Agricultural-GIS-Sphere – An innovative expert system for national renewable energy and food planning

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Abstract

Estimations concerning the future use of agricultural areas and forestry for the competing production of food and renewable energy mostly rely only on rough statistics. At the Agricultural Research and Education Centre (AREC) Raumberg-Gumpenstein, an experimental platform was developed dealing with the transformation of this problem down to farm level. The system integrates a strong spatial reference, which can be used for embedding of scientific data as well as for local aggregation. The agricultural production data is taken from the Integrated Administration and Control System (IACS). Thus, future political demands in terms of the necessary contingent of renewable energy and the degree of availability can be better controlled in the future. The aim is an easy possible increase of the contingent on agricultural areas until the practical maximum-limit. The system proposed supports this by a preselection of areas for the cultivation of energy crop and by the regulation of intensity in livestock-farming.

Keywords: renewable energy, food production, production strategy, scientific model, GIS

1 Introduction

Listening to national and European authorities, the lack of energy supply can be avoided by using renewable energy in the future. Changing from “energy for field”, which describes the period of oil, to “energy from field” we have developed a GI-System to balance, estimate and control the production of food and energy for all of Austria based on farm level.

The tool is called Agricultural-GIS-Sphere (AGS) and is an experimental platform on the basis of the actual agricultural management (Guggenberger and Bartelme 2005). The spatial resolution at a small scale is distinct from the approach of all existing models and studies, which almost always rely on more or less rough summaries of national statistics. Also the scientific set-up is different. In the AGS, each branch of agriculture is modelled in detail. Thus, future changes can make a start at different parameters. Examples are possible changes of growing conditions (climate and soil) or changes by political decisions (cultivation of different crops, altered intensities of livestock farming).

From the technical point of view, we have already developed a hierarchic design pattern on farm level to implement all typical functions of Austrian farms into an object-oriented data model (Coad et al. 1999). This model represents an expert system, which connects the carbon, nitrogen, energy cycle, the produced greenhouse gases and commodity outputs (milk, meat, cereals) with the local farmland represented by spatial data objects on plot level. They are embedded in standard GI-Software (Arc Map, ESRI). As data source, we used the anonymous IACS (Integrated administration and control system) data of 144,000 farms and over

3,000,000 plots of farmland with a total area of 21,800 km² (BMLFUW 2008). As a second step, the local results are generalized in spatial homogeneous units from the European Reference Grid in different resolutions (EEA 2003). Momentarily, we are working on the integration of Austrian forestry data based on spatial cells with a size of 10 to 10 km. All cells together will be used in the last challenge – the navigation system for food and energy. On the Austrian road and train network, we will first simulate the flow of milk, meat, cereals and energy to local factories and traders. While milk, meat and renewable energy are delivered to consumers, a lot of cereals flow back into livestock farming. This paper presents the structure and functions of the Agricultural Data Model (ADM) and the Spatial Data Model (SDM). First results of agricultural biomass potentials and their conversion into food are shown in the last chapter. The final step, the naviation system is allready in construction, but not finished yet.

2 Agricultural data model (ADM)

The ADM integrates agricultural data into multifunctional spatial data. The implementation of an object oriented database allows the close-to-reality-transformation of the most different agricultural subject-specific models. In the final extension of the model, the three main topics plots, livestock and subject-specific input are implemented on farm level. Valuable regional and national strategies can be derived from the balance of the individual farms concerning its full production and costs (food production, cumulated expenditures of energy, material flux concerning nitrogen, phosphor and potassium, greenhouse gases, economy). The model offers plot-polygons and farm centroid as a spatial interface. An overview of the work flow is given in figure 1.

2.1 General description of the most important domains

- Individual farm: these are all farms recorded by the IACS. Therefore, it is not possible that really *all* the farms are included. The part of grassland farms is nearly up to 100%. In terms of crop farms and fruit/wine farms a degree of more than 80% is reached. The primary key of the data model is represented by the farm identification number, which connects all indications of the IACS.
- Plots: The plot-ID is the key for spatial data processing of information for applications concerning agricultural subsidies. The single plots are already interfaced with all position parameters and the longstanding environmental data of the Austrian hydrographic atlas (ZAMG 2001). Parameters include: altitude, aspect, slope, annual average of air temperature, annual average of precipitation, average evapotranspiration, mean duration of drought, maximum duration of drought. An individual treatment of the plots is possible through the assignation of plot usage in the application. First, a separation into grassland and cropland takes place. For both classes the yields and nutrient content are rated. Models of forage preservation build the connection to livestock farming, which for its part delivers the farm manure back to the model.
- Livestock: Dairy farming located in grassland areas as well as in the transition of grassland to arable land and sheep breeding as well as livestock like pigs, cattle and poultry in arable land take a large amount of nutrients. Especially the demand of concentrate supplement with the focal point energy- and protein supply additionally leads to a high national/transnational material transport. Aim of this block is the calculation of local yields of milk and meat and the external feed being necessary for this purpose. The relation between the farm area and the farm’s amounts of manure allows controlling a production, which is adapted to the location.

