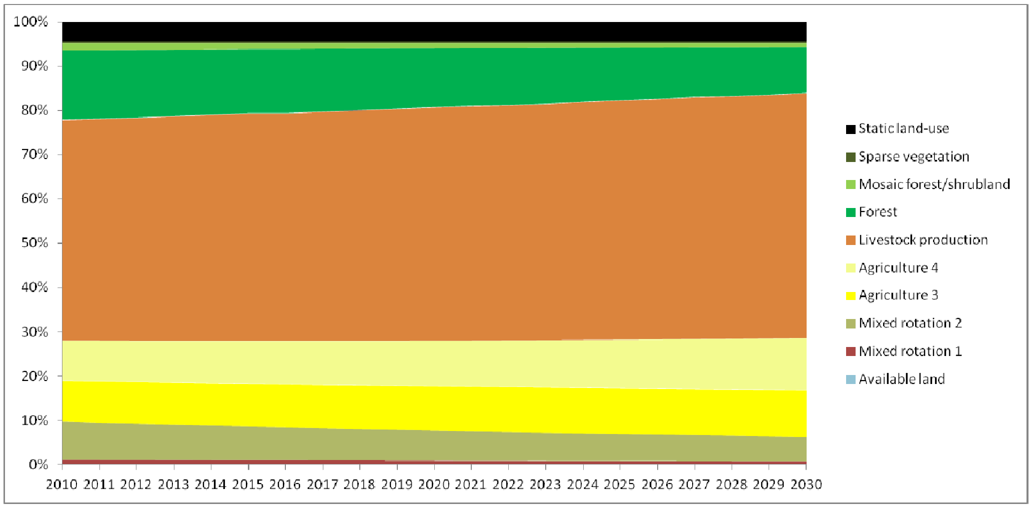

Figure 17: Land-use during 2010-2030 according to BAU scenario

In Figure 18, the land-use system in 2030 and land-use changes between 2009 and 2030 according to the BAU are depicted. It can be seen that the current trends of land-use change are maintained during the considered timeframe: (1) mixed production systems in the provinces of Buenos Aires and La Pampa are gradually substituted by pure agricultural systems; (2) the share of soy in the agricultural rotation schemes tends to increase in the provinces of Buenos Aires, Santa Fe and Cordoba; (3) pastoral systems for livestock production keep expanding at the expense of nature areas, particularly in areas previously covered with forests in Chaco eco-region. However, the conversion of pure pastoral systems to new agricultural areas does not appear to be significant.

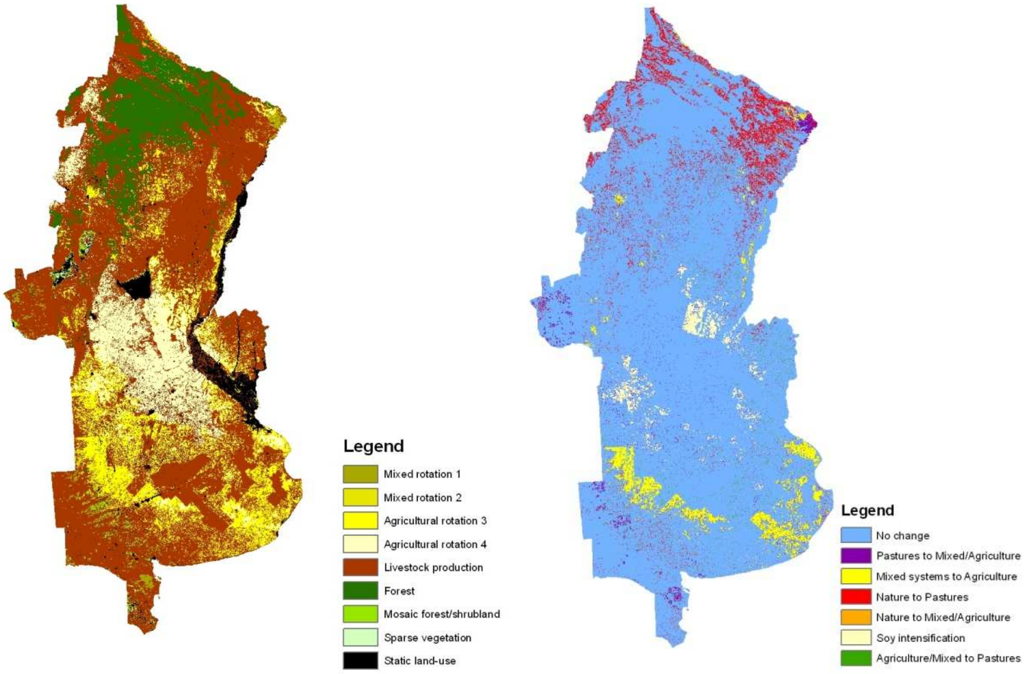

Figure 18.1-2: Land-use in 2030 BAU scenario (left) and resulting land-use change 2009-2030 (right)

4.5.2. PS scenario

The development of land-use according to the PS scenario between 2010 and 2030 is depicted in Figure 19. With the increase of meat production in intensive landless systems and increased feed conversion efficiency and use of feed crops in the food composition, less area is required for livestock production in pastoral grazing systems. Moreover, despite the larger demand for food crops, the increase on attainable yields imply that the total area of land devoted to agriculture and mixed rotation systems remains almost constant during the considered timeframe. Consequently, around 32.6 Mha could become available for dedicated biofuel production by 2030. The decrease in area required for livestock production also implies that the conversion of nature areas to pastoral grazing systems observed in the BAU scenario does not occur.

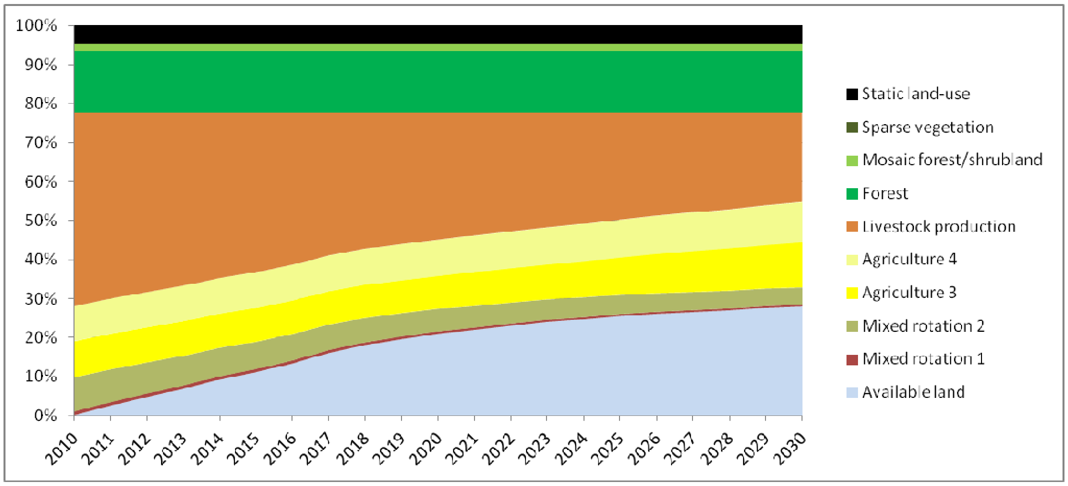

Figure 19: Land-use during 2010-2030 according to PS scenario

Figure 20 shows that the largest share of surplus land that could become available for biofuel production was previously used for livestock production in pastoral systems (82.3%), followed by mixed production systems (15.0%) and agriculture (2.7%). A large part of surplus land is located in the south-east part of Buenos Aires province and in La Pampa provinces, where the biophysical suitability for conventional crops is low. This result is in line with the findings of van Dam et al. (2009) which had also identified the province of La Pampa as a promising region in terms of land availability for the deployment of large-scale biofuel feedstock. Some land also becomes available in the northern regions of the study area, but here the patterns appear to be more scattered. The most productive regions in the centre of the country are allocated for food crop production and thus are not available for energy crops.

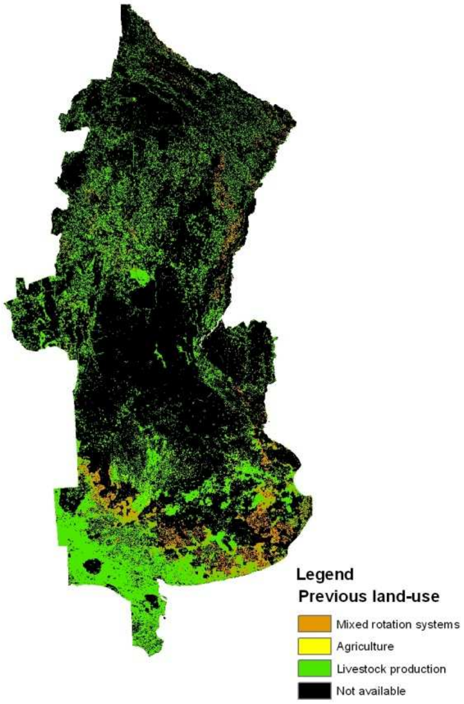

Figure 20: Land available for biofuel production by 2030 PS scenario and respective previous land-use

Figure 21 shows the economic performance of soybeans and switchgrass on the surplus land in comparison to the other agricultural production systems, namely by depicting the NPV of the production system with maximum NPV subtracted by the NPV of the respective biofuel crop for every location within the study area. The locations with negative values (green) are those in which biofuel crops outcompete the remaining production systems, while in locations with positive values (red) biofuel crops are outcompeted by at least one of the considered production systems. It can be concluded that soybeans are the most attractive option in 4.3 Mha, i.e. around 13% of total surplus land available for biofuel production. The majority of this area is located in the southwest of Buenos Aires province, in the areas with average to good suitability which were not taken by the agricultural production systems to supply food production during the dynamic simulation.

On the other hand, swithgrass appears to be most attractive option from an economic point of view in 18.6 Mha, i.e. 57% of the total surplus land. Particularly, switchgrass NPV appears to outperform the other agricultural options by more than 3000 US$/ha in a large region on the transition between Buenos Aires and La Pampa provinces. This is explained by the fact that biophysical suitability for conventional crops is relatively low in this region, but not for switchgrass.

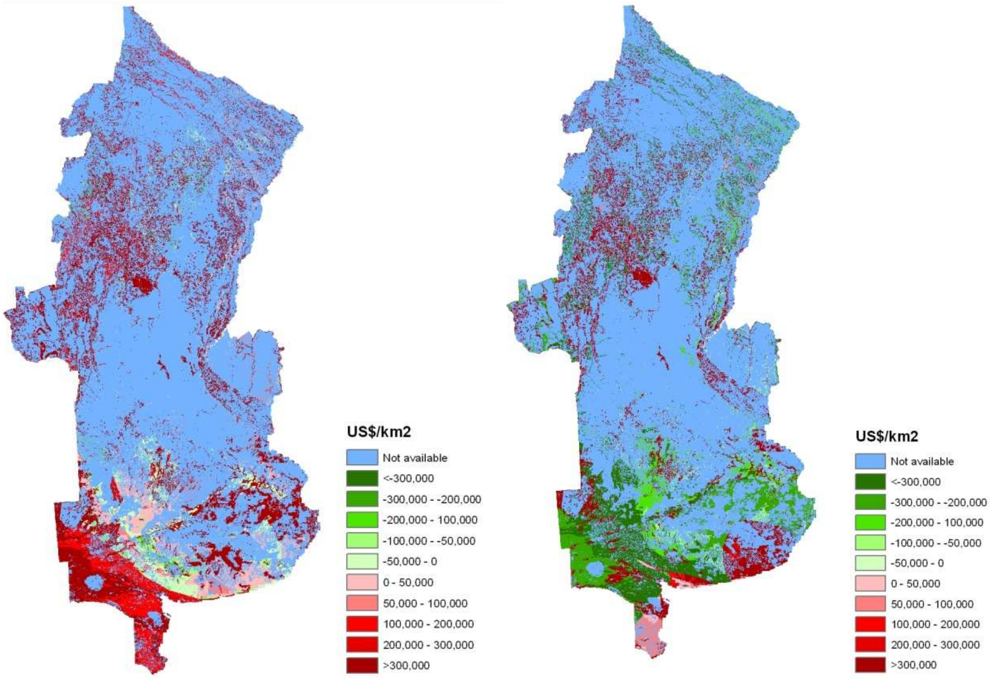

Figure 21.1-2: Maximum NPV production systems minus NPV soy (left) / switchgrass (right)

4.6. Biofuel potential

4.6.1. BAU Scenario

According to the dynamic simulation of future land-use, no surplus land is expected to become available for biofuel production by 2030 according to the BAU scenario. Therefore, there is no potencial for biofuel produced from switchgrass in this scenario. However, a large potential for biodiesel production can be expected from the existing soy complex, namely by converting to biofuel the by-product of soymeal production which is not required to fulfil the expected demand for soyoil. Hence, taking into account the expected demand for soybean exports, soymeal and soyoil, a total potential of 80.6 PJ for soy-based biodiesel production can be expected by 2030.

4.6.2. PS Scenario

Following the dynamic simulation of future land-use and the assessment of the economic performance of biofuel crops in the available surplus land, the potential for biofuel production was determined. Soybean cultivation appeared to be economically viable only in a small portion of the surplus land. Taking into accound the local specific yields, a soybean production of $16.1*10^6$ odt on the surplus land could be attained, which after dedicated conversion to biodiesel could lead to an additional potential of 114.1 PJ.

As concluded in BAU scenario, 80.6 PJ can be expected from the existing soy complex. In addition, an increase on the demand for soy is also expected in this scenario ($8.51*10^6$ odt), due to the increase of food crops in the feed composition for livestock production. Since the expected demand for soyoil is already fulfilled, the by-product that results from the additional soymeal production is fully available to be converted to biodiesel, providing an additional potential of 59.6 PJ by 2030. Hence, a total potential of 254.4 PJ for soybean biodiesel could be expected by 2030, according to the PS scenario.

Switchgrass is still not commercially produced in Argentina, but the economic assessment on the surplus land showed that it could become an attractive crop to be produced in a large portion of the available surplus land. Considering the local specific yields, a potential of 596.3 PJ for switchgrass bioethanol could be expected by 2030.

4.7. Uncertainty analysis

The model was run according to the Monte Carlo analysis configuration using 100 samples. The results of the uncertainty analysis for BAU scenario are shown in Figure 22, which depicts the probability of land being available for biofuel production in 2015, 2020, 2025 and 2030. It can be seen that even taking into account the uncertainty on demand and productivity, the probability of having land available land biofuels is low. The spatial patterns of the regions that still hold a somewhat higher probability resemble to some extent those that appeared to be available in the PS scenario's deterministic simulation. Nevertheless, even in these areas the probability of land becoming available is below 40%.

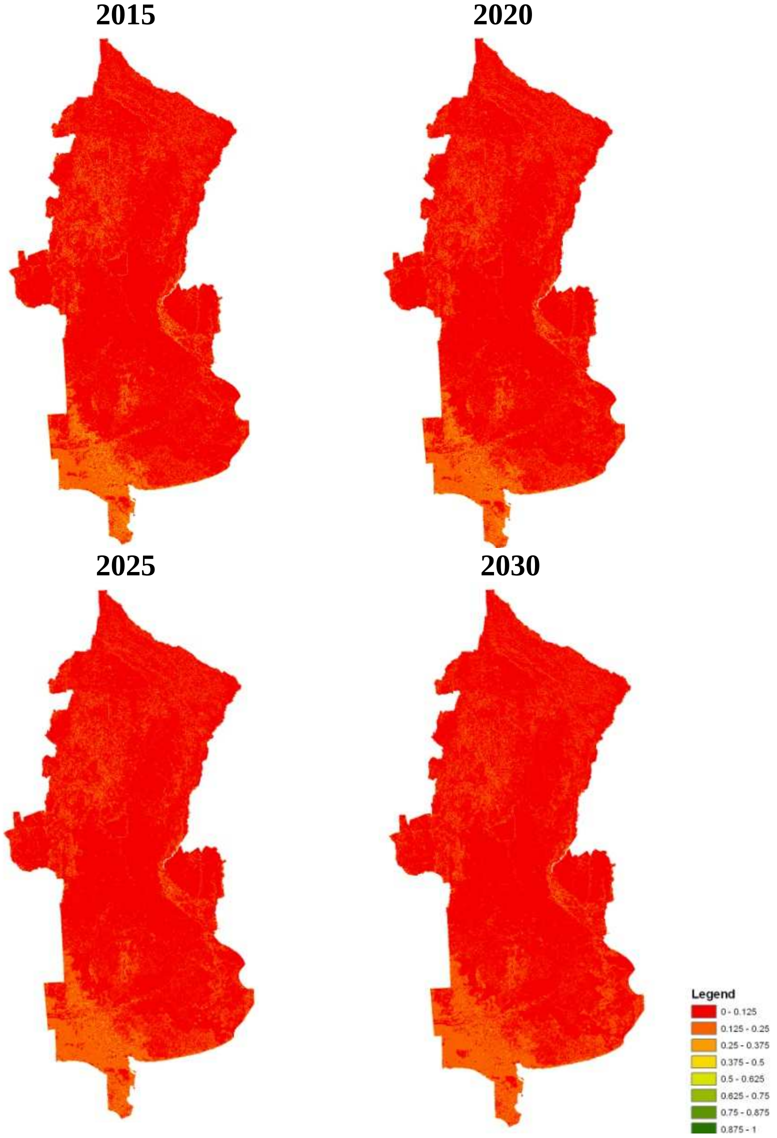

Figure 22.1-4: Uncertainty analysis BAU scenario

Regarding PS scenario (Figure 23), comparable spatial patterns can also be identified, but with a higher probability. It can also be observed how they evolve in time. La Pampa and southwest Buenos Aires provinces are the first regions to account for a large area with high probability of becoming available for biofuel crops. Then, some high-probability clusters appear in northwest Cordoba, La Rioja, Santiago del Estero and centre of Buenos Aires provinces. These clusters seem then to expand to their surrounding through neighbourhood interactions. The north and northeast of the study region also present areas with high probability, but here the patterns seem more scattered. By 2030, there are 2.8 million hectares with a 100% probability of being available for biofuel production; 9.9 million with a probability higher than 75%; and 29.5 million with a probability higher than 50%, which is 91% of the land considered as available on the deterministic simulation.

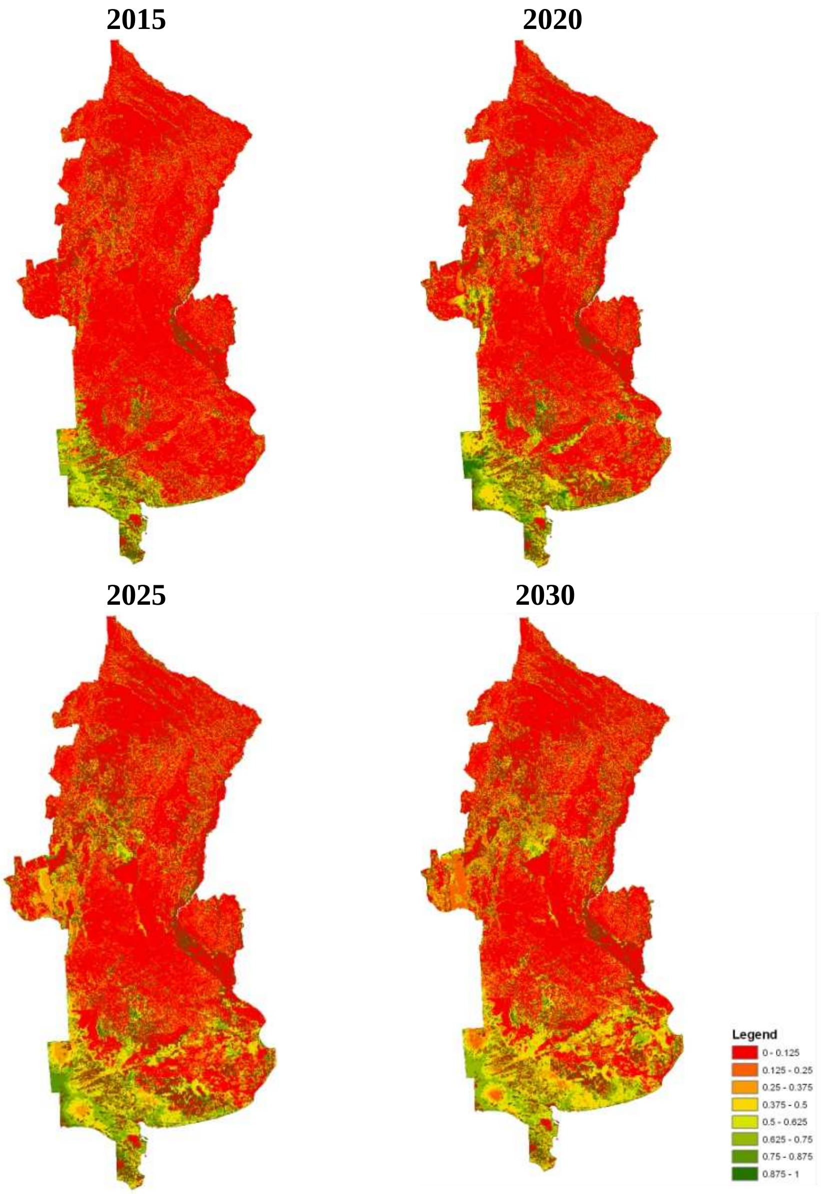

Figure 23.1-4: Uncertainty analysis PS scenario

The uncertainty analysis in both scenarios underpinned the previous results that identified the pastoral areas in La Pampa and southwest Buenos Aires provinces as a region potentially suitable for large-scale biofuel production, in terms of land availability. This shows that the uncertainty on the most important suitability factors does not seem to affect the spatial patterns of the locations where land is likely to become available. On the other hand, the uncertainty on total food demand and factors related to technology development (particularly, feed conversion efficiency and share of intensive systems in bovine meat production) seems to play an important in the extent to which land may become available in the future. It can be concluded that if current trends of technology adoption are maintained, it is not likely that land will become available for biofuel crops. It also showed that even though there is a large potential for land becoming available in case of higher rate of technology adoption, the availability of land for biofuel crops still depends to a large extent on the future development of food demand.

4.8. Sensitivity analysis on the economic performance

Switchgrass appeared to be the crop with the best economic performance in all kinds of biophysical conditions. However, it is also the crop holding higher uncertainties in terms of management and outcomes. A sensitivity analysis on the economic performance of the production systems was performed in order to assess the sensitivity of NPV to changes in the key components of the cost breakdown. The sensitivity analysis on the economic performance of switchgrass (Figure 24) and soy (Figure 25) on the locations with the best biophysical suitability is shown below as an example (a distance of 10 km to roads and 100 km to the main markets was assumed, in order to include transportation costs).

It can be concluded that the economic performance of both crops is very sensitive to changes in yields and market prices. These appear to be the factors with the largest impact on the economic performance. Variations on the discount rate also appeared to have a significant effect on the NPV, especially for switchgrass, due to its initial investment costs and long-term project profile. On the other hand, variations on input and field operation costs appeared to not affect so much the economic performance. Nevertheless changes in these factors are slightly more significant for annual crops such as soy, due to being more intensively managed.

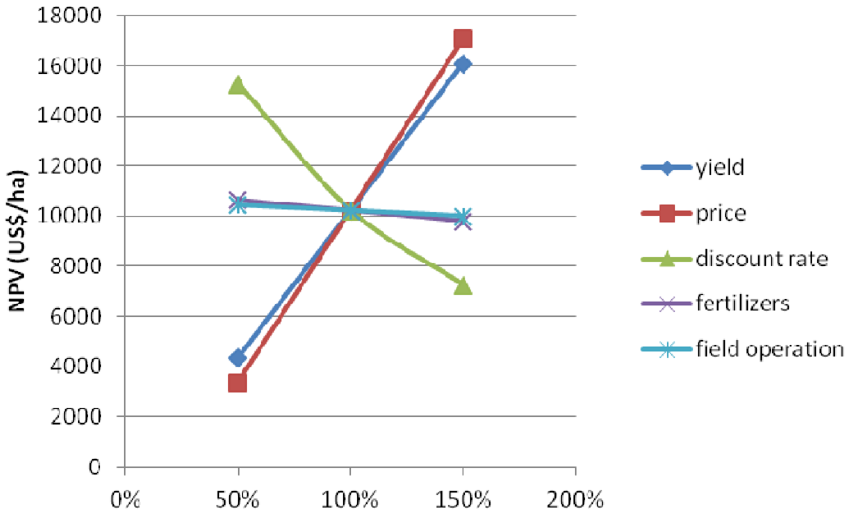

Figure 24: Sensitivity analysis on the economic performance of switchgrass cultivation

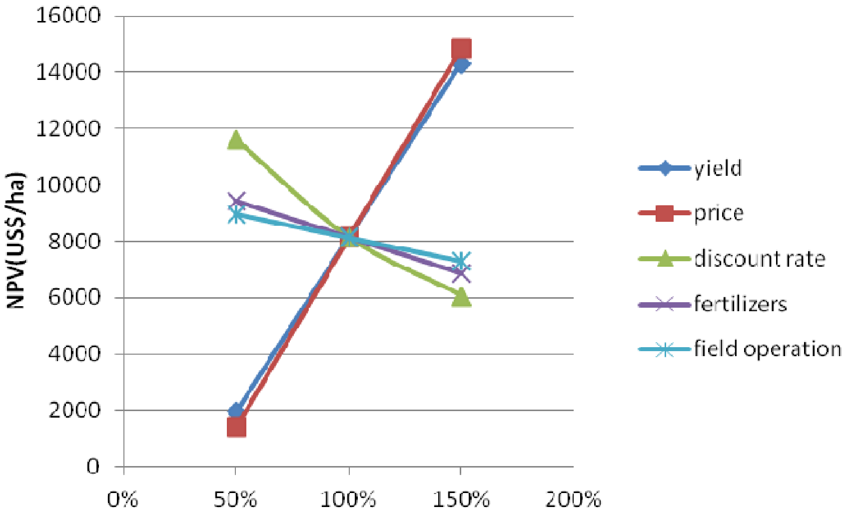

Figure 25: Sensitivity analysis on the economic performance of soy cultivation

5. Discussion

5.1. Method and data

The present study determined the availability of land and resulting potential for biofuel production in Argentina. Firstly, the availability of surplus land for biofuel crops was assessed through dynamic land-use modelling using statistical analysis to calibrate the allocation module. In the model validation, it was demonstrated that the model was able to replicate past land-use patterns while using recorded statistics to calibrate crop yields and production to calibrate the demand module. However, since this modelling approach is based on the extrapolation of past short-term land-use trends, the results of the long-term scenarios should be interpreted with cautious. High volatility on political and market conditions can be expected over the considered time period, especially in a country such as Argentina, where agriculture and livestock production are highly regulated and policy frameworks are rather unstable. The same applies to the biophysical environment, which is likely to change due to dynamic processes such as soil degradation/erosion and climate change. Thus the results should not be taken as a prediction, but instead as a projection of possible future outcomes according to the trends currently observed. Accordingly, the PS scenario should be interpreted as a projection of what developments could be expected if current trends were taking place within a framework promoting technology adoption in agriculture production. The model can thus be presumed of providing a plausible representation of the likely future developments on the land-use system at a national level, under these premises.

The potential for biofuel production on the surplus land was then determined according to economic theory. The relative economic performance of the different agricultural options was assumed to be the main driver of decision-making on land-use. However, farmers may to some extent be averse to change (Colomer, 2011): investment may have to be made in new machinery and it may require a learning period before optimal outcomes are attained. Other societal aspects may also play a role, such as unwillingness to change traditional practices in family farms (Lorda, 2011). In some cases, financing may be also difficult to obtain, particularly for small producers. Factors related to economies of scale were not either taken into account, such as clustering of production systems and its effects on the production function. Although these factors have not been explicitly addressed, this method was nevertheless able to pinpoint the main areas where biofuel production could become economically attractive and thus provide an indication for researchers and policy-makers on the regions where the abovementioned factors could be worth of further research.

Finally, the modelling methodology relied to a great extent in the use of spatially-explicit GIS data depicting current and historical land-use, as well as biophysical and socio-economic suitability factors. GIS datasets are usually fraught by a number of quality issues related to classification inconsistencies, inaccuracy, low resolution and lack of precision. An attempt to refine the land-use classification system was made, in order to provide a more detailed representation of the agricultural production systems in Argentina. This approach has allowed improving the characterization of the land-use system, by explicitly incorporating different types of agricultural practices and their spatial distribution within the model. It was also shown that there was a good match between the statistics on use of land by the assumed production systems and the base land-use map. However, a generalization of several characteristics was necessary to maintain the model operational at a national level. The profiles of the existing production systems show a large degree of regional variability in terms of productivity, labour structure, technology adoption and land ownership, sometimes even in small extent areas. Therefore, it should be kept in mind that although the present study provides a reliable overview of the expected general developments at a national level, its findings should nevertheless be further researched at a regional/local scale in the most relevant areas, using more accurate and local-specific data.

5.2. Results

The present study showed that under current trends no land is expected to become available for dedicated biofuel production. Only if major technological developments take place on the agricultural and particularly on the livestock production sector, land could become available in a number of locations. The provinces of La Pampa and southwest Buenos Aires were identified as the regions showing a higher potential for biofuel production, due to land availability and good economic performance of biofuel crops. Particularly switchgrass appeared to be a very promising option in this region. It should be noted, however, that the management practices for switchgrass cultivation were based in a European study and not in practices specific to Argentina. Nevertheless, significant differences should not be expected since this crop generally requires relatively low inputs and little field operations. On the other hand, there is still no experience in commercial exploitation of switchgrass in Argentina and therefore large uncertainties still exist regarding market prices and attainable yields, which were shown to have a great impact on the economic performance. Therefore, the results on the economic performance of switchgrass should be interpreted with cautious.

It should be also kept in mind that prices were assumed to remain the same for a period of 20 years while in fact commodity market prices can fluctuate strongly over such a long period. Changes on taxation schemes of food commodities and trade bans are also frequent in Argentina and have shown to have impacts on farmers' managerial decisions (Carballo, 2011; Garre, 2011). Furthermore, by assuming endogenous prices, the modelling framework fails to incorporate price formation processes and their possible feedbacks. For instance, a surge on the supply of biofuel crops could potentially lead to a decrease in market prices, thus decreasing the competitiveness of biofuel crops over other agricultural land-uses. On the other hand, the larger use of food crops for feed in the PS scenario can potentially lead to an increase in food crop prices.

The use of yield reduction maps allowed to determine both the amount of land required to supply the expected demand for agricultural commodities and the relative economic performance of competing production systems. An underlying assumption of such approach is that attainable yields solely depend on the local biophysical suitability, specifically soil and climate characteristics, thus implying the implementation of the same farming practices for each production system irrespective of the local suitability. However, farmer practices can vary, e.g. due to farmers' preferences, knowledge, access to capital, farm structure, etc. This issue has been partly addressed by distinguishing different type production systems according to their location and profile, and modelling them as dedicated land-use classes. However, local suitability is nevertheless assumed to be static and maximum local yields are assumed to be always attained, which is to some extent an unrealistic assumption, since short-term events such as ground frost, draught or excess of rainfall and long-term dynamic processes such as climate change and soil erosion may take place in time. Therefore, the model might be over-optimizing the capacity of the land-use system for delivering the requested services and products. As a result, land availability can be actually lower than what is being determined by the model. Likewise, the economic performance of both biofuel crops and agricultural production systems might be poorer, since it is very sensitive to changes in yield levels. As such, the actual potential might be lower than the figures determined in this study, but nevertheless, it provides an indication on what could be attained under optimal socio-economic and biophysical circumstances.

It could be observed that while direct deforestation for soy cultivation is relatively limited, indirect land-use changes may to some extent be resulting from livestock displacement for agriculture expansion. Therefore, even though biodiesel production is not the main driver of the demand for soy, the production of biofuel may be related to a production chain accountable for loss of biodiversity and indirect GHG emissions, thus being inconsistent with its sustainability goals. Nevertheless, they should be further researched at regional and local levels in order to gain a deeper insight on the sustainability of biofuel production from soybeans. Nevertheless, it should be also taken into account that this outcome also results from assuming that the current rates of annual growth of the share of each production system in total production are maintained in the future.

In addition, serious concerns on the sustainability of soy cultivation have been recently raised, such soil degradation due to monoculture practices, water contamination due to excessive use of pesticides, negative health impacts in rural communities, land tenure issues and loss of livelihoods of indigenous populations and small-scale farmers in areas where soy has been recently introduced (Tomei and Upham, 2009; van Dam et al. 2009b; Volante, 2011; Seghezzo et al., 2011). Addressing these issues is out of the scope of this research, as they are to a great extent local-specific and therefore, unable to be captured in a study at national level.

It should be also noted that this study did not take into account the enforcement of the Forest law, which defines the areas where agricultural expansion is allowed to take place and where it is restricted. This is an important limitation of the study

Finally, the uncertainty analysis confirmed the regions of La Pampa and southwest Buenos Aires as those with higher probability of becoming available for biofuel production. While in the BAU scenario this probability was low, in the PS scenario, most of the area showed a probability higher than 50%. Nevertheless, it should be taken into account that land availability will always depend on the future developments of demand and particularly of technology adoption in the livestock production. Therefore, the results should not be interpreted as a deterministic projection but instead as an indication of the potential that might be attainable if the appropriate frameworks are implemented.

6. Conclusions

6.1. Main findings

The present study aimed to determine the potential for sustainable large-scale production in Argentina up to 2030. A land-use modeling framework combining an empirical approach based on statistical analysis with a theoretical approach based on economic theory was found to be the most appropriate method to explore the dynamics and future developments of the land-use system in Argentina. The most important agricultural production systems at national scale were identified, as well as the driving forces determining their geographical distribution and extension. According to this characterization, the future provision of food commodities by the land-use system was simulated in order to determine the availability of land and the resulting potential for biofuel crop cultivation that does not compete with food production. The empirical approach explored the dynamic features of the land-use system in providing food products, while the theoretical approach aimed to reproduce the decision-making processes of farmers and assess the extent to which they would be willing to grow biofuel crops on the surplus land.

According to the BAU scenario, it was found that under current trends no surplus land for dedicated biofuel production is expected to become available. However, the demand for soy products is expected to keep growing, namely for exports of soybeans, soymeal and soy oil. Soy-based biodiesel can be obtained as a by-product of bean crushing for soymeal production, by further converting the oil that is not required to supply the demand for soy oil. Hence, this implies that a potential of 80.1 PJ of soy-based biodiesel production could be available by 2030. However, there are large uncertainties surrounding this value. To a great extent, the potential for soy-based biodiesel will depend on the demand for other soy products. In case the share of the demand for soyoil decreases in the soy supply-chain, a larger amount of raw vegetable oil could become available for biodiesel conversion, and thus the potential could be higher. The same applies if the demand for soymeal is higher than assumed.

According to the PS scenario, in case large technological developments in the agricultural and especially in the livestock sectors occur, around 32.6 Mha could become available for dedicated biofuel production by 2030. Due to the intensification of livestock production, increase in feed conversion efficiency and the increased use of food crops in the feed composition, large pasture areas would not be required food production. However, only a small portion of this area appeared to be economically attractive for biofuel production: 13.4% and 57.0% of the surplus land had a positive economic performance for soybeans and switchgrass cultivation, respectively, in relation to other possible uses. Considering the local specific yields, $16.1*10^6$ odt soybeans and $70.0*10^6$ odt switchgrass could be produced on the surplus land where biofuel crops showed a positive economic performance, which after conversion to biofuel could lead to a potential of 114.1 PJ for soybean biodiesel and 596.3 PJ for switchgrass bioethanol by 2030. An increase on the demand for soy can also be expected in this scenario ($8.51*10^6$ odt), due to the increase of food crops in the feed composition of livestock production. The by-product that results from the additional soymeal production could provide an additional potential of 59.6 PJ, leading to a total potential of 254.4 PJ of soy-based biodiesel by 2030.

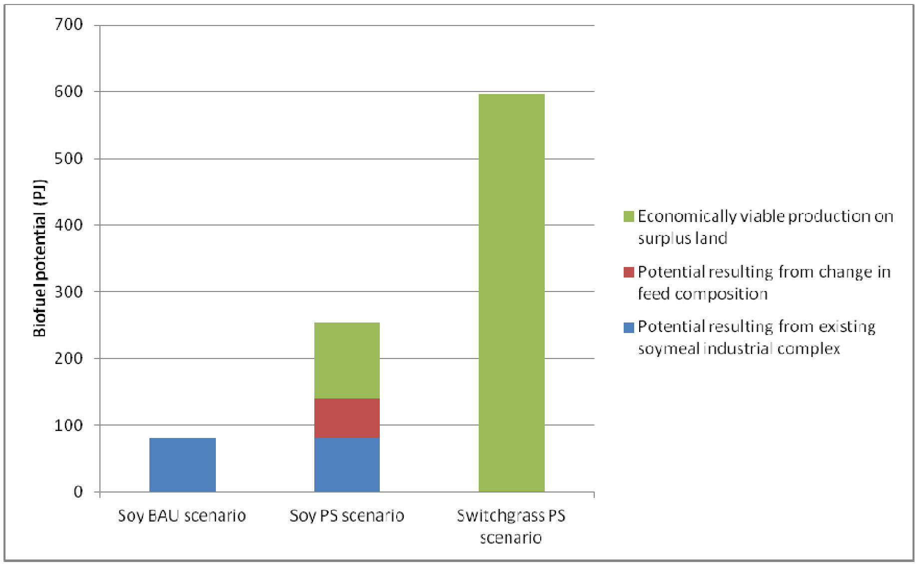

Figure 26: Biofuel production potential in 2030

The region of southwest Buenos Aires and La Pampa provinces appeared to be particularly promising for switchgrass cultivation. These areas have low suitability for conventional crops, and therefore a high-yielding perennial crop such as switchgrass could become an attractive alternative for farmers in this region. This finding is line with previous research on biofuel potential in Argentina (van Dam et al., 2009a). Switchgrass has also shown to have a better environmental performance than soybeans, particularly in terms of total GHG emissions (van Dam et al., 2009b). This is especially relevant because the emissions resulting from direct land-use change of pastures for biofuel production are quite significant (e.g. van Dam et al. 2009b; van der Hilst et al., 2012).

