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D3.2
Report about the modeling of water demand and land use in GINFORS

WP 3 - Scenarios and modeling of policy implementation for resource efficiency

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1. Introduction

POLFREE (Policy Options for a Resource-Efficient Economy) is a major EU funded project that aims to design policy pathways towards a resource efficient Europe. A main goal of research within the POLFREE project regarding the model-based analysis of impacts of policies directed at resource efficiency as well as of behavioural changes based on intrinsic motivation on the economy, society and environment in work package 3, is to give new insights in the interlinkages between the different spheres using a two-way linked modelling approach of three systems: the economic environmental models EXIOMOD (TNO) and GINFORS (GWS) and the biophysical model LPJmL (PIK).

The deliverable at hand discusses in this context the extension of the GINFORS (Global INterindustry FORecasting System) model by water demand and land use decisions, two aspects that have not been addressed explicitly in former versions of the model. By doing so, the aspect of interlinkages between the biophysical sphere represented in the LPJmL-model and the economic decisions covered by GINFORS already appears, although the task of linking the two models will be subject of an report to be prepared later on (deliverable 3.4).

The analytical framework for understanding resource efficiency Kemp & Djik, 2013 state that "the production and use of goods and services is associated with the use of natural resources: water, land and a range of minerals and materials. A common distinction of resources is in fossil fuels, construction minerals, metallic minerals, biomass, water and land." (p. 3) The modeling of resource use is discussed here in the context of an adequate integration of the demand for natural resources in physical terms into the economic system, which among other things means that the interaction of supply and demand has to be mentioned. In the case of fossil fuels and minerals one can argue that the supply side (physical availability) can be covered by price developments. As i.e. Bardi, 2013 shows, for these resources an increasing scarcity does not mean that the earth system will run empty of them one day. But an overuse leads to an increasing need for exploration of resource deposits with lower yields and therefore higher costs and increasing ecological problems.

In contrast the integration of land and water use decisions is much more complicated: The supply of water depends from the geographical unit's hydro-geological and biogeochemical characterictics, which change in time and are interrelated to the economic system, which itself creates also the demand for water. "The interaction between the hydrological and the economic realm works both ways: water is transformed for economic use and the impact of economic use on water availability and quality consequently has implications in both the short and long term for the transformation process to modify water for economic use" (Brouwer & Hofkes, 2008, p.17). A similar situation is given for agricultural land use: Economic decisions determine which crops are where produced, but the soil quality, water availability and other dynamic physical factors determine the growth of crops and the result of the economic activities. Further soil quality and water availability are influenced by economic factors.

With this background of a need for a hard link between the models LPJmL and GINFORS the paper at hand asks how agricultural land use, the demand for agricultural products, the extraction of biomass and the water demand can be modeled in GINFORS. As this is the first deliverable within POLFREE that refers to this model the paper starts (chapter 2) with a short description of the actual version of GINFORS (denoted as $GINFORS_3$). The description of the new features of $GINFORS_3$ with regard to water demand and land use begins (chapter 3) with a discussion of the economy - agriculture – water – land use nexus and the system boundaries of the both models to be linked. Which information has to be delivered from $GINFORS_3$ to LPJmL and which output is generated by LPJmL for input in $GINFORS_3$? In a next chapter the data background for new features of GINFORS3 is discussed. The main empirical backbone of the model is the WIOD database, which describes the global economic development and the resource use in deep sectoral and country differentiation yearly for the period 1995 to 2009. As will be shown this database has to be complemented by additional data from other sources for the modeling purposes. Chapter 5 describes the concept for the new model features: a farming module, the explanation of land use and water abstractions and the explanation of biomass extraction. Some conclusions and an outlook close the paper.