- Input: Infrastructure and livestock need a lot of input. Especially the machinery and buildings as well as their operating require cumulated energy demand expressed as mega joule calorific value (MJ CV).

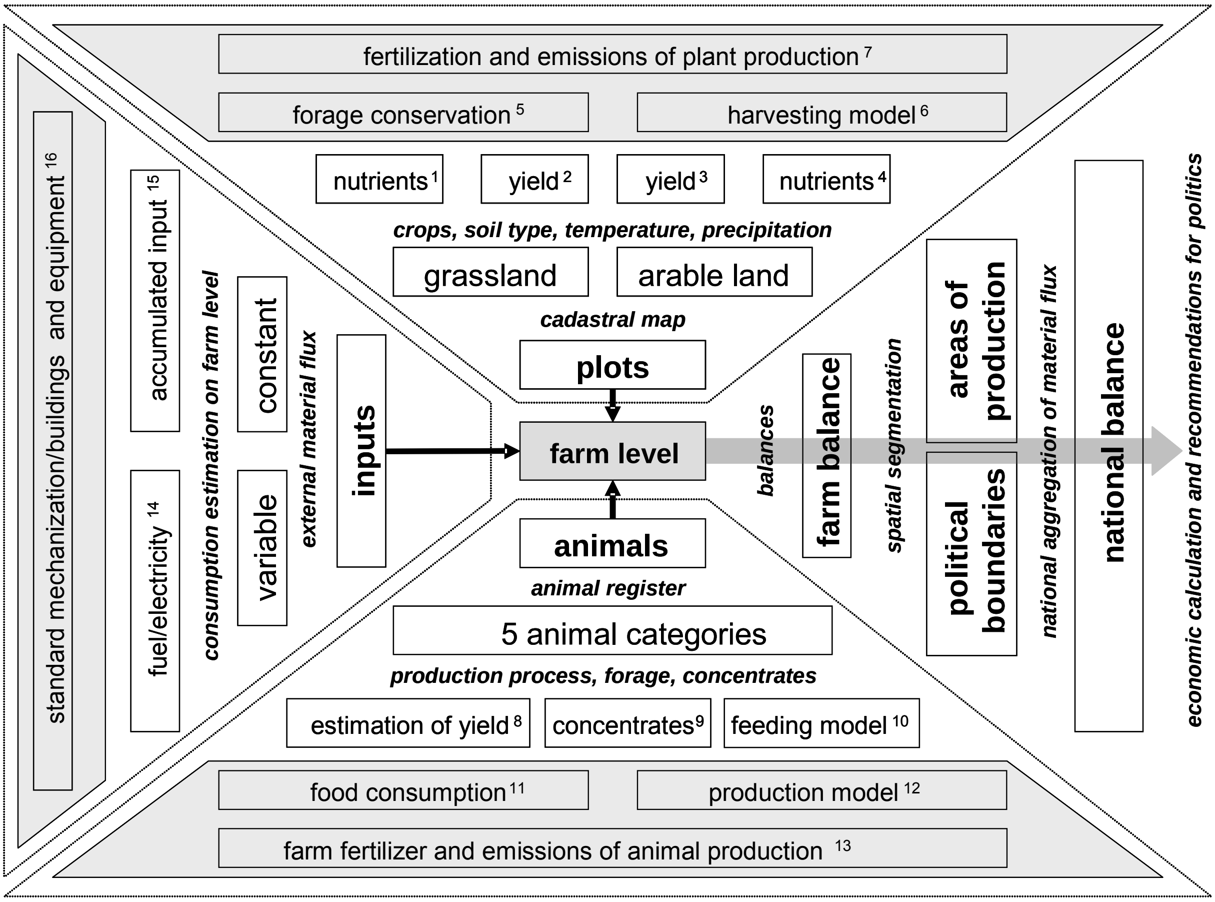

Figure 1: The basic work flow of the ADM: The numbers indicated refer to the points in chapter 2.2