The determined potentials are considerably lower than those obtained in previous studies (e.g. van Dam et al, 2009a). The incorporation of a human behavioural component in the potential assessment is the main reason for these large differences, since biofuel crops cultivation on the surplus land was assumed to be grown only in the areas where it is more competitive than other alternatives. The advantage of including economic processes within the modelling framework is that it allowed to take into account not only land availability but also farmers decision-making processes as a key factor for the determination of biofuel potential. However this method is fraught by several limitations, especially for not taking into account uncertainty and variation in market prices. Therefore, the results should be interpreted with cautious.

6.2. Policy recommendations

Soy already accounts for a large potential for biofuel production due to existence of a highly developed industrial complex and agricultural sector, and therefore this potential is likely to prevail in future decades. However, a number of important issues can be found regarding its socio-environmental performance and therefore its sustainability is still debatable. Due to the magnitude of the potential and its relative economic advantages, the design of a system for tracing the origin and monitoring the local conditions of soy production used as biofuel feedstock should be pondered, to ensure that Argentinean soy-based biodiesel is able to comply with sustainability criteria other than non-competition with food production and direct GHG emissions and thus maintain its competitive position in environmentally-stringent markets such as European Union.

On the other hand, there are technological opportunities to simultaneously increase the existing biofuel potential and avoid undesirable environmental impacts. For instance, intensive agro-industrial systems combining soymeal, biodiesel and intensive meat/milk production in a closed system could be promoted to avoid indirect land-use changes as a result of livestock displacement for agricultural expansion, since soy biodiesel can be produced as by-product of feed soymeal production.

Furthermore, it was shown that switchgrass could become a very promising option to diversify the feedstock for sustainable large-scale deployment of biofuels in Argentina. It is able to become an economically attractive option in marginal areas and thus promote the development of regional economies, while being accountable for a better environmental performance than soy. However, large uncertainties still remain regarding the use of this crop for biofuel production: (1) there is little practice of commercial cultivation and a market is still inexistent; (2) the availability of land depends to a great extent on the developments in technology adoption in agriculture and particularly livestock production, as well as in the future demand for food commodities (3) the conversion of second generation crops to bioethanol is itself a rather immature technology and it may take a few years until it becomes economically viable. Therefore, it should be essentially regarded as long-term option. Nevertheless, the present study is able to inform and provide insights to policy makers on how to steer and promote the use of such a crop for biofuel deployment and fully achieve the identified potential. A sound and integrative long-term strategy is required, including:

- Promoting R&D programs to improve the knowledge and optimize the economic performance of cultivating switchgrass. This is particularly relevant in the areas that were identified as more promising, i.e. province of La Pampa and southwest Buenos Aires, and therefore management practices should be improved according to the biophysical characteristics of this region;

- Providing technology and knowledge transfer programs to promote the cultivation of switchgrass among farmers;

- Promoting market development initiatives, to allow farmers to have a long-term and clearer foresight of future developments to make their investments;

- Providing stable policy frameworks for livestock production and particularly to promote the rate of technology adoption in this sector, to allow that land becomes available for biofuel production without endangering food security and biodiversity. This encompasses setting stable and long-term market-regulation mechanisms to reduce uncertainty and create favorable conditions for investment in the intensification of the livestock sector.

- Promoting R&D programs to improve the economic performance of converting second generation crops, and in particular switchgrass, to bioethanol.

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APPENDIXES

8. Appendix A: Spatial patterns of agricultural and livestock production

Firstly, it can be seen that the agriculture intensity per department (calculated as the total amount of land used for cultivation of the considered crops divided by total department area) varies considerably along the study area (Figure 27). In Region Pampeana, agriculture intensity appears to be quite high in the east of Cordoba and south of Santa Fe provinces and surrounding zones, and to a lesser extent, in the centre-south of Buenos Aires. A combination of factors such as soil suitability and proximity to export hubs seems to explain this pattern (INTA, 2009a; INTA, 2009c; INTA, 2009d).

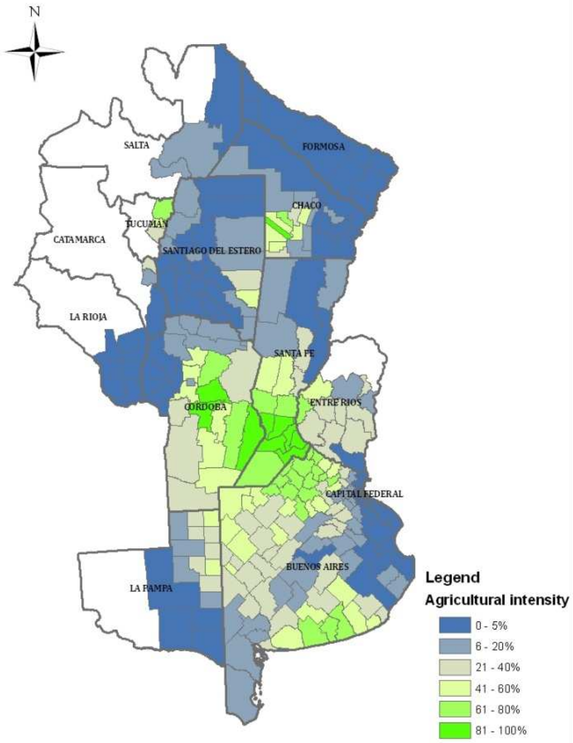


Figure 27: Average agriculture intensity per department 2003-2011 (adapted from INDEC/SIIA data)

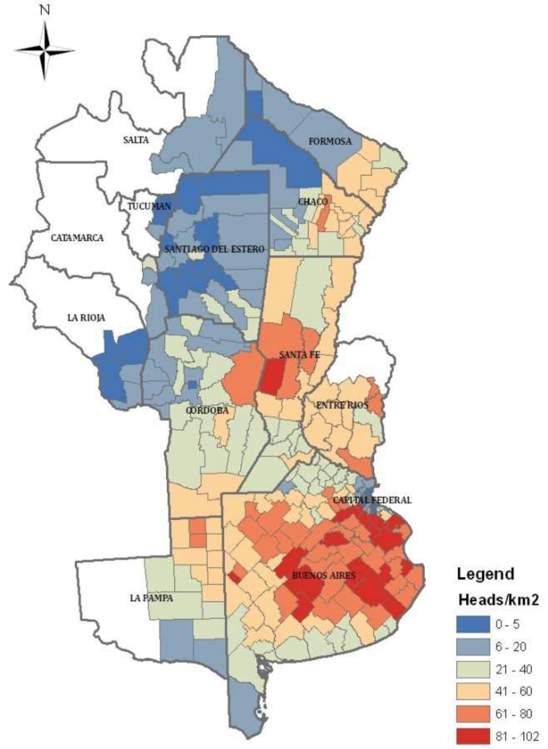


Figure 28: Average livestock density per department 2009 – 2011 (adapted from INDEC/RIAN data)

Livestock density (measured as number of cattle heads per unit of department area) appears to be somewhat negatively correlated with this pattern (Figure 28), showing a higher density on Salado's river basin (centre-east Buenos Aires province), an important cattle breeding zone (INTA, 2009a) and in the north-east of Cordoba and centre of Santa Fe, an important region not only for cattle breeding and fattening but also for milk production (INTA, 2009c; INTA, 2009d - see Figure 29). West/northwest Buenos Aires and Entre Rios also seem to have significant share of milk production.

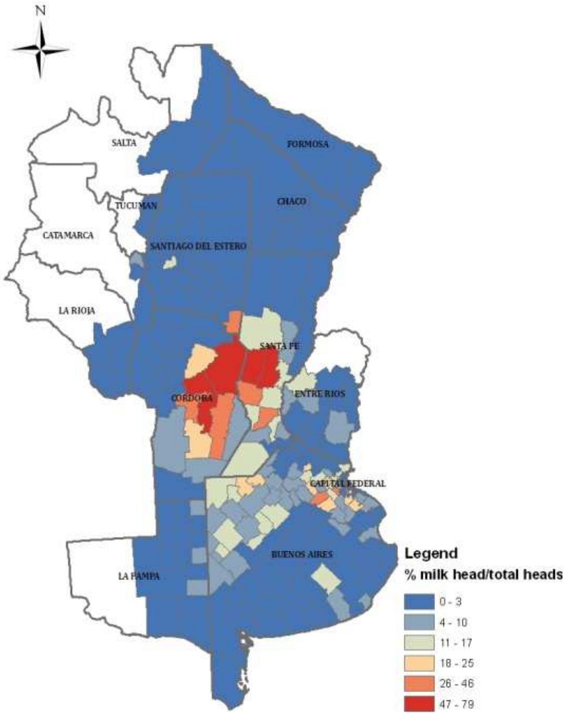
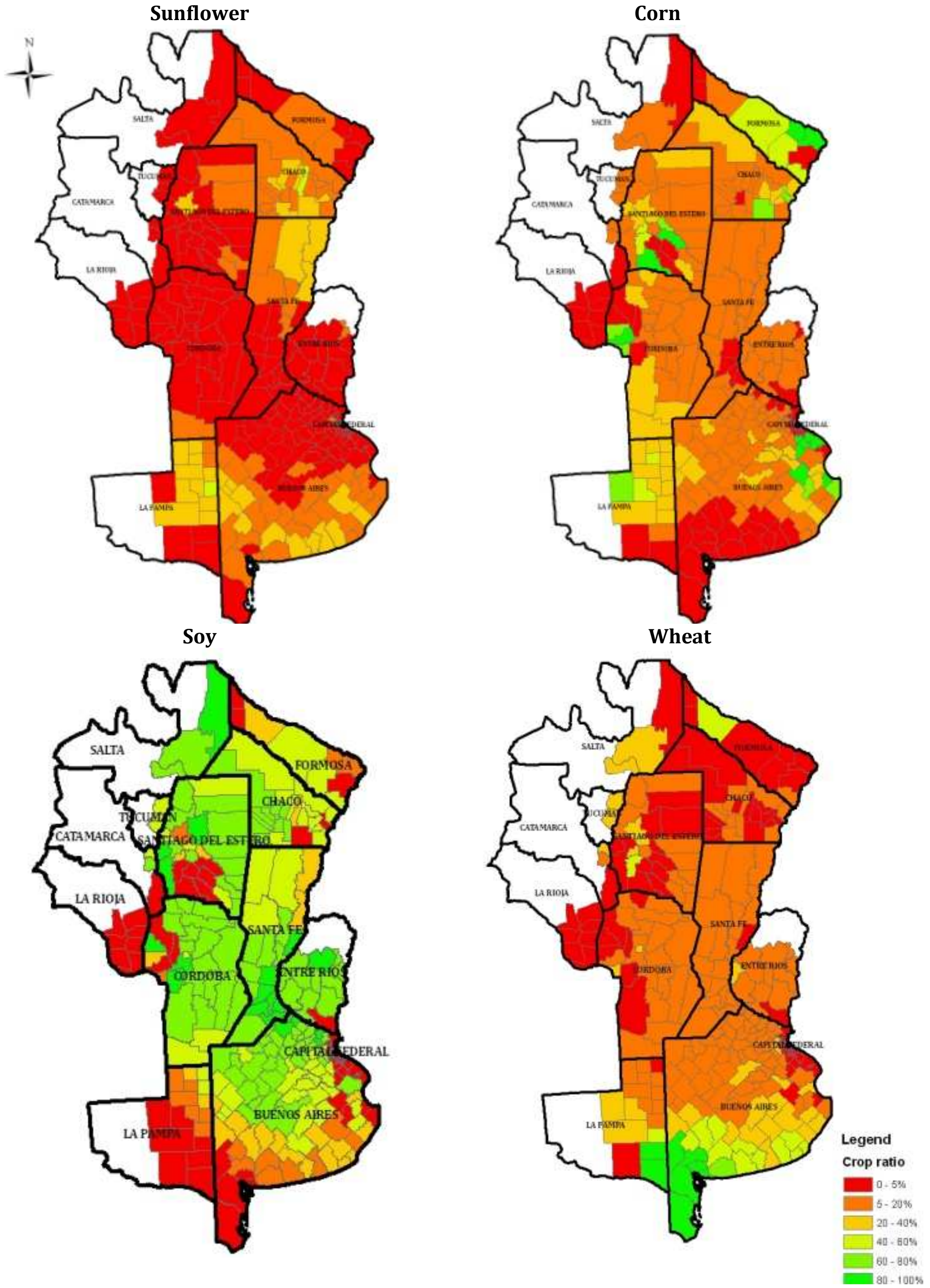


Figure 29: Average share of milk bovines on total number of cattle heads per department 2009 – 2011 (adapted from INDEC/RIAN data)

The observed patterns seem to underpin an increased specialization either in annual crops cultivation or livestock for meat and milk production and the occurrence of land competition between these activities within Region Pampeana. Surrounding these more specialized zones, there still appear regions that do not show yet a clear predominance, suggesting instead the occurrence of mixed production systems. In arid regions such as southwest of Region Pampeana, both agriculture intensity and livestock density are low due to lower biophysical suitability.

Soy is by far the most prevalent crop in the majority of the departments within the study area (Figure 30), having a share higher than 60% both in areas with high and low agricultural intensity. Particularly in south Santa Fe and north Buenos Aires it seems to be cultivated mostly as a monoculture. In opposition, in south Buenos Aires province soy shows to partially lose its predominance to wheat and sunflower, while in the area ranging from centre of La Pampa to southwest of Buenos Aires it is virtually absent.



Sunflower **Corn**

Soy **Wheat**

Figure 30.1-4: Average share of sunflower, corn, soy and wheat on total cultivated area per department 2003 – 2011 (INDEC/SIIA, 2011)

To a certain extent, sunflower's share appears to be negatively correlated with the occurrence of soy, being practically absent in the areas where soy holds a higher share and increasing its share in the regions where soy is less predominant. In general, wheat and corn are not as predominant as soy but in comparison to sunflower they have a relatively more homogeneous distribution along the country, both accounting for 10%-20% of the share on cultivated land in the majority of the departments. Corn appears to hold a higher share in the southwest of Cordoba, northeast of La Pampa and northeast of Chaco eco-region, but is absent in the south of Buenos Aires, where conversely wheat is largely predominant.

9. Appendix B: Review on land-use change science

Land-use systems are groups of interdependent parts linked by flows of matter, energy and information (Figure 31), characterized by strong interactions between the parts, including complex feedback loops that make difficult to distinguish cause from effect (Constanza and Wainger, 1993). Hence, land-use systems are often regarded as complex adaptive systems on which complexity arises from both human decision making and the spatially-explicit patterns of the landscape environment (Parker et al., 2003).

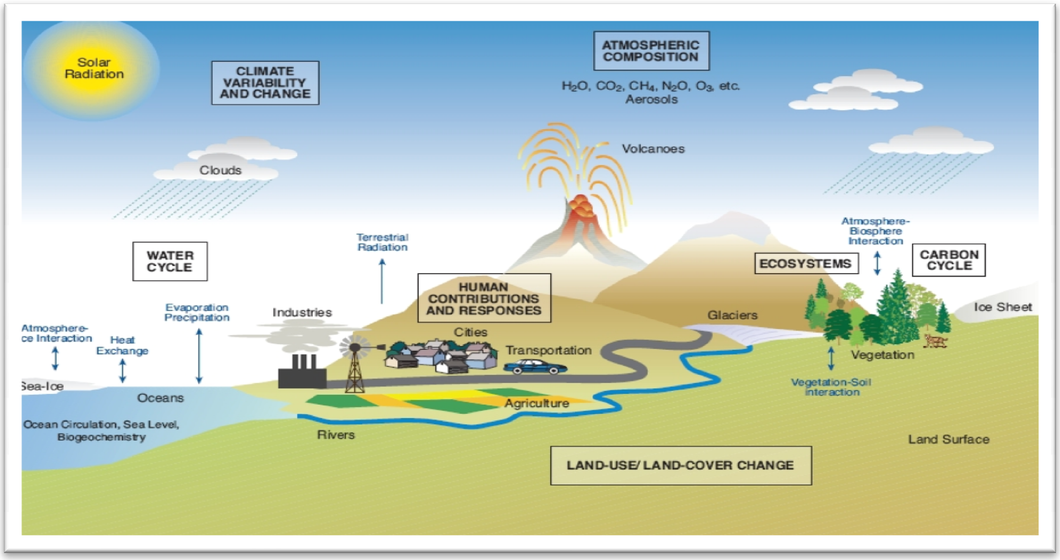


Figure 31: Land-use system and its interconnections with other systems

Emergent phenomena are a possible result of such systems, i.e. macro-level structures that are qualitatively differently from their lower level structures and are not obtainable through superposition (e.g. aggregation or averaging) of micro-level components (Auyang, 1998 cited by Parker et al., 2003). In this sense, they are assumed to be dynamic, to exhibit recognizable patterns of organization across spatial and temporal scales and to be structurally characterized by interdependencies, heterogeneity and nested hierarchies among agents and their environment (Manson, 2001).

Land-use patterns result from complex interactions between numerous factors operating simultaneously at different spatial scales (Lambin et al, 2001). Furthermore, land-use change processes depend on their context, since driving forces will operate differently in distinct social and environmental backgrounds (Riebsame et al, 1994). For instance, on the one hand, restrictions imposed by poverty can direct to inappropriate land use and environmental degradation; on the other hand, concentration of wealth typically leads to exacerbated development and resource exhaustion (Lambin et al, 2001). Ultimately, land-use change can be conceptualized as being driven by responses to opportunities and constraints provided by the physical environment, socio-cultural context and technological capacity, in the pursuit of economic and socio-cultural welfare (Verburg et al, 2004b).

Currently, no unifying theory including all processes relevant to land-use change exists and therefore the determination of the main driving factors of land-use change is still a debatable topic in the field of land-use change analysis and modelling (Lambin et al. 2001). Nonetheless, five major types of driving forces that are assumed to influence land-use development have been empirically identified (Hesperger and Burgi, 2007; Verburg et al., 2004b):

- biophysical driving forces, e.g. slope, elevation, climate, soil characteristics and drainage conditions, which determine the biophysical potentials and constraints for natural and agricultural vegetation;

- socio-cultural driving forces, including demography, lifestyle, diet and historical events;

- economic driving forces, comprising market structure, existing accessibilities and infrastructures, consumer demands and governmental incentives, subsidies and taxes;

- political driving forces, particularly policies with a spatial materialization, such as those on nature conservation, infrastructure and defense;

- technological driving forces, such as the mechanization of agriculture, including not only the related physical apparatus but also the social and organizational expertise.

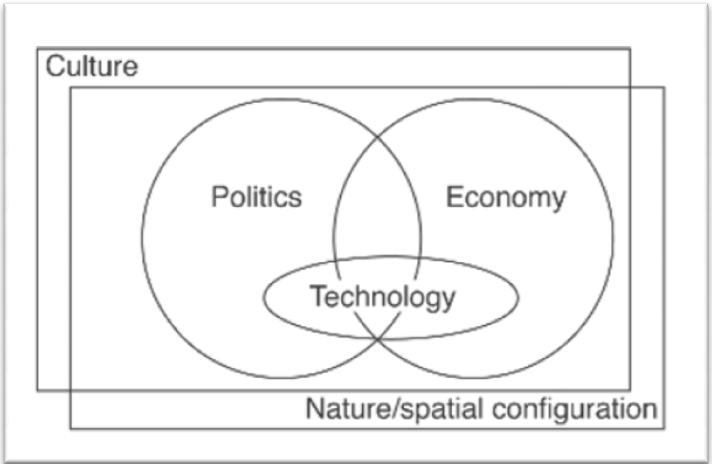


Figure 32: Conceptual framework for the main types of land-use driving forces (source: Hesperger and Burgi, 2007)

Due to the uniqueness of each study area, researchers have refrained from extrapolating and generalizing the human-environment processes causing land-use change. Nevertheless, comparative analysis between cases studies at different times, in different regions and from the perspective of different disciplines has been able to identify common driving forces that have been found important in case studies from different parts of the world that share the same outcome, e.g. as deforestation, agricultural intensification or desertification. For instance, Geist et al. (2006) identified the following factors as the most relevant driving forces influencing agricultural land-use change:

- biophysical factors - precipitation, topography, presence and proximity of water bodies, soil suitability;

- economic factors –market demand, level of affluence, market access;

- technological factors - agrotechnical change, adoption of new crops, improvement of pastoral systems, the provision of water-related infrastructure;

- socio-cultural factors – population growth, population density, diet;

- institutional/political factors – access to land, labor, capital, technology, and information is structured and frequently constrained by local and national policies and institutions, through establishment of property rights, control and support of prices, subsidies and credit schemes, imposition of tariffs and taxes, promotion of industrialization and exports, and provision and maintenance of infrastructure. Other examples are state policies to attain self-sufficiency in food, decentralization, investments in monitoring and guarding natural resources, land consolidation and nationalization. Structural adjustment of the economy through market liberalization, privatization and currency devaluation also play a role.

These factors can influence land-use change in different ways. A fundamental distinction can be made between proximate factors, which entail the human activities and physical actions on the land cover and therefore are related to local characteristics; and underlying factors, which constitute the systemic conditions in human-environment relations that influence the level of production and consumption of ecosystem services and induce the trajectory of land and resource use (Geist et al., 2006). The interplay of several proximate and underlying factors appears to drive land-use change in a synergetic way with large variations caused by location specific conditions and activities, and specific contexts at the local, regional, or global scale (Verburg et al., 2002; Verburg et al., 2006).

Furthermore, land-use patterns frequently exhibit spatial interaction and neighbourhood effects, such as positive spatial autocorrelation. To some extent, this results as consequence of the clustered distribution and gradients of landscape features that determine land use patterns (Verburg et al., 2006). Economies of scale may also account for these phenomena in location decision regarding e.g. urban areas, business parks or cultivation patterns. For instance, when production takes place under conditions of constant or diminishing returns to scale, industry is expected to spread out in order to minimize the transportation costs related to reaching consumers in different locations. This is actually what classic economy predicts: many small plants supplying local markets (Henderson et al., 2001). However, observed industrial land-use patterns show a large degree of concentration. This has inspired the so-called new economic geography that states that the presence of increasing returns to scale is the main factor leading to the decision of firms to strongly concentrate production in relatively few locations (Krugman, 1991; Borck et al., 2010). Increasing returns that are necessary for agglomeration may be either external or internal to the firms (Ciccone and Hall, 1996):

- external mechanisms – knowledge and information spillovers between neighbouring firms, such as learning about their activities, technological development, whom to buy from and sell to, whom to hire, what product lines are selling; externalities arising in the labour market, such as locating in a thick labour market and in a location where other firms have already trained a supply of skilled workers;

- internal mechanisms – location decision based both on input price considerations and on ease of access to markets; positive feedback between location decision of intermediate goods producers and firms with high a demand for intermediates, since they can economize on transport costs and inputs by agglomerating in the same location.

On the other hand, some land use types might preferably be located at a distance from each other (e.g. an airport and a residential area), leading to negative spatial externalities such as congestion effects (Irwin and Geoghegan, 2001). Spatial interactions can also act over larger distances through network interactions such as functional connectivity between the upstream and downstream parts of a river (Verburg et al., 2004c).

Being the land-use system a complex adaptive system, it is also important to take feedback mechanisms into account as determinants of land-use dynamics and system evolution (Parker et al. 2003). Three different types of feedbacks have been identified (Verburg, 2006):

- feedbacks between the driving factors and the effects of land-use change, i.e. impacts of land-use change may affect future land-use decisions (e.g. change in soil suitability due to soil degradation, change in climate conditions due to large deforestation);

- feedbacks between local and regional processes of land-use change, since processes and driving forces operate at different scales (e.g. aggregation of localised changes over space generate larger-scale emergent patterns of land-use, while changes on the macro level such as infra-structural or policy interventions affect land-use decisions at the micro-level);

- feedbacks between agents of land use-change that make decisions and the spatial units of the environment.

While some land-use decisions are made at longer time-scales, others are based on short term dynamics such as weather fluctuations. Furthermore, several external features such as agricultural goods and timber prices, subsidies and land tenure rules may change over time, affecting land-use decisions (Irwin and Geoghegan, 2001). Though, due to the characteristics of both ecological and social systems, the resulting land-use systems often show stability and resilience to disturbances and external influences (Verburg et al., 2002). Consequently, sudden changes in driving factors will not immediately result in a change of the structure of the land-use system. For instance, if a fall in prices of a certain agricultural commodity occurs, farmers will wait a few years depending on the investments made, instead of immediately changing their cropping system.

10. Appendix C: Review on land-use modelling

A large diversity of modelling approaches has evolved over the past years, with considerable differences in terms of background, starting point and range of applications. Koomen and Stillwell (2007) refer a number of theories and approaches that have been implemented in recent land-use modelling efforts:

- Economic theories, which consider land as a special economic asset, characterized by particular features: the supply is fixed, every parcel of land has a fixed location with unique biophysical features and land-use at a certain location influences its surroundings and vice-versa (externality of land-use);
- Spatial interaction modelling theory, including assumptions on the influence of available transport network on land-use and vice-versa;

- Cellular automata methods, which assume that every cell has a certain state that is influenced by its surroundings as well as its own characteristics;

- Statistical analysis, namely regression analysis, has helped to quantify the contribution of individual forces that drive land-use change and as such provide information to properly calibrate land-use change models;

- Optimisation techniques, such as linear integer programming and neural networks, where the optimal land-use category is calculated given a prior set of conditions, criteria and decision variables;

- Rule-based simulation, which aim to imitate land processes by describing strict, quantitative location-based rules, such as soil erosion or landscape dynamics;

- Multi-agent models, which simulate actors with strategies that make them react to their environment and the actions of other actors;

- Microsimulation, which aims to simulate individual actors who influence changes in the land use on the scale level on which the actual choices are made.

The theories and methods described above have their own strengths and weaknesses and there is no single approach that can be clearly considered better than the other. In fact, the choice of the model often depends on the research question, on the characteristics of the study area and to a certain extent on the availability of data (Verburg et al., 2006). Yet, a number of characteristics can be used to distinguish the most common modelling approaches (Verburg et al., 2006; Koomen and Stillwell, 2007):

- spatial vs. non-spatial models, depending on whether land-use change is represented on a spatially explicit manner or the focus lies solely on the rate and magnitude of land-use change without specific attention on the spatial distribution;

- dynamic vs. static models, with the former accounting for temporal characteristics such as feedbacks and path-dependencies;

- agent-based vs. pixel-based models, depending on whether the unit of analysis represents a farm, plot or census tracks that matches with agents of land-use change, or a pixel as part of a raster-based representation;

- integrated vs. sectoral models, depending on whether the focus is only in one specific sector (e.g. housing, agriculture) or mutual relationships between sectors are considered;

- descriptive vs. prescriptive models, while the former aims to simulate the functioning of the land-use system and explore future patterns (land-use transformation), the latter aims to calculate an optimized land-use configuration that best match a set of goals (land-use allocation).

- deductive vs. inductive models, which differ in terms of the role of theory: while deductive (deterministic) models are based on theory that predicts pattern from the process, inductive (probabilistic) approaches specify the model based on the correlation between land-use change and explanatory factors assumed to drive this change.

A review of existing spatially explicit land-use modelling tools is provided in the following sub-sections, with a particular emphasis on the way how the aforementioned features. This review is not meant to be exhaustive, but rather illustrative of current approaches, their applicability, advantages and drawbacks. Similarly to previous discussions on land-use models (e.g. Irwin and Geoghegan, 2001, Overmars et al. 2007) a broad distinction between empirical and theoretical models will be made while reviewing current land-use modelling applications. This procedure is deemed as appropriate as it allows to distinguish between approaches that aim to construct hypothesis about the relation between land-use and its explanatory factors from those on which a structured theory is specified for a real case without recurring to any fitting of empirical data.

10.1. Empirical models

10.1.1. Cellular automata models

Cellular automata (CA) are a class of models derived from mathematics which were originally conceived to provide a framework to investigate the behaviour of complex systems (von Neumann, 1966). They are defined by a spatial grid of cells in which the state of every individual cell is a result of the states of the neighbouring cells and its own in the previous time step. The behaviour of the system is determined by a set of deterministic or probabilistic transition rules that give the degree and direction of interaction between cells.

When applied to a land-use system, CA models simulate the transition of a cell from one land use to another. The reasoning of this approach is that the interaction of a location with its surrounding has empirically proven to be a determinant of land-use change (Verburg et al., 2004b). Moreover, CA models allow complex global patterns to emerge spontaneously from the collective behaviour of interacting individual cells (Wolfram, 1986), thus being able to reproduce emergent phenomena as observed in land-use systems.

This modelling approach has been extensively applied to model land-use in an urban context, particularly to simulate and reproduce urban dynamics (e.g. White and Engelen, 1993; Webster and Wu, 1999), to simulate the direction and pattern of future urban development based on real data sets (e.g. White et al., 1997; Clarke and Gaydos, 1998) and to support normative planning by simulating different urban forms based on planning objectives (e.g. Yeh and Li, 2001). Besides urbanization, CA models are also able to simulate other processes of land-use change such as conversion of forest to agricultural land (e.g. Messina and Walsh, 2001) and structural change in agriculture (Balmann, 1997).

A recent example of such a CA model is *MOLAND* – Monitoring Land Cover/Use Dynamics, an urban and regional scenario simulation model which has been applied in the last decade to an extensive network of cities and regions in Europe, being capable of simulating up to 32 different types of land uses (Petrov et al., 2009). *MOLAND* simulates land-use change based on suitability maps representing local biophysical features (e.g. elevation, slope, soil, agricultural capacity, exposure to pollutants, hazards, etc), accessibility of the transport network, socio-economic characteristics of the studied area (e.g. population, income, production, employment) and a number of constraints (zoning status, institutional suitability, legal constraints, etc). Thus, it can be concluded CA models are now moving beyond the classical focus on spatial interactions (Koomen and Stillwell, 2007).

The parameter calibration procedure in CA models is often based on historic data, aiming to produce a set of transition rules that generates a model output with the best possible goodness of fit between the simulated map and the actual available map. However, standardized methods to derive the transition rules are still lacking and parameter calibration models is often complex, since the use of many interacting coefficients may involve that more than one solution is possible; that is, different processes may lead to identical patterns (Verburg et al., 2006). Hence, even though researchers claim that CA models yield a good representation of actual urban forms, conclusions about their explanatory power should not be overpraised (Irwin and Geoghegan, 2001).

10.1.2. Multi-agent models

CA models have been recently combined with multi-agent (MA) models. According to Parker et al. (2003) agents are decision-making entities that besides being autonomous (i.e. they control their own actions and internal states in order to achieve their design goals), they share an environment through communication and interaction, adjusting their behaviour according to the signals provided by the environment and other agents. Thus, land-use multi-agent models explicitly address interactions among agents while simulating land-use decisions (Verburg et al., 2004c). However, an agent is not necessarily an individual itself but it can rather represent any level of social organization (Bousquet and Le Page, 2004), thus being able to simulate the behaviour and interactions of in-homogeneous groups of actors (Verburg et al., 2004c). Such models are normally based on detailed information of socio-economic behaviour under different circumstances obtained from sociological field studies, in order to represent heterogeneous groups with different internalized social norms and internal behavioral rules (Tesfatsion, 2001),

When CA and MA models are coupled together, the CA part typically describes the natural system over which actors make decisions, including the interaction between ecological processes, while the MA part describes the choice behavior architecture of the key actors in the system (Koomen and Stillwell, 2007), namely the decision-making mechanisms, the hierarchical relationships among agents and their communication protocols (Bousquet and Le Page, 2004). The advantages of this approach are the ability to incorporate social processes and non-monetary influences on decision-making and to dynamically link social and environmental processes, thus expressing the co-evolution of the human and landscape systems based on the interactions between human actors and their environment (Parker et al., 2003; Matthews et al., 2007; Le et al., 2008). As such, a vast range of applications has been implemented for policy analysis and planning, participatory modelling, explaining spatial patterns of land use or settlement, testing social science concepts and explaining land-use functions, on topics such as crop choices, natural-resource management, deforestation and urbanization.

The Land Use Dynamics Simulator - *LUDAS* is a recent example of a land-use model combining MA and CA approaches together. It has been applied to a watershed in Vietnam for integrated assessments of policy impacts on landscape and community dynamics, such as forest protection zoning, agricultural extension and agrochemical subsidies (Le et al., 2008; Le et al., 2010). Its framework is composed by four main components (
Figure 33: Conceptual framework of *LUDAS* modelling approach
Figure 33):

1) a system of human population defining specific behavioural patterns of farm household agents in land-use decision-making according to typological livelihood groups. The state of household agent is determined by the household profile and the landscape as perceived by the agent. The household profile is represented by a list of household socio-economic variables (e.g. educational status, size, labour, land endowment, income) and variables measuring accessibilities of the household to certain institutions (e.g. agricultural extension services, agrochemical subsidy). Generally, variables of the household profile change over time, such as annual income and land endowment, which may change due to annual land-use activities. Institution-related variables change in response to changes in policy. Demographic variables, such as household's ethnicity and size, are stable with small stochastic variance, but household age advances regularly over time. The decision-making mechanism is based on the household profile, its perceived landscape information, and information from other household agents. The decision procedure is the same for all household agents in terms of its logical sequence but the agent's state, parameters and structure of utility functions are individual-specific and thus decision outcomes may vary;

2) a system of landscape environment characterizing individual land patches with multiple attributes and ecological response mechanisms to environmental changes and human intervention, representing the dynamics of crop and forest yields as well as land-use/cover transitions in response to household behaviour and natural constraints. State variables are corresponding to biophysical spatial variables (e.g. terrain condition, land cover, accessibility to rivers), economical spatial-variables (e.g. distance to roads), institutional spatial-variables (e.g. owner, village territory, protection zoning class), and history of particular patch properties. Ecological response mechanisms are represented by internal sub-models of agricultural and forest productivity dynamics which operate in response to the current state, history, and spatial neighbourhood of the landscape agents. Since the ecological sub-models work autonomously, the attributes of landscape are able to change over time, even without any human intervention. A cellular automata sub-model of land-cover transition is built into the landscape system, enabling it to transform through small and gradual changes (vegetation growth and/or modification) into categorical changes (conversions) in land cover.

3) a decision-making procedure integrating household, environmental and policy information into land-use decisions of household agents, namely tenure rules and a perception–response loop. Regarding *de facto* tenure rules, the model focuses on ownership and village territory, as they are often strongest tenure rules shaping land use. While ownership is applied specifically for individual households, village

territory is applied specifically to a group of households who share the same village membership. *De jure* tenure regulations, which are defined by policies, are applied uniformly for all household agents in the system. The perception–response loop involves information and physical flows between household agents and their environments. Perception corresponds to the perceived spatial status of the biophysical conditions around them, as well as anticipated benefits that can be derived from land-use decisions (e.g. agricultural products), which can lead to changes in certain attributes of their profile. Response reflects the physical effects of household agents on the environment through their land-use actions. Thus, the household agents modify the structure of spatial organisation in their environments through land-use activities and if this happen within the view of other households, it may affect their behaviour as well.

4) a set of relevant policy factors for land-use choices. Policy influences system behaviour by modifying the functional relationships between the human and environment systems. Policy factors also affect the system behaviour through policy-related variables of household agents, institutional variables of landscape agents, adding, cancelling, or modifying interaction rules. For instance, a subsidy on agricultural inputs or agricultural extension, may affect policy-related variables in the household profile, while zoning regulations can modify spatial patterns of ownership and protection zones, thus changing the spatial organisation perceived by the household agents.

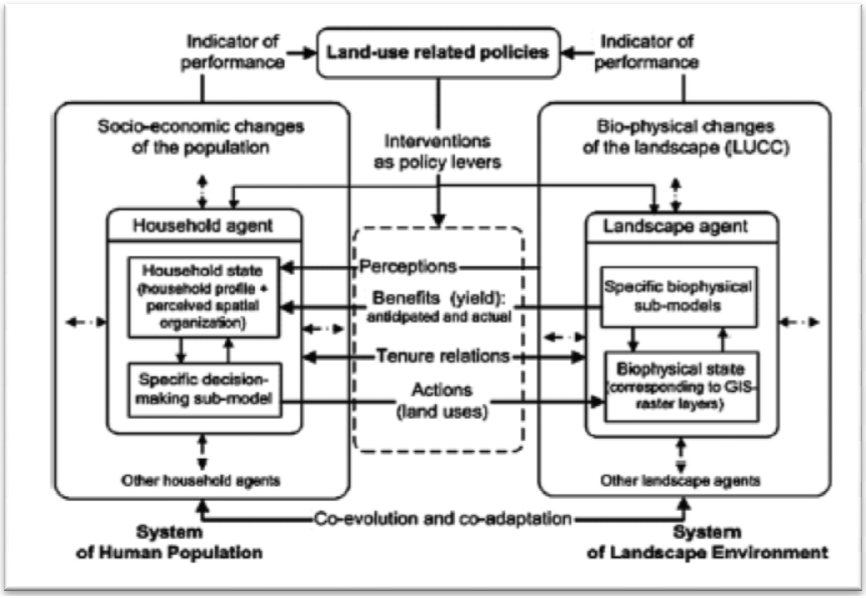


Figure 33: Conceptual framework of *LUDAS* modelling approach (source: Le et al., 2008)

Two types of state variables can be found in the model, namely static variables and dynamic variables. Static variables, such as topographical indices and village codes, do not change over time. Regarding dynamic variables, there are two sub-types: those driven by natural process that are beyond human control (e.g. the age of the household agents and natural forest growth of forested pixels), and variables induced by household decisions and/or policy interventions (e.g. land holdings and income of household agents; cover type, crop yield and land protection). Since most dynamic variables act simultaneously as causes in some interactive processes and consequences in other processes, many multi-directional causal relationships can be established within the coupled human–landscape system. Parameters specifying household behaviour are also treated as state variables, including a set of preference weighting coefficients reflecting the relative importance of various environmental, socioeconomic and policy factors in the household decision about land uses, and a set of ratios determining the amount of labour allocated for each branch of livelihood activities.