2. The model $GINFORS_3$

From a methodological viewpoint GINFORS might be characterised as a dynamic Input-Output simulation model which is based on a comprehensive MRIO database. GINFORS evolved from the COMPASS model (see Meyer & Uno, 1999 or Uno, 2002) in the course of the MOSUS project. As a global Input-Output simulation model, aims and scope of the GINFORS model are generally closely related to GTAP applications. However, whereas the later follows a standard Computable General Equilibrium (CGE) approach, GINFORS does not rely on long run equilibria of competitive markets or Say's law for a macroeconomic closure. Moreover, GINFORS assumes that agents have to make their decisions under conditions of bounded rationality on imperfect markets.

This section is not intended to echo relevant distinctive features with regards to CGE models. Interested readers are referred to Giljum et al., 2009 for a short comparison of COMPASS/ GINFORS with GTAP or the related annotations of Wiedmann et al., 2007 in this regard. We would rather like to point out that the modelling of bounded rationality is not a straightforward task: Apparently, the models' reaction functions cannot be derived explicitly by applications of plain optimisation calculus. According to our view, an empirical analysis of historical developments therefore represents the natural starting point for model calibration. Economic theory provides competing behavioural hypotheses which, for each reaction function under consideration, are subject to statistical falsification tests. Accordingly, GINFORS is often also classified as an econometric model (see, e.g., Wiedmann et al., 2007).

From this follows that the availability of historical time series datasets constitutes a necessary condition for the implementation of our bounded rationality philosophy. Up to now, essential model building efforts therefore had to be devoted to the (more or less preparatory) compilation and maintenance of sufficient datasets. We do not intend to recapitulate individual challenges and possible shortcomings of this extensive and time consuming traditional practice but rather annotate that the GRAM-accounting method is basically rooted upon identical practice. Interested readers might therefore, e.g. look-up Wiebe et al., 2012 and the corresponding annotations with regard to the construction of the latest database. Apart from that, technical details of selective former GINFORS implementations were, e.g., also documented by Meyer et al., 2007 or Barker et al., 2011.

Due to the availability of the WIOD database (see Timmer, M. P. (Ed.), 2012) this situation had changed tremendously. Hence, the empirical backbone of $GINFORS_3$ is now given by the fully harmonized annual set of national Supply and Use Tables (SUT) within its IO module as outlined by Dietzenbacher et al., 2013. This set of bottom up information has been merged with population and sequence of accounts and balancing items datasets of the UN Statistics Division as well as financial data of the International Monetary Fund. Beyond this it has to been stressed, that the WIOD database also contains a comprehensive set of environmental accounts (energy use, emissions, material extractions) which serve as the empirical backbone of the energy and environment modules of GINFORS3.

The model therefore enables to simulate global developments, especially with regards to:

- the evolution of 35 industries in 38 national economies and a Rest of World region,
- international patterns of trade for 59 products,
- the resulting effects on main economic aggregates of national economies (e.g., public debt or disposable income of private households),
- emissions stemming from 28 energy carriers
- and global material extractions (biomass, fossil energy carriers, minerals).

This list already reflects that GINFORS features a high degree of endogeneity. Actually, only national population growth rates as well as world market basic prices for fossil fuels and minerals and of course all policy variables (like tax rates) have to be determined exogenously. The computational implementation is then based on an iterative solve algorithm.

3. Links between the global socio-economic developments, crop production, water and land availabilities

The analysis of the water and land use nexus deals quite a lot with processes in the agricultural sector. “Crops and livestock need water to grow, and lots of it. Agriculture accounts for 70% of all water withdrawn by the agricultural, municipal and industrial (including energy) sectors.” World Water Assessment Programme, 2012, p. 46). Another 19% of total freshwater withdrawals are direct withdrawals by industries and 11% are municipal withdrawals to serve the water needs of households and enterprises (without own water withdrawals). But, as figure 1 shows, one has to be aware that this world average distribution differs tremendously among countries and world regions. On the one hand countries or regions with little or only seasonal precipitation (like Africa, India, Greece and Spain) feature a high share of agricultural withdrawals. On the other hand in countries or regions with high and regular precipitation (like Germany and Sweden) the withdrawals by agriculture play a minor role. In addition the figure illustrates (black caskets) the big differences among countries and world regions with regard to per capita water withdrawals per year. The documented value for the United States is more than six times higher than the one for Africa.