2.2 *Detail (Enumerations follow figure 1)*

Behind each part of the ADM – each of them provided with a number – there is another detailed model, which is described as follows:

1. Grassland nutrients: A multiple model of estimation for forage was conducted from more than 13,000 spatial referenced forage analyses of the forage laboratory Rosenau (regional chamber for agriculture of Lower Austria) (Guggenberger et al. 2008; Resch et al. 2006; Wiedner et al. 2001)
2. Grassland yield: For dairy farms with grassland and a closed production cycle, the yield of forage must be adapted to the forage requirements of livestock (bottom-up).
3. Yield of cropfarms: Data of the most important crops concerning small spatial regions were provided by Statistics Austria (Statistik Austria 2007).
4. Crop nutrients: The values of a feed-table published by the German Association of Agriculture, completed by national results from the forage laboratory Rosenau, were assigned to the separate crops.(DLG 1997) .
5. Forage conservation: Basis of the model is a questionnaire sent to the heads of all Austrian machinery syndicates about the proportion of different types of conservation in their regions.

6. Harvesting model: deals with the calculation of usable quantities of plants. Crops are therefore dissected into corn and straw and treated accordingly.
7. Fertilization and emissions in plant production: In this complex module the plots are supplied with possible manure of livestock farming. Additionally, the fertilization is supplemented with mineral fertilizer according to the national recommendations for fertilizing. Scenarios of farm manure distribution are to be taken into account (BMLFUW 2006).
8. Feeding for production: The base for a realistic estimation of the nutrient flux in animal husbandry is the assumption of a farm-specific production level. For the milk production the amount of milk is specified for each farm. A mean national level is assumed for the meat production with cattle, pigs and poultry (GfE 1998; GfE 2001).
9. Commercial feeding stuff: a theoretical feed consumption for each category of animals is conducted by the national distribution of feedstuff. In the module this is differentiated into two ways of supplement, energy and proteins.
10. Rationing model: the concentration of nutrients in basic forage and commercial feeding stuff as well as the calculations of the production level go into a farm-specific feeding calculation.
11. Forage consumption: all yield components of an area are contrasted with the requirements of livestock farming.
12. Production model: links the farm internal production level of arable farming to animal husbandry.
13. Output of farm manure and emissions of animal husbandry: according to guidelines of the European Union, the flow of nutrients into the farm manure is calculated by including the intake of nutrients and the consequently produced amount of food (EWG 1991).
14. Fuel and electricity: The days of field work possible and an average degree of mechanization is assumed for each farm, its national position and its dimension. The energy requirement primarily complies with animal husbandry and preservation procedures (Hopfner et al. 1999).
15. Cumulated expenditure of energy (fixed): beside the already described machinery above all also the buildings need a certain amount of energy, for the quotation of which the necessary space for housings in animal husbandry and for storing of forage (per animal unit) was multiplied with the number of animals. Additionally, a small amount for additional buildings was taken into account.
16. Standard mechanization, buildings and equipment: was already described in 14 and 15 (Greimel et al. 2002).

3 Spatial data model (SDM)

3.1 Data enrichment

Via the primary key of its database, the ADM has a direct access to the world of geo-information, which uses the plots of the Austrian digital cadastre map as well as the crop-polygons having been investigated by the IACS-GIS as data base. As a next step, each polygon is intersected with various consistent raster-data of zonal functions. Examples are: altitude, slope, aspect, solar radiation, different kinds of temperature data, precipitation, soil type, etc.. This leads to an enrichment of the ADM on a local level. Many of the partial models presented in 2.2 use these data.