In this model, the bounded-rational approach, based on utility maximization and using spatial multinomial logistic functions, is nested with heuristic rule-based techniques to represent decision-making mechanisms of households regarding land use. Due to its extension, a more detailed description on the theoretical specification and mathematical formulation of the model is not provided here and can be found elsewhere (e.g. Le et al. 2008).

Since the number of possible interacting agents and variety of factors is very large, it is extremely difficult to design a comprehensive MA model which is actually able to provide realistic simulations (Rindfuss, 2004). Large amounts of data are required to build a well-parameterized model of decision-making; yet, the observed land-use changes are not sufficient to validate such a model, since there is the possibility that a model that matches the real-world processes well may actually fit the observed patterns less well than another model with less realistic processes, due to the limited predictability of a real-world system exhibiting feedback and path-dependent behaviour (Brown et al., 2005). As a result, these models are only able to simulate special cases with simplified, hypothetical landscapes. In fact, even though these tools have been proved to be useful in organising knowledge from empirical studies and for exploring theoretical aspects of particular systems, they still have to demonstrate that they are able to solve problems in the real world better than other traditional modelling approaches (Matthews et al., 2007; Castella and Verburg, 2007).

10.1.3. Microsimulation models

In addition to MA models, microsimulation techniques have been developed. The latter deviates from the former in the sense that instead of using a cross-sectional average description of the relevant decision-making groups, it explicitly includes all actors (e.g. persons, households, individual firms) that influence the land-use system. Thus, actor's likely behaviour is modelled taking into account their individual characteristics and location. The advantage is that land-use changes are modelled on the scale level in which choices are actually made (Koomen and Stillwell, 2007), shifting from the traditional focus on aggregated sectors of the economy to individual decision-making units.

Spatial microsimulation has been designed to explore spatial relationships and analyse spatial implications of economic development and policy changes at a more disaggregated level (Van Leeuwen, 2009). These models demand enormous amounts of detailed data on individuals and the characteristics of their spatial location. Still, they are still unable to capture and integrate macroeconomic processes resulting from structural economic change and demographic developments (Alberti and Waddell, 2000).

10.1.4. Statistical models

While the abovementioned models are based on a micro-level perspective accounting for bottom-up processes of decision-making, other modelling approaches have taken a macro-level perspective based on the analysis of the spatial structure of land use through remote sensing and geographic information systems (GIS) and using macro-properties of social organization. GIS can be used to process all spatial data and convert it into a regular grid, allowing to overlay land-use patterns with maps depicting biophysical and socioeconomic conditions.

Hence, most of these approaches try to capture the relation between land-use and the spatial variability in the biophysical and socio-economic environment through statistical techniques, namely regression analysis (Verburg et al. 2004c; Koomen and Stillwell, 2007). Regression-based models have two main purposes: to improve the explanation of the mechanisms and processes driving change (e.g. Diogo and Koomen, 2010) and to predict spatially-explicit projections of the change itself (e.g. Verburg et al., 2008).

Logistic regression is a multivariate generalized linear model that allows one to predict a discrete outcome from a set of variables. Because land-use change is usually represented as a discrete change from one land-use type to other, logistic regression is deemed as an appropriate statistical model to analyse these phenomena (Millington et al, 2007). Typically, the dependent variable is categorical and can be either dichotomous (binomial logistic regression model) or have more than two possible cases (multinomial logistic regression model). Each category of the dependent variable is then compared to a reference category and coefficients are estimated indicating the direction and intensity of each explanatory variable, which may be either continuous or categorical (Lesschen et al, 2005). The logistic regression model transforms the dependent variable into a logit variable, thus estimating the odds of a certain event occurring:

$$z_i = \ln\left[\frac{P(event_i)}{P(reference\ category)}\right] = b_0 + b_1X_1 + b_2X_2 + \cdots + b_kX_k$$

where z_i is the natural log of the odds of event *i*, X_n are independent explanatory variables, *k* is the number of independent variables used in the model, b_0 is a constant (the intercept) and b_n are the logistic regression coefficients (also called parameter estimates), which are determined through maximum likelihood estimation. Thus, the probability of occurrence of a certain event can be calculated as follows:

$$P(event_i) = \frac{e^{z_i}}{1 + \sum_{p=1}^{P} e^{z_x}}$$

where p is the number of categories of the dependent variable (that is, possible events, e.g. land-use types).

As such, logistic regression analysis has been used to quantify the relation between the occurrence of land-use types and a set of explanatory variables that are considered to drive land-use allocation. This was the case in several versions of the Conversion of Land Use and its Effects (*CLUE*) model family. Originally presented by Veldkamp and Fresco (1996), the *CLUE* framework has been implemented in several scale and context specific regional applications, including the simulation of deforestation (e.g. Verburg and Veldkamp, 2004), land degradation (e.g. Veldkamp et al. 2001), urbanization (e.g. Lin et al., 2009), land abandonment (e.g. Verburg and Overmars, 2009) and integrated assessment of land cover change (e.g. Verburg et al., 2008), in areas ranging from small regions to entire continents.

In the *CLUE* framework, multiple land-use types are simulated simultaneously through dynamic simulation of competition between land-use types, which can lead to land-use conversion and change in space and time (Veldkamp and Fresco, 1996). Land-use changes are assumed to occur only when biophysical and human demands cannot be met by the existing land-use configuration. Final land use decisions are made on a local grid level as a result of interacting biophysical and human drivers. Important biophysical drivers considered in the framework are:

- local biophysical suitability of the land for crops and other land-use types, according to soil characteristics, climate conditions and slope, and its seasonal fluctuations resulting from changes in temperature and precipitation levels;
- land-use history, namely the effects of past land-use, e.g. erosion, compaction, soil sealing;
- spatial distribution of infrastructure and land-use;
- occurrence of pests and diseases.

Furthermore, the following human-land use drivers are also taken into account:

- population size and density, which are assumed to determine the demands for food, that is taken as a proxy for primary agricultural products, such as food, animal products, basic fibres and export crops. Moreover, urban expansion rate is also considered proportionally related to population growth.
- technology level, a key determinant in attainable yield levels;
- affluence level, which determines the diet and thus the composition of the food demand and consequently the land-use strategy;
- target markets for products, which require a minimum critical product volume, quality and infrastructure to make them economically feasible;
- economical conditions;
- attitudes and values.

Some of these factors directly influence the rate and quantity of land-use change (e.g. population growth rate), while others determine the location of land-use change (e.g. soil suitability for agriculture) leading to spatially differentiated pathways of change (Verburg et al., 2002)

The *CLUE* model was firstly applied for the continental and national level, namely for Central America (Kok and Winograd 2001), Ecuador (de Koning et al., 1999), China (Verburg et al.,2000), and Java, Indonesia (Verburg et al., 1999), using very coarse spatial resolution. The model was posteriorly adapted for regional applications as *CLUE-S* - Conversion of Land Use and its Effects at Small regional extent (Verburg et al. 2002) - representing land-use systems with pixel sizes varying between a few meters up to 1x1 km.

The *CLUE-S* model is sub-divided into two distinct modules, namely a non-spatial demand module and a spatially explicit allocation procedure. The non-spatial module determines the area change for all land-use types at the aggregate level, while the allocation procedure translates these demands into land-use changes at different locations using a raster-based system. For the land-use demand module, different alternative specifications are possible, ranging from simple trend extrapolations to complex economic models, depending on the nature of the most important land-use conversions taking place within the study area and the scenarios that need to be considered. The results from the demand module are specified on a yearly basis, establishing the area covered by the different land-use types.

The allocation module is based upon a combination of empirical spatial analysis, and dynamic modelling. The empirical analysis establishes the relations between the spatial distribution of land-use and a series of factors that are assumed to behave as drivers and constraints of land-use. The relations between land-use and driving factors are quantified using binomial logistic regression, in order to indicate the probability of a certain grid cell to be assigned to a certain land-use type, given a set of driving factors:

The results of this empirical analysis are used to calculate a probability map for each land use type in order to simulate the competition between land-use types for a specific location. Neighbourhood interactions can also be incorporated in the regression analysis. Verburg et al (2004a) proposes a method to perform an empirical analysis for the implementation and quantification of neighbourhood interactions. The enrichment factor, a measure based on the representation of different land use types in the neighbourhood of a location, is defined as the occurrence of a land use type in the neighbourhood of a location relative to the occurrence of this land use type in the study area as a whole:

being $F_{i,k,d}$ the enrichment factor of neighbourhood d of location i with land use type k, $n_{i,k,d}$ the number of cells of land use type k in the neighbourhood d of cell i and $n_{d,i}$ is the total number of cells in the neighbourhood, while N_k is the number of cells with land use type k in the whole map and N the number of all cells in the map. The neighbourhood d of a location refers to the shape and the distance of the neighbourhood from the central grid-cell i, which may vary as exemplified in Figure 34.

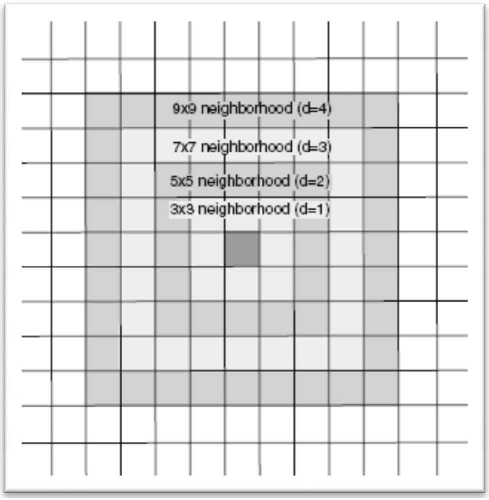


Figure 34: Neighbourhood configurations (source: Verburg et al., 2004a)

Hence the probability of conversion of a grid cell can also be described as a function of a set of enrichment factors by performing a logistic regression analysis as follows:

where the independent variables $F_{i,k,d}$ are the enrichment factors of the individual grid-cells *i* of the neighbourhood *d* with land use *k* and $b_{k,d}$ are the estimated coefficients.

In addition, a set of decision rules can be specified by the user, determining the conditions under which changes are allowed to occur. The goal is to restrict the conversions that can take place based on the actual land-use pattern, thus giving a certain resistance to change in order to generate stability in the land-use structure (Figure 35).

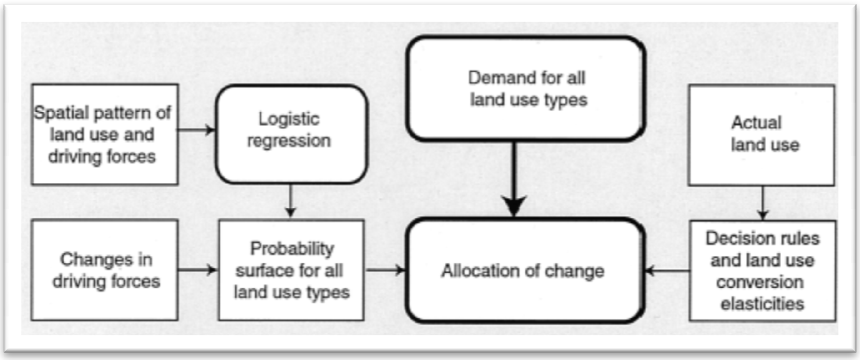


Figure 35: Land-use allocation procedure in *CLUE-S* (source: Verburg et al., 2002)

Decision rules can be either land-use type or location specific. Location specific decision rules may include the delineation of protected areas such as nature reserves, where no changes are allowed within this area. Land-use type decision rules determine the conditions under which each land-use type is allowed to change in the next time step, including three different situations:

1) Some land-use types are very unlikely to be converted into another land-use type; e.g. urbanized areas are not expected to return to agriculture or to be converted into forest. Therefore, the locations covered by this land use are no longer available for potential land-use changes, unless a decrease in area demand for this land-use type occurs.

2) Other land-use types, such as swidden agriculture, are more easily converted into another land-use type soon after its initial conversion and thus no restrictions to change are considered in the allocation module.

3) A number of land-use types operate in between these two extremes. For instance, permanent agriculture requires a considerable initial investment and therefore it is not very likely that to be converted soon after into another land-use type. However, when another land-use type becomes more profitable, a conversion is possible.

In order to deal with these features, a relative elasticity for change is defined for every possible conversion from one land-use type into any other type. The relative elasticity can range between 0 and 1, with high values indicating a high conversion cost (either monetary or institutional) and thus a higher total probability for the location to remain under the current land use type (Verburg et al., 2008). This elasticity is usually defined based on the user's knowledge, yet it can also be tuned during the calibration of the model.

The allocation of land-use is performed on yearly time-steps through an iterative procedure, taking into account the decision rules in combination with the actual land-use map, the demand for the different land-use types and the probability maps (Figure 36). Firstly, all grid cells that are allowed to change are identified and consequently cells that are either part of a protected area or under a land-use type that is not allowed to change are excluded from further calculation. Thereafter, for each grid cell *i* the total probability is calculated for each of the land-use types *u*:

where $TPROP_{i,u}$ is the total probability of grid cell *i* for land-use type *u*, $Ploc_{i,u}$ and $Pnbh_{i,u}$ are the probability of grid cell *i* for land-use type *u* determined by the local suitability and neighbourhood interactions respectively calculated according to the logistic regression analysis, $ELAS_u$ is the relative elasticity for change of land-use type *u* and $ITER_u$ is an iteration variable that is specific to the land-use. A preliminary allocation is made with an equal value of the iteration variable for all land-use types by allocating the land-use type with the highest total probability for each considered grid cell. The total allocated area of each land use is then compared to the demand; for land-use types where the allocated area is smaller than the demanded area the value of the iteration variable is increased, while for land-use types for which too much area is allocated the value is decreased. These steps are repeated until demand is correctly allocated and then the calculations proceed for the next yearly time-step.

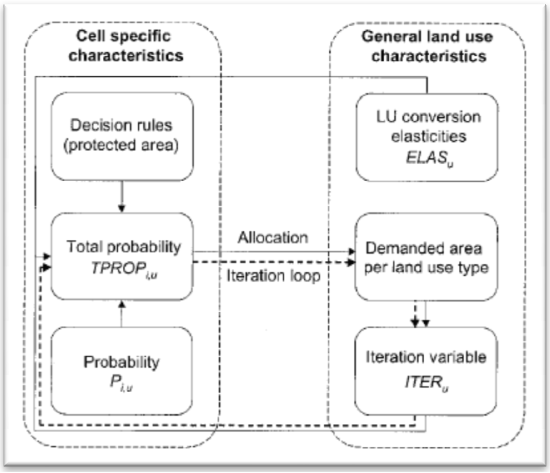


Figure 36: Interactive procedure for land-use allocation in *CLUE-S* (source: Verburg et al., 2002)

CLUE-S has been coupled with a series of models, namely with a version of *GTAP* - Global Trade Analysis Project, a computable general equilibrium (CGE) economic model and *IMAGE* - Integrated Model to Assess the Global Environment (Figure 37), in order to explore land-use change in Europe at different scales. The *GTAP-IMAGE* framework was developed to analyze the global economic and environmental consequences of economic, policy and demographic changes, capturing the interaction between economy and natural resources (Meijl, 2006). *GTAP* takes into consideration macro-economic, demographic and technology developments and changes in agricultural and trade policies influencing the demand and supply for land-use related products, including the impact of non-agricultural sectors on agriculture. On the other hand, *IMAGE* accounts for changes in productivity resulting from climate change and global land allocation. Thus, global interactions determining the production and consumption of different regions are modelled accounting for feedbacks from changes in climate. In Verburg et al. (2008), this framework was used to calculate changes in demand for agricultural areas at the country level in Europe. Accordingly, *CLUE-S* was used to translate these land demands and downscale them to land-use patterns at 1 km^2 resolution, making use of country specific biophysical and socio-economic driving forces, thus linking global level developments influencing land-use to local level patterns.

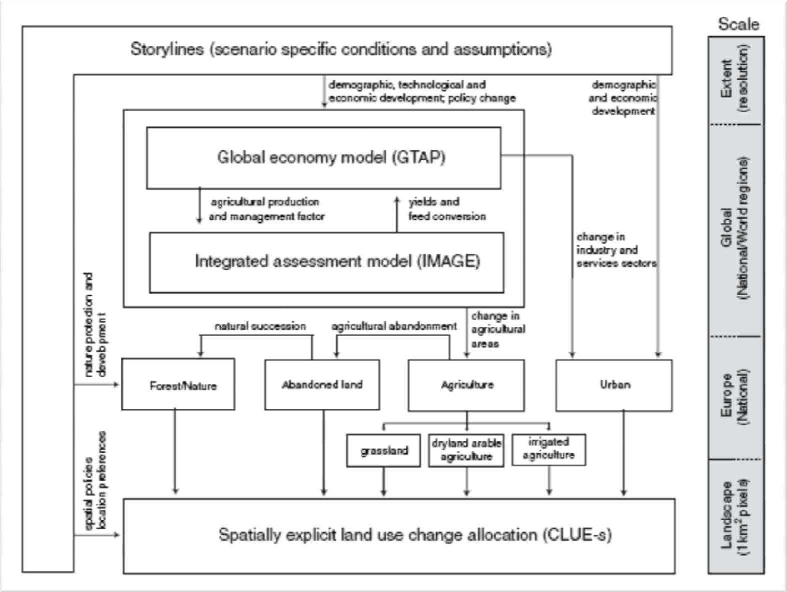
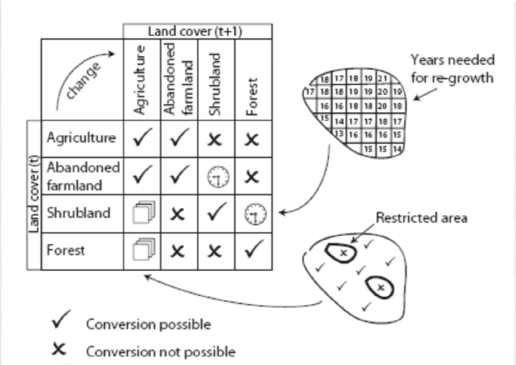


Figure 37: Multi-scale and –model modelling approach (source: Verburg et al., 2008)

This approach was further improved in *Dyna-CLUE* (Verburg and Overmars, 2009), by explicitly addressing the interactions between changing demands for agricultural land and vegetation processes leading to the re-growth of vegetation on abandoned farmland. This was achieved through the integration of the aforementioned top-down allocation methods with bottom-up algorithms of vegetation dynamics determined by local conditions. These algorithms are specified in a conversion matrix as exemplified in Figure 38, which indicates the conversions that are possible for each land use type. These specifications overrule the maximization of total probability and thus the land use type with the highest total probability for which the conversion is allowed will be selected. Besides of restricting a specific conversion, it is also possible to enforce a conversion between land use types. For instance, when a specific conversion is expected within a specific number of years, this will be enforced as soon as the number of years is exceeded.



Land cover (t) \ Land cover (t+1)	Agriculture	Abandoned farmland	Shrubland	Forest
Agriculture	✓	✓	✕	✕
Abandoned farmland	✓	✓	◷	✕
Shrubland	❐	✕	✓	◷
Forest	❐	✕	✕	✓

Figure 38: Simplified land cover conversion matrix as used in Dyna-CLUE (source: Verburg and Overmars, 2009)

Empiric statistical models such as those belonging to the *CLUE* model family are able to simulate multiple interconnected spatial scales, thus representing the hierarchical organization of land-use systems. Special attention is given to the driving factors of land-use change, distinguishing drivers that determine the quantity of change from drivers of the location of change, although taking into account the resilience and stability of land-use systems. However, these approaches result in a low degree of explanation due to the relative short-time period of analysis, variability over this time period and most importantly the induced uncertainty with respect to the causality of the assumed relations (Verburg et al., 2004c). Since they are based on an extrapolation of past trends in land-use, this type of models are somewhat less suitable for long-term scenario analysis, as they are only valid within the time range on which they are based. However, when these models are based on the analysis of land-use patterns with dynamic modelling of competition between land-use types, they are suitable for a wider range of applications (Verburg et al., 2006).

10.2. Theoretical models

In contrast with empirical models, theoretical models aim to predict land-use patterns from processes using theory to guide the characterization of land-use systems and explain the casual relationships between land-use choices and outcomes (Verburg et al., 2006). Such models assume that landowners make decisions in order to maximize either expected returns or utility derived from land, often using economic theory to choose the model's functional form and explanatory variables (Irwin and Geoghegan, 2001). The role of land in economic theories has changed over time, reflecting changes in society such as the transition from a feudal to an agrarian society, the focus on labour and capital as production factors resulting from the industrial revolution and more recently the awareness of land as a scarce production and consumption factor due to increased environmental concerns, scarcity of natural resources and demand for land in densely populated areas (Buurman, 2003).

The early theories from Ricardo (1817) and Von Thunen (1826) have laid the foundations of land price and land-use theories (Koomen and Stillwell, 2007). Ricardian models explain the existence of land rents due to differences in land quality, focusing on the fertility of agricultural land as the explanatory factor. By assuming that the market price paid for agricultural goods is determined by the production costs on less fertile soils, Ricardo concluded that farmers owning more fertile land have lower production costs and thus will profit a surplus equal to the difference between price and production costs. As a result, farmers are willing to pay for high yielding land, leading to an increase in land rents on fertile soils. This approach was later generalized to consider exogenous technological differences for all types of goods. On the other hand, Von Thunen has focused on the influence of distance and transportation costs to explain land-use and prices. Assuming that producers prefer to locate closer to the market, typically a city, to gain higher profits by reducing transportation costs, it is concluded that they are willing to pay a higher rent for land closer to the city, which consequently will have a higher price than land located further away.

More recently, the economic analysis based on bid rent theory (Alonso, 1964) focused on the relationship between the value of urban land and urban land-use, assuming that households and firms consider land prices, transportation costs and the amount of land that they need while making decisions. Using microeconomic theory, bid price curves can be derived for households and companies, depicting the set of prices for land that could be payed at various distances while maximizing their profit or utility. In a competitive land market the bidder with the highest bid will be able to purchase/rent the land. The resulting land-use pattern of this model is typically a monocentric city with concentric rings of residential development surrounding the urban centre and decreasing land prices and residential density as one moves away from the centre. As such, higher revenue activities such as commerce and services concentrate at the city centre, while industrial and housing functions will select locations on its surroundings. The edge of the city will coincide with the locations where the offer of urban bidders equals those of farmers.

Agricultural land prices can also be derived through bid rent theory. The reasoning of this approach is that the crop producing the higher revenue at a certain location will be able to make the highest bid, calculated according to:

$$r(d) = N[p_z - c_z - p(d)]$$

where $r(d)$ is the rent at distance d from the market, N is the output of a unit of land, p_z is the price at the market of crop z, c are the production costs for the crop and $p(d)$ are the transportation costs at distance d from the market. Thus a farmer can choose among different crops with different selling prices, production costs and transportation, as well as adjust the yield. However, the possibility of growing different crops is usually constrained by biophysical variables such as soil characteristics and climate.

In this context, discrete choice theory has also contributed on explaining land-use patterns (Koomen and Stillwell, 2007). According to this theory, mutually exclusive alternatives are selected by assuming that the probability of selecting a certain alternative is dependent on the utility of that specific alternative in relation to the total utility of all alternatives. When applied to land-use modelling, this implies that the probability of a certain land-use type at a certain location depends on the utility that can be derived from that location for that specific type of use in relation to the total utility of all other possible uses. The utility of a location can be interpreted as the suitability for a certain land-use and thus this probability can be calculated as follows:

$$X_{c,i} = e^{\beta * S_{c,i}} / \sum_k e^{\beta * S_{c,k}}$$

where $X_{c,i}$ is the probability of cell c being used for land-use type i, $S_{c,i}$ is the suitability of cell c for land use type i, $S_{c,k}$ is the suitability of cell c for all k land-use types and β is a parameter to adjust the sensitivity of the model. As in empirical models, different factors may explain the suitability of a location. Soil characteristics largely determine the most profitable type of agricultural use, while accessibility to relevant infrastructures and spatial policies will restrict or promote certain land-use types.

Suitability is assessed by different potential users and as such can be interpreted as a hedonic price (Buurman, 2003). Hedonic prices can be regarded as the implicit prices of attributes, as they are revealed to economic agents from observed prices of differentiated products and the specific amounts of characteristics associated with them (Rosen, 1974). In the case of land, the hedonic price of a parcel can be determined by valuing its features. This valuation process differs among agents according to the parcel's properties and the amenities each one can derive from them. By coupling together bid rent and discrete choice theories, it is thus possible to describe the land market clearing process, where a land seller compares alternative bids and sells to the actor with the highest bid. The user deriving the highest benefit from a location will offer the highest price. In this way, the revenue of the sellers is maximized, as well as the utility of the buyers (Martinez, 1992).

Two model applications applying an economic framework will be presented below. While the first model is able simulate land-use patterns at the national level, the other is intended to simulate urbanization patterns at the local scale.

10.2.1. Land Use Scanner

Land Use Scanner (Hilferink and Rietveld, 1999) is an example of a land-use model in which bid rent theory and an allocation algorithm based on discrete choice theory are implemented to investigate future land-use patterns. *Land Use Scanner* has been extensively used for policy-related research projects in the Netherlands, such as the evaluation of alternatives for a new national airport (Scholten et al., 1999), the simulation of future land use following different scenarios (Schotten and Heunks, 2001), the preparation of the Fifth National Physical Planning Report (Schotten et al., 2001) an outlook for the prospects of agricultural land use in the Netherlands (Koomen et al., 2005), assessment of water management options (Dekkers and Koomen, 2007) and to explore the feasibility of bioenergy crops under climate change scenarios (Kulmahn et al., forthcoming).

In this model, the allocation of competing land-use classes is simulated by assuming that each cell will obtain the land-use yielding the highest net socio-economic benefits. Thus the model mimics a land market, in which land-use classes fulfil the role of buyers. Their bid prices for a particular cell are determined by the benefits they can extract from it, and those in turn depend on its suitability for each land-use class. The definition of local suitability may incorporate a large number of spatially explicit datasets encompassing four main characteristics considered to influence the suitability for any particular use, namely (Loonen and Koomen, 2009):

- present land-use, which entails the starting point of the simulation of future land use, being therefore an important element on the specification of suitability and regional land-use claims;
- physical characteristics such as soil, groundwater level and relief, which are specially important on the definition of suitability for agricultural uses as they directly influence possible crop yields;
- market forces, generally expressed in distance relations such as proximity to urban areas, infrastructure and other relevant places;
- zoning policies, such national nature development zones, water management, preservation of landscape values and municipal urbanization plans;

- amount of similar land-use in the neighbourhood, by using a potential function with a parameterised range and decay.

On the basis of these characteristics, the model constructs scenario-dependent suitability maps for any particular land-use. Then, model then optimizes future land-use according to external regional projections on land-use claims derived from sector-specific models developed by specialised institutes (Hilferink and Rietveld 1999, Loonen and Koomen, 2009). Hence, the local suitability s_{cj}, representing the net benefits of land-use type j in cell c, constitutes a crucial variable for the allocation model. The greater the suitability for land-use type j, the greater the probability that the cell will be used for this type. A doubly constrained logit model is established to determine this probability, by imposing two conditions: (1) the overall demand for each land-use function, and (2) the amount of land which is available.

The Land Use Scanner provides an integration framework for sectoral models and policy proposals, being capable of simulating simultaneously several different urban, industrial, agricultural and nature land-use types, depending on the level of data aggregation in the input models. However, some limitations have been pointed out to this modelling framework. Firstly, the demand for land is not linked with land prices, though one would expect that the demand for land decreases when land prices rise. In fact, the bid rent theory was originally developed according to the North American situation, thus assuming abundance of land. Therefore, it could be claimed that the principles of the land market are not sufficiently addressed in order to confront supply and demand for land, specially in densely populated areas. Furthermore, the calibration parameters on suitability are often based on expert judgement, thus lacking transparency. Nevertheless it has shown capable of providing sensible spatial patterns of land-use (Loonen and Koomen, 2009).

10.2.2. Patuxtent River Watershed project

Irwin and Geoghegan (2001) developed an economic spatially explicit land-use model to simulate land-use change, particularly residential urbanization processes, within the counties of the Patuxent River Watershed in central Maryland, USA. Similarly to the *Land Use Scanner* approach, a framework based on discrete choice theory was developed, considering that the underlying motivation for landowners to convert land is profit maximization over an infinite time horizon. Accordingly to Bockstael (1996), it was initially assumed that a parcel j under state u will be converted to state r in time t only if:

$$W_{j,r,t|u} - C_{j,r,t|u} \geq W_{j,m,t|u} - C_{j,m,t|u}$$

for all land-uses $m=1,\ldots, a,\ldots, M$, being $W_{j,r,t|u}$ the net present value (discussed more extensively in the following section) of the future stream of returns to parcel j in state r at time t (considering that the parcel was in state u in time $t-1$) and $C_{j,\, r,\, t|u}$ the cost of converting parcel j from state u to state r in period t.

A spatially explicit hedonic pricing model of residential use was estimated and used to determine the value of residential land use, according to landscape features such as lot size, accessibility measures, neighbourhood zoning and ratio of land in different uses. Combining that with other variables representing costs of development and the value of land in agricultural use (estimated from separated models), a binary discrete model of land-use conversion was estimated using observations on actual residential development and then used to predict the probability of future development.

The temporal dimension was posteriorly taken into account by considering the land-use conversion decision as an optimal timing decision in which the land owner aims to maximize expected profits by choosing the optimal time in which the present discounted value of expected returns from converting the parcel to a residential use is maximized. Taking δ as the discount rate and A as the return that would be derived from land in its undeveloped use in one period, land-use development is hypothesized to happen in the first period where the following conditions are simultaneously true:

1) $W_{j,r,t|u} - C_{j,r,t|u} - \sum_{t=0}^{\infty} A_{j,u,t+T} * \delta^{T+t} > 0$, which states that the parcel will be converted when the net returns from urbanization are greater than the forgone returns from keeping the land in an undeveloped use over an infinite time horizon (thus being the NPV of the forgone returns from agricultural land-use represented by the last term of the first condition);

2) $W_{j,r,T|u} - C_{j,r,T|u} - A_{j,u,T} > \delta(W_{j,r,T+1|u} - C_{j,r,T+1|u})$, which states that the parcel will be converted when the expected returns from converting in period T minus the opportunity costs of conversion are greater than the discounted net returns from converting in period T+1.

Thus the model is able to predict both the spatial location and the timing of residential development, allowing the assessment of the effect of different policies on land-use patterns, providing insights into the spatial and temporal dynamics of land-use change (Irwin and Geoghegan, 2001). However, likewise Land Use Scanner, considerations on the elasticity of land prices according to land demand and availability are not taken into account.

10.2.3. Optimization models

Optimization models are an alternative modelling approach in which mathematical optimization techniques such as linear integer programming or neural networks are applied to calculate the optimal land-use configuration, given a set of prior conditions, criteria and decisions variables (Koomen and Stillwell, 2007). While the simplest applications aim to optimise a single objective (e.g. profit maximisation), there are also more elaborated techniques that are able to determine the optimal solution for different and even divergent objectives.

Optimization techniques have been recently used in a number of applications regarding biofuel plant siting (e.g. Tittman et al. 2010; Giarola et al., 2011). For instance, the Bioenergy Sitting Model (BSM) is an optimization model that was developed to determine the optimal biorefinery location, size, and type in California (Tittman et al., 2010). Transportation network analysis using GIS was coupled with a mixed integer-linear programming optimization model applying techno-economic optimization algorithms and taking into account parameters such biomass yield, feedstock supply and price, transportation infrastructures and costs, conversion technology and efficiency and (regional) biofuel demand. The BSM goal is to maximize the total industry profit from the production of bioenergy at a given market price for fuels, electricity, and their co-products.

Giarola et al. (2011) proposed a multi-objective mixed integer linear programming framework to optimize simultaneously the environmental and economic performances of hybrid first and second generation bioethanol supply chains, considering alternative production technologies as well as optimizing the whole biofuel system within the same modeling framework. This is conceived as an optimisation problem in which the production system is required to comply with two objectives: (1) maximisation of the economic performance of the business (Net Present Value) and (2) minimisation of the impact on global warming in terms of overall GHG emissions in operating the system. A long list of parameters is taken into account, namely fuel demand and geographical distribution of demand centres; biomass geographical availability, production costs and location of biomass production sites; yields, capital and operating costs as a function of biomass type, production technology and plant scale; environmental impact of biomass and biofuel production as a function of biomass type, geographical region and production technology; transport logistics such as modes, capacities, distances, availability, environmental impacts and costs; biofuel market characteristics; and finally, energy market prices and existing subsidies. Ultimately, the goal is to optimise the following variables: geographical location of biomass production sites; biomass production rate and feedstock mix to the plant; bioethanol facilities technology selection, location and scale; characterisation of transport logistics; economic performance of the system; system impact on global warming.

Although these models provide insight into the economic potential of using biomass resources, they normally put the emphasis on the economic drivers, while using very coarse resolutions when dealing with biophysical drivers for crop production and modelling. As such, they somewhat neglect the importance of spatial variation of biophysical parameters on the biofuel production potential, thus being more indicated for biofuel plant siting rather than biofuel crops allocation.

10.3. Final remarks on empirical vs. theoretical models

In the previous section, a number of land-use modelling approaches were reviewed. It can be concluded that both empirical and theoretical approaches have their advantages and drawbacks for different purposes. *Ad hoc* empirical models are able to incorporate a larger number of processes than theoretical models and have proven to fit the spatial allocation processes reasonably well (Overmars et al., 2007). However, they do not explain the human behaviour leading decision-making processes in a systematic manner (Irwin and Geoghegan, 2001). Moreover, empirical models are based on the extrapolation of past land-use trends and as result they are not well suited to handle discontinuities in the land system, such as introducing new land-use types.

Conversely, since theoretical models describe land-use processes explicitly, they are able to handle discontinuities (e.g. a new biofuel crop), thus allowing to evaluate a wider range of scenarios. However, despite of explicitly explaining the causality between human behaviour and land-use changes, an economic framework does not always imply an improvement in the model's predictive power (Overmars et al., 2007). Furthermore, the realism of the conventional concept of rational behaviour underlying most of these theoretical approaches remains debatable, due to the difficulty that people can have in evaluating their own preferences, short-run propensity to pursue immediate gratification and the pursue of other goals than self-interest such as fairness, reciprocal altruism and revenge (Rabin, 2002; Verburg et al., 2004c).

11. Appendix D: Choosing the modelling approach

The choice of the land-use modelling approach depends on the research question, on the characteristics of the study area and to a certain extent on the availability of data (Verburg et al., 2006). According to these criteria and based on the review provided in Appendix C, the empirical and theoretical approaches to be implemented in the present assessment will be chosen.

11.1. Empirical approach

A number of empirical modelling approaches were previously discussed. It can be concluded that cellular automata, multi-agent models and microsimulation are not appropriate for this project as they appear to be more suitable for small extent areas, while the research question aims for an analysis at the national level. Furthermore, calibration processes are not standardized and are often quite complex, while demanding a great amount of detailed data at the local level which may not be readily available. This may lead to a time-consuming process without however guaranteeing a comprehensive model (Verburg et al., 2006; Rindfuss, 2004).

Instead, a model calibrated through statistical analysis will be developed. This type of modelling approach has proved to be able of successfully modelling and exploring the effect of land-use policies in agricultural systems in large extent areas (e.g. Verburg et al. 2009; Perez-Soba et al., 2010) thus fitting in the study area extent and research goals. Furthermore, the calibration of such a model relies in standardized statistical methods which are available through regular statistics software packages and are easily reproducible by others, thus guaranteeing transparency.

Statistical models try to capture the relation between land-use and the spatial variability in the biophysical and socio-economic environment through statistical techniques (e.g. regression analysis) in order to improve the explanation of the processes driving land-use change and to predict spatially-explicit projections of the change itself (Verburg et al. 2004c; Koomen and Stillwell, 2007). They are normally based on the analysis of the spatial structure of land use through remote sensing, geographic information systems (GIS) and macro-properties of social organization. A GIS software package can be used to process all spatial data and convert it into a regular grid, allowing to overlay land-use patterns with maps depicting biophysical and socio-economic characteristics. In such a setting, the study area can be regarded as a statistical population where each gridcell constitutes an individual observation with certain attributes specific to its location, namely land-use type (e.g. residential area, agriculture, nature), biophysical properties (e.g. soil type, annual precipitation, slope) and socio-economic features (e.g. population density, accessibility to main cities).

11.2. Theoretical approach

Regarding the theoretical approach, two different methods were identified in the literature review, namely optimization models and economic models based on bid rent theory. However, optimization models are normally only able to handle biophysical factors at very coarse resolutions, especially in large extent areas. Therefore they somewhat neglect the importance of spatial heterogeneity of these drivers on determining land-use, thus being better tailored to simulate biofuel plant sitting rather than the allocation of biofuel crops. Hence this approach does not fit the research goals and it will be discarded.