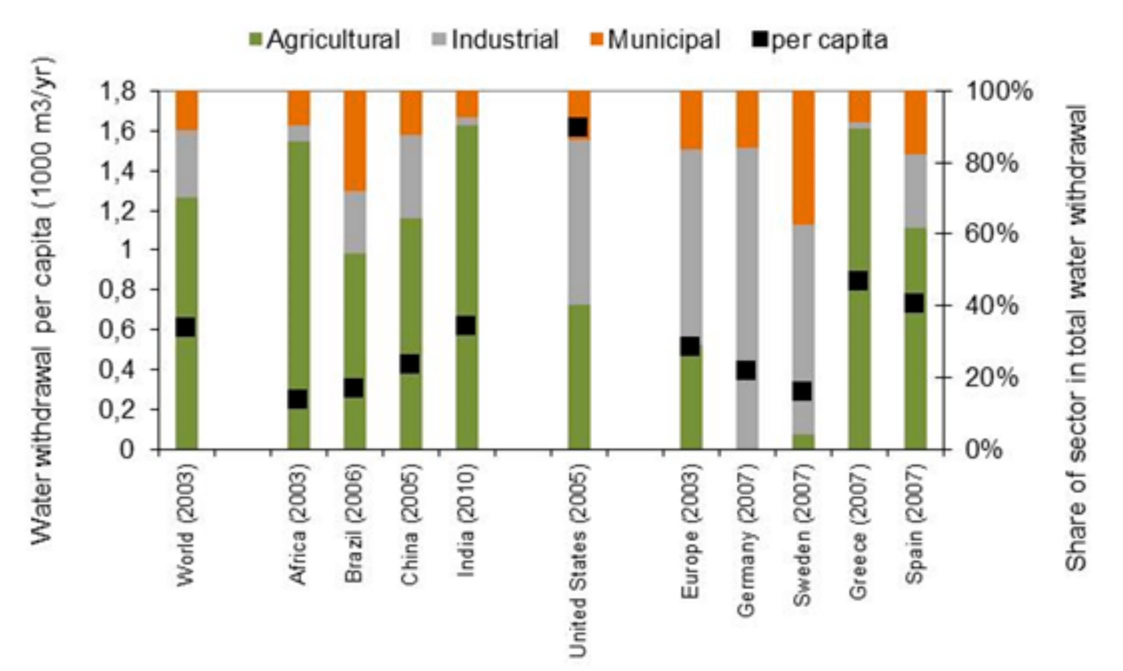

Figure 1. Water withdrawals by sector for selected countries and world regions (data source: FAO Aquastat)

This background stresses again the prominence of a hard link between the economic environmental model GINFORS and the biophysical model LPJmL for dealing with questions that arise with regard to the use of water and land. In a first step we have to ask for the links between the global socio-economic developments, crop production and water and land availabilities. The following figure 2 tries to depict the main links in this regard and shows in addition in which of the both models which aspect of the nexus is covered. In the center of the figure we see the crop growth (supply), which is modeled in the biophysical model LPJmL in deep regional and product detail. The development of the quantity and structure – regional as well as composition of crops – of this supply depends from three elements: the availability of water and land for agricultural production and the demand for crops. In turn the development of the (biophysical) crop growth influences the global economic-environmental system, which is depicted by the box "global farming market module" of figure 2 as well as by the box "socio-economic development, energy and emissions, resource use". As will be shown later on the latter aspect refers to content already covered in $GINFORS_3$, whilst the global farming market module is one the new features of GINFORS discussed in the paper at hand. Therefore a more detailed illustration for the complex interdepencies within the global farming market nexus is given later on in chapter 5.1.