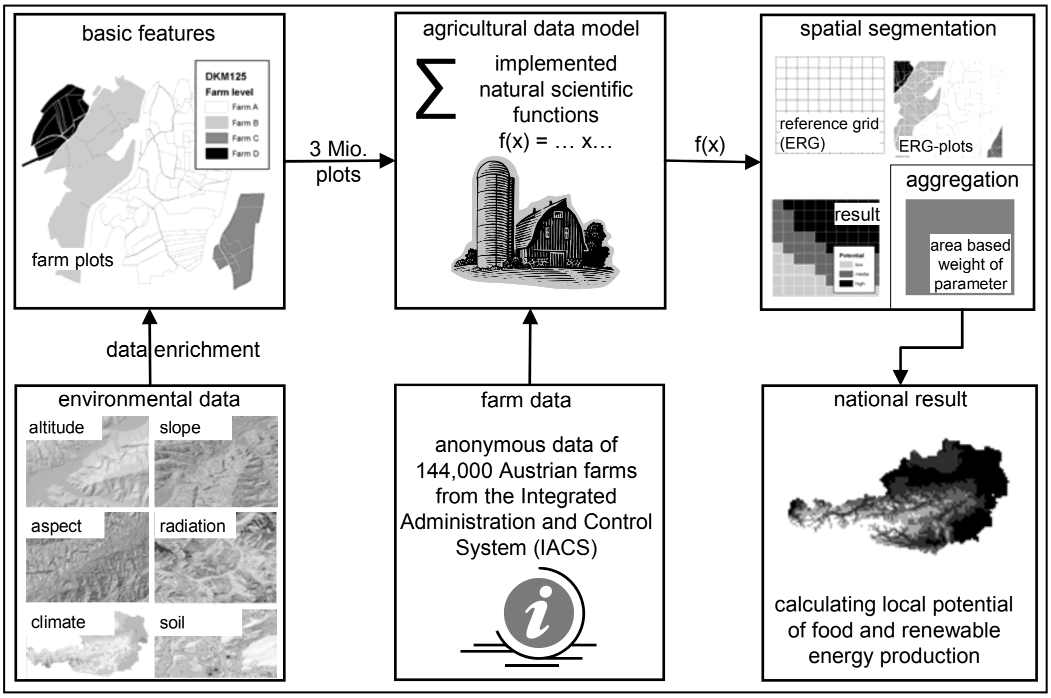

Figure 2: The integration of ADM into the spatial context

3.2 Spatial segmentation and aggregation

Most results of the ADM were calculated on farm level. To connect these data to the spatial part of the project, the values are stored as attributes into the polygons of the plots. These results should not be directly used further for the following reasons:

- The big number of plots (3 Mio.) cannot be mastered by the planned methods on today's hardware (topology, flow of materials).
- The direct presentation of small plots is forbidden for reasons of data privacy. At least three farms have to exist in one entity.
- The distribution and extent of the plots cannot be charted clearly or distinctively.
- Topological operations need homogeneous relations to their vicinity. These are given by a simple raster.

For these reasons, the plots are referred to a European Reference Grid (EEA 2003). Each of the plots is cut into intersections, in order to be able to be clearly referred to a single cell. According to the sort of parameter (concentration or amount) the original values of the plot are assigned to the new intersections depending on their extent. According to the demand these values are summarized as mean value or sum for each cell (Guggenberger 2007).

4 First result: Energy balance of food production

One of the results derived from the AGS, is the energy balance of Austrian agriculture. Calorific value (CV) is used for measurements, of which the unit is Joule, used as Terajoule (10^{12}) here.

4.1 Local results of food production

The biomass energy yield (Fig. 3) of a spatial unit of 10 by 10 km (100 km²) depends on the actual location of the area, the type of cultivation and its energy concentration. In the Alps for example, within such a big quadrant we only find very few agricultural areas and additionally they are only covered by a small energy density. We will find the biggest yields in the areas of corn production.

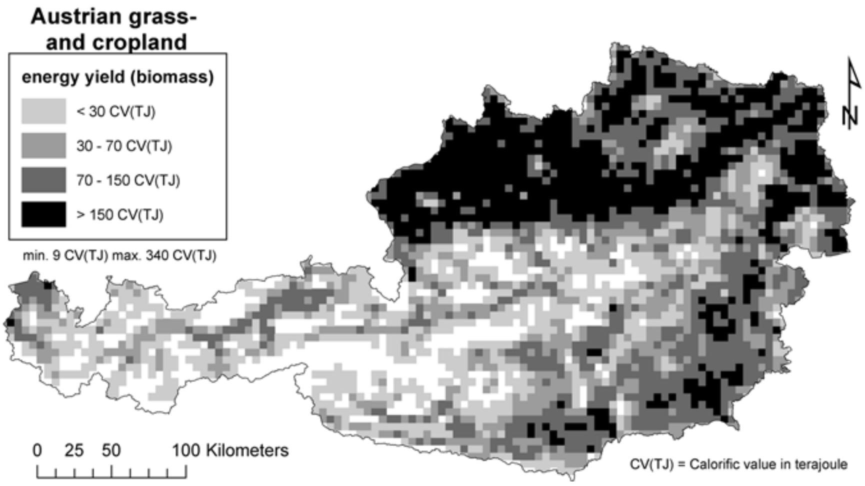

Figure 3: Biomass energy yield on 100 km²

Due to the different ways of running a farm, different amounts of external energy are needed. As it is shown in Fig. 1, the energy is imported to the farm as food, manure, fuel, electric current, machines and buildings. The highest import of energy (Fig. 4) is found in locations, where milk and pork production is located.