Instead, a model based in bid rent theory is developed. This type of modelling technique has proved to be capable of investigating future land-use patterns in policy-related research projects at the national level, namely on the simulation of future land-use following different scenarios (Schotten and Heunks, 2001), an outlook for the prospects of agricultural land use (Koomen et al., 2005), and to explore the feasibility of bioenergy crops under different climate change scenarios (Kulmahn et al., forthcoming). Therefore, this method is well-suited to answer the research question and thus is deemed as the most appropriate theoretical approach to be implemented in this study.

The bid rent theory assumes that in a competitive land market the bidder with the highest bid will be able to purchase/rent the land (Alonso, 1964). The economic performance of different land-use types is performed by assuming that each cell will obtain the land-use yielding the highest net economic benefits. Thus this model mimics a land market, in which land-use types fulfil the role of buyers. The bid prices for a particular cell are determined by the benefits that can be extracted, which in turn depend on its suitability for each land-use type.

12. Appendix E: Characteristics of the land-use model

12.1. Unit of analysis

In the large majority of spatially explicit land-use models, the unit of analysis is a spatial object representing an area of land, either a vectorial polygon representing a plot or census track, or a pixel cell as part of a raster grid (Figure 39). Ideally, the unit of analysis should coincide with individual decision-making agents. For instance, at the most local level, if the unit of analysis is the farm, then the match between land unit and the land-use agents (i.e. the farmers) is very good (Verburg et al. 2006). Therefore, modelling land-use accordingly to the boundaries of land ownership would be greatly preferable, since that would allow to distinguish effects of technology or policy change among large and small landowners.

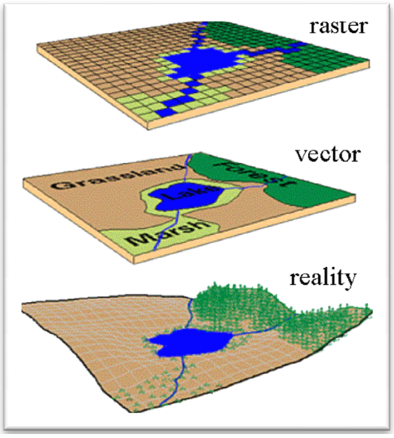


Figure 39: Comparison of raster and vector data structures on representing real-world features (source: www.lincoln.ac.nz)

However, land-use models rely to a great extent on geographical information databases, which traditionally represent land cover and features in grid cells defined in a regular raster pattern (Koomen and Stillwell, 2007). The reason for this is because raster data are computationally more efficient than vector data, specially when carrying out algebraic and logical operations in multiple layers. Furthermore, vector layers are not as well suited to represent spatially continuous data (e.g. elevation, slope, soil clay content, etc) as raster layers. Since vector and raster data cannot be used simultaneously when doing GIS analysis, raster databases are the most common option for land-use models. This was indeed the case in similar previous modelling frameworks (e.g. Hilferink and Rietveld, 1999; Verburg and Overmars, 2009; Koomen et al., 2010). Therefore, raster-based grid cells will be used as the model unit of analysis in this research project.

12.2. Spatial and temporal scale

Scale refers to the quantitative or analytic dimension used to measure and study objects and processes (Gibson et al. 2000). As such, all scales have extent, i.e. the magnitude of a dimension used in measuring, and resolution, i.e. the precision used this measurement (Verburg et al., 2004c).

The total extent of the study area corresponds to the area of the Argentinean mainland territory. According to Verburg et al. (2006), the functioning of land-use systems should be represented at different scales in order to properly capture the result of multiple processes occurring at distinct levels. However, models relying on geographic data often use a regular grid to represent all data and processes and therefore the resolution of analysis is determined by the measurement technique and data quality rather than by the specified processes (Verburg et al., 2004c).

Ideally, the data resolution should allow for a detailed analysis. However, modelling such extensive areas can be very demanding in terms of computing power and involves the management of large datasets, which can result in technical troubleshooting and/or lengthy simulation runs. Frequently, a coarser map resolution is used in order to overcome these issues, but that implies a lower level of detail on the analysis. Furthermore, one of the requirements of the modelling tool in use is that all maps have to keep the same measurement unit. Thus it was decided to adopt a map resolution of $1km^2$, which is also one of the most commonly used spatial resolution for large extent areas in existing modelling tools, since it allows for a compromise between a reasonably good level of detail, efficient computing time and a more practical data handling during modelling and further calculations.

At the same time, the temporal dimension is also a relevant feature in land-use modelling. Regarding the temporal extent, a time-frame up to 2030 will be considered. Land-use change shows non-linear behaviour, accounting for feedbacks, path-dependency and dependency to initial conditions. Furthermore, land-use decisions can be made at different time-scales, as previously discussed. Thus, dynamic modelling with short-time steps is often required (Verburg et al., 2004c). However, surveys on economic statistics are normally available on a yearly basis and as a result, most land-use models use annual time-steps in the calculations. That will be indeed the temporal resolution used in the present modelling framework.

12.3. Neighbourhood interactions

Land use patterns frequently exhibit spatial interaction and neighbourhood effects. This implies that developments in land-use do not occur independently at each individual location, but rather they affect and are affected by the conditions of neighbouring locations (Verburg et al., 2004b). Positive spatial autocorrelation can be explained by the clustered distribution and gradients of landscape features (Verburg et al., 2006), and increasing returns to scale (Krugman, 1991; Borck et al., 2010), while negative spatial autocorrelation often occur due to negative externalities such as congestion effects (Irwin and Geoghegan, 2001).

In agricultural systems, environmental spatial externalities resulting from the movements of materials such as water, soil, plants, pests, pollens, and contaminants, and social spatial externalities involving changes in information flows, transaction costs, fixed costs and shared infrastructure have been empirically identified as being able of affecting the returns on farmers' income in either a positive or a negative direction depending on the context (Lewis et al., 2008).

Verburg et al. (2004a) proposes a method to quantify and implement neighbourhood interactions in land-use modelling through empirical analysis. In this approach, neighbourhood enrichment factors are included as explanatory variables in statistical analysis. The enrichment factor consists in a measure determined by the occurrence of a land-use type in a particular neighbourhood ring surrounding a central grid-cell.

Similarly, in the present model framework, the amount of grid cells in the immediate surrounding that are already part of a particular land-use class will be also taken into account as a driving factor. As land-use change in time, the model counts in every time step and for every dynamic land-use class the cells in the immediate surrounding that are already from that a land-use class.

12.4. Land-use conversion elasticity

Due to the characteristics of both ecological and social systems, the resulting land-use systems often show stability and resilience to disturbances and external influences (Verburg et al., 2002). Consequently, sudden changes in driving factors will not immediately result in a change of the structure of the land-use system.

In order to deal with these features while modelling land-use systems, conversion elasticity is normally introduced for every possible conversion from one land-use type into any other. It can be interpreted as the monetary or institutional cost of converting from one land-use to another. Within the present model, current land-use is taken into account by using a matrix in which is depicted to which land use type can be converted to another and the relative probability of this conversion.

12.5. Feedback mechanisms

Feedback loops are important features of land-use systems. According to Verburg (2006), three different types of feedbacks can be identified:

- feedbacks between the driving factors and the effects of land-use change
- feedbacks between local and regional processes of land-use change
- feedbacks between agents of land use-change and the spatial units of the environment.

Since, the unit of analysis of the modelling framework is a grid-cell, it is not possible to take into account the latter type of feedback mechanism. Feedbacks between driving forces and impacts can be operationalized by coupling a land-use model with a landscape process model e.g. simulating water and tillage erosion and sedimentation (Claessens et al., 2009). However, the development of such a framework is extremely complex and requires the necessary expertise to provide consistent results.

On the other hand, cross-scale dynamics and processes can be unravelled through multi-level statistics techniques on hierarchally-structured data (e.g. Overmars and Verburg, 2006). Yet, such approach depends on the availability of refined data and it has been fundamentally implemented to analyse cross-scale dynamics between scales at the micro-level (e.g. from field and household to village scale), while the present framework is essentially focused on analysis at macrolevel.

Therefore, the only feedback mechanism that is going to be incorporated in the present modelling framework is the one resulting from dynamic modelling, that is land-use patterns and resulting neighbourhood relationships in a certain time-step will influence the land-use configuration in the following time-step, leading to a path-dependent evolution of the land-use system. Even though this does not fully reflect the whole complexity of the land system, a simpler model will allow to trace back the causality of the simulated outcomes and thus to provide meaningful results.

12.6. Land-use typology

Land systems can be depicted in a map according to the observed land-cover, i.e. natural vegetation, crops and human structures, and land-use i.e. the purpose for which humans exploit the land cover, including the provision of marketable goods and services

(Lambin et al., 2006). Land-use change is usually represented as a discrete change from one land-use type to other. As a result, land-uses systems have to be characterized according to a typology of distinct land-cover/use classes (e.g. urban areas, cropland, grassland, etc) in order to model land-use change.

The present model is flexible enough to allow the user to tailor its own land-use classification, according to the characteristics of the study area and research goals. Hence, a land-use typology will be designed specifically for this study case. Since the focus of this project is on modelling the provision of different goods from the agricultural sector, special attention will be given to the main land management practices in this sector, namely to the most relevant crop rotation schemes and livestock production systems currently existing in Argentina.

Land-use systems are usually represented through maps using a typology based on more or less general land-use types (e.g. urban areas, cropland, grassland, pastures, forests, mosaics of land-uses, etc). However, Argentina is a very large country with quite significant regional differences in terms of agricultural production. Therefore, such a general typology is not able to capture the diversity of the existing production systems. In fact, Carballo (2011) argues that meaningful results can only be obtained if these regional differences are explicitly incorporated in the model, namely by explicitly simulating the spatial distribution of each type of production system as a dedicated land-use class. Therefore, a more refined land-use typology was derived.

Firstly, the most common types of production systems were identified. This characterization was performed according to the spatially-explicit analysis of regional statistics on agricultural productivity at the department level presented in section 2.2.2, literature review and consultation with experts and stakeholders in Argentina. After identifying the main production systems, it had to be ensured that each type production system would correspond to a land-use type in the map that is used as starting point for simulation. Firstly, a map depicting the regions where each type of production system is dominant at the department level was created, according to the information gathered in the previous step. Then, this map was overlapped with an available land-use map originally using a more general land-use typology.

12.6.1. Main production systems in Argentina

Agricultural production systems are extremely varied along the study area. More than 100 homogeneous agroeconomic zones (HAZ) can be identified in Argentina, according to their environmental characteristics and socio-economic aspects such as production orientation, predominant activities, number and size of agricultural holdings, type of land tenure and social organization of labor (INTA, 2009a). Despite of providing a very detailed description of the existing production systems, such a comprehensive characterization is not deemed as appropriate to be applied as a land-use modelling typology. Thus, it is necessary to proceed to a further generalization of these features in order to design a land-use typology capable of, on the one hand, providing meaningful results, and on the other hand, allowing for an efficient computation.

Two main criteria were used to define land-use types: production orientation (i.e. whether production system is oriented to agriculture, mixed rotations or livestock production) and the share of each crop and livestock in the rotation scheme of each production system. Firstly, the dominant types of production systems were identified by analysing the spatially explicit statistics on crop cultivation at the department level already presented in section 2.2.2. According to literature review, the description of the production systems is completed by identifying the main types of production orientation in each region. Three types of production orientation will be considered: agricultural, mixed rotations and livestock production systems.

The study area is essentially characterized by rural production systems with intensive use of equipment and management and extensive use of land, essentially comprising oilseeds, grain crops and cattle-raising to produce beef and dairy products. Land-intensive activities such as horticulture, floriculture and fruit production are also important in economic terms. However, their use of land is virtually insignificant when compared with land-extensive activities and they are mostly concentrated in relatively small areas next to the main urban centres and transportation hubs, such as the cities of Buenos Aires, Cordoba, Santa Fe and Rosario and along the Uruguay river coast in Entre-Rios province (INTA, 2009a; INTA, 2009b; INTA, 2009c; INTA 2009d). Henceforth, the present study will solely focus in the future developments of activities with extensive use of land, in particular livestock production for beef and milk production and cultivation of soy, corn, wheat and sunflower. These activities represented altogether 77% of the total value in exports of agriculture production in Argentina during 2005-2007 (Lence, 2010). Furthermore, the cultivation of soy, corn, wheat and sunflower accounts for roughly 86% of the total area used for land extensive agriculture in the study area (INDEC/SIIA, 2011).

Cotton appears to be quite an important crop in the provinces of Chaco (23.5% of total cultivated area) and specially Formosa (40% of total cultivated area). However, these regions only account respectively for 5.2% and 0.1%, of the total cultivated area within the study region. Other crops such as sorghum, oat and malting barley are becoming relatively important in the study area, but they are usually cultivated as part of a rotation scheme in which at least one of the aforementioned crops is predominant. For instance, malting barley has been increasingly incorporated in soy/corn/wheat rotation schemes in less suitable zones of southeast Buenos Aires province. Malting barley has been found to increase yields of soy cultivated as so-called *soja de segunda*, a multicropping practice in which soy is seeded right after the harvest of a winter crop (in this case, barley). Attainable soy yields are lower in comparison to regular soy cultivation (so-called *soja de primera*) because the practice is performed out of the optimal season for soy cultivation and growing periods are smaller. Nevertheless, the main goal is actually to generate higher profits from an additional annual soy harvest rather than the cultivation of barley itself, which accounts for a much smaller margin (Garre, 2011).

Therefore, characterizing the study area according to the observed patterns of livestock production and cultivation of soy, sunflower, wheat and corn can be considered a good approximation and allows focusing in the production systems that are more relevant in terms of land-use. Statistics on production, amount of cultivated area and number of cattle heads at deparment level (the second level of administrative division in the provinces of Argentina and the smallest unit for which statistics on agricultural production are available (INDEC, 2011)) were collected in order to analyze and visualize the spatial patterns of the considered production systems. The period between 2003 and 2011 was considered, which according to Carballo (2011) it is a good reference timeframe, since it follows a period of relative economic stability.
Region Pampeana was taken as the reference for the definition of production systems. Three main reasons account for this option:

- statistics regarding agricultural production in Chaco eco-region are not as consistent and reliable as those available for Region Pampeana (e.g. statistiscs for a certain crop might be available at the provincial level, but not at the department level);

- Region Pampeana is currently the area in Argentina with the highest agriculture intensity and livestock density, accounting for the majority of the agricultural production, thus allowing for a more significant statistical analysis;

- the expansion commercial agriculture in Chaco eco-region occurs mainly due to the investment coming from producers and enterprises already operating in Region Pampeana (RIAN/INTA, 2009). Thus, comparable farming techniques and technological packages can be expected to be transferred from Region Pampeana to Chaco eco-region.

Statistics regarding the share of each crop on the total cultivated area per department in Region Pampeana were overlapped. Four main regions could be identified according to the observed patterns of agricultural production (Figure 40):

- region 1 (red): this region is mostly characterized by the absence of soy cultivation and thus only wheat, corn and sunflower are assumed to be produced within these areas. It largely coincides with the so-called *Zona de Riego y Ganadera del sur de la provincia de Buenos Aires y faja central de La Pampa* (Lorda et al., 2008; INTA 2009f). Within this region, livestock production systems are the most predominant production orientation, while pure agricultural systems are almost inexistent (Caviglia et al., 2009; INTA. 2009f). Therefore, crop cultivation will be assumed to occur only in mixed rotations.

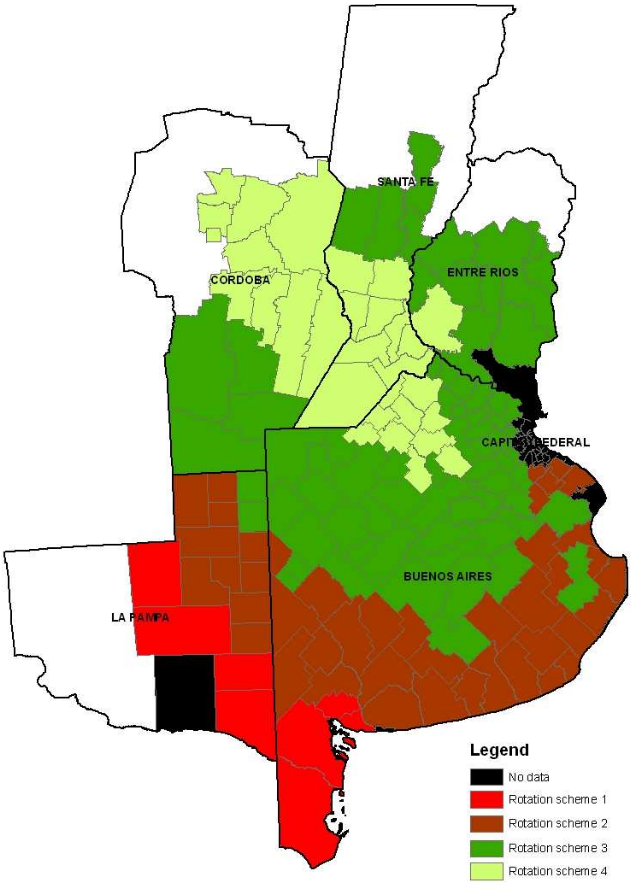


Figure 40: Main rotation schemes in Region Pampeana

- region 2 (brown): this region is characterized by rotation schemes in which soy has a share lower than 40% on the total cultivated, while the remaining area is cultivated with wheat, maize and sunflower. This region largely coincides with the so-called *Zona Mixta del suroeste de Buenos Aires y centro norte de La Pampa* (Lorda et al., 2008, INTA, 2009f) and *Zona Mixta del centro sur de Buenos Aires* (INTA, 2009f). In these regions, mixed rotations are the most prevalent type of production orientation, followed by livestock production systems. Albeit existing, agricultural systems have a very low occurrence (INTA, 2009f).

- region 3 (dark green): in this region, soy is the most prevalent crop, showing a share on the total cultivated area higher than 40%. Wheat, corn and, to a lesser extent, sunflower account for the remaining share. This region largely coincides with the so-called *Zona Mixta del noroeste de Buenos Aires, este de La Pampa y sur de Córdoba* (Lorda et al., 2008; INTA, 2009a; INTA, 2009c), *Zona Ganadera Agrícola del sureste de Entre Ríos* (INTA, 2009b) and *Zona Mixta Ganadero Agrícola del norte de Santa Fe* (INTA, 20009e). These regions are characterized by having similar shares of livestock production and agricultural production. Region 3 also partly overlaps with the so-called *Zona Ganadera de la cuenca del Salado* (INTA, 2009f) and *Zona Lechera del centro este de Córdoba y centro de Santa Fe* (INTA, 2009d), which were zones previously renowned as being highly specialized in cattle-raising for meat and milk production, respectively. While these regions still remain mostly oriented for livestock production, the observed high share of soy cultivation may provide an indication that this crop is already being introduced in these otherwise livestock-specialized regions, thus resulting in displacement of livestock (INTA, 2009f).

- region 4 (light green): the main characteristics of this region are soy being clearly the most dominant crop with a share higher than 60% and sunflower being almost absent, with a share lower than 5%. The area under the influence of this rotation scheme mostly overlaps with the so-called *Zona Núcleo Agrícola del norte de Buenos Aires, sur de Santa Fe y sureste de Córdoba* (INTA, 2009a; INTA, 2009c; INTA, 2009d). This region is characterized by being highly specialized in agricultural production systems and high adoption rates of farming technology. Unlike the other regions, where land ownership is the most common land tenure regime, in region 4 land rental, partnerships and accidental contracts account for more than 50% of the farming production systems. On the other hand, it is also the region where issues on soil conservation resulting from soy monoculture have been more prominent (INTA, 2009d).

The criteria used to identify and classify production system regions in Region Pampeana were then applied to assign a type of production system to each department in Chaco eco-region. Some departments could not be automatically classified due to the lack of statistics, namely all departments in La Rioja province and a few departments in Santiago del Estero, Formosa, Cordoba and Entre Rios provinces. La Rioja departments were assigned as having production systems of region 1-type because its arid climate features resemble the arid regions of La Pampa were this type of production system can be found. The remaining departments were classified according to information on homogeneous agroeconomic zones available in relevant literature (Bravo et al., 2004, INTA, 2009a; INTA, 2009b; INTA, 2009c; INTA, 2009g). The resulting spatial distribution of production system types can be visualized in **Error! Reference source not found.**Figure 41).

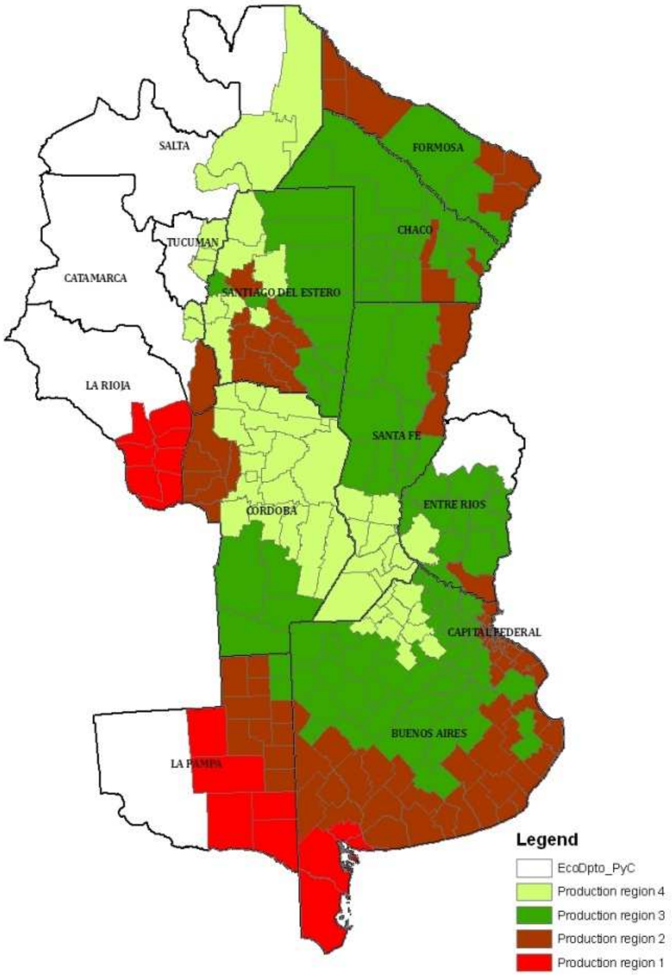


Figure 41: Spatial distribution of production system types in the study area

12.6.2. Land-use typology for agricultural land-use types in Argentina

The identified production systems had ti be translated into land-use types, by means of assigning a rotation scheme to each type of production system and specify how the original land-use types were assigned with a type of production system. **Error! Reference source not found.** summarizes the agricultural land-use typology used in this assessment, the relation between the identified production system types and the land-use types in the original land-use map, and the share of livestock and crops in each rotation scheme.

Table 21: Land-use typology and related rotation scheme

Land-use type	***Type of production system***	***Original land-use type to be assigned***	***Rotation***	***Source***
Mixed rotation 1	Region 1	- Cropland - Mosaic cropland/grassland	50% livestock 35% wheat 10% sunflower 5% corn	Adapted from Iturrioz et al., 2011, Lorda, 2011, according to statistics available in SIIA,2011
Mixed rotation 2	Region 2	- Cropland - Mosaic cropland/grassland	50% livestock 20% wheat 10% soy 5% corn 15% sunflower	Adapted from *Margenes Agropecuarias*, 2011, according to statistics available in SIIA, 2011
Agricultural rotation 3	Region 3	- Cropland	50% soy (*soja de primera*) 20% soy (*soja de segunda*) 20% wheat 20% corn 10% sunflower	Adapted from *Margenes Agropecuarias,* 2011, according to statistics available in SIIA, 2011
Agricultural rotation 4	Region 4	- Cropland	70% soy (*soja de primera*) 15% soy (*soja de segunda*) 15% wheat 15% corn	Adapted from Lorda, 2011, according to statistics available in SIIA, 2011
Livestock production	Region 1, 2, 3 and 4	- Grassland - Mosaic cropland/grassland in region 3 and 4	100% livestock	-

It was assumed that in the areas under the influence of production regions 1 and 2, crop cultivation only takes place in mixed rotation systems. As a result, these regions do not account for a pure agricultural land-use type. On the other hand, in Region 3 and 4, agriculture was assumed to take place only in pure agricultural rotation schemes, in order to reflect the observed specialization either in agriculture or livestock production (2011a). It should be noted that both agricultural rotation schemes 3 and 4 exceed 100%. This is due to the fact that the multicropping soy cultivation practice known as *soja de segunda* is assumed to be performed in the same land plots where wheat was previously cultivated. In fact, if the share of *soja de segunda* is not taken into account, the sum of the crop ratios does amount to 100%.

Livestock production will be assigned to all cells classified as grassland/shrubland in the study area and to mosaic of grassland in region 3 and 4. No distinction was made between livestock production systems for meat and milk production. According to the demand for these products, the total number of grass feed required to fulfill the demand was determined, according to which the allocation of land for livestock production will take place, irrespectively of the final product.

12.7. Land-use driving forces

Land-use driving forces can influence land-use change in different ways. While some of these factors mainly determine the location of land-use change (e.g. the soil suitability for agricultural land-use) others also influence the rate and quantity of land-use change (Verburg et al., 2002). Therefore, driving forces will be treated separately in two distinct modules: a non-spatial demand module that determines the area change for all land-use types at the aggregate level, and an allocation module that translates these demands into spatially-explicit land-use changes (Figure 42).

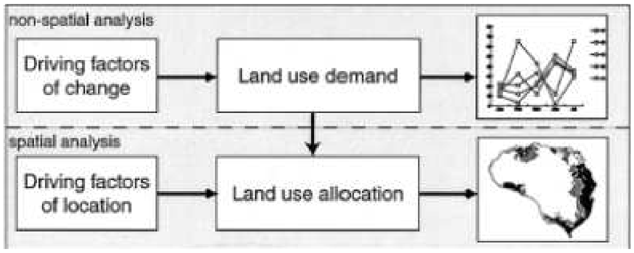


Figure 42: Demand and allocation modules of land-use driving forces (source: Verburg et al. 2002)

In the following sub-sections, the driving forces determining the demand and allocation module will be discussed.

12.7.1. Demand module

The area of land claimed by different agricultural land-uses will be assumed to depend on the demand for feed and crops, which in turn depends on the development in population size, level of affluence, consumer preferences and diet, exports and self sufficiency ratio (i.e. the extent to which domestic supply meets domestic demand). A similar assumption has been considered in previous assessments of bioenergy production potential (Smeets et al., 2007; de Wit and Faaij, 2008; Van der Hilst and Faaij, 2011).

The efficiency of the agricultural sector and possible future technological developments also play an important role, as those are a key factor in terms of land requirements to meet the total demand. The efficiency is determined by the type production system, the feed composition and the level of advancement of agricultural technology.

Since the evolution of the aforementioned drivers is highly uncertain, a scenario approach will be implemented in order to explore potential long term developments (as discussed in Section 3.9). The amount of land required to meet these demands will also depend on how land is allocated, since livestock productivity and attainable crop yields are local specific.

12.7.2. Allocation module

The spatial allocation of land depends on the relative local suitability for different land-uses. Biophysical factors affecting maximum attainable crop yields and pasture suitability and socio-economic factors have been identified as keys variable in the agricultural sector (Geist et al., 2006). Zoning policies such as nature conservation and land concessions may also imply restrictions on the use of land. The driving forces that are currently operating in the agricultural land-use system in Argentina were investigated through literature review and interviews with experts and stakeholders. Accordingly, the following driving forces will beassumed to influence the agricultural land-use system:

- Local biophysical characteristics, namely climate and soil suitability for crop cultivation and feed productivity, which directly determines the attainable yields. This has been identified has the most important factor determining the allocation of production systems, specially for crop rotation schemes. As technology developments such as no-till seeding allow for crop cultivation crops in otherwise economically unviable land, a trend of gradual substitution of pastoral and mixed systems by fully agricultural rotation systems has been observed in recent years (Lorda, 2011; Garre, 2011).

- Distance to the main markets and ports, which determines transportation costs (Lorda, 2011; Garre, 2011; Amorosi, 2011). The cities and ports of Rosario, San Lorenzo, Buenos Aires, Quequen, Bahia Blanca, Trenque Lauquen and Ibicuy have been identified as the main markets for agricultural commodities,

- Distance to cities and villages, which determines the availability of services. For instance, Garre (2011) has referred the importance of having services such as enterprises specialized in harvesting operations available nearby.

- Being surrounded by similar production systems, since it allows for joint contracts for particular services, such as harvesting, thus reducing operation costs (Garre, 2011). This factor relates to the issue of spatial autocorrelation and neighborhood relationships (see section 12.3).

- The availability of water resources have been considered important for livestock production, but not that relevant for crop cultivation. In fact, the share of irrigated agriculture in total arable land is below 5% (FAO, 2010). As installing and maintaining irrigation systems is considered too expensive by the majority of private producers, allocation of crop cultivation will rather depend on the reliability of local raining patterns.

- Population density is normally regarded as an important factor driving land-use change, but in this case it was not considered a relevant factor by any expert. In reality, with the exception of the metropolitan area of Buenos Aires federal capital, population density is rather low in Argentina. Furthermore, the process of agriculture expansion in Argentina appears to be more related to external demands than subsistence agriculture (Volante et al., 2005). Nevertheless, its importance in explaining the observed spatial patterns will be tested in the statistical analysis.

- Amorosi (2011) and Lorda (2011) have also mentioned the importance of the historical land-use in terms of decision-making on crop cultivation. For instance, a crop such as soy is not likely to be cultivated immediately after peanut, since peanut harvesting is executed by removing the entire plant from the soil including the roots, which significantly affects the soil texture and consequently its suitability. However, since spatially-explicit data on historical crop cultivation is not available, this factor cannot be taken into account.

13. Appendix F: Data

13.1. Demand module

The agricultural land system will be assumed to be driven by the demand for crops and feed, which will determined by the demand for food. Food demand is composed by the national demand and exports. The national demand for food depends on the population growth and per capita food demand, which can also vary resulting from changes in the level of affluence, diet and consumer preferences. The data sources regarding these variables are given in Table 22.

Table 22: Data sources for the variables determining food demand

Variable	*Data source*
Population	UNDP, 2010a
Level of affluence (GDP)	World DataBank, 2011; FAO, 2011
Food consumption	FAO, 2010; FAOSTAT, 2011; FAO 2011
Self-sufficiency ratio and exports	FAO 2011
Food processing, seed use and waste	FAO, 2011

Given the demand for food, the amount of land claimed for food production will depend on the efficiency of the production system. Regarding biofuel and food crops, this entails the maximum attainable yield by the different crops, while for livestock production it depends on the type of production system, feed composition, feed conversion efficiency and other technical conversion factors (e.g. milk production per animal, meat production per carcass, off-take rate). The data sources for these factors are summarized below in Table 23.

Table 23: Data sources for the variables determining the efficiency of the production systems

Variable	Data source
Maximum attainable yields	SIIA, 2011; *Margenes Agropecuarias*, 2011;
Production type	Bouwman et al., 2005; UNDP, 2010b; INTA, 2010b; SENASA, 2011; INTA, 2011b
Feed composition and feed conversion efficiency	Bouwman et al., 2005; Pordomingo, 2005; Vernet 2005; Machado, 2007; Vacrezza et al., 2009;
Technical conversion factors	Bouwman et al., 2005; Cap et al., 2010; UNDP, 2010b; Demarco, 2011; FAO, 2011;

Table 24: Projections of future population in Argentina, thousands of people (UNDP, 2010a)

Variant	2000	2005	2010	2015	2020	2025	2030
Medium	36931	38681	40412	42177	43856	45391	46761
High	36931	38681	40412	42570	44889	47228	49430
Low	36931	38681	40412	41784	42823	43555	44103

13.2. Allocation module

13.2.1. Spatially-explicit GIS datasets

The functioning of the land-use model depends on the availability of spatially-explicit raster datasets depicting the administrative boundaries of the country, spatially-explicit driving forces and current land-use. Historical land-use maps are also required to perform model validation. Table 25 summarizes the datasets that have been collected.. Similarly to Van Rossum (2011), all datasets have been reprojected according to the Universal Transverse Mercator projection system, due to the need to calculate surface areas in metric units.

Table 25: Spatially-explicit GIS datasets

Variable	*Data source*	*Year of recording*
Land-use GlobCover 2005	European Spatial Agency	2004 - 2006
Land-use GlobCover 2009	European Spatial Agency	2009
Land-use PNECO 2006/07	Instituto de Suelos, INTA CNIA	2006 - 2007
Soy suitability	Instituto de Clima y Agua, INTA CNIA	2009
Sunflower suitability	Instituto de Clima y Agua, INTA CNIA	2009
Corn Suitability	Instituto de Clima y Agua, INTA CNIA	2009
Switchgrass suitability	Instituto de Clima y Agua, INTA CNIA	2009
Wheat suitability	FGGD - FAO Geonetwork	2007
Pasture suitability	FGGD - FAO Geonetwork	2007
Cattle density	GLiPHA - FAO Geonetwork	2005
Road network	Instituto de Clima y Agua, INTA CNIA	2007
Railroad network	Instituto de Clima y Agua, INTA CNIA	2007
Population density	FAO Geonetwork	2007
Cities and towns	Instituto de Clima y Agua, INTA CNIA	2007
Protected nature areas	Instituto de Clima y Agua, INTA CNIA	2007
Elevation	PRORENOA, INTA	2007
Slope	Instituto de Clima y Agua, INTA CNIA	2007
Precipitation	Instituto de Clima y Agua, INTA CNIA	2007
Soils	RIAN, INTA	2010
Water bodies	Instituto de Clima y Agua, INTA CNIA	2007
Temporarily flooded areas	Instituto de Clima y Agua, INTA CNIA	2007
Salt flats	Instituto de Clima y Agua, INTA CNIA	2007