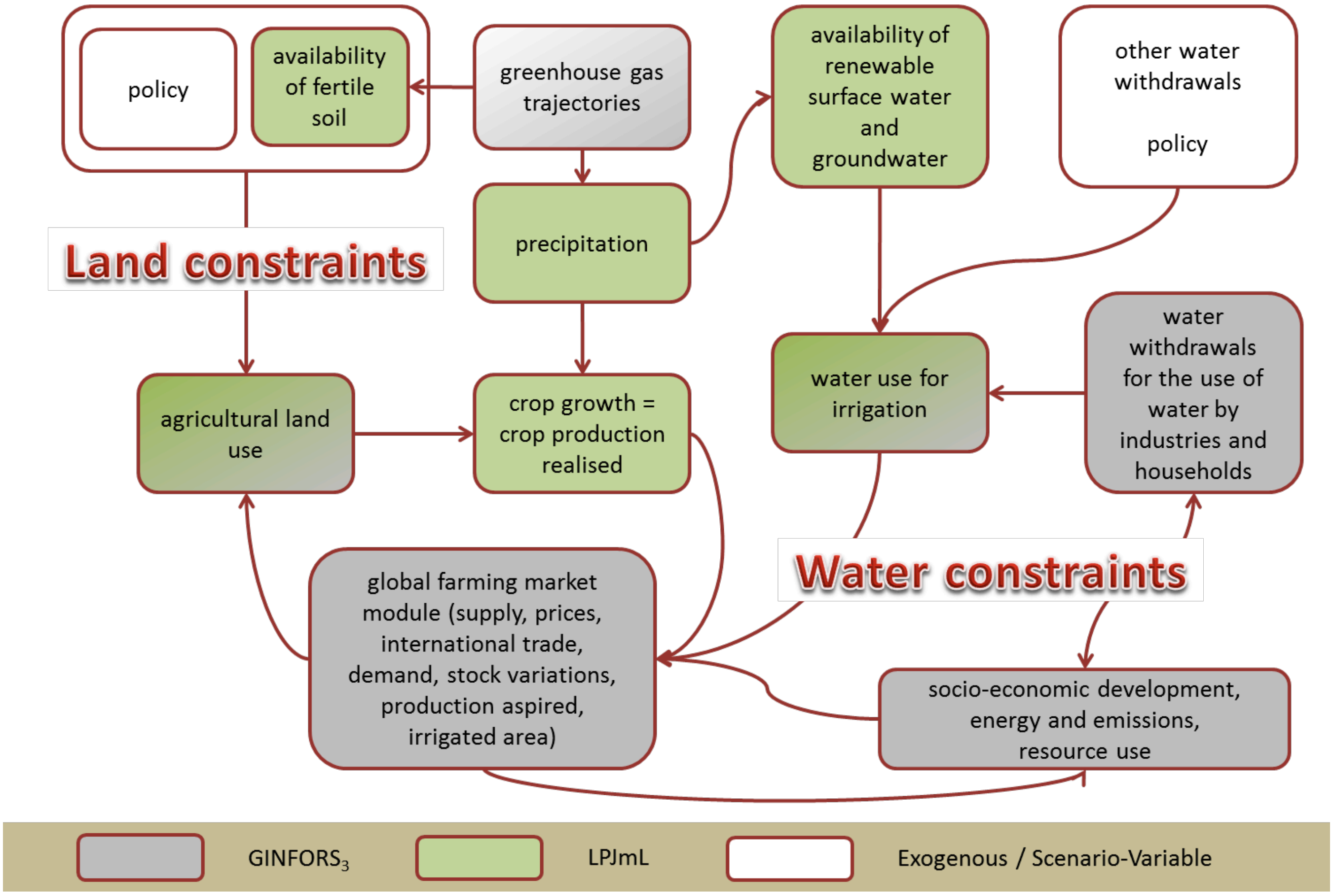

Figure 2. Structure of the modelling challenge

4. Data needs

In a next step it has to be asked whether the environmental as well as the economy data available from the main empirical backbone of GINFORS – the WIOD database – alone is feasible for the modeling task or has to be added by additional data sources. Hereby the objectives of the model extensions have to be regarded which are twofold: On the one hand the model should cover as precise as possible the (driving forces of) demand for agricultural products as well as for water and for agricultural land. On the other hand the model should be able to report about the future development of resource productivity indicators like $RMC_{biomass}$ and water and land indicators. We start this discussion of data needs and data availabilities with the data on agricultural products.