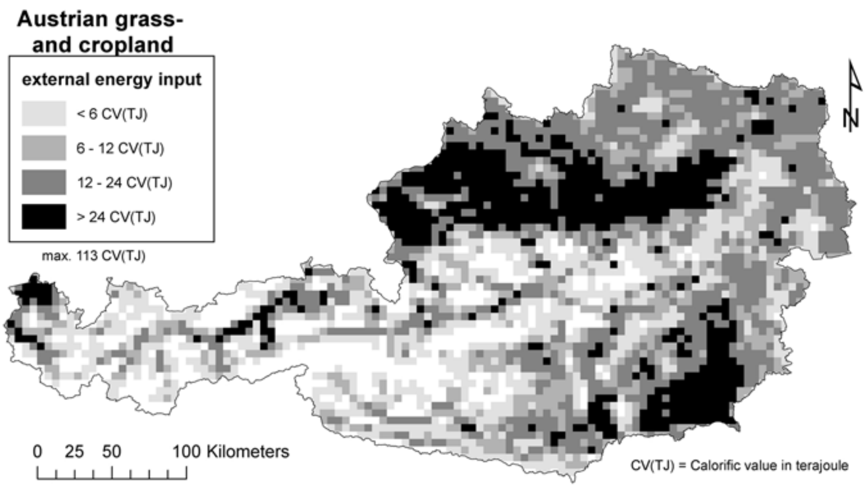

Figure 4: External energy input on 100 km²

Part of the energy used in agriculture is given off as food. The amount of food energy primarily derives from the kind of the final product. Having only a small energy loss, crop production leads to high energy yields. On the contrary, a high loss in milk production and refinement leads to small final yields.

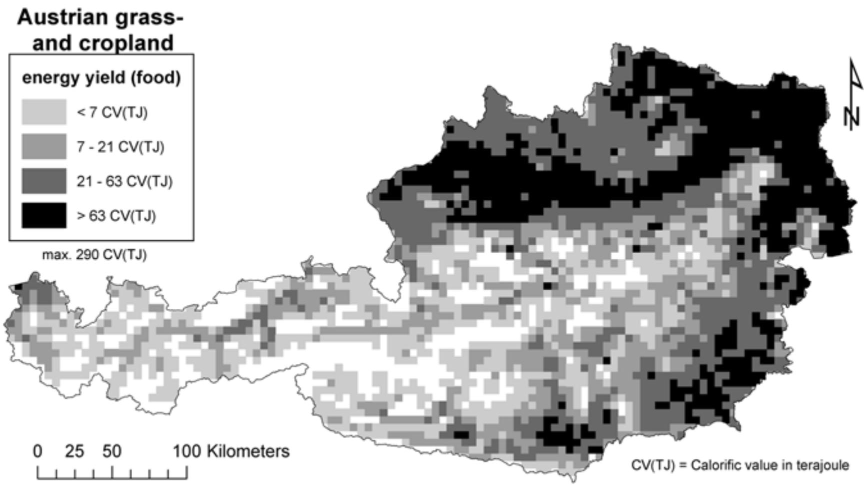

Figure 5: Energy yield of food on 100 km²

4.2 National food energy balance

As a result of these energy and food balances, all Austrian farms together have a surplus in their energy balance of meat, milk and cereals. The total amount of energy in products (102 Petajoule PJ) is 2.3 times higher than the input of energy (45 PJ), but the quality is different. Low quality energy from pastures and fuels is transformed into food. The national food balance has a surplus in energy input – we have a higher import of feedstuff (soy bean) in comparison to export of food (meat, cheese). In Austria, grassland and crops are well used in 2008.

5 Conclusions

Concerning the expected gain of the total amount of renewable energy in Austria by local authorities it seems their forecasts will fail. We have calculated that there is no farmland to produce the crops for the estimated 74 PJ (result of a national study) of fuel or energy forests without changing human diet and production systems. AGS is an impressive tool to estimate and plan the national energy and food supply, but also to check the different agricultural production systems. AGS can also be used to plan the location for new biogas plants or to show the area of supply for cities.

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