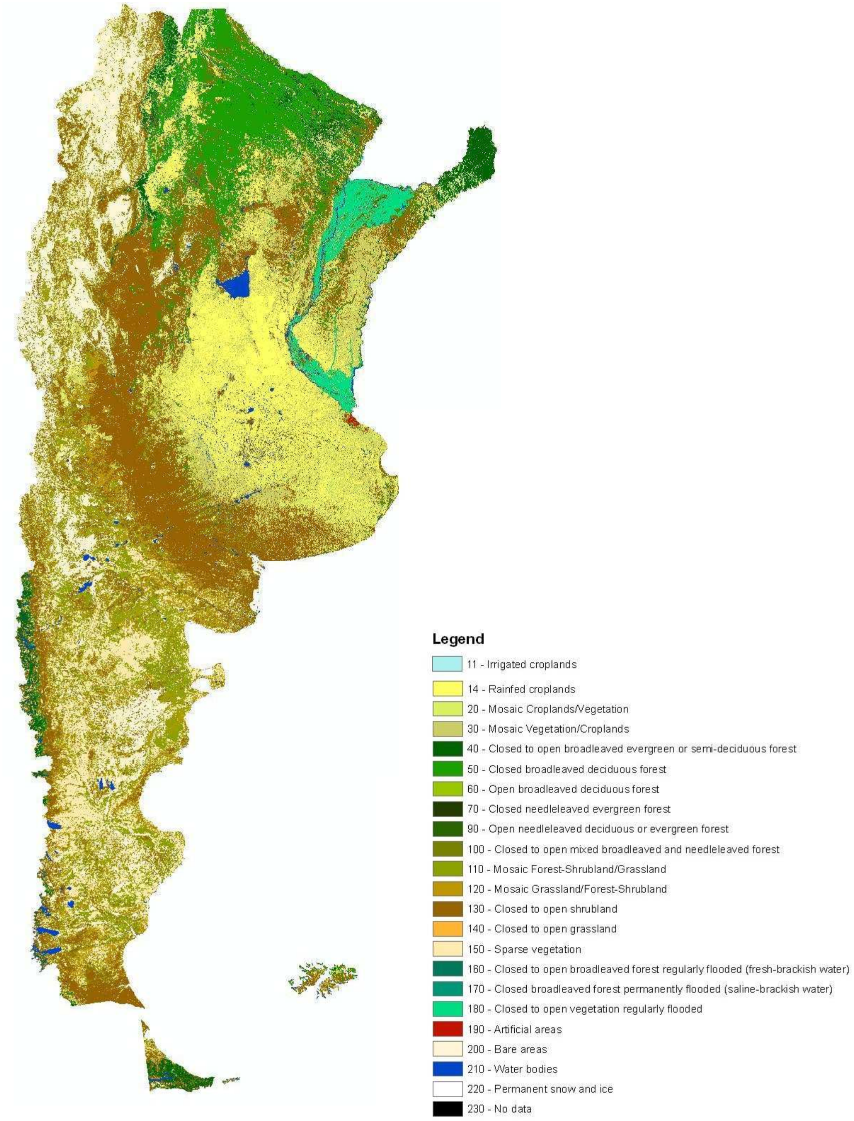


Figure 43: GlobCover 2009 – Argentina

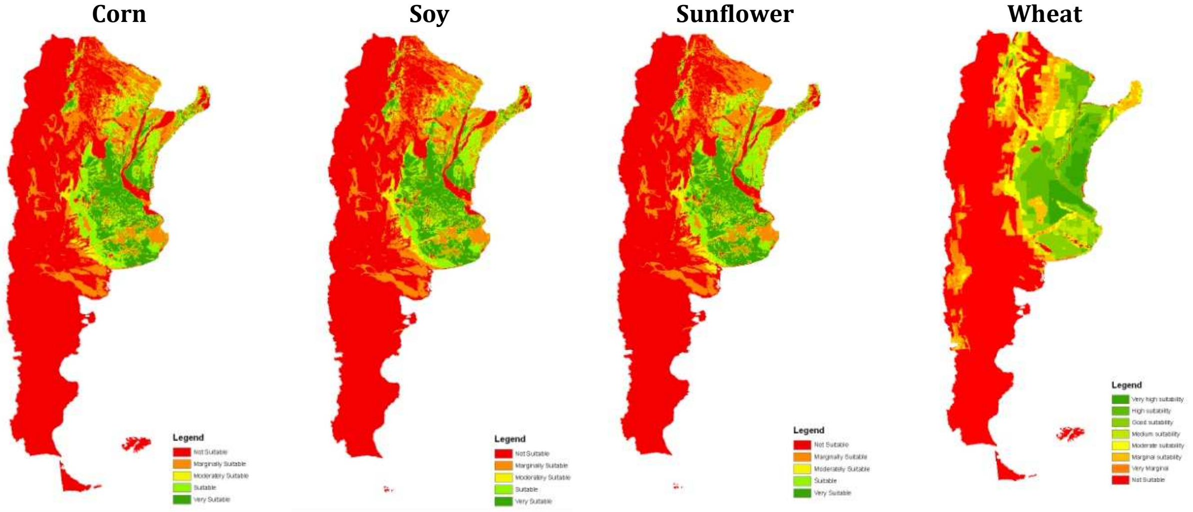

Corn **Soy** **Sunflower** **Wheat**

Figure 44.1-4: Corn, soy, sunflower and wheat biophysical suitability

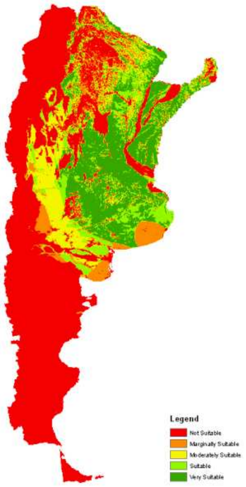


Figure 45: Switchgrass biophysical suitability

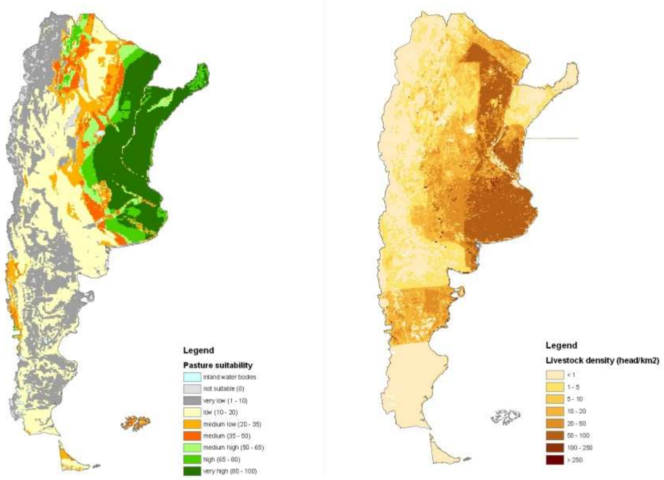


Figure 46: Pasture suitability and maximum livestock density

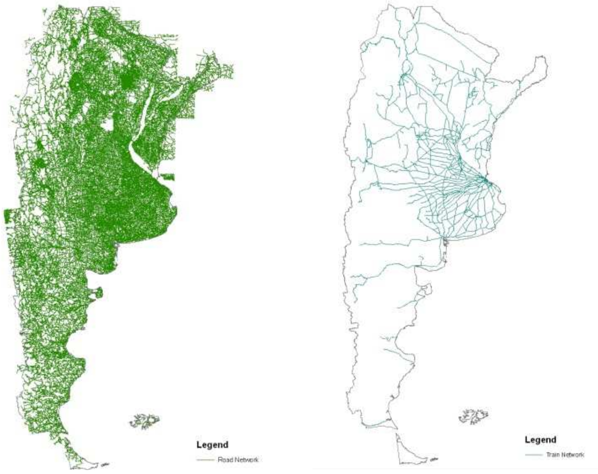


Figure 47.1-2: Road and train network

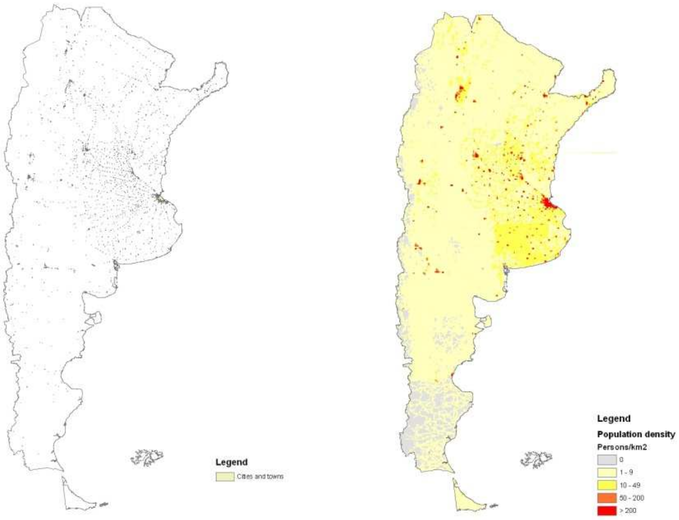


Figure 48.1-2 Urban areas and population density

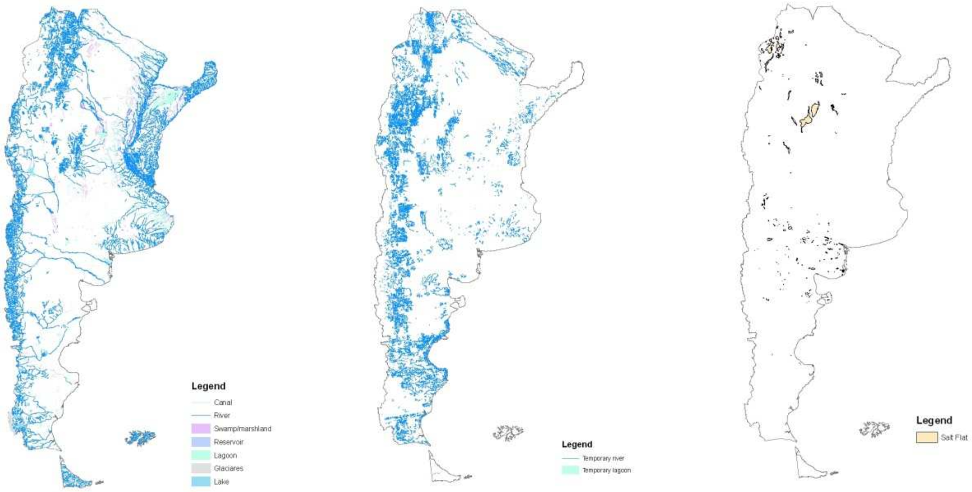


Figure 49.1-3: Permanent water bodies, temporary water bodies and salt flats

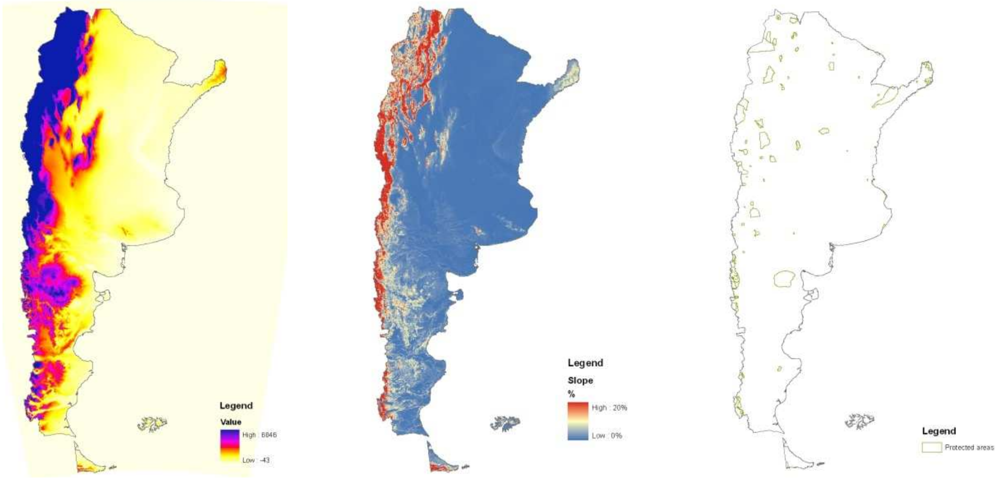


Figure 50.1-3: Elevation, slope and protected nature areas

Within the Eco-regions Nacional Program (PNECO) framework, a land-cover map depicting Argentina's territory in 2006/2007 was developed by INTA according to FAO Land Cover Classification System and based on Landsat TM and Modis-Terra satellite imagery. However, the map was produced with the goal of providing support on studies regarding dynamics of landscape ecology and territory planning and management at the regional level (INTA, 2009i), rather than assessments of land-use change at the local level. In fact, the dataset is originally in the shape file format, which is more suitable to depict and differentiate among areas with relatively homogeneous landscapes and do not reproduce so well the heterogeneity of landscape at the local level, for which raster files are more appropriate. For instance, large regions are depicted as being covered by agricultural use "*Graminoid crops*", but it is not distinguished at local level whether agricultural systems, mixed agriculture or cultivated pastures occur in these regions (Figure 51.1). Furthermore, this map consists in the first effort from INTA to produce digital cartographic information on land-cover and –use of the entire territory (INTA, 2009i). As a result, a comparable map from previous years is not available, which does not allow performing the validation of the model.

Therefore, ESA's global land-cover and -use map series (GlobCover) will be used instead. GlobCover is a dataset with a 300 meter resolution based on reflectance measurements of the MERIS medium resolution spectrometer of the ENVISAT satellite. Its typology includes not only dominant land-use types but also mixed land-use types expressing landscapes composed by a mosaic of crops, shrubland, grassland and forests. GlobCover2009 will be used as the base land-use map for simulation, while GlobCover2005 will be considered as the historical land-use map to perform the validation of the model. However, misclassification of land-use may occur in such global land-use datasets, due to either the use of general and somewhat ambiguous typology or issues on the interpretation of satellite imagery. For instance, the region of Salado river basin in Buenos Aires Province, an area renowned for livestock production, appears to be classified to a great extent as "*Cropland*" land-use type in GlobCover maps, while in fact it is mostly covered by natural grasslands (Figure 51.2). This issue may result from the fact that "*Cropland*" land-use type also includes herbaceous crops (Bontemps et al., 2010), thus explaining why pastures in this region are misclassified as farming land. Therefore, INTA's PNECO land-use map will be used to correct the occurrence of pastures in the GlobCover datasets.

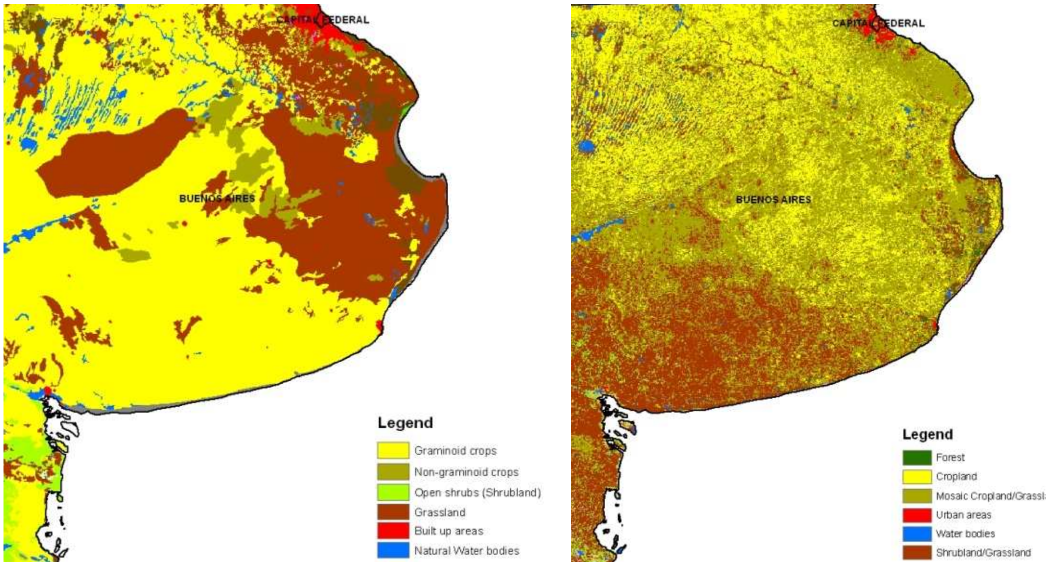


Figure 51.1-2: Comparison between PNECO and GlobCover 2009 land-use maps in Salado river basin

Maps depicting crop suitability were determined according to spatially explicit data on soil characteristics and crop requirements regarding raining patterns, temperature, solar radiation and frost resistance (FAO, 2009). These maps were then combined according to the weight of each crop in each rotation scheme to produce maps depicting the suitability of the considered production systems.

Datasets on water bodies, transportation network, cities and towns had to be further processed with ArcGIS software package in order to represent some of the factors assumed to drive the land-use system in Argentina, namely distance to water bodies, distance to markets and distance to cities and villages. Regarding distance to markets, firstly the main roads of the road network were selected (*Autopista* and *Ruta*). According to this, the distance to the main markets was calculated using the *Cost distance* function of Spatial Analyst toolset, which calculates the least cumulative cost distance for each cell to the nearest destination (i.e. one of the main markets) over a cost surface (in this case, main road network). However, this only depicts the distance to the markets of the cells that make part of the road network, while it is required to assign every cell in the study area with a distance value. Therefore, the remaining cells where assigned with the distance value of the closest road cell using the *Euclidean allocation* function (Figure 52). At the same time, the distance of each cell to the nearest road cell was determined using the *Euclidean dista*nce function (Figure 53).

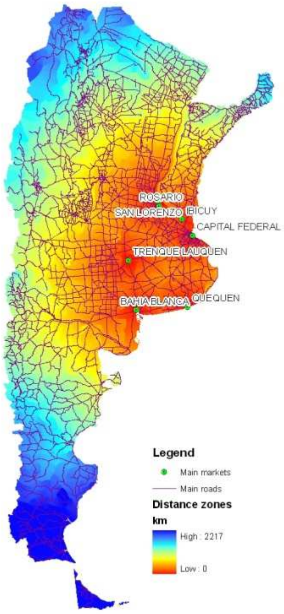


Figure 52: Distance zones to main markets according the distance of the nearest main road

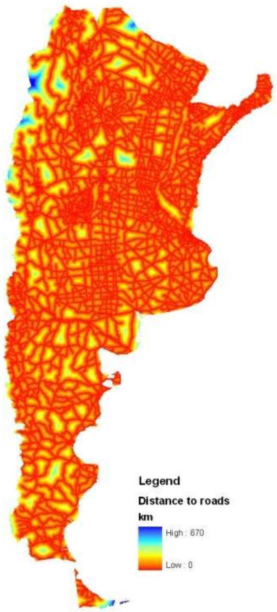


Figure 53: Euclidean distance to main roads

Finally, the previous two maps were overlapped and for every cell their values were summed, allowing to obtain a map depicting the least cumulative distance to the main markets according to the existing road network (Figure 54). This map will be used to calibrate the model in the empirical approach. However, it should be noted that regarding the economic assessment, the two previous maps will actually allow to distinguish between transportation costs on paved roads and transportation costs on dirt tracks, which can differ considerably (Donato, 2011; Garre, 2011).

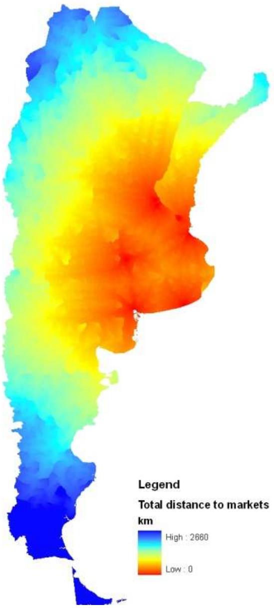


Figure 54: Total distance to markets

Regarding distance to water bodies and distance to cities and towns, the Euclidean distance function was used to produce the related maps (Figure 55 and Figure 56, respectively).

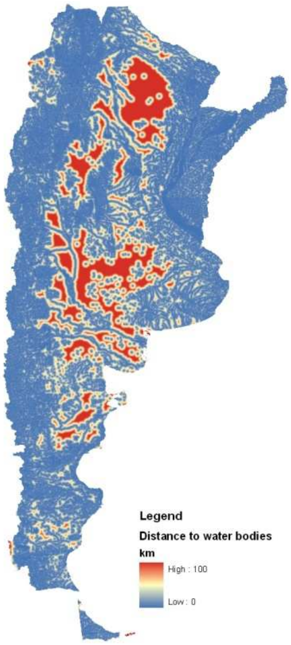


Figure 55: Euclidean distance to water bodies

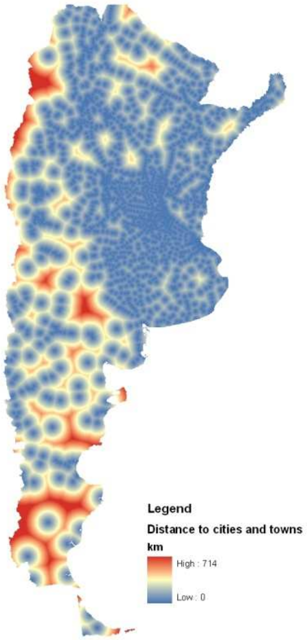


Figure 56: Euclidean distance to cities and towns

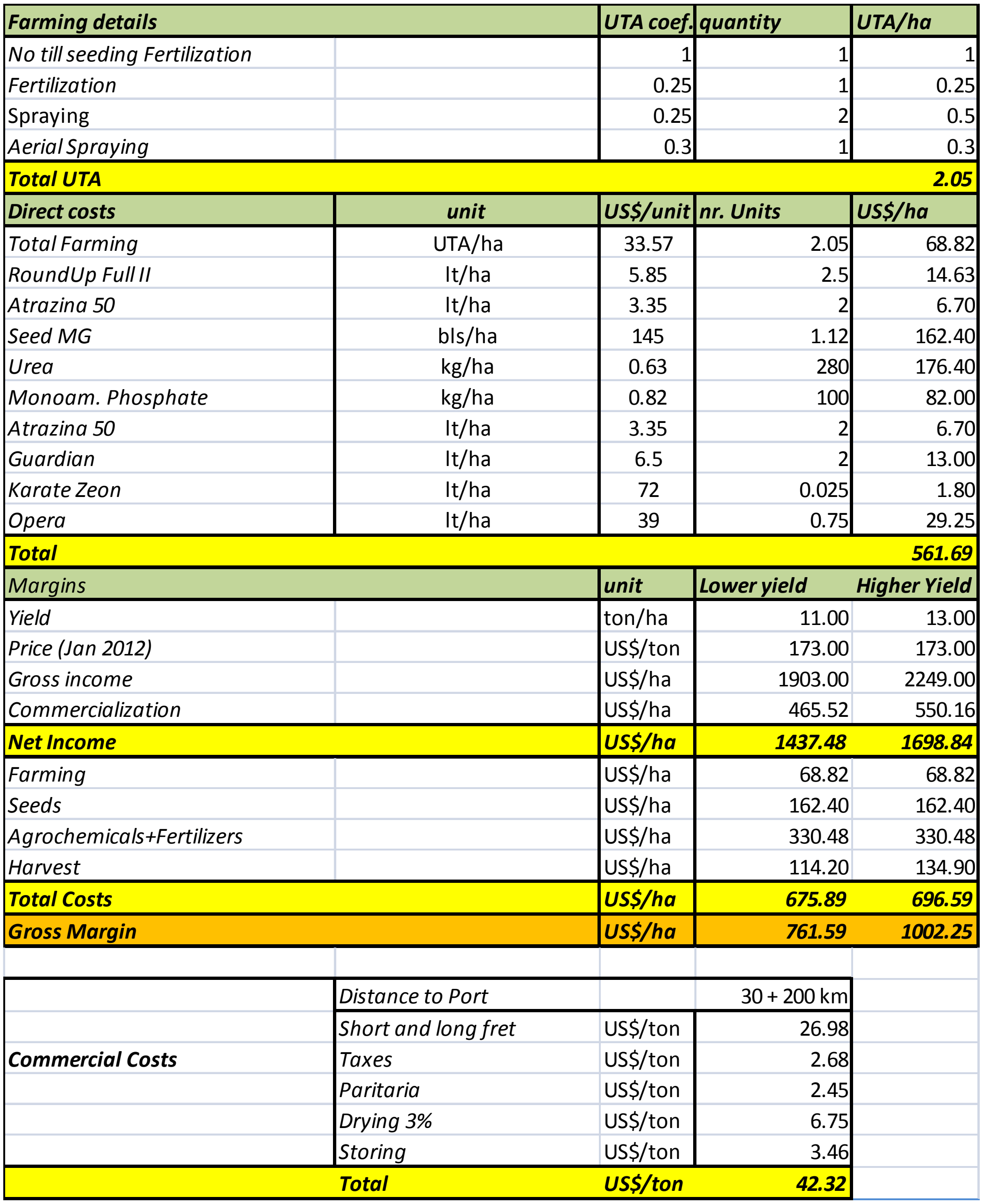
13.2.2. Economic data

In order to determine the economic performance of agricultural and livestock production systems, data on the revenues and costs associated to these activities has been collected. The type of data and their sources is summarized in below in Table 26.

Table 26: Economic data

Variable	Data source
Specific costs per unit of area	
Field operation costs	Margenes Agropecuarias 2003 - 2011
Input costs	Margenes Agropecuarias 2003 - 2011
Fixed costs	Margenes Agropecuarias 2003 - 2011
Specific costs per unit of mass yield	
Drying and storage costs	Margenes Agropecuarias 2003 - 2011
Taxes	Margenes Agropecuarias 2003 - 2011
Specific revenues per unit of mass yield	
Crop, meat and milk farmgate prices	Margenes Agropecuarias 2003 – 2011; Garre, 2011
Specific transportation costs	INTA, 2008; Donato, 2011; Garre, 2011
Discount rate	Garre, 2011

Table 27: Economic data on corn cultivation with cutting-edge technology in 2011 (Reference zone: north Buenos Aires)

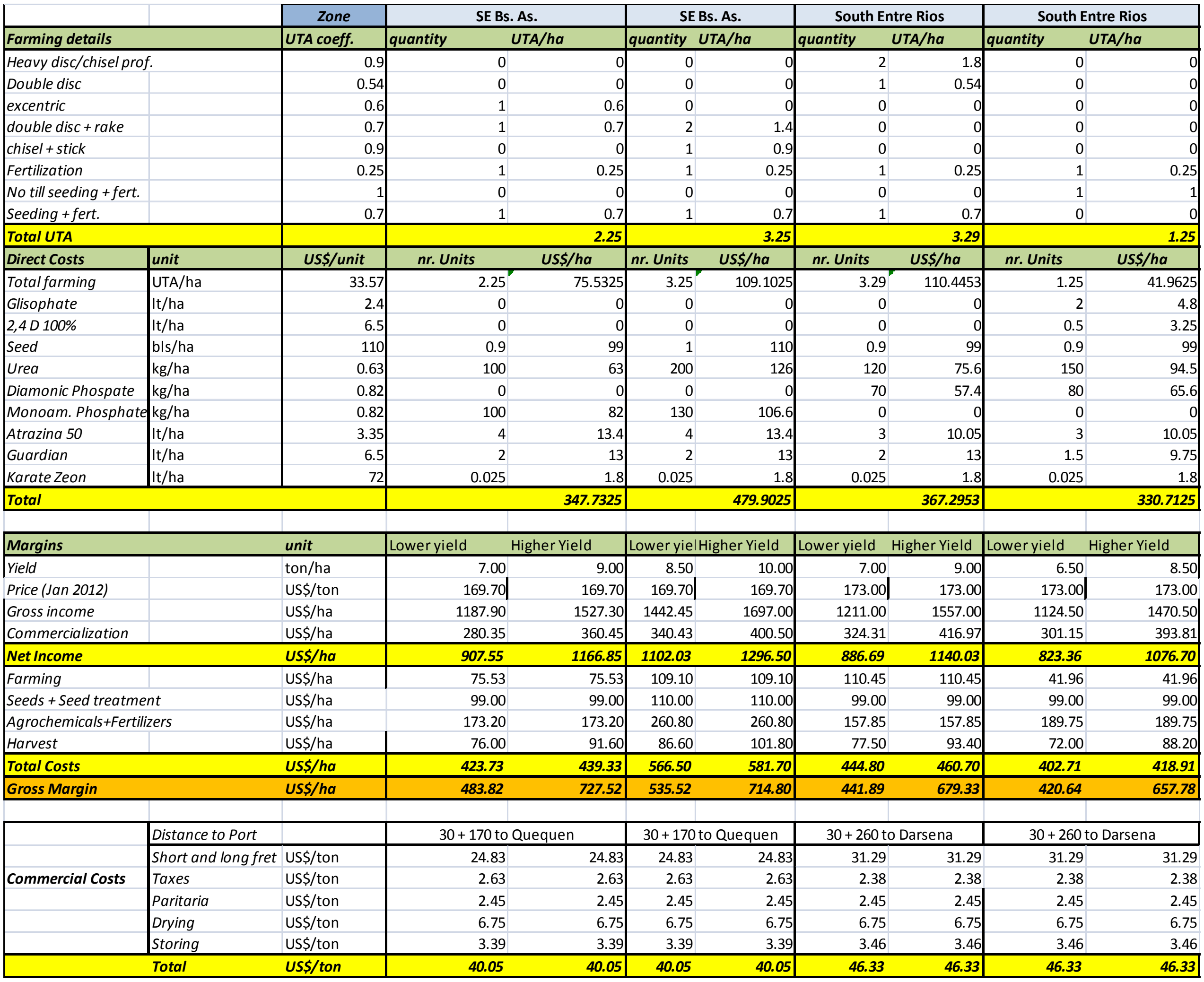


Farming details		**UTA coef.**	**quantity**	**UTA/ha**
No till seeding Fertilization		1	1	1
Fertilization		0.25	1	0.25
Spraying		0.25	2	0.5
Aerial Spraying		0.3	1	0.3
Total UTA				**2.05**
Direct costs	**unit**	**US$/unit**	**nr. Units**	**US$/ha**
Total Farming	UTA/ha	33.57	2.05	68.82
RoundUp Full II	lt/ha	5.85	2.5	14.63
Atrazina 50	lt/ha	3.35	2	6.70
Seed MG	bls/ha	145	1.12	162.40
Urea	kg/ha	0.63	280	176.40
Monoam. Phosphate	kg/ha	0.82	100	82.00
Atrazina 50	lt/ha	3.35	2	6.70
Guardian	lt/ha	6.5	2	13.00
Karate Zeon	lt/ha	72	0.025	1.80
Opera	lt/ha	39	0.75	29.25
Total				**561.69**
Margins		**unit**	**Lower yield**	**Higher Yield**
Yield		ton/ha	11.00	13.00
Price (Jan 2012)		US$/ton	173.00	173.00
Gross income		US$/ha	1903.00	2249.00
Commercialization		US$/ha	465.52	550.16
Net Income		**US$/ha**	**1437.48**	**1698.84**
Farming		US$/ha	68.82	68.82
Seeds		US$/ha	162.40	162.40
Agrochemicals+Fertilizers		US$/ha	330.48	330.48
Harvest		US$/ha	114.20	134.90
Total Costs		**US$/ha**	**675.89**	**696.59**
Gross Margin		**US$/ha**	**761.59**	**1002.25**
	Distance to Port		30 + 200 km	
	Short and long fret	US$/ton	26.98	
Commercial Costs	Taxes	US$/ton	2.68	
	Paritaria	US$/ton	2.45	
	Drying 3%	US$/ton	6.75	
	Storing	US$/ton	3.46	
	Total	**US$/ton**	**42.32**	

Table 28: Economic data on corn cultivation north Buenos Aires and south Santa Fe in 2011

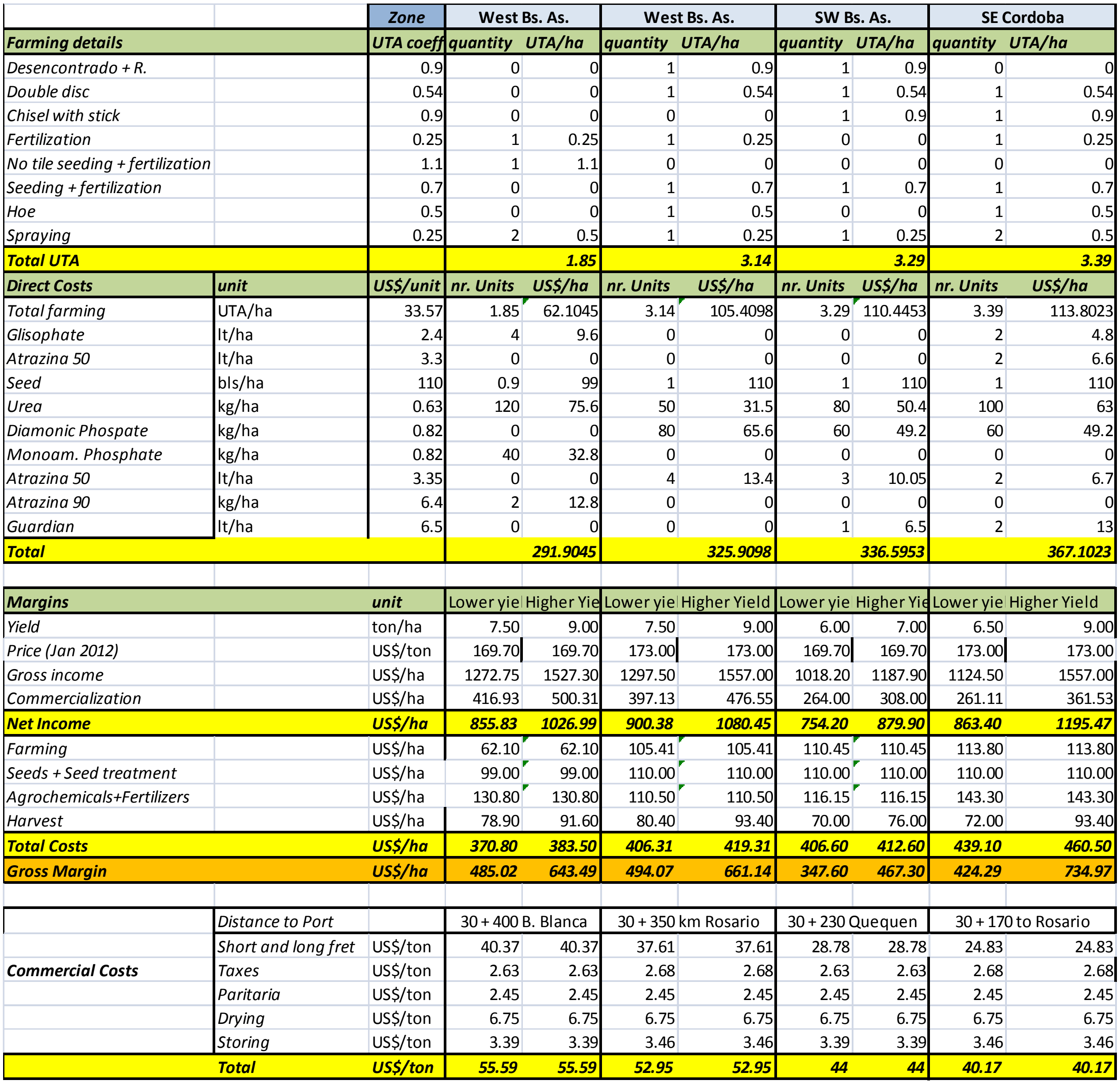
		Zone	***North Buenos Aires / South Santa Fe***							
Farming details		***UTA coeff.***	***quantity***	***UTA/ha***	***quantity***	***UTA/ha***	***quantity***	***UTA/ha***	***quantity***	***UTA/ha***
Chisel		0.9	0	0	1	0.9	0	0	0	0
Double disc + rake		0.7	2	1.4	1	0.7	0	0	0	0
Cultivator		0.7	0	0	1	0.7	0	0	0	0
Chisel with stick		0.9	1	0.9	0	0	0	0	0	0
Fertilization		0.25	1	0.25	1	0.25	1	0.25	1	0.25
No till seeding + Fertilization		1	0	0	0	0	1	1	1	1
Seeding + Fertilization		0.7	1	0.7	1	0.7	0	0	0	0
Spraying		0.25	1	0.25	1	0.25	2	0.5	2	0.5
Total UTA				***3.5***		***3.5***		***1.75***		***1.75***
Direct costs	***unit***	***US$/unit***	***nr. Units***	***US$/ha***	***nr. Units***	***US$/ha***	***nr. Units***	***US$/ha***	***nr. Units***	***US$/ha***
Total farming	UTA/ha	33.57	3.5	117.495	3.5	117.495	1.75	58.7475	1.75	58.7475
Glisophate	lt/ha	2.4	0	0	0	0	2	4.8	2	4.8
2,4 D 100%	lt/ha	6.5	0	0	0	0	0.5	3.25	0.5	3.25
Seed	bls/ha	110	0.9	99	1	110	0.9	99	0	0
Seed BT	bls/ha	145	0	0	0	0	0	0	0.9	130.5
Urea	kg/ha	0.63	150	94.5	150	94.5	180	113.4	180	113.4
Monoam. Phosphate	kg/ha	0.82	75	61.5	80	65.6	75	61.5	75	61.5
Atrazina 50	kg/ha	3.35	4	13.4	4	13.4	3	10.05	3	10.05
Guardian	lt/ha	6.5	2	13	2	13	1.6	10.4	1.6	10.4
Fighter Plus	lt/ha	66	0.02	1.32	0.02	1.32	0.02	1.32	0.02	1.32
Total				***400.215***		***415.315***		***362.4675***		***393.9675***
Margins		***unit***	Lower yield	Higher Yield	Lower yield	Higher Yield	Lower yield	Higher Yield	Lower yield	Higher Yield
Yield		ton/ha	7.50	9.50	7.50	9.50	7.50	9.50	8.00	10.00
Price (Jan 2012)		US$/ton	173.00	173.00	173.00	173.00	173.00	173.00	173.00	173.00
Gross income		US$/ha	1297.50	1643.50	1297.50	1643.50	1297.50	1643.50	1384.00	1730.00
Commercialization		US$/ha	317.40	402.04	317.40	402.04	317.40	402.04	338.56	423.20
Net Income		***US$/ha***	***980.10***	***1241.46***	***980.10***	***1241.46***	***980.10***	***1241.46***	***1045.44***	***1306.80***
Farming		US$/ha	117.50	117.50	117.50	117.50	58.75	58.75	58.75	58.75
Seed		US$/ha	99.00	99.00	110.00	110.00	99.00	99.00	130.50	130.50
Agrochemicals+Fertilizers		US$/ha	183.72	183.72	187.82	187.82	204.72	204.72	204.72	204.72
Harvest		US$/ha	80.40	98.60	80.40	98.60	80.40	98.60	85.80	103.80
Total Costs		***US$/ha***	***480.62***	***498.82***	***495.72***	***513.92***	***442.87***	***461.07***	***479.77***	***497.77***
Gross Margin		***US$/ha***	***499.49***	***742.65***	***484.39***	***727.55***	***537.23***	***780.39***	***565.67***	***809.03***
	Distance to Port		30 + 200 km to Rosario							
Commercial Costs	*Short and long fret*	US$/ton	26.98	26.98	26.98	26.98	26.98	26.98	26.98	26.98
	Taxes	US$/ton	2.68	2.68	2.68	2.68	2.68	2.68	2.68	2.68
	Paritaria	US$/ton	2.45	2.45	2.45	2.45	2.45	2.45	2.45	2.45
	Drying	US$/ton	6.75	6.75	6.75	6.75	6.75	6.75	6.75	6.75
	Storing	US$/ton	3.46	3.46	3.46	3.46	3.46	3.46	3.46	3.46
	Total	***US$/ton***	***42.32***	***42.32***	***42.32***	***42.32***	***42.32***	***42.32***	***42.32***	***42.32***

Table 29: Economic data on corn cultivation in southeast Buenos Aires and south Entre Rios in 2011



		Zone	SE Bs. As.		SE Bs. As.		South Entre Rios		South Entre Rios	
Farming details		***UTA coeff.***	***quantity***	***UTA/ha***	***quantity***	***UTA/ha***	***quantity***	***UTA/ha***	***quantity***	***UTA/ha***
Heavy disc/chisel prof.		0.9	0	0	0	0	2	1.8	0	0
Double disc		0.54	0	0	0	0	1	0.54	0	0
excentric		0.6	1	0.6	0	0	0	0	0	0
double disc + rake		0.7	1	0.7	2	1.4	0	0	0	0
chisel + stick		0.9	0	0	1	0.9	0	0	0	0
Fertilization		0.25	1	0.25	1	0.25	1	0.25	1	0.25
No till seeding + fert.		1	0	0	0	0	0	0	1	1
Seeding + fert.		0.7	1	0.7	1	0.7	1	0.7	0	0
Total UTA				***2.25***		***3.25***		***3.29***		***1.25***
Direct Costs	***unit***	***US$/unit***	***nr. Units***	***US$/ha***	***nr. Units***	***US$/ha***	***nr. Units***	***US$/ha***	***nr. Units***	***US$/ha***
Total farming	UTA/ha	33.57	2.25	75.5325	3.25	109.1025	3.29	110.4453	1.25	41.9625
Glisophate	lt/ha	2.4	0	0	0	0	0	0	2	4.8
2,4 D 100%	lt/ha	6.5	0	0	0	0	0	0	0.5	3.25
Seed	bls/ha	110	0.9	99	1	110	0.9	99	0.9	99
Urea	kg/ha	0.63	100	63	200	126	120	75.6	150	94.5
Diamonic Phospate	kg/ha	0.82	0	0	0	0	70	57.4	80	65.6
Monoam. Phosphate	kg/ha	0.82	100	82	130	106.6	0	0	0	0
Atrazina 50	lt/ha	3.35	4	13.4	4	13.4	3	10.05	3	10.05
Guardian	lt/ha	6.5	2	13	2	13	2	13	1.5	9.75
Karate Zeon	lt/ha	72	0.025	1.8	0.025	1.8	0.025	1.8	0.025	1.8
Total				***347.7325***		***479.9025***		***367.2953***		***330.7125***
Margins		***unit***	Lower yield	Higher Yield	Lower yie	Higher Yield	Lower yield	Higher Yield	Lower yield	Higher Yield
Yield		ton/ha	7.00	9.00	8.50	10.00	7.00	9.00	6.50	8.50
Price (Jan 2012)		US$/ton	169.70	169.70	169.70	169.70	173.00	173.00	173.00	173.00
Gross income		US$/ha	1187.90	1527.30	1442.45	1697.00	1211.00	1557.00	1124.50	1470.50
Commercialization		US$/ha	280.35	360.45	340.43	400.50	324.31	416.97	301.15	393.81
Net Income		***US$/ha***	***907.55***	***1166.85***	***1102.03***	***1296.50***	***886.69***	***1140.03***	***823.36***	***1076.70***
Farming		US$/ha	75.53	75.53	109.10	109.10	110.45	110.45	41.96	41.96
Seeds + Seed treatment		US$/ha	99.00	99.00	110.00	110.00	99.00	99.00	99.00	99.00
Agrochemicals+Fertilizers		US$/ha	173.20	173.20	260.80	260.80	157.85	157.85	189.75	189.75
Harvest		US$/ha	76.00	91.60	86.60	101.80	77.50	93.40	72.00	88.20
Total Costs		***US$/ha***	***423.73***	***439.33***	***566.50***	***581.70***	***444.80***	***460.70***	***402.71***	***418.91***
Gross Margin		***US$/ha***	***483.82***	***727.52***	***535.52***	***714.80***	***441.89***	***679.33***	***420.64***	***657.78***
Commercial Costs	*Distance to Port*		30 + 170 to Quequen		30 + 170 to Quequen		30 + 260 to Darsena		30 + 260 to Darsena	
	Short and long fret	US$/ton	24.83	24.83	24.83	24.83	31.29	31.29	31.29	31.29
	Taxes	US$/ton	2.63	2.63	2.63	2.63	2.38	2.38	2.38	2.38
	Paritaria	US$/ton	2.45	2.45	2.45	2.45	2.45	2.45	2.45	2.45
	Drying	US$/ton	6.75	6.75	6.75	6.75	6.75	6.75	6.75	6.75
	Storing	US$/ton	3.39	3.39	3.39	3.39	3.46	3.46	3.46	3.46
	Total	***US$/ton***	***40.05***	***40.05***	***40.05***	***40.05***	***46.33***	***46.33***	***46.33***	***46.33***

Table 30: Economic data on corn cultivation west and southwest Buenos Aires and southeast Cordoba in 2011



		Zone	West Bs. As.		West Bs. As.		SW Bs. As.		SE Cordoba	
Farming details		***UTA coeff***	***quantity***	***UTA/ha***	***quantity***	***UTA/ha***	***quantity***	***UTA/ha***	***quantity***	***UTA/ha***
Desencontrado + R.		0.9	0	0	1	0.9	1	0.9	0	0
Double disc		0.54	0	0	1	0.54	1	0.54	1	0.54
Chisel with stick		0.9	0	0	0	0	1	0.9	1	0.9
Fertilization		0.25	1	0.25	1	0.25	0	0	1	0.25
No tile seeding + fertilization		1.1	1	1.1	0	0	0	0	0	0
Seeding + fertilization		0.7	0	0	1	0.7	1	0.7	1	0.7
Hoe		0.5	0	0	1	0.5	0	0	1	0.5
Spraying		0.25	2	0.5	1	0.25	1	0.25	2	0.5
Total UTA				***1.85***		***3.14***		***3.29***		***3.39***
Direct Costs	***unit***	***US$/unit***	***nr. Units***	***US$/ha***	***nr. Units***	***US$/ha***	***nr. Units***	***US$/ha***	***nr. Units***	***US$/ha***
Total farming	UTA/ha	33.57	1.85	62.1045	3.14	105.4098	3.29	110.4453	3.39	113.8023
Glisophate	lt/ha	2.4	4	9.6	0	0	0	0	2	4.8
Atrazina 50	lt/ha	3.3	0	0	0	0	0	0	2	6.6
Seed	bls/ha	110	0.9	99	1	110	1	110	1	110
Urea	kg/ha	0.63	120	75.6	50	31.5	80	50.4	100	63
Diamonic Phospate	kg/ha	0.82	0	0	80	65.6	60	49.2	60	49.2
Monoam. Phosphate	kg/ha	0.82	40	32.8	0	0	0	0	0	0
Atrazina 50	lt/ha	3.35	0	0	4	13.4	3	10.05	2	6.7
Atrazina 90	kg/ha	6.4	2	12.8	0	0	0	0	0	0
Guardian	lt/ha	6.5	0	0	0	0	1	6.5	2	13
Total				***291.9045***		***325.9098***		***336.5953***		***367.1023***
Margins		***unit***	Lower yie	Higher Yie	Lower yie	Higher Yield	Lower yie	Higher Yie	Lower yie	Higher Yield
Yield		ton/ha	7.50	9.00	7.50	9.00	6.00	7.00	6.50	9.00
Price (Jan 2012)		US$/ton	169.70	169.70	173.00	173.00	169.70	169.70	173.00	173.00
Gross income		US$/ha	1272.75	1527.30	1297.50	1557.00	1018.20	1187.90	1124.50	1557.00
Commercialization		US$/ha	416.93	500.31	397.13	476.55	264.00	308.00	261.11	361.53
Net Income		***US$/ha***	***855.83***	***1026.99***	***900.38***	***1080.45***	***754.20***	***879.90***	***863.40***	***1195.47***
Farming		US$/ha	62.10	62.10	105.41	105.41	110.45	110.45	113.80	113.80
Seeds + Seed treatment		US$/ha	99.00	99.00	110.00	110.00	110.00	110.00	110.00	110.00
Agrochemicals+Fertilizers		US$/ha	130.80	130.80	110.50	110.50	116.15	116.15	143.30	143.30
Harvest		US$/ha	78.90	91.60	80.40	93.40	70.00	76.00	72.00	93.40
Total Costs		***US$/ha***	***370.80***	***383.50***	***406.31***	***419.31***	***406.60***	***412.60***	***439.10***	***460.50***
Gross Margin		***US$/ha***	***485.02***	***643.49***	***494.07***	***661.14***	***347.60***	***467.30***	***424.29***	***734.97***
	Distance to Port		30 + 400 B. Blanca		30 + 350 km Rosario		30 + 230 Quequen		30 + 170 to Rosario	
	Short and long fret	US$/ton	40.37	40.37	37.61	37.61	28.78	28.78	24.83	24.83
Commercial Costs	*Taxes*	US$/ton	2.63	2.63	2.68	2.68	2.63	2.63	2.68	2.68
	Paritaria	US$/ton	2.45	2.45	2.45	2.45	2.45	2.45	2.45	2.45
	Drying	US$/ton	6.75	6.75	6.75	6.75	6.75	6.75	6.75	6.75
	Storing	US$/ton	3.39	3.39	3.46	3.46	3.39	3.39	3.46	3.46
	Total	***US$/ton***	***55.59***	***55.59***	***52.95***	***52.95***	***44***	***44***	***40.17***	***40.17***

Table 31: Economic data on soy cultivation with cutting-edge technology in 2011 (Reference zone: south Santa Fe)

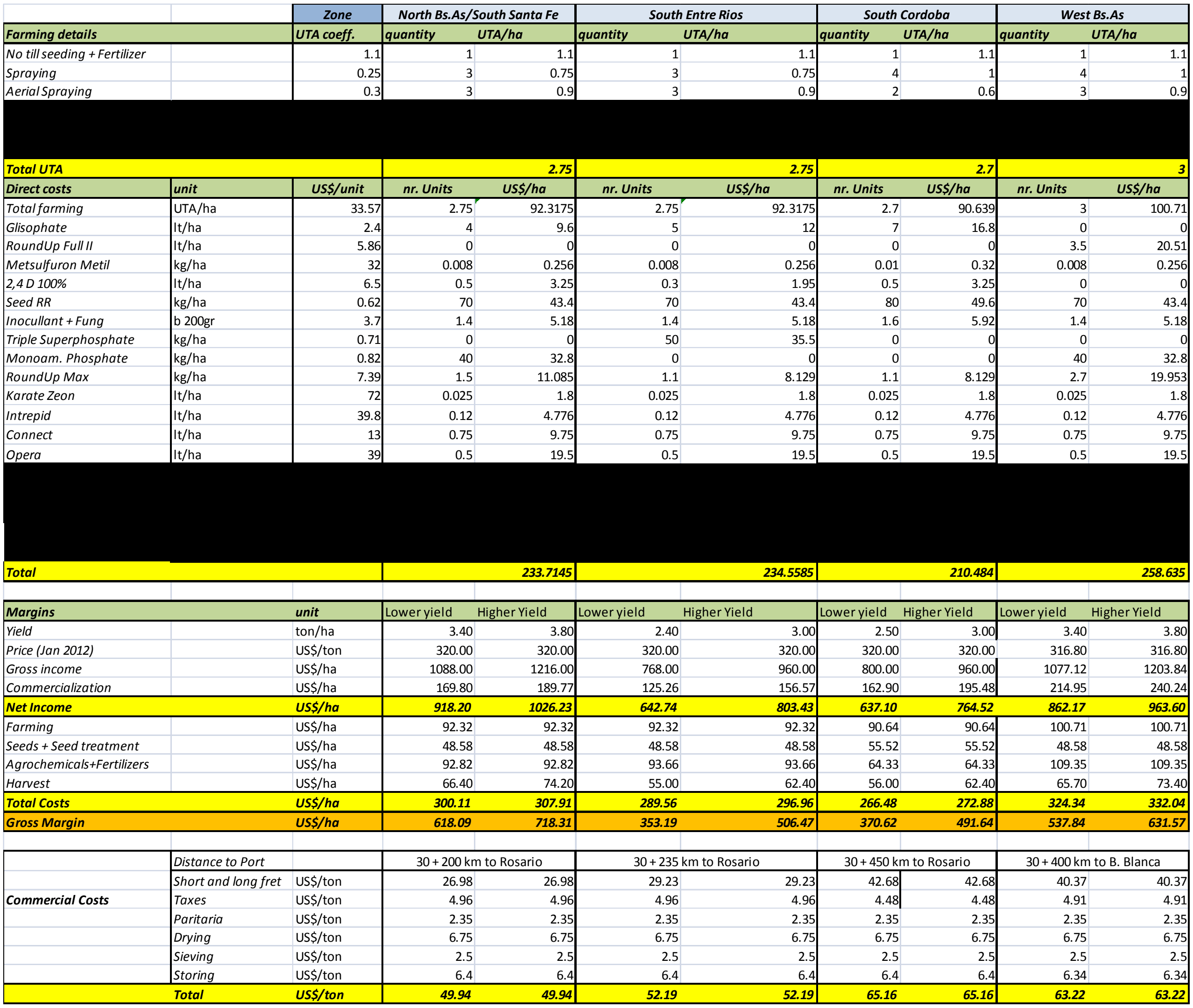
Farming details		***UTA coef.***	***quantity***	***UTA/ha***
No till seeding		1.1	1	1.1
Fertilization		0.25	1	0.25
Spraying		0.25	3	0.75
Aerial Spraying		0.3	2	0.6
Total UTA				***2.7***

Direct costs	***unit***	***US$/unit***	***nr. Units***	***US$/ha***
Total Farming	UTA/ha	33.57	2.7	90.64
Seed RR	kg/ha	0.62	60	37.20
Innoculant + Funguicide	c/50 kg	3.7	1.2	4.44
RoundUp Full II	lt/ha	5.86	4	23.44
RoundUp Max	kg/ha	7.39	1.5	11.09
Fertilizer Map	kg/ha	0.82	100	82.00
Fertilizer Azufre S-15	kg/ha	0.72	120	86.40
Karate Zeon	lt/ha	72	0.02	1.44
Intrepid	lt/ha	39.8	0.12	4.78
Connect	lt/ha	13	0.75	9.75
Opera	lt/ha	39	0.5	19.50
Total				***370.67***

Margins		***unit***	***Lower yield***	***Higher Yield***
Yield		ton/ha	4.20	4.80
Price (Jan 2012)		US$/ton	320.00	320.00
Gross income		US$/ha	1344.00	1536.00
Commercialization		US$/ha	0.00	0.00
Net Income		***US$/ha***	***1344.00***	***1536.00***
Farming		US$/ha	90.64	90.64
Seeds + Innoculant		US$/ha	41.64	41.64
Agrochemicals+Fertilizers		US$/ha	238.39	238.39
Harvest		US$/ha	82.00	93.70
Total Costs		***US$/ha***	***452.67***	***464.37***
Gross Margin		***US$/ha***	***891.33***	***1071.63***

Commercial Costs	*Distance to Port*		30 + 200 km
	Short and long fret	US$/ton	26.98
	Taxes	US$/ton	4.96
	Paritaria	US$/ton	2.35
	Drying	US$/ton	6.75
	Sieving	US$/ton	2.5
	Storing	US$/ton	6.4
	Total	***US$/ton***	***49.94***

Table 32: Economic data on soy cultivation in north and west Buenos Aires, south Entre Rios, South Cordoba in 2011



		Zone	**North Bs.As/South Santa Fe**		**South Entre Rios**		**South Cordoba**		**West Bs.As**	
Farming details		**UTA coeff.**	**quantity**	**UTA/ha**	**quantity**	**UTA/ha**	**quantity**	**UTA/ha**	**quantity**	**UTA/ha**
No till seeding + Fertilizer		1.1	1	1.1	1	1.1	1	1.1	1	1.1
Spraying		0.25	3	0.75	3	0.75	4	1	4	1
Aerial Spraying		0.3	3	0.9	3	0.9	2	0.6	3	0.9
[redacted]										
Total UTA				**2.75**		**2.75**		**2.7**		**3**
Direct costs	**unit**	**US$/unit**	**nr. Units**	**US$/ha**	**nr. Units**	**US$/ha**	**nr. Units**	**US$/ha**	**nr. Units**	**US$/ha**
Total farming	UTA/ha	33.57	2.75	92.3175	2.75	92.3175	2.7	90.639	3	100.71
Glisophate	lt/ha	2.4	4	9.6	5	12	7	16.8	0	0
RoundUp Full II	lt/ha	5.86	0	0	0	0	0	0	3.5	20.51
Metsulfuron Metil	kg/ha	32	0.008	0.256	0.008	0.256	0.01	0.32	0.008	0.256
2,4 D 100%	lt/ha	6.5	0.5	3.25	0.3	1.95	0.5	3.25	0	0
Seed RR	kg/ha	0.62	70	43.4	70	43.4	80	49.6	70	43.4
Inocullant + Fung	b 200gr	3.7	1.4	5.18	1.4	5.18	1.6	5.92	1.4	5.18
Triple Superphosphate	kg/ha	0.71	0	0	50	35.5	0	0	0	0
Monoam. Phosphate	kg/ha	0.82	40	32.8	0	0	0	0	40	32.8
RoundUp Max	kg/ha	7.39	1.5	11.085	1.1	8.129	1.1	8.129	2.7	19.953
Karate Zeon	lt/ha	72	0.025	1.8	0.025	1.8	0.025	1.8	0.025	1.8
Intrepid	lt/ha	39.8	0.12	4.776	0.12	4.776	0.12	4.776	0.12	4.776
Connect	lt/ha	13	0.75	9.75	0.75	9.75	0.75	9.75	0.75	9.75
Opera	lt/ha	39	0.5	19.5	0.5	19.5	0.5	19.5	0.5	19.5
[redacted]										
Total				**233.7145**		**234.5585**		**210.484**		**258.635**
Margins		**unit**	Lower yield	Higher Yield	Lower yield	Higher Yield	Lower yield	Higher Yield	Lower yield	Higher Yield
Yield		ton/ha	3.40	3.80	2.40	3.00	2.50	3.00	3.40	3.80
Price (Jan 2012)		US$/ton	320.00	320.00	320.00	320.00	320.00	320.00	316.80	316.80
Gross income		US$/ha	1088.00	1216.00	768.00	960.00	800.00	960.00	1077.12	1203.84
Commercialization		US$/ha	169.80	189.77	125.26	156.57	162.90	195.48	214.95	240.24
Net Income		**US$/ha**	**918.20**	**1026.23**	**642.74**	**803.43**	**637.10**	**764.52**	**862.17**	**963.60**
Farming		US$/ha	92.32	92.32	92.32	92.32	90.64	90.64	100.71	100.71
Seeds + Seed treatment		US$/ha	48.58	48.58	48.58	48.58	55.52	55.52	48.58	48.58
Agrochemicals+Fertilizers		US$/ha	92.82	92.82	93.66	93.66	64.33	64.33	109.35	109.35
Harvest		US$/ha	66.40	74.20	55.00	62.40	56.00	62.40	65.70	73.40
Total Costs		**US$/ha**	**300.11**	**307.91**	**289.56**	**296.96**	**266.48**	**272.88**	**324.34**	**332.04**
Gross Margin		**US$/ha**	**618.09**	**718.31**	**353.19**	**506.47**	**370.62**	**491.64**	**537.84**	**631.57**
Commercial Costs	*Distance to Port*		30 + 200 km to Rosario		30 + 235 km to Rosario		30 + 450 km to Rosario		30 + 400 km to B. Blanca	
	Short and long fret	US$/ton	26.98	26.98	29.23	29.23	42.68	42.68	40.37	40.37
	Taxes	US$/ton	4.96	4.96	4.96	4.96	4.48	4.48	4.91	4.91
	Paritaria	US$/ton	2.35	2.35	2.35	2.35	2.35	2.35	2.35	2.35
	Drying	US$/ton	6.75	6.75	6.75	6.75	6.75	6.75	6.75	6.75
	Sieving	US$/ton	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5
	Storing	US$/ton	6.4	6.4	6.4	6.4	6.4	6.4	6.34	6.34
	Total	**US$/ton**	**49.94**	**49.94**	**52.19**	**52.19**	**65.16**	**65.16**	**63.22**	**63.22**

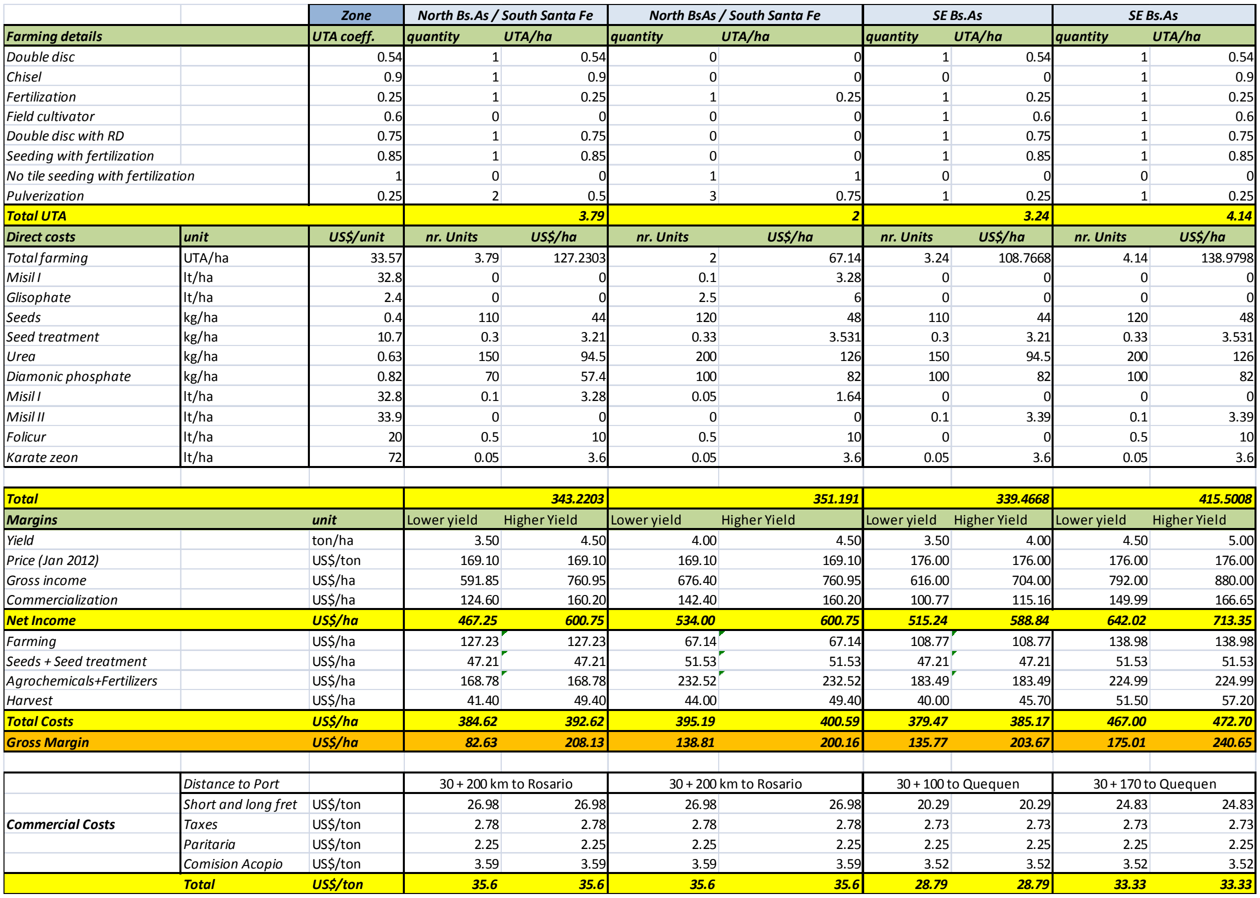
Table 33: Economic data on soy cultivation in Santiago del Estero, Salta, southwest and southeast Buenos Aires in 2011

		Zone	**Stgo del Estero**		**Salta**		**SW Bs. As**		**SE Bs. As.**	
Farming details		***UTA coeff.***	***quantity***	***UTA/ha***	***quantity***	***UTA/ha***	***quantity***	***UTA/ha***	***quantity***	***UTA/ha***
Double disc		0.54	0	0	0	0	0	0	2	1.08
Vibrocultivator+RD		0.77	0	0	0	0	0	0	1	0.77
Seeding+Fert.		0.7	0	0	0	0	0	0	1	0.7
No till seeding+Fert.		1.1	1	1.1	1	1.1	1	1.1	0	0
Aerial Spraying		0.3	2	0.6	3	0.9	1	0.3	2	0.6
Spraying		0.25	4	1	3	0.75	3	0.75	1	0.25
Total UTA				***2.7***		***2.75***		***2.15***		***3.4***
Direct Costs	***unit***	***US$/unit***	***nr. Units***	***US$/ha***	***nr. Units***	***US$/ha***	***nr. Units***	***US$/ha***	***nr. Units***	***US$/ha***
Total farming	UTA/ha	33.57	2.7	90.639	2.75	92.3175	2.15	72.1755	3.4	114.138
Glisophate	lt/ha	2.4	7	16.8	6	14.4	6	14.4	0	0
Seed RR	kg/ha	0.62	80	49.6	80	49.6	80	49.6	70	43.4
Inocullant + Fung	c/50 kg	3.7	1.6	5.92	1.6	5.92	1.6	5.92	1.4	5.18
Triple Superphosphat	kg/ha	0.71	0	0	0	0	40	28.4	50	35.5
Monoam. Phosphate	kg/ha	0.82	0	0	0	0	0	0	0	0
Metsulfuron metil	kh/ha	32	0.004	0.128	0	0	0	0	0	0
2,4 D 100%	lt/ha	6.5	0.5	3.25	0	0	0.35	2.275	0	0
Sencorex	lt/ha	25	0	0	0	0	0	0	1.1	27.5
Acetocolor	lt/ha	5.4	0	0	0	0	0	0	2.5	13.5
RoundUp Max	kg/ha	7.39	0	0	1.1	8.129	0	0	0	0
Correctors	lt/ha	4.47	1	4.47	0	0	0	0	0	0
Decis Dan	lt/ha	10.5	0	0	0.5	5.25	0	0	0	0
Lorsban Plus	lt/ha	10	0	0	0	0	0	0	0.7	7
Lorsban 48 E	lt/ha	5.8	1.4	8.12	1.4	8.12	0.7	4.06	1.4	8.12
Cipermetrina	lt/ha	5.7	0.45	2.565	0.1	0.57	0.2	1.14	0.15	0.855
Endosulfan	lt/ha	56	1.5	84	0	0	0	0	0	0
Taspa	lt/ha	68.7	0	0	0.15	10.305	0	0	0	0
Opera	lt/ha	39	0.5	19.5	0.5	19.5	0	0	0	0
Total				***284.992***		***214.1115***		***177.9705***		***255.193***
Margins		***unit***	Lower yield	Higher Yield	Lower yie	Higher Yield	Lower yield	Higher Yield	Lower yield	Higher Yield
Yield		ton/ha	1.80	2.60	2.50	3.00	1.80	2.40	2.40	3.20
Price (Jan 2012)		US$/ton	320.00	320.00	320.00	320.00	316.80	316.80	304.00	304.00
Gross income		US$/ha	576.00	832.00	800.00	960.00	570.24	760.32	729.60	972.80
Commercialization		US$/ha	106.72	154.15	195.38	234.45	89.69	119.59	113.33	151.10
Net Income		***US$/ha***	***469.28***	***677.85***	***604.63***	***725.55***	***480.55***	***640.73***	***616.27***	***821.70***
Farming		US$/ha	90.64	90.64	92.32	92.32	72.18	72.18	114.14	114.14
Seeds + Seed treatment		US$/ha	55.52	55.52	55.52	55.52	55.52	55.52	48.58	48.58
Agrochemicals+Fertilizers		US$/ha	138.83	138.83	66.27	66.27	50.28	50.28	92.48	92.48
Harvest		US$/ha	55.00	58.20	56.00	62.40	55.00	55.00	55.00	63.20
Total Costs		***US$/ha***	***339.99***	***343.19***	***270.11***	***276.51***	***232.97***	***232.97***	***310.19***	***318.39***
Gross Margin		***US$/ha***	***129.29***	***334.65***	***334.51***	***449.04***	***247.58***	***407.76***	***306.08***	***503.30***
	Distance to Port		560 km to Rosario		30 + 1100 km to Rosario		30 + 200 km to B. Blanca		30 + 170 km to Quequen	
	Short and long f	US$/ton	36.33	36.33	55.19	55.19	26.98	26.98	24.83	24.83
Commercial Costs	*Taxes*	US$/ton	4.96	4.96	4.96	4.96	4.91	4.91	4.71	4.71
	Paritaria	US$/ton	2.35	2.35	2.35	2.35	2.35	2.35	2.35	2.35
	Drying	US$/ton	6.75	6.75	6.75	6.75	6.75	6.75	6.75	6.75
	Sieving	US$/ton	2.5	2.5	2.5	2.5	2.5	2.5	2.5	2.5
	Storing	US$/ton	6.4	6.4	6.4	6.4	6.34	6.34	6.08	6.08

Table 34: Economic data on wheat cultivation with cutting-edge technology in 2011 (Reference zone: southeast Buenos Aires)

Farming details		UTA coef.	quantity	UTA/ha
Fertilization		0.25	2	0.5
No till seeding		1	1	1
Spraying		0.25	3	0.75
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Total UTA				2.25
Direct costs	unit	US$/unit	nr. Units	US$/ha
Total Farming	UTA/ha	33.57	2.25	75.5325
Glisophate	lt/ha	2.4	2	4.8
Seeds	kg/ha	0.4	120	48
Seed treatment	kg/ha	10.7	0.33	3.531
UAN	kg/ha	0.52	120	62.4
Urea	kg/ha	0.63	80	50.4
Diamonic Phosphate	kg/ha	0.82	120	98.4
Misil II	lt/ha	33.9	0.1	3.39
Allegro	lt/ha	32.5	0.75	24.375
Karate Zeon	lt/ha	72	0.04	2.88
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Total				373.7085
Margins		unit	Lower yield	Higher Yield
Yield		ton/ha	4.50	6.50
Price (Jan 2012)		US$/ton	176.00	176.00
Gross income		US$/ha	792.00	1144.00
Commercialization		US$/ha	149.99	216.65
Net Income		US$/ha	642.02	927.36
Farming		US$/ha	75.53	75.53
Seeds		US$/ha	48.00	48.00
Agrochemicals+Fertilizers		US$/ha	250.18	250.18
Harvest		US$/ha	51.50	74.30
Total Costs		US$/ha	425.21	448.01
Gross Margin		US$/ha	216.81	479.35
Commercial Costs	Distance to Port		30 + 170 km	
	Short and long fret	US$/ton	24.83	
	Taxes	US$/ton	2.73	
	Paritaria	US$/ton	2.25	
	Comision Acopio	US$/ton	3.52	
	Total	US$/ton	33.33	

Table 35: Economic data on wheat cultivation in north Buenos Aires/South Santa Fe and southeast Buenos Aires in 2011



		Zone	**North Bs.As / South Santa Fe**		**North BsAs / South Santa Fe**		**SE Bs.As**		**SE Bs.As**	
Farming details		***UTA coeff.***	***quantity***	***UTA/ha***	***quantity***	***UTA/ha***	***quantity***	***UTA/ha***	***quantity***	***UTA/ha***
Double disc		0.54	1	0.54	0	0	1	0.54	1	0.54
Chisel		0.9	1	0.9	0	0	0	0	1	0.9
Fertilization		0.25	1	0.25	1	0.25	1	0.25	1	0.25
Field cultivator		0.6	0	0	0	0	1	0.6	1	0.6
Double disc with RD		0.75	1	0.75	0	0	1	0.75	1	0.75
Seeding with fertilization		0.85	1	0.85	0	0	1	0.85	1	0.85
No tile seeding with fertilization		1	0	0	1	1	0	0	0	0
Pulverization		0.25	2	0.5	3	0.75	1	0.25	1	0.25
Total UTA				***3.79***		***2***		***3.24***		***4.14***
Direct costs	***unit***	***US$/unit***	***nr. Units***	***US$/ha***	***nr. Units***	***US$/ha***	***nr. Units***	***US$/ha***	***nr. Units***	***US$/ha***
Total farming	UTA/ha	33.57	3.79	127.2303	2	67.14	3.24	108.7668	4.14	138.9798
Misil I	lt/ha	32.8	0	0	0.1	3.28	0	0	0	0
Glisophate	lt/ha	2.4	0	0	2.5	6	0	0	0	0
Seeds	kg/ha	0.4	110	44	120	48	110	44	120	48
Seed treatment	kg/ha	10.7	0.3	3.21	0.33	3.531	0.3	3.21	0.33	3.531
Urea	kg/ha	0.63	150	94.5	200	126	150	94.5	200	126
Diamonic phosphate	kg/ha	0.82	70	57.4	100	82	100	82	100	82
Misil I	lt/ha	32.8	0.1	3.28	0.05	1.64	0	0	0	0
Misil II	lt/ha	33.9	0	0	0	0	0.1	3.39	0.1	3.39
Folicur	lt/ha	20	0.5	10	0.5	10	0	0	0.5	10
Karate zeon	lt/ha	72	0.05	3.6	0.05	3.6	0.05	3.6	0.05	3.6
Total				***343.2203***		***351.191***		***339.4668***		***415.5008***
Margins		***unit***	Lower yield	Higher Yield	Lower yield	Higher Yield	Lower yield	Higher Yield	Lower yield	Higher Yield
Yield		ton/ha	3.50	4.50	4.00	4.50	3.50	4.00	4.50	5.00
Price (Jan 2012)		US$/ton	169.10	169.10	169.10	169.10	176.00	176.00	176.00	176.00
Gross income		US$/ha	591.85	760.95	676.40	760.95	616.00	704.00	792.00	880.00
Commercialization		US$/ha	124.60	160.20	142.40	160.20	100.77	115.16	149.99	166.65
Net Income		***US$/ha***	***467.25***	***600.75***	***534.00***	***600.75***	***515.24***	***588.84***	***642.02***	***713.35***
Farming		US$/ha	127.23	127.23	67.14	67.14	108.77	108.77	138.98	138.98
Seeds + Seed treatment		US$/ha	47.21	47.21	51.53	51.53	47.21	47.21	51.53	51.53
Agrochemicals+Fertilizers		US$/ha	168.78	168.78	232.52	232.52	183.49	183.49	224.99	224.99
Harvest		US$/ha	41.40	49.40	44.00	49.40	40.00	45.70	51.50	57.20
Total Costs		***US$/ha***	***384.62***	***392.62***	***395.19***	***400.59***	***379.47***	***385.17***	***467.00***	***472.70***
Gross Margin		***US$/ha***	***82.63***	***208.13***	***138.81***	***200.16***	***135.77***	***203.67***	***175.01***	***240.65***
Commercial Costs	*Distance to Port*		30 + 200 km to Rosario		30 + 200 km to Rosario		30 + 100 to Quequen		30 + 170 to Quequen	
	Short and long fret	US$/ton	26.98	26.98	26.98	26.98	20.29	20.29	24.83	24.83
	Taxes	US$/ton	2.78	2.78	2.78	2.78	2.73	2.73	2.73	2.73
	Paritaria	US$/ton	2.25	2.25	2.25	2.25	2.25	2.25	2.25	2.25
	Comision Acopio	US$/ton	3.59	3.59	3.59	3.59	3.52	3.52	3.52	3.52
	Total	***US$/ton***	***35.6***	***35.6***	***35.6***	***35.6***	***28.79***	***28.79***	***33.33***	***33.33***

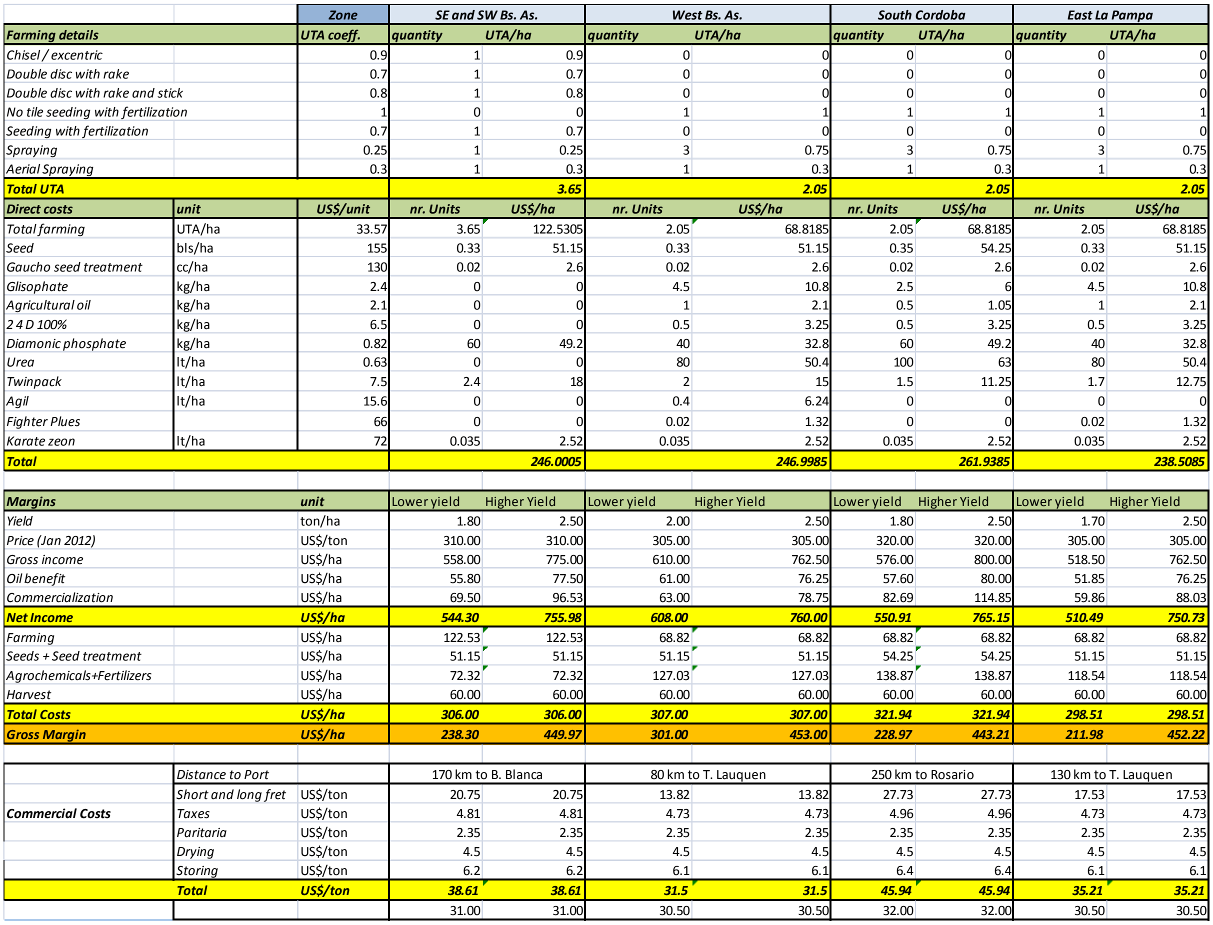
Table 36: Economic data on wheat cultivation in West southwest Buenos Aires and southeast Cordoba in 2011

		Zone	SO Bs.As.		SE Cordoba		West Bs As.		West Bs As.	
Farming details		***UTA coeff.***	***quantity***	***UTA/ha***	***quantity***	***UTA/ha***	***quantity***	***UTA/ha***	***quantity***	***UTA/ha***
Heavy disc		0.75	2	1.5	0	0	0	0	0	0
Double disc		0.54	0	0	1	0.54	2	1.08	2	1.08
Fertilization		0.25	1	0.25	1	0.25	0	0	0	0
Fertilization + Spraying		0.5	0	0	0	0	1	0.5	1	0.5
Double disc + RD		0.75	1	0.75	1	0.75	1	0.75	1	0.75
Seeding +fertilization		0.85	1	0.85	1	0.85	1	0.85	1	0.85
Pulverization		0.25	1	0.25	1	0.25	0	0	0	0
Aerial Pulverization		0.3	0	0	1	0.3	0	0	0	0
Total UTA				***3.6***		***2.94***		***3.18***		***3.18***
Direct Costs	***unit***	***US$/unit***	***nr. Units***	***US$/ha***	***nr. Units***	***US$/ha***	***nr. Units***	***US$/ha***	***nr. Units***	***US$/ha***
Total farming	UTA/ha	33.57	3.6	120.852	2.94	98.6958	3.18	106.7526	3.18	106.7526
Seeds	kg/ha	0.4	125	50	110	44	120	48	120	48
Seed treatment	kg/ha	10.7	0.34	3.638	0.3	3.21	0.33	3.531	0.33	3.531
Urea	kg/ha	0.63	80	50.4	110	69.3	120	75.6	65	40.95
Diamonic phosphate	kg/ha	0.82	60	49.2	60	49.2	100	82	55	45.1
Misil I	lt/ha	32.8	0	0	0.1	3.28	0.1	3.28	0.1	3.28
Misil II	lt/ha	33.9	0.1	3.39	0	0	0	0	0	0
Karate zeon	lt/ha	72	0	0	0.05	3.6	0	0	0	0
[redacted]										
Total				***277.48***		***271.2858***		***319.1636***		***247.6136***
Margins		***unit***	Lower yield	Higher Yield	Lower yie	Higher Yield	Lower yield	Higher Yield	Lower yield	Higher Yield
Yield		ton/ha	2.60	3.60	2.50	3.50	4.00	5.00	3.00	4.00
Price (Jan 2012)		US$/ton	179.40	179.40	169.10	169.10	179.40	179.40	179.40	179.40
Gross income		US$/ha	466.44	645.84	422.75	591.85	717.60	897.00	538.20	717.60
Commercialization		US$/ha	97.24	134.64	82.70	115.78	195.96	244.95	146.97	195.96
Net Income		***US$/ha***	***369.20***	***511.20***	***340.05***	***476.07***	***521.64***	***652.05***	***391.23***	***521.64***
Farming		US$/ha	120.85	120.85	98.70	98.70	106.75	106.75	106.75	106.75
Seeds + Seed treatment		US$/ha	99.60	99.60	118.50	118.50	157.60	157.60	86.05	86.05
Agrochemicals+Fertilizers		US$/ha	57.03	57.03	54.09	54.09	54.81	54.81	54.81	54.81
Harvest		US$/ha	40.00	45.20	40.00	41.40	46.60	58.30	40.00	46.60
Total Costs		***US$/ha***	***317.48***	***322.68***	***311.29***	***312.69***	***365.76***	***377.46***	***287.61***	***294.21***
Gross Margin		***US$/ha***	***51.72***	***188.52***	***28.76***	***163.38***	***155.88***	***274.59***	***103.62***	***227.43***
	Distance to Port		30 + 230 km to B. Blanca		30 + 170 to Rosario		30 + 400 to B. Blanca		30 + 400 to B. Blanca	
	Short and long f	US$/ton	28.78	28.78	24.83	24.83	40.37	40.37	40.37	40.37
Commercial Costs	*Taxes*	US$/ton	2.78	2.78	2.62	2.62	2.78	2.78	2.78	2.78
	Paritaria	US$/ton	2.25	2.25	2.25	2.25	2.25	2.25	2.25	2.25
	Comision Acopic	US$/ton	3.59	3.59	3.38	3.38	3.59	3.59	3.59	3.59
	Total	***US$/ton***	***37.4***	***37.4***	***33.08***	***33.08***	***48.99***	***48.99***	***48.99***	***48.99***

Table 37: Economic data on sunflower cultivation with cutting-edge technology in 2011 (Reference zone: west Buenos Aires)

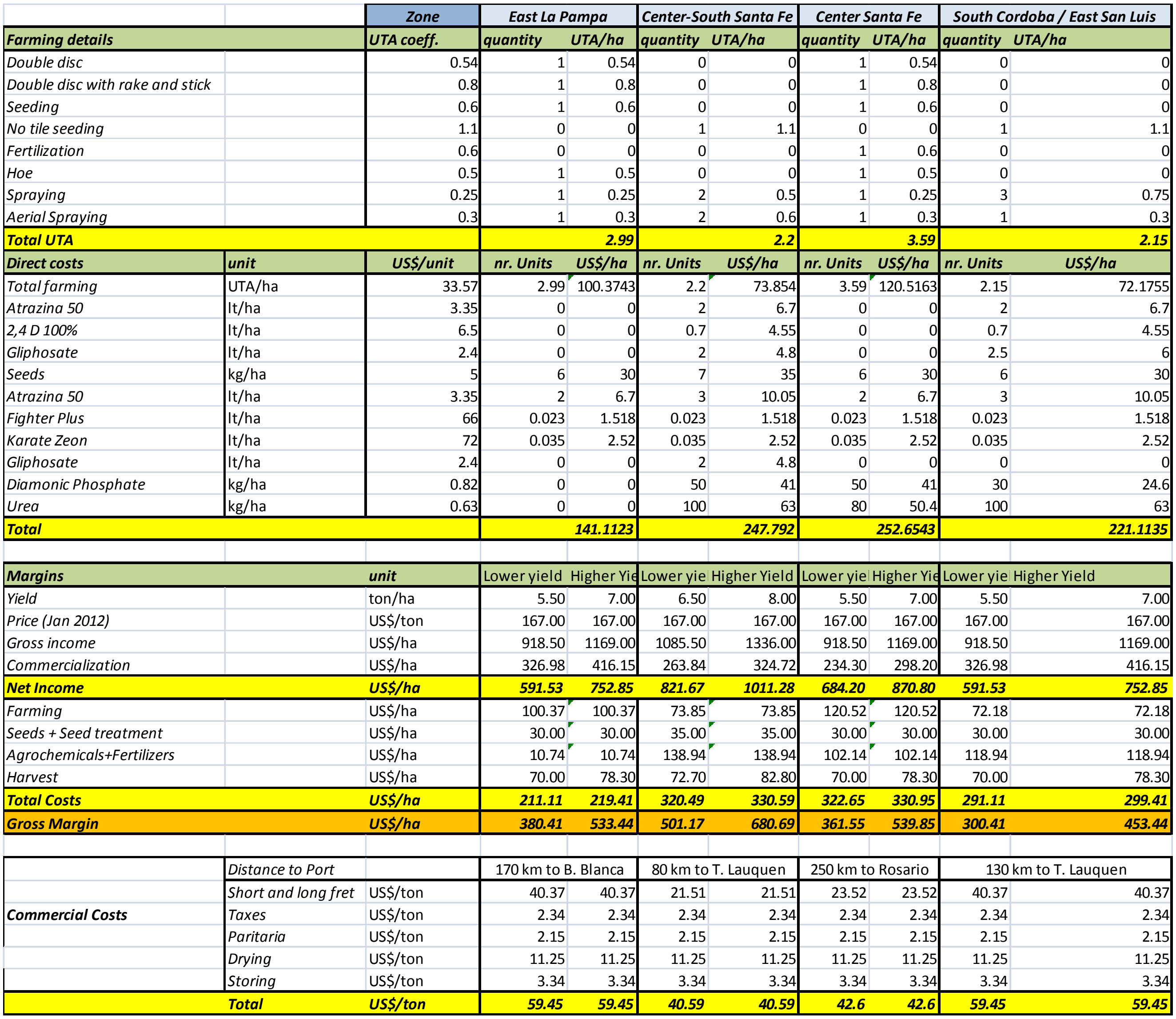
Farming details		***UTA coef.***	***quantity***	***UTA/ha***
Fertilization		0.25	1	0.25
No till seeding		1.1	1	1.1
Spraying		0.25	3	0.75
Aerial Spraying		0.3	1	0.3
[redacted]				
Total UTA				***2.4***
Direct costs	***unit***	***US$/unit***	***nr. Units***	***US$/ha***
Total Farming	UTA/ha	33.57	2.4	80.568
Seeds	bl/ha	160	0.33	52.8
RoundUp Full II	lt/ha	5.86	3	17.58
Diamonic Phosphate	kg/ha	0.82	50	41
Urea	kg/ha	0.63	90	56.7
Boro	kg/ha	3.6	1	3.6
Twinpack golb	lt/ha	12.6	2	25.2
Karate Zeon	lt/ha	72	0.025	1.8
Intrepid	lt/ha	39.8	0.12	4.776
[redacted]				
Total				***284.024***
Margins		***unit***	Lower yield	Higher Yield
Yield		ton/ha	2.30	3.00
Price (Jan 2012)		US$/ton	305.00	305.00
Gross income		US$/ha	701.50	915.00
Oil benefit		US$/ha	70.15	91.50
Commercialization		US$/ha	72.45	94.50
Net Income		***US$/ha***	***699.20***	***912.00***
Farming		US$/ha	80.57	80.57
Seeds		US$/ha	52.80	52.80
Agrochemicals+Fertilizers		US$/ha	150.66	150.66
Harvest		US$/ha	60.00	68.60
Total Costs		***US$/ha***	***344.02***	***352.62***
Gross Margin		***US$/ha***	***355.18***	***559.38***
	Distance to plant		80 km	
	Short and long fret	US$/ton	13.82	
Commercial Costs	*Taxes*	US$/ton	4.73	
	Paritaria	US$/ton	2.35	
	Drying	US$/ton	4.5	
	Storing	US$/ton	6.1	
	Total	***US$/ton***	***31.5***	
	Oil Benefit	US$/ton	30.5	

Table 38: Economic data on sunflower cultivation in southeast, southwest and west Buenos Aires, south Cordoba and east La Pampa in 2011



		Zone	*SE and SW Bs. As.*		*West Bs. As.*		*South Cordoba*		*East La Pampa*	
Farming details		***UTA coeff.***	***quantity***	***UTA/ha***	***quantity***	***UTA/ha***	***quantity***	***UTA/ha***	***quantity***	***UTA/ha***
Chisel / excentric		0.9	1	0.9	0	0	0	0	0	0
Double disc with rake		0.7	1	0.7	0	0	0	0	0	0
Double disc with rake and stick		0.8	1	0.8	0	0	0	0	0	0
No tile seeding with fertilization		1	0	0	1	1	1	1	1	1
Seeding with fertilization		0.7	1	0.7	0	0	0	0	0	0
Spraying		0.25	1	0.25	3	0.75	3	0.75	3	0.75
Aerial Spraying		0.3	1	0.3	1	0.3	1	0.3	1	0.3
Total UTA				***3.65***		***2.05***		***2.05***		***2.05***
Direct costs	***unit***	***US$/unit***	***nr. Units***	***US$/ha***	***nr. Units***	***US$/ha***	***nr. Units***	***US$/ha***	***nr. Units***	***US$/ha***
Total farming	UTA/ha	33.57	3.65	122.5305	2.05	68.8185	2.05	68.8185	2.05	68.8185
Seed	bls/ha	155	0.33	51.15	0.33	51.15	0.35	54.25	0.33	51.15
Gaucho seed treatment	cc/ha	130	0.02	2.6	0.02	2.6	0.02	2.6	0.02	2.6
Glisophate	kg/ha	2.4	0	0	4.5	10.8	2.5	6	4.5	10.8
Agricultural oil	kg/ha	2.1	0	0	1	2.1	0.5	1.05	1	2.1
2 4 D 100%	kg/ha	6.5	0	0	0.5	3.25	0.5	3.25	0.5	3.25
Diamonic phosphate	kg/ha	0.82	60	49.2	40	32.8	60	49.2	40	32.8
Urea	lt/ha	0.63	0	0	80	50.4	100	63	80	50.4
Twinpack	lt/ha	7.5	2.4	18	2	15	1.5	11.25	1.7	12.75
Agil	lt/ha	15.6	0	0	0.4	6.24	0	0	0	0
Fighter Plues		66	0	0	0.02	1.32	0	0	0.02	1.32
Karate zeon	lt/ha	72	0.035	2.52	0.035	2.52	0.035	2.52	0.035	2.52
Total				***246.0005***		***246.9985***		***261.9385***		***238.5085***
Margins		***unit***	Lower yield	Higher Yield	Lower yield	Higher Yield	Lower yield	Higher Yield	Lower yield	Higher Yield
Yield		ton/ha	1.80	2.50	2.00	2.50	1.80	2.50	1.70	2.50
Price (Jan 2012)		US$/ton	310.00	310.00	305.00	305.00	320.00	320.00	305.00	305.00
Gross income		US$/ha	558.00	775.00	610.00	762.50	576.00	800.00	518.50	762.50
Oil benefit		US$/ha	55.80	77.50	61.00	76.25	57.60	80.00	51.85	76.25
Commercialization		US$/ha	69.50	96.53	63.00	78.75	82.69	114.85	59.86	88.03
Net Income		***US$/ha***	***544.30***	***755.98***	***608.00***	***760.00***	***550.91***	***765.15***	***510.49***	***750.73***
Farming		US$/ha	122.53	122.53	68.82	68.82	68.82	68.82	68.82	68.82
Seeds + Seed treatment		US$/ha	51.15	51.15	51.15	51.15	54.25	54.25	51.15	51.15
Agrochemicals+Fertilizers		US$/ha	72.32	72.32	127.03	127.03	138.87	138.87	118.54	118.54
Harvest		US$/ha	60.00	60.00	60.00	60.00	60.00	60.00	60.00	60.00
Total Costs		***US$/ha***	***306.00***	***306.00***	***307.00***	***307.00***	***321.94***	***321.94***	***298.51***	***298.51***
Gross Margin		***US$/ha***	***238.30***	***449.97***	***301.00***	***453.00***	***228.97***	***443.21***	***211.98***	***452.22***
	Distance to Port		170 km to B. Blanca		80 km to T. Lauquen		250 km to Rosario		130 km to T. Lauquen	
	Short and long fret	US$/ton	20.75	20.75	13.82	13.82	27.73	27.73	17.53	17.53
Commercial Costs	*Taxes*	US$/ton	4.81	4.81	4.73	4.73	4.96	4.96	4.73	4.73
	Paritaria	US$/ton	2.35	2.35	2.35	2.35	2.35	2.35	2.35	2.35
	Drying	US$/ton	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5
	Storing	US$/ton	6.2	6.2	6.1	6.1	6.4	6.4	6.1	6.1
	Total	***US$/ton***	***38.61***	***38.61***	***31.5***	***31.5***	***45.94***	***45.94***	***35.21***	***35.21***
			31.00	31.00	30.50	30.50	32.00	32.00	30.50	30.50

Table 39: Economic data on sorghum cultivation in La Pampa, Santa and Cordoba



		Zone	East La Pampa		Center-South Santa Fe		Center Santa Fe		South Cordoba / East San Luis	
Farming details		UTA coeff.	quantity	UTA/ha	quantity	UTA/ha	quantity	UTA/ha	quantity	UTA/ha
Double disc		0.54	1	0.54	0	0	1	0.54	0	0
Double disc with rake and stick		0.8	1	0.8	0	0	1	0.8	0	0
Seeding		0.6	1	0.6	0	0	1	0.6	0	0
No tile seeding		1.1	0	0	1	1.1	0	0	1	1.1
Fertilization		0.6	0	0	0	0	1	0.6	0	0
Hoe		0.5	1	0.5	0	0	1	0.5	0	0
Spraying		0.25	1	0.25	2	0.5	1	0.25	3	0.75
Aerial Spraying		0.3	1	0.3	2	0.6	1	0.3	1	0.3
Total UTA				2.99		2.2		3.59		2.15
Direct costs	unit	US$/unit	nr. Units	US$/ha	nr. Units	US$/ha	nr. Units	US$/ha	nr. Units	US$/ha
Total farming	UTA/ha	33.57	2.99	100.3743	2.2	73.854	3.59	120.5163	2.15	72.1755
Atrazina 50	lt/ha	3.35	0	0	2	6.7	0	0	2	6.7
2,4 D 100%	lt/ha	6.5	0	0	0.7	4.55	0	0	0.7	4.55
Gliphosate	lt/ha	2.4	0	0	2	4.8	0	0	2.5	6
Seeds	kg/ha	5	6	30	7	35	6	30	6	30
Atrazina 50	lt/ha	3.35	2	6.7	3	10.05	2	6.7	3	10.05
Fighter Plus	lt/ha	66	0.023	1.518	0.023	1.518	0.023	1.518	0.023	1.518
Karate Zeon	lt/ha	72	0.035	2.52	0.035	2.52	0.035	2.52	0.035	2.52
Gliphosate	lt/ha	2.4	0	0	2	4.8	0	0	0	0
Diamonic Phosphate	kg/ha	0.82	0	0	50	41	50	41	30	24.6
Urea	kg/ha	0.63	0	0	100	63	80	50.4	100	63
Total				141.1123		247.792		252.6543		221.1135
Margins		unit	Lower yield	Higher Yie	Lower yie	Higher Yield	Lower yie	Higher Yie	Lower yie	Higher Yield
Yield		ton/ha	5.50	7.00	6.50	8.00	5.50	7.00	5.50	7.00
Price (Jan 2012)		US$/ton	167.00	167.00	167.00	167.00	167.00	167.00	167.00	167.00
Gross income		US$/ha	918.50	1169.00	1085.50	1336.00	918.50	1169.00	918.50	1169.00
Commercialization		US$/ha	326.98	416.15	263.84	324.72	234.30	298.20	326.98	416.15
Net Income		US$/ha	591.53	752.85	821.67	1011.28	684.20	870.80	591.53	752.85
Farming		US$/ha	100.37	100.37	73.85	73.85	120.52	120.52	72.18	72.18
Seeds + Seed treatment		US$/ha	30.00	30.00	35.00	35.00	30.00	30.00	30.00	30.00
Agrochemicals+Fertilizers		US$/ha	10.74	10.74	138.94	138.94	102.14	102.14	118.94	118.94
Harvest		US$/ha	70.00	78.30	72.70	82.80	70.00	78.30	70.00	78.30
Total Costs		US$/ha	211.11	219.41	320.49	330.59	322.65	330.95	291.11	299.41
Gross Margin		US$/ha	380.41	533.44	501.17	680.69	361.55	539.85	300.41	453.44
Commercial Costs	Distance to Port		170 km to B. Blanca		80 km to T. Lauquen		250 km to Rosario		130 km to T. Lauquen	
	Short and long fret	US$/ton	40.37	40.37	21.51	21.51	23.52	23.52	40.37	40.37
	Taxes	US$/ton	2.34	2.34	2.34	2.34	2.34	2.34	2.34	2.34
	Paritaria	US$/ton	2.15	2.15	2.15	2.15	2.15	2.15	2.15	2.15
	Drying	US$/ton	11.25	11.25	11.25	11.25	11.25	11.25	11.25	11.25
	Storing	US$/ton	3.34	3.34	3.34	3.34	3.34	3.34	3.34	3.34
	Total	US$/ton	59.45	59.45	40.59	40.59	42.6	42.6	59.45	59.45

14. Appendix G: Past trends of population, level of affluence and diet

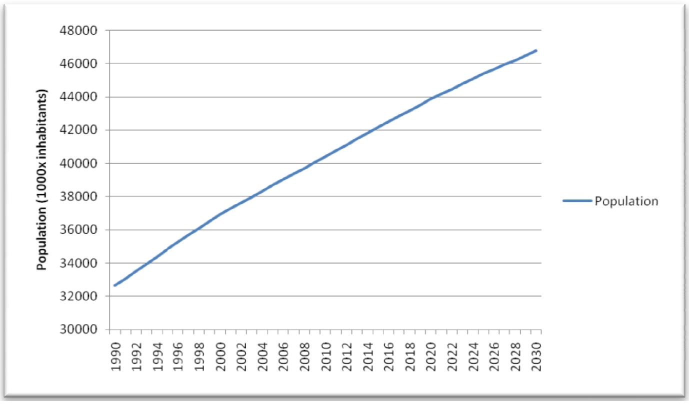


Figure 57: Observed and expected population growth in Argentina (Source: UNDP, 2010a)

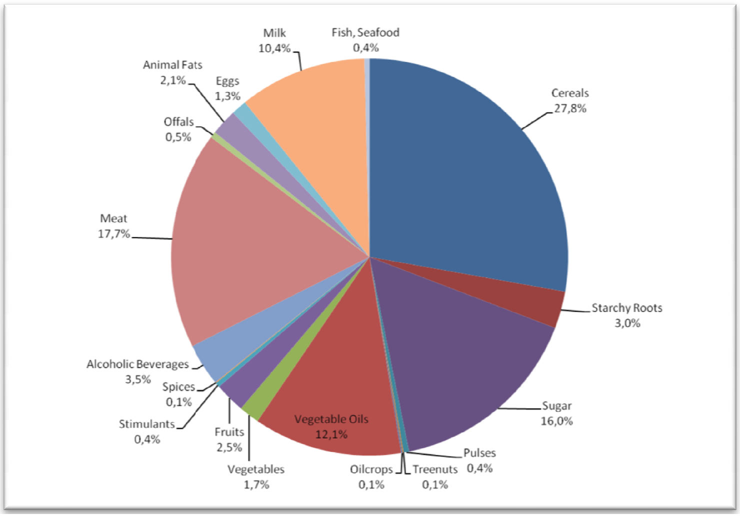


Figure 58: Diet composition (caloric content) in Argentina, 2007 (Source: Food Balance Sheet - FAOSTAT)

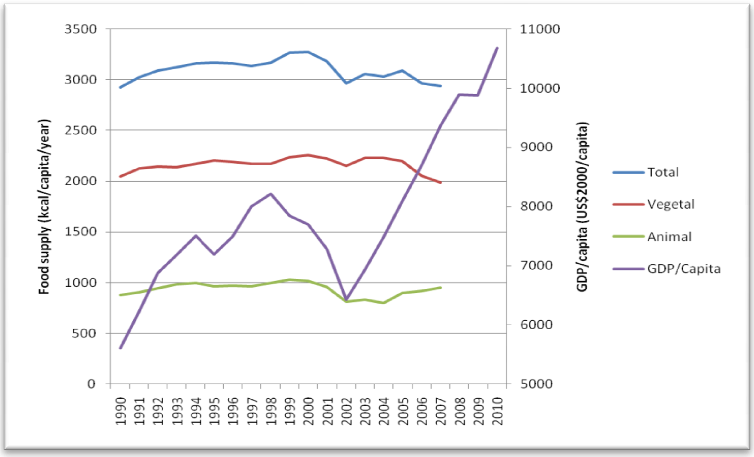


Figure 59: Daily food supply (total, vegetal and animal) and level of affluence (GDP/capita) in Argentina 1990 – 2010 (Source: FBS – FAOSTAT; World DataBank)

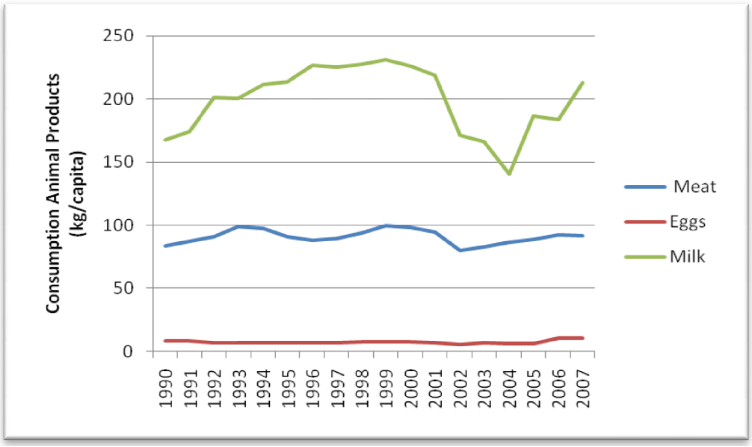


Figure 60: Consumption per capita of animal products in Argentina (Source: Food Balance Sheets - FAOSTAT)

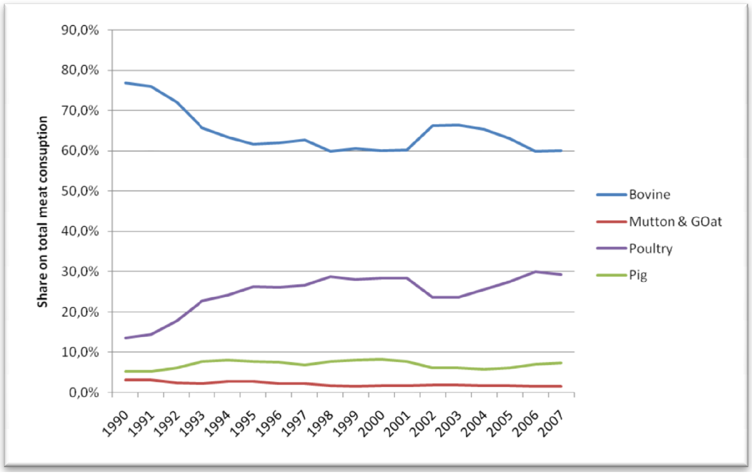


Figure 61: Share on total meat consumption per livestock specie (Source: Food Balance Sheets - FAOSTAT)

15. Appendix H: Past yield trends

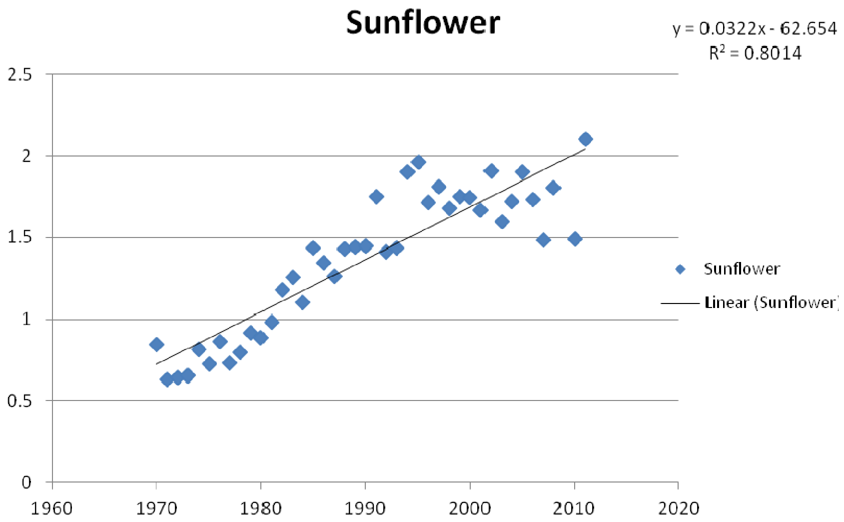


Figure 62: National average yields for sunflower 1970-2011 (Source: SIIA, 2011)

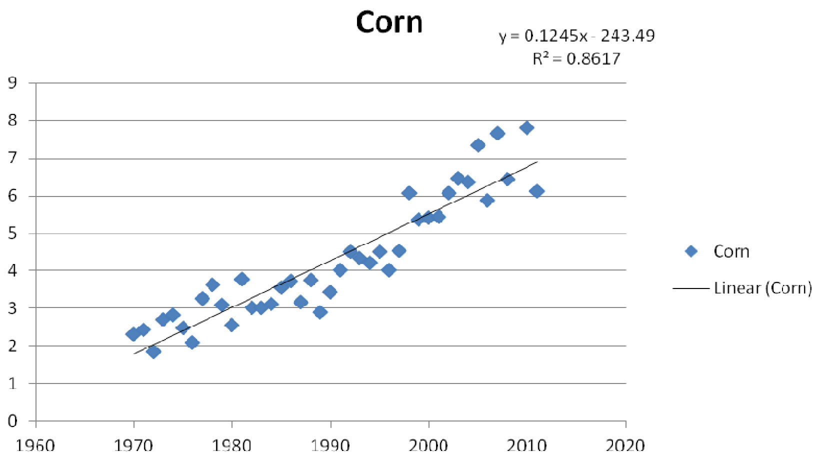


Figure 63: National average yields for corn 1970-2011 (Source: SIIA, 2011)

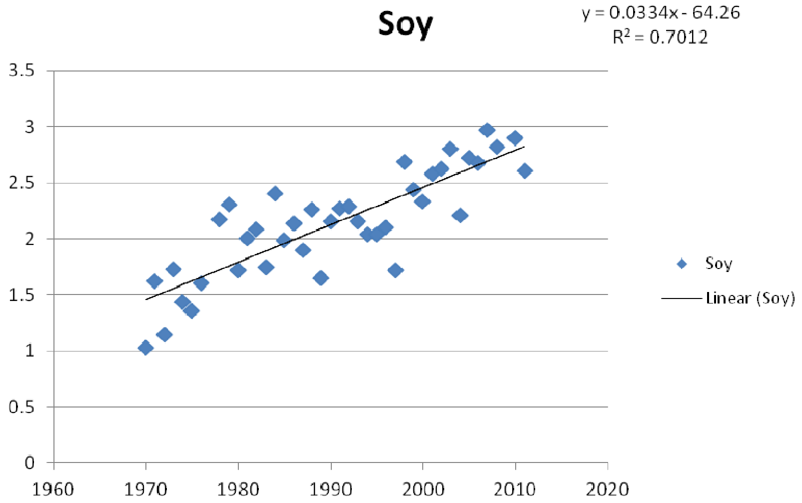


Figure 64: National average yields for soy 1970-2011 (Source: SIIA, 2011)

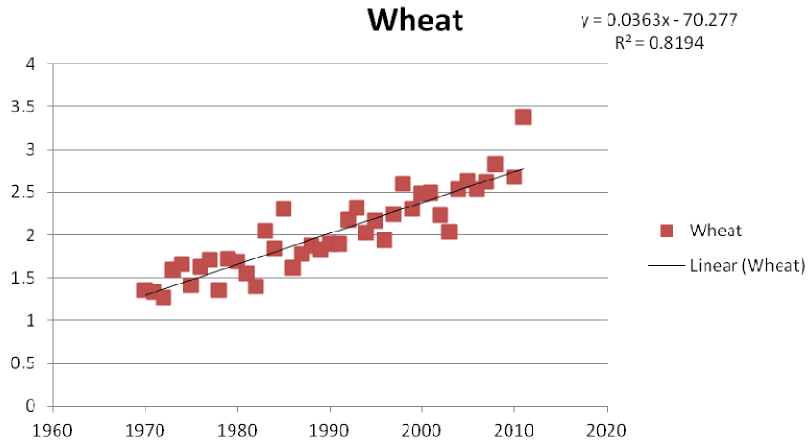


Figure 65: National average yields for wheat 1970-2011 (Source: SIIA, 2011)

16. Appendix I: Statistical analysis

16.1. Mixed rotation system 1

Case Processing Summary

Unweighted Cases[a]		N	Percent
Selected Cases	Included in Analysis	226358	100,0
	Missing Cases	0	,0
	Total	226358	100,0
	Unselected Cases	0	,0
	Total	226358	100,0

a. If weight is in effect, see classification table for the total number of cases.

Block 1: Method = Forward Stepwise (Likelihood Ratio)

Omnibus Tests of Model Coefficients

		Chi-square	df	Sig.
Step 1	Step	26492,086	1	,000
	Block	26492,086	1	,000
	Model	26492,086	1	,000
Step 2	Step	170,618	1	,000
	Block	26662,703	2	,000
	Model	26662,703	2	,000
Step 3	Step	221,002	1	,000
	Block	26883,705	3	,000
	Model	26883,705	3	,000
Step 4	Step	9,877	1	,002
	Block	26893,582	4	,000
	Model	26893,582	4	,000

Model Summary

Step	-2 Log likelihood	Cox & Snell R Square	Nagelkerke R Square
1	1422,000[a]	,110	,952
2	1251,382[a]	,111	,958
3	1030,380[b]	,112	,965
4	1020,503[b]	,112	,966

a. Estimation terminated at iteration number 12 because parameter estimates changed by less than ,001.

b. Estimation terminated at iteration number 13 because parameter estimates changed by less than ,001.

Classification Table[a]

			Predicted		
			lu_prod_2009f		
	Observed		0	1	Percentage Correct
Step 1	lu_prod_2009f	0	223724	88	100,0
		1	0	2546	100,0
		Overall Percentage			100,0
Step 2	lu_prod_2009f	0	223725	87	100,0
		1	30	2516	98,8
		Overall Percentage			99,9
Step 3	lu_prod_2009f	0	223750	62	100,0
		1	34	2512	98,7
		Overall Percentage			100,0
Step 4	lu_prod_2009f	0	223752	60	100,0
		1	42	2504	98,4
		Overall Percentage			100,0

a. The cut value is ,500

Variables in the Equation

		B	S.E.	Wald	df	Sig.	Exp(B)
Step 1[a]	neigh1_norm	88,401	1,653	2861,246	1	,000	2,467E38
	Constant	-8,580	,154	3091,664	1	,000	,000
Step 2[b]	dmarkets_norm	-6,408	,507	159,738	1	,000	,002
	neigh1_norm	77,168	1,706	2045,284	1	,000	3,263E33
	Constant	-5,423	,242	503,319	1	,000	,004
Step 3[c]	dmarkets_norm	-9,809	,591	275,074	1	,000	,000
	precipitation_norm	-12,984	,949	187,022	1	,000	,000
	neigh1_norm	61,086	1,885	1050,152	1	,000	3,383E26
	Constant	1,583	,490	10,443	1	,001	4,868

Step 4[d]	dmarkets_norm	-10,016	,585	293,134	1	,000	,000
	precipitation_norm	-12,658	,936	182,697	1	,000	,000
	dtown_norm	2,474	,802	9,510	1	,002	11,875
	neigh1_norm	61,527	1,910	1037,894	1	,000	5,260E26
	Constant	1,091	,498	4,801	1	,028	2,977

a. Variable(s) entered on step 1: neigh1_norm.

b. Variable(s) entered on step 2: dmarkets_norm.

c. Variable(s) entered on step 3: precipitation_norm.

d. Variable(s) entered on step 4: dtown_norm.

Correlation Matrix

		Constant	neigh1_norm	Constant	dmarkets_norm
Step 1	Constant	1,000	-,840		
	neigh1_norm	-,840	1,000		
Step 2	Constant			1,000	-,769
	dmarkets_norm			-,769	1,000
	neigh1_norm			-,564	,057

Correlation Matrix

		neigh1_norm	Constant	dmarkets_norm	precipitation_norm
Step 2	Constant	-,564			
	dmarkets_norm	,057			
	neigh1_norm	1,000			
Step 3	Constant		1,000	-,669	-,845
	dmarkets_norm		-,669	1,000	,346
	precipitation_norm		-,845	,346	1,000
	neigh1_norm		-,484	,147	,187
Step 4	Constant		1,000	-,556	-,819
	dmarkets_norm		-,556	1,000	,284
	precipitation_norm		-,819	,284	1,000
	dtown_norm		-,289	-,185	,070
	neigh1_norm		-,505	,120	,189

Correlation Matrix

		neigh1_norm	dtown_norm
Step 3	Constant	-,484	
	dmarkets_norm	,147	
	precipitation_norm	,187	
	neigh1_norm	1,000	
Step 4	Constant	-,505	-,289
	dmarkets_norm	,120	-,185
	precipitation_norm	,189	,070
	dtown_norm	,159	1,000
	neigh1_norm	1,000	,159

Model if Term Removed

Variable		Model Log Likelihood	Change in -2 Log Likelihood	df	Sig. of the Change
Step 1	neigh1_norm	-13957,043	26492,086	1	,000
Step 2	dmarkets_norm	-711,000	170,618	1	,000
	neigh1_norm	-8384,789	15518,196	1	,000
Step 3	dmarkets_norm	-685,708	341,035	1	,000
	precipitation_norm	-625,691	221,002	1	,000
	neigh1_norm	-2821,417	4612,453	1	,000
Step 4	dmarkets_norm	-685,605	350,706	1	,000
	precipitation_norm	-611,302	202,101	1	,000
	dtown_norm	-515,190	9,877	1	,002
	neigh1_norm	-2821,392	4622,281	1	,000

Variables not in the Equation

			Score	df	Sig.
Step 1	Variables	yield1_norm	,040	1	,842
		popdensity_norm	4,568	1	,033
		dmarkets_norm	179,265	1	,000
		dem_norm	66,947	1	,000
		precipitation_norm	39,517	1	,000
		dwater_norm	1,150	1	,284

		dtown_norm	4,139	1	,042
		Overall Statistics	422,701	7	,000
Step 2	Variables	yield1_norm	44,199	1	,000
		popdensity_norm	,114	1	,736
		dem_norm	,219	1	,640
		precipitation_norm	205,685	1	,000
		dwater_norm	6,628	1	,010
		dtown_norm	27,852	1	,000
		Overall Statistics	214,281	6	,000
Step 3	Variables	yield1_norm	,150	1	,699
		popdensity_norm	2,742	1	,098
		dem_norm	,080	1	,777
		dwater_norm	5,202	1	,023
		dtown_norm	9,441	1	,002
		Overall Statistics	16,764	5	,005
Step 4	Variables	yield1_norm	,010	1	,922
		popdensity_norm	3,810	1	,051
		dem_norm	,172	1	,678
		dwater_norm	2,859	1	,091
		Overall Statistics	7,604	4	,107

16.2. Mixed rotation 2

Case Processing Summary

Unweighted Cases[a]		N	Percent
Selected Cases	Included in Analysis	322260	100,0
	Missing Cases	0	,0
	Total	322260	100,0
	Unselected Cases	0	,0
	Total	322260	100,0

a. If weight is in effect, see classification table for the total number of cases.

Block 1: Method = Forward Stepwise (Likelihood Ratio)

Omnibus Tests of Model Coefficients

		Chi-square	df	Sig.
Step 1	Step	337874,052	1	,000
	Block	337874,052	1	,000
	Model	337874,052	1	,000
Step 2	Step	10345,632	1	,000
	Block	348219,684	2	,000
	Model	348219,684	2	,000
Step 3	Step	373,969	1	,000
	Block	348593,654	3	,000
	Model	348593,654	3	,000
Step 4	Step	232,155	1	,000
	Block	348825,809	4	,000
	Model	348825,809	4	,000
Step 5	Step	98,949	1	,000
	Block	348924,758	5	,000
	Model	348924,758	5	,000
Step 6	Step	12,378	1	,000
	Block	348937,136	6	,000
	Model	348937,136	6	,000

Model Summary

Step	-2 Log likelihood	Cox & Snell R Square	Nagelkerke R Square
1	58793,508[a]	,650	,917
2	48447,876[a]	,661	,933
3	48073,907[a]	,661	,934
4	47841,752[a]	,661	,934
5	47742,803[a]	,661	,934
6	47730,425[a]	,661	,934

a. Estimation terminated at iteration number 8 because parameter estimates changed by less than ,001.

Classification Table[a]

Observed			Predicted		
			lu_prod_2009f		
			0	2	Percentage Correct
Step 1	lu_prod_2009f	0	220021	3791	98,3
		2	6620	91828	93,3
		Overall Percentage			96,8
Step 2	lu_prod_2009f	0	220418	3394	98,5
		2	5068	93380	94,9
		Overall Percentage			97,4
Step 3	lu_prod_2009f	0	220519	3293	98,5
		2	5102	93346	94,8
		Overall Percentage			97,4
Step 4	lu_prod_2009f	0	220551	3261	98,5
		2	5123	93325	94,8
		Overall Percentage			97,4
Step 5	lu_prod_2009f	0	220533	3279	98,5
		2	5093	93355	94,8
		Overall Percentage			97,4
Step 6	lu_prod_2009f	0	220535	3277	98,5
		2	5103	93345	94,8
		Overall Percentage			97,4

Model Summary

Step	-2 Log likelihood	Cox & Snell R Square	Nagelkerke R Square
1	58793,508[a]	,650	,917
2	48447,876[a]	,661	,933
3	48073,907[a]	,661	,934
4	47841,752[a]	,661	,934
5	47742,803[a]	,661	,934
6	47730,425[a]	,661	,934

a. The cut value is ,500

Variables in the Equation

		B	S.E.	Wald	df	Sig.	Exp(B)
Step 1[a]	neigh2_norm	15,714	,071	48355,044	1	,000	6678523,570
	Constant	-4,296	,017	62347,106	1	,000	,014
Step 2[b]	dmarkets_norm	-5,700	,059	9331,868	1	,000	,003
	neigh2_norm	13,147	,073	32097,915	1	,000	512229,565
	Constant	-1,526	,029	2740,289	1	,000	,217
Step 3[c]	yield2_norm	,986	,051	380,845	1	,000	2,682
	dmarkets_norm	-5,262	,063	6998,184	1	,000	,005
	neigh2_norm	12,947	,073	31040,161	1	,000	419770,791
	Constant	-1,975	,038	2733,413	1	,000	,139
Step 4[d]	yield2_norm	,805	,052	239,812	1	,000	2,237
	dmarkets_norm	-5,298	,063	7114,599	1	,000	,005
	dwater_norm	-1,763	,122	210,420	1	,000	,172
	neigh2_norm	12,857	,073	30782,764	1	,000	383451,861
	Constant	-1,755	,040	1910,748	1	,000	,173
Step 5[e]	yield2_norm	,835	,052	253,329	1	,000	2,306
	dmarkets_norm	-5,506	,066	6855,971	1	,000	,004
	dwater_norm	-1,877	,122	235,427	1	,000	,153
	neigh2_norm	12,940	,074	30379,495	1	,000	416575,673
	dtown_norm	1,243	,123	101,976	1	,000	3,466
	Constant	-1,892	,043	1971,186	1	,000	,151
Step 6[f]	yield2_norm	,851	,053	261,743	1	,000	2,343
	popdensity_norm	-,384	,109	12,540	1	,000	,681
	dmarkets_norm	-5,542	,067	6779,731	1	,000	,004
	dwater_norm	-1,896	,123	238,382	1	,000	,150

	neigh2_norm	12,947	,074	30360,124	1	,000	419594,148
	dtown_norm	1,194	,124	92,306	1	,000	3,300
	Constant	-1,856	,044	1789,423	1	,000	,156

a. Variable(s) entered on step 1: neigh2_norm.

b. Variable(s) entered on step 2: dmarkets_norm.

c. Variable(s) entered on step 3: yield2_norm.

d. Variable(s) entered on step 4: dwater_norm.

e. Variable(s) entered on step 5: dtown_norm.

f. Variable(s) entered on step 6: popdensity_norm.

Correlation Matrix

		Constant	neigh2_norm	Constant	dmarkets_norm	neigh2_norm
Step 1	Constant	1,000	-,728			
	neigh2_norm	-,728	1,000			
Step 2	Constant			1,000	-,768	-,485
	dmarkets_norm			-,768	1,000	,026
	neigh2_norm			-,485	,026	1,000
Step 3	Constant			1,000	-,775	-,330
	yield2_norm			-,631	,340	-,068
	dmarkets_norm			-,775	1,000	-,003
	neigh2_norm			-,330	-,003	1,000
Step 4	Constant			1,000	-,743	-,313
	yield2_norm			-,656	,340	-,064
	dmarkets_norm			-,743	1,000	-,006
	dwater_norm			-,349	,074	,007
	neigh2_norm			-,313	-,006	1,000
Step 5	Constant			1,000	-,553	-,340
	yield2_norm			-,640	,302	-,057
	dmarkets_norm			-,553	1,000	-,057
	dwater_norm			-,295	,101	-,008
	neigh2_norm			-,340	-,057	1,000
	dtown_norm			-,327	-,337	,152

Correlation Matrix

		yield2_norm	dwater_norm	dtown_norm	Constant
Step 3	Constant	-,631			
	yield2_norm	1,000			
	dmarkets_norm	,340			
	neigh2_norm	-,068			
Step 4	Constant	-,656	-,349		
	yield2_norm	1,000	,222		
	dmarkets_norm	,340	,074		
	dwater_norm	,222	1,000		
	neigh2_norm	-,064	,007		
Step 5	Constant	-,640	-,295	-,327	
	yield2_norm	1,000	,216	,064	
	dmarkets_norm	,302	,101	-,337	
	dwater_norm	,216	1,000	-,101	
	neigh2_norm	-,057	-,008	,152	
	dtown_norm	,064	-,101	1,000	
Step 6	Constant				1,000
	yield2_norm				-,600
	popdensity_norm				-,237
	dmarkets_norm				-,567
	dwater_norm				-,297
	neigh2_norm				-,321
	dtown_norm				-,343

Correlation Matrix

		yield2_norm	popdensity_norm	dmarkets_norm	dwater_norm
Step 6	Constant	-,600	-,237	-,567	-,297
	yield2_norm	1,000	-,084	,284	,211
	popdensity_norm	-,084	1,000	,156	,044
	dmarkets_norm	,284	,156	1,000	,107
	dwater_norm	,211	,044	,107	1,000
	neigh2_norm	-,053	-,038	-,062	-,010
	dtown_norm	,053	,111	-,312	-,094

Correlation Matrix

		neigh2_norm	dtown_norm
Step 6	Constant	-,321	-,343
	yield2_norm	-,053	,053
	popdensity_norm	-,038	,111
	dmarkets_norm	-,062	-,312
	dwater_norm	-,010	-,094
	neigh2_norm	1,000	,146
	dtown_norm	,146	1,000

Model if Term Removed

Variable		Model Log Likelihood	Change in -2 Log Likelihood	df	Sig. of the Change
Step 1	neigh2_norm	-198333,780	337874,052	1	,000
Step 2	dmarkets_norm	-29396,754	10345,632	1	,000
	neigh2_norm	-77113,130	105778,383	1	,000
Step 3	yield2_norm	-24223,938	373,969	1	,000
	dmarkets_norm	-27791,644	7509,381	1	,000
	neigh2_norm	-73652,153	99230,399	1	,000
Step 4	yield2_norm	-24039,121	236,490	1	,000
	dmarkets_norm	-27743,888	7646,024	1	,000
	dwater_norm	-24036,953	232,155	1	,000
	neigh2_norm	-73511,051	99180,351	1	,000
Step 5	yield2_norm	-23996,453	250,103	1	,000
	dmarkets_norm	-27593,785	7444,767	1	,000
	dwater_norm	-24001,742	260,682	1	,000
	neigh2_norm	-73329,673	98916,543	1	,000
	dtown_norm	-23920,876	98,949	1	,000
Step 6	yield2_norm	-23994,295	258,165	1	,000
	popdensity_norm	-23871,401	12,378	1	,000
	dmarkets_norm	-27539,484	7348,544	1	,000
	dwater_norm	-23997,388	264,352	1	,000
	neigh2_norm	-73329,099	98927,773	1	,000
	dtown_norm	-23909,996	89,567	1	,000

Variables not in the Equation

			Score	df	Sig.
Step 1	Variables	yield2_norm	3446,218	1	,000
		popdensity_norm	544,901	1	,000
		dmarkets_norm	11035,305	1	,000
		dwater_norm	426,338	1	,000
		dtown_norm	769,648	1	,000
		Overall Statistics	11867,463	5	,000
Step 2	Variables	yield2_norm	383,270	1	,000
		popdensity_norm	3,190	1	,074
		dwater_norm	321,902	1	,000
		dtown_norm	50,428	1	,000
		Overall Statistics	687,314	4	,000
Step 3	Variables	popdensity_norm	15,660	1	,000
		dwater_norm	207,435	1	,000
		dtown_norm	72,379	1	,000
		Overall Statistics	316,995	3	,000
Step 4	Variables	popdensity_norm	22,110	1	,000
		dtown_norm	102,005	1	,000
		Overall Statistics	113,930	2	,000
Step 5	Variables	popdensity_norm	12,535	1	,000
		Overall Statistics	12,535	1	,000

16.3. Agriculture 3

Case Processing Summary

Unweighted Cases[a]		N	Percent
Selected Cases	Included in Analysis	338634	100,0
	Missing Cases	0	,0
	Total	338634	100,0
	Unselected Cases	0	,0
	Total	338634	100,0

a. If weight is in effect, see classification table for the total number of cases.

Block 1: Method = Forward Stepwise (Likelihood Ratio)

Omnibus Tests of Model Coefficients

		Chi-square	df	Sig.
Step 1	Step	388573,064	1	,000
	Block	388573,064	1	,000
	Model	388573,064	1	,000
Step 2	Step	7613,573	1	,000
	Block	396186,637	2	,000
	Model	396186,637	2	,000
Step 3	Step	2021,659	1	,000
	Block	398208,296	3	,000
	Model	398208,296	3	,000
Step 4	Step	184,091	1	,000
	Block	398392,387	4	,000
	Model	398392,387	4	,000
Step 5	Step	4,565	1	,033
	Block	398396,952	5	,000
	Model	398396,952	5	,000

Model Summary

Step	-2 Log likelihood	Cox & Snell R Square	Nagelkerke R Square
1	45162,493[a]	,683	,945
2	37548,919[a]	,690	,955
3	35527,260[a]	,691	,957
4	35343,170[a]	,692	,958
5	35338,605[a]	,692	,958

a. Estimation terminated at iteration number 9 because parameter estimates changed by less than ,001.

Classification Table[a]

			Predicted		
			lu_prod_2009f		
Observed			0	3	Percentage Correct
Step 1	lu_prod_2009f	0	220636	3176	98,6
		3	3209	111613	97,2
		Overall Percentage			98,1
Step 2	lu_prod_2009f	0	221611	2201	99,0
		3	4082	110740	96,4
		Overall Percentage			98,1
Step 3	lu_prod_2009f	0	221542	2270	99,0
		3	3320	111502	97,1
		Overall Percentage			98,3
Step 4	lu_prod_2009f	0	221558	2254	99,0
		3	3369	111453	97,1
		Overall Percentage			98,3
Step 5	lu_prod_2009f	0	221554	2258	99,0
		3	3365	111457	97,1
		Overall Percentage			98,3

a. The cut value is ,500

Variables in the Equation

		B	S.E.	Wald	df	Sig.	Exp(B)
Step 1[a]	neigh3_norm	22,823	,115	39142,745	1	,000	8,164E9
	Constant	-4,531	,020	53952,484	1	,000	,011
Step 2[b]	dmarkets_norm	-6,512	,077	7131,128	1	,000	,001
	neigh3_norm	18,302	,115	25260,225	1	,000	8,880E7
	Constant	-1,418	,035	1634,315	1	,000	,242
Step 3[c]	dmarkets_norm	-5,121	,084	3745,149	1	,000	,006
	yield3_norm	2,035	,045	2039,690	1	,000	7,652
	neigh3_norm	17,479	,116	22685,527	1	,000	3,901E7
	Constant	-2,573	,047	3028,124	1	,000	,076
Step 4[d]	dmarkets_norm	-5,592	,092	3690,638	1	,000	,004
	dwater_norm	1,091	,079	190,567	1	,000	2,977
	yield3_norm	2,079	,045	2124,802	1	,000	7,998

	neigh3_norm	16,946	,120	20060,238	1	,000	2,290E7
	Constant	-2,530	,047	2944,595	1	,000	,080
Step 5[e]	dmarkets_norm	-5,545	,095	3430,490	1	,000	,004
	dtown_norm	-,337	,158	4,526	1	,033	,714
	dwater_norm	1,096	,079	192,087	1	,000	2,991
	yield3_norm	2,063	,046	2038,655	1	,000	7,868
	neigh3_norm	16,934	,120	20019,067	1	,000	2,262E7
	Constant	-2,488	,051	2417,468	1	,000	,083

a. Variable(s) entered on step 1: neigh3_norm.

b. Variable(s) entered on step 2: dmarkets_norm.

c. Variable(s) entered on step 3: yield3_norm.

d. Variable(s) entered on step 4: dwater_norm.

e. Variable(s) entered on step 5: dtown_norm.

Correlation Matrix

		Constant	neigh3_norm	Constant	dmarkets_norm	neigh3_norm
Step 1	Constant	1,000	-,709			
	neigh3_norm	-,709	1,000			
Step 2	Constant			1,000	-,801	-,484
	dmarkets_norm			-,801	1,000	,072
	neigh3_norm			-,484	,072	1,000
Step 3	Constant			1,000	-,811	-,413
	dmarkets_norm			-,811	1,000	,106
	yield3_norm			-,605	,331	,029
	neigh3_norm			-,413	,106	1,000
Step 4	Constant			1,000	-,761	-,410
	dmarkets_norm			-,761	1,000	,194
	dwater_norm			,052	-,400	-,269
	yield3_norm			-,598	,270	,003
	neigh3_norm			-,410	,194	1,000
Step 5	Constant			1,000	-,594	-,392
	dmarkets_norm			-,594	1,000	,179
	dtown_norm			-,390	-,228	,038
	dwater_norm			,060	-,382	-,271
	yield3_norm			-,607	,220	,009
	neigh3_norm			-,392	,179	1,000

Correlation Matrix

		yield3_norm	dwater_norm	dtown_norm
Step 3	Constant	-,605		
	dmarkets_norm	,331		
	yield3_norm	1,000		
	neigh3_norm	,029		
Step 4	Constant	-,598	,052	
	dmarkets_norm	,270	-,400	
	dwater_norm	,086	1,000	
	yield3_norm	1,000	,086	
	neigh3_norm	,003	-,269	
Step 5	Constant	-,607	,060	-,390
	dmarkets_norm	,220	-,382	-,228
	dtown_norm	,165	-,029	1,000
	dwater_norm	,080	1,000	-,029
	yield3_norm	1,000	,080	,165
	neigh3_norm	,009	-,271	,038

Model if Term Removed

Variable		Model Log Likelihood	Change in -2 Log Likelihood	df	Sig. of the Change
Step 1	neigh3_norm	-216867,778	388573,064	1	,000
Step 2	dmarkets_norm	-22581,246	7613,573	1	,000
	neigh3_norm	-79493,778	121438,637	1	,000
Step 3	dmarkets_norm	-19649,173	3771,086	1	,000
	yield3_norm	-18774,460	2021,659	1	,000
	neigh3_norm	-64816,027	94104,793	1	,000
Step 4	dmarkets_norm	-19619,427	3895,685	1	,000
	dwater_norm	-17763,630	184,091	1	,000
	yield3_norm	-18726,367	2109,563	1	,000
	neigh3_norm	-58527,354	81711,539	1	,000
Step 5	dmarkets_norm	-19471,677	3604,750	1	,000
	dtown_norm	-17671,585	4,565	1	,033
	dwater_norm	-17762,061	185,516	1	,000
	yield3_norm	-18689,134	2039,663	1	,000

Correlation Matrix

		yield3_norm	dwater_norm	dtown_norm	
Step 3	Constant	-,605			
	dmarkets_norm	,331			
	yield3_norm	1,000			
	neigh3_norm	,029			
Step 4	Constant	-,598	,052		
	dmarkets_norm	,270	-,400		
	dwater_norm	,086	1,000		
	yield3_norm	1,000	,086		
	neigh3_norm	,003	-,269		
Step 5	Constant	-,607	,060	-,390	
	dmarkets_norm	,220	-,382	-,228	
	dtown_norm	,165	-,029	1,000	
	dwater_norm	,080	1,000	-,029	
	yield3_norm	1,000	,080	,165	
	neigh3_norm	-58501,043	81663,482	1	,000

Variables not in the Equation

			Score	df	Sig.
Step 1	Variables	dem_norm	685,926	1	,000
		popdensity_norm	927,310	1	,000
		dmarkets_norm	8402,852	1	,000
		dtown_norm	1202,145	1	,000
		dwater_norm	576,232	1	,000
		yield3_norm	6674,977	1	,000
		Overall Statistics	10888,339	6	,000
Step 2	Variables	dem_norm	54,432	1	,000
		popdensity_norm	4,506	1	,034
		dtown_norm	66,023	1	,000
		dwater_norm	98,929	1	,000
		yield3_norm	2138,882	1	,000
		Overall Statistics	2364,824	5	,000
Step 3	Variables	dem_norm	,835	1	,361
		popdensity_norm	,020	1	,889

		dtown_norm	3,116	1	,078
		dwater_norm	191,420	1	,000
		Overall Statistics	195,979	4	,000
Step 4	Variables	dem_norm	,017	1	,896
		popdensity_norm	,150	1	,698
		dtown_norm	4,525	1	,033
		Overall Statistics	4,601	3	,203
Step 5	Variables	dem_norm	,064	1	,801
		popdensity_norm	,013	1	,910
		Overall Statistics	,074	2	,964

1.1. Agriculture 4

Case Processing Summary

Unweighted Cases[a]		N	Percent
Selected Cases	Included in Analysis	327295	100,0
	Missing Cases	0	,0
	Total	327295	100,0
	Unselected Cases	0	,0
	Total	327295	100,0

a. If weight is in effect, see classification table for the total number of cases.

Block 1: Method = Forward Stepwise (Likelihood Ratio)

Omnibus Tests of Model Coefficients

		Chi-square	df	Sig.
Step 1	Step	387450,734	1	,000
	Block	387450,734	1	,000
	Model	387450,734	1	,000
Step 2	Step	1210,370	1	,000
	Block	388661,104	2	,000
	Model	388661,104	2	,000
Step 3	Step	360,147	1	,000
	Block	389021,251	3	,000
	Model	389021,251	3	,000
Step 4	Step	244,563	1	,000
	Block	389265,814	4	,000

	Model	389265,814	4	,000
Step 5	Step	21,537	1	,000
	Block	389287,351	5	,000
	Model	389287,351	5	,000
Step 6	Step	4,082	1	,043
	Block	389291,433	6	,000
	Model	389291,433	6	,000

Model Summary

Step	-2 Log likelihood	Cox & Snell R Square	Nagelkerke R Square
1	20983,169[a]	,694	,973
2	19772,799[b]	,695	,975
3	19412,652[b]	,695	,975
4	19168,089[b]	,696	,976
5	19146,552[b]	,696	,976
6	19142,470[b]	,696	,976

a. Estimation terminated at iteration number 9 because parameter estimates changed by less than ,001.

b. Estimation terminated at iteration number 10 because parameter estimates changed by less than ,001.

Classification Table[a]

			Predicted		
			lu_prod_2009f		
	Observed		0	4	Percentage Correct
Step 1	lu_prod_2009f	0	222751	1061	99,5
		4	2344	101139	97,7
		Overall Percentage			99,0
Step 2	lu_prod_2009f	0	222713	1099	99,5
		4	1898	101585	98,2
		Overall Percentage			99,1
Step 3	lu_prod_2009f	0	222721	1091	99,5
		4	1876	101607	98,2
		Overall Percentage			99,1

Step 4	lu_prod_2009f	0	222757	1055	99,5
		4	1848	101635	98,2
		Overall Percentage			99,1
Step 5	lu_prod_2009f	0	222754	1058	99,5
		4	1839	101644	98,2
		Overall Percentage			99,1
Step 6	lu_prod_2009f	0	222756	1056	99,5
		4	1831	101652	98,2
		Overall Percentage			99,1

a. The cut value is ,500

Variables in the Equation

		B	S.E.	Wald	df	Sig.	Exp(B)
Step 1[a]	neigh4_norm	20,863	,140	22181,870	1	,000	1,150E9
	Constant	-5,393	,030	32625,632	1	,000	,005
Step 2[b]	dmarkets_norm	-3,565	,103	1199,388	1	,000	,028
	neigh4_norm	19,599	,143	18884,098	1	,000	3,248E8
	Constant	-3,459	,058	3606,905	1	,000	,031
Step 3[c]	dmarkets_norm	-2,694	,113	563,880	1	,000	,068
	yield4_norm	1,345	,070	373,000	1	,000	3,840
	neigh4_norm	19,075	,144	17580,750	1	,000	1,924E8
	Constant	-4,171	,072	3379,720	1	,000	,015
Step 4[d]	dmarkets_norm	-2,616	,112	542,664	1	,000	,073
	dwater_norm	-3,127	,223	197,410	1	,000	,044
	yield4_norm	1,296	,069	348,302	1	,000	3,654
	neigh4_norm	19,088	,145	17312,456	1	,000	1,948E8
	Constant	-3,933	,072	2966,601	1	,000	,020
Step 5[e]	dmarkets_norm	-2,813	,120	547,574	1	,000	,060
	dwater_norm	-3,216	,224	206,831	1	,000	,040
	dtown_norm	,878	,187	22,089	1	,000	2,407
	yield4_norm	1,331	,070	359,304	1	,000	3,784
	neigh4_norm	19,253	,151	16317,232	1	,000	2,299E8
	Constant	-4,011	,074	2919,902	1	,000	,018
Step 6[f]	popdensity_norm	,404	,198	4,144	1	,042	1,498
	dmarkets_norm	-2,780	,121	525,103	1	,000	,062

dwater_norm	-3,179	,224	201,885	1	,000	,042
dtown_norm	,906	,187	23,456	1	,000	2,474
yield4_norm	1,322	,070	352,414	1	,000	3,750
neigh4_norm	19,237	,151	16281,304	1	,000	2,263E8
Constant	-4,049	,077	2789,528	1	,000	,017

a. Variable(s) entered on step 1: neigh4_norm.

b. Variable(s) entered on step 2: dmarkets_norm.

c. Variable(s) entered on step 3: yield4_norm.

d. Variable(s) entered on step 4: dwater_norm.

e. Variable(s) entered on step 5: dtown_norm.

f. Variable(s) entered on step 6: popdensity_norm.

Model if Term Removed

Variable		Model Log Likelihood	Change in -2 Log Likelihood	df	Sig. of the Change
Step 1	neigh4_norm	-204216,951	387450,734	1	,000
Step 2	dmarkets_norm	-10491,584	1210,370	1	,000
	neigh4_norm	-95430,436	171088,074	1	,000
Step 3	dmarkets_norm	-9986,341	560,030	1	,000
	yield4_norm	-9886,399	360,147	1	,000
	neigh4_norm	-69947,052	120481,452	1	,000
Step 4	dmarkets_norm	-9853,632	539,175	1	,000
	dwater_norm	-9706,326	244,563	1	,000
	yield4_norm	-9752,411	336,733	1	,000
	neigh4_norm	-69837,312	120506,536	1	,000
Step 5	dmarkets_norm	-9846,538	546,523	1	,000
	dwater_norm	-9701,635	256,718	1	,000
	dtown_norm	-9584,045	21,537	1	,000
	yield4_norm	-9747,755	348,958	1	,000
	neigh4_norm	-66174,040	113201,528	1	,000
Step 6	popdensity_norm	-9573,276	4,082	1	,043
	dmarkets_norm	-9833,243	524,016	1	,000
	dwater_norm	-9696,386	250,302	1	,000
	dtown_norm	-9582,657	22,843	1	,000
	yield4_norm	-9742,357	342,245	1	,000
	neigh4_norm	-66025,705	112908,941	1	,000

Variables not in the Equation

			Score	df	Sig.
Step 1	Variables	popdensity_norm	121,853	1	,000
		dmarkets_norm	1249,278	1	,000
		dwater_norm	255,947	1	,000
		dtown_norm	158,258	1	,000
		yield4_norm	1099,903	1	,000
		slope_norm	3,219	1	,073
		Overall Statistics	1888,296	6	,000
Step 2	Variables	popdensity_norm	20,485	1	,000
		dwater_norm	211,530	1	,000
		dtown_norm	1,847	1	,174
		yield4_norm	378,721	1	,000
		slope_norm	,109	1	,741
		Overall Statistics	589,792	5	,000
Step 3	Variables	popdensity_norm	9,027	1	,003
		dwater_norm	193,759	1	,000
		dtown_norm	9,557	1	,002
		slope_norm	1,220	1	,269
		Overall Statistics	219,335	4	,000
Step 4	Variables	popdensity_norm	2,804	1	,094
		dtown_norm	22,108	1	,000
		slope_norm	,276	1	,599
		Overall Statistics	26,276	3	,000
Step 5	Variables	popdensity_norm	4,129	1	,042
		slope_norm	,011	1	,918
		Overall Statistics	4,135	2	,127
Step 6	Variables	slope_norm	,007	1	,935
		Overall Statistics	,007	1	,935

16.4. Livestock production

Case Processing Summary

Unweighted Cases[a]		N	Percent
Selected Cases	Included in Analysis	783247	100,0
	Missing Cases	0	,0
	Total	783247	100,0
	Unselected Cases	0	,0
	Total	783247	100,0

a. If weight is in effect, see classification table for the total number of cases.

Block 1: Method = Forward Stepwise (Likelihood Ratio)

Omnibus Tests of Model Coefficients

		Chi-square	df	Sig.
Step 1	Step	547552,757	1	,000
	Block	547552,757	1	,000
	Model	547552,757	1	,000
Step 2	Step	65151,111	1	,000
	Block	612703,868	2	,000
	Model	612703,868	2	,000
Step 3	Step	588,811	1	,000
	Block	613292,679	3	,000
	Model	613292,679	3	,000
Step 4	Step	276,388	1	,000
	Block	613569,067	4	,000
	Model	613569,067	4	,000
Step 5	Step	89,137	1	,000
	Block	613658,203	5	,000
	Model	613658,203	5	,000
Step 6	Step	94,323	1	,000
	Block	613752,527	6	,000
	Model	613752,527	6	,000

Model Summary

Step	-2 Log likelihood	Cox & Snell R Square	Nagelkerke R Square
1	389682,701[a]	,503	,721
2	324531,590[a]	,543	,778
3	323942,779[a]	,543	,778
4	323666,391[a]	,543	,778
5	323577,254[a]	,543	,778
6	323482,931[a]	,543	,779

a. Estimation terminated at iteration number 7 because parameter estimates changed by less than ,001.

Classification Table[a]

Observed			Predicted		
			lu_prod_2009f		
			0	5	Percentage Correct
Step 1	lu_prod_2009f	0	170824	52988	76,3
		5	26732	532703	95,2
		Overall Percentage			89,8
Step 2	lu_prod_2009f	0	187296	36516	83,7
		5	25979	533456	95,4
		Overall Percentage			92,0
Step 3	lu_prod_2009f	0	187327	36485	83,7
		5	25938	533497	95,4
		Overall Percentage			92,0
Step 4	lu_prod_2009f	0	187644	36168	83,8
		5	26355	533080	95,3
		Overall Percentage			92,0
Step 5	lu_prod_2009f	0	187662	36150	83,8
		5	26257	533178	95,3
		Overall Percentage			92,0
Step 6	lu_prod_2009f	0	187780	36032	83,9
		5	26323	533112	95,3
		Overall Percentage			92,0

Classification Table[a]

	Observed		Predicted		
			lu_prod_2009f		Percentage Correct
			0	5	
Step 1	lu_prod_2009f	0	170824	52988	76,3
		5	26732	532703	95,2
		Overall Percentage			89,8
Step 2	lu_prod_2009f	0	187296	36516	83,7
		5	25979	533456	95,4
		Overall Percentage			92,0
Step 3	lu_prod_2009f	0	187327	36485	83,7
		5	25938	533497	95,4
		Overall Percentage			92,0
Step 4	lu_prod_2009f	0	187644	36168	83,8
		5	26355	533080	95,3
		Overall Percentage			92,0
Step 5	lu_prod_2009f	0	187662	36150	83,8
		5	26257	533178	95,3
		Overall Percentage			92,0
Step 6	lu_prod_2009f	0	187780	36032	83,9
		5	26323	533112	95,3
		Overall Percentage			92,0

a. The cut value is ,500

Variables in the Equation

		B	S.E.	Wald	df	Sig.	Exp(B)
Step 1[a]	neighpast_norm	8,041	,018	200427,572	1	,000	3104,343
	Constant	-2,623	,008	117882,865	1	,000	,073
Step 2[b]	dmarkets_norm	-5,315	,023	53869,903	1	,000	,005
	neighpast_norm	6,700	,019	122344,206	1	,000	812,494
	Constant	,130	,014	89,290	1	,000	1,139
Step 3[c]	popdensity_norm	1,483	,067	491,212	1	,000	4,405
	dmarkets_norm	-5,187	,023	48773,941	1	,000	,006
	neighpast_norm	6,708	,019	122359,123	1	,000	818,626

	Constant	,012	,015	,670	1	,413	1,012
Step 4[d]	popdensity_norm	1,563	,067	536,756	1	,000	4,773
	dmarkets_norm	-5,295	,024	47000,297	1	,000	,005
	pasture_norm	-,240	,014	275,382	1	,000	,787
	neighpast_norm	6,708	,019	122164,481	1	,000	818,722
	Constant	,177	,018	99,679	1	,000	1,193
Step 5[e]	dem_norm	,679	,072	88,590	1	,000	1,972
	popdensity_norm	1,538	,067	522,472	1	,000	4,656
	dmarkets_norm	-5,316	,025	47002,377	1	,000	,005
	pasture_norm	-,190	,015	152,242	1	,000	,827
	neighpast_norm	6,698	,019	121487,771	1	,000	811,007
	Constant	,112	,019	35,123	1	,000	1,119
Step 6[f]	dem_norm	,788	,073	116,113	1	,000	2,198
	popdensity_norm	1,602	,068	555,656	1	,000	4,961
	dmarkets_norm	-5,388	,026	44024,337	1	,000	,005
	dtown_norm	,404	,042	94,445	1	,000	1,497
	pasture_norm	-,154	,016	94,698	1	,000	,857
	neighpast_norm	6,707	,019	121116,181	1	,000	818,018
	Constant	,043	,020	4,528	1	,033	1,044

a. Variable(s) entered on step 1: neighpast_norm.

b. Variable(s) entered on step 2: dmarkets_norm.

c. Variable(s) entered on step 3: popdensity_norm.

d. Variable(s) entered on step 4: pasture_norm.

e. Variable(s) entered on step 5: dem_norm.

f. Variable(s) entered on step 6: dtown_norm.

Correlation Matrix

		Constant	neighpast_norm	dmarkets_norm	Constant
Step 1	Constant	1,000	-,841		
	neighpast_norm	-,841	1,000		
Step 2	Constant	1,000	-,592	-,772	
	dmarkets_norm	-,772	,067	1,000	
	neighpast_norm	-,592	1,000	,067	
Step 3	Constant				1,000
	popdensity_norm				-,331
	dmarkets_norm				-,783

	neighpast_norm				-,568
Step 4	Constant				1,000
	popdensity_norm				-,235
	dmarkets_norm				-,778
	pasture_norm				-,562
	neighpast_norm				-,459
Step 5	Constant				1,000
	dem_norm				-,358
	popdensity_norm				-,205
	dmarkets_norm				-,687
	pasture_norm				-,615
	neighpast_norm				-,413
Step 6	Constant				1,000
	dem_norm				-,385
	popdensity_norm				-,225
	dmarkets_norm				-,510
	dtown_norm				-,353
	pasture_norm				-,641
	neighpast_norm				-,406

Correlation Matrix

		popdensity_norm	dmarkets_norm	neighpast_norm	pasture_norm
Step 3	Constant	-,331	-,783	-,568	
	popdensity_norm	1,000	,209	,025	
	dmarkets_norm	,209	1,000	,074	
	neighpast_norm	,025	,074	1,000	
Step 4	Constant	-,235	-,778	-,459	-,562
	popdensity_norm	1,000	,182	,025	-,072
	dmarkets_norm	,182	1,000	,066	,277
	pasture_norm	-,072	,277	-,018	1,000
	neighpast_norm	,025	,066	1,000	-,018
Step 5	Constant	-,205	-,687	-,413	-,615
	dem_norm	-,039	-,099	-,041	,340
	popdensity_norm	1,000	,185	,026	-,081
	dmarkets_norm	,185	1,000	,069	,224
	pasture_norm	-,081	,224	-,032	1,000

	neighpast_norm	,026	,069	1,000	-,032
Step 6	Constant	-,225	-,510	-,406	-,641
	dem_norm	-,024	-,139	-,031	,361
	popdensity_norm	1,000	,148	,031	-,055
	dmarkets_norm	,148	1,000	,048	,140
	dtown_norm	,096	-,297	,061	,233
	pasture_norm	-,055	,140	-,019	1,000
	neighpast_norm	,031	,048	1,000	-,019

Correlation Matrix

		dem_norm	dtown_norm
Step 5	Constant	-,358	
	dem_norm	1,000	
	popdensity_norm	-,039	
	dmarkets_norm	-,099	
	pasture_norm	,340	
	neighpast_norm	-,041	
Step 6	Constant	-,385	-,353
	dem_norm	1,000	,154
	popdensity_norm	-,024	,096
	dmarkets_norm	-,139	-,297
	dtown_norm	,154	1,000
	pasture_norm	,361	,233
	neighpast_norm	-,031	,061

Model if Term Removed

Variable		Model Log Likelihood	Change in -2 Log Likelihood	df	Sig. of the Change
Step 1	neighpast_norm	-468617,729	547552,757	1	,000
Step 2	dmarkets_norm	-194841,351	65151,111	1	,000
	neighpast_norm	-274066,513	223601,437	1	,000
Step 3	popdensity_norm	-162265,795	588,811	1	,000
	dmarkets_norm	-190537,391	57132,004	1	,000
	neighpast_norm	-273925,619	223908,458	1	,000
Step 4	popdensity_norm	-162157,597	648,802	1	,000

	dmarkets_norm	-189284,400	54902,410	1	,000
	pasture_norm	-161971,390	276,388	1	,000
	neighpast_norm	-273423,072	223179,753	1	,000
Step 5	dem_norm	-161833,196	89,137	1	,000
	popdensity_norm	-162103,727	630,200	1	,000
	dmarkets_norm	-189121,653	54666,052	1	,000
	pasture_norm	-161865,020	152,785	1	,000
	neighpast_norm	-271964,118	220350,983	1	,000
Step 6	dem_norm	-161799,929	116,927	1	,000
	popdensity_norm	-162078,612	674,292	1	,000
	dmarkets_norm	-187517,164	51551,396	1	,000
	dtown_norm	-161788,627	94,323	1	,000
	pasture_norm	-161788,929	94,927	1	,000
	neighpast_norm	-271963,514	220444,096	1	,000

Variables not in the Equation

			Score	df	Sig.
Step 1	Variables	dem_norm	1694,481	1	,000
		popdensity_norm	5773,655	1	,000
		dmarkets_norm	64681,518	1	,000
		dtown_norm	7070,046	1	,000
		dwater_norm	358,370	1	,000
		pasture_norm	4336,927	1	,000
		Overall Statistics	65608,190	6	,000
Step 2	Variables	dem_norm	215,662	1	,000
		popdensity_norm	507,147	1	,000
		dtown_norm	67,601	1	,000
		dwater_norm	11,135	1	,001
		pasture_norm	215,853	1	,000
		Overall Statistics	959,523	5	,000
Step 3	Variables	dem_norm	209,629	1	,000
		dtown_norm	126,136	1	,000
		dwater_norm	24,658	1	,000
		pasture_norm	275,637	1	,000
		Overall Statistics	457,525	4	,000

Step 4	Variables	dem_norm	88,565	1	,000
		dtown_norm	66,606	1	,000
		dwater_norm	1,963	1	,161
		Overall Statistics	184,990	3	,000
Step 5	Variables	dtown_norm	94,423	1	,000
		dwater_norm	1,269	1	,260
		Overall Statistics	96,728	2	,000
Step 6	Variables	dwater_norm	2,292	1	,130
		Overall Statistics	2,292	1	,130