Data needs for modeling the demand for crops

The classification concept of the monetary part of the WIOD database (input-output-tables, socio-economic accounts, international trade) does not distinguish different agricultural products or sectors (see classification tables in the annex). Although it has to be stressed, that the economic core of $GINFORS_3$ already gives insights in very important aspects with regard to agriculture:

- The main demand for agricultural products comes from the food and beverage industry and the direct purchases to private households. These two uses in 2008 accounted for about three-fourths of the total demand for agricultural products.[1] Considering that the private households are the essential users of food products and beverages, the explanation of private household demand for agricultural products as well as for food products and beverages plays a crucial role for the development of the agricultural sector. In $GINFORS_3$ explanatory variables for this are the disposable income[2] as well as (relative) prices. Since this explanation takes place for per capita values worldwide, changes in population are covered explicitly in all simulation runs.[3]

- In the recent past the use of agricultural products for energy purposes (biogasoline, biodiesel and biogas) has become a feature with increasing importance. In the period from 1995 to 2009 the world wide gross energy use of these three carriers has quintupled.[4] Against this background concerns evolved whether there might arise a food vs. fuel dilemma (see e.g. Marshall, 2007). As the explanation of the energy use of 28 different energy carriers by different industries and private households in all 38 countries and rest of world is subject of the energy module of $GINFORS_3$ this nexus is covered in all simulations.[5]
- Besides the food and energy use of agricultural products the IO-module of $GINFORS_3$ also covers the development of agricultural products as input in other industries and hereby gives indications for changing patterns in agricultural demand and supply. For example the intermediate use of agricultural products by agriculture itself mainly can be associated with the use of seed and feed crops. The development of intermediate demand by other industries alludes to the demand for the use of crops for other utilities.
- Last but not least $GINFORS_3$ explains the development of input structures (intermediate use for 59 product groups, labour and capital inputs) of the agriculture, forestry and fishing industry in all 38 countries and rest of world. Together with information about taxes and subsidies on production this allows for the calculation of unit costs of the sector which serve as explanatory variable of average production prices of the sector. These in turn play an essential role not only in the explanation of domestic prices for agricultural products but also in the explanation of the competition on the world market.

Although this sounds not too bad we have to admit that this up to now content of $GINFORS_3$ with regard to agriculture does not fulfill all the needs within the POLFREE research objectives. Why this?

- The biophysical model LPJmL explains the supply of agricultural biomass under given environmental constraints and economic demands in a very detailed manner. As has been shown, some hints for changing demand patterns with regard to agricultural

1 Adding the intermediate use of agricultural products by agriculture itself, which can mainly be associated with the use of seed and feed crops and hereby predominantly also serves for the production of food, leads to a rise of this share to 86%.

2 The development of disposable income by private households and non-profit organisations serving households (NPISH) in GINFORS3 is endogenously explained within the module „sequence of accounts and balancing items" (see Meyer et al., 2013).

3 In $GINFORS_3$ the world population prospects by the UN serve as an important exogenous model variable.

4 Data sources: WIOD, Eurostat

5 The evolution of gross energy use of biogasoline, biodiesel and biogas in physical terms (TJ) in the energy module serves as driver for the demand of agricultural products by the petroleum and the electricity supply industry in monetary terms in the IO-module and hereby influences the production of agricultural products. If agricultural production is restricted due to water or land scarcity – issues that will be addressed by the interlinkages with LPJmL – this will lead to changes in agricultural prices, production and international trade patterns (see chapter 3.3.1).

products already can be derived from $GINFORS_3$. But for an exchange with LPJmL it would be very helpful if this information with regard to agricultural demand explicitly allows for a differentiation of crops.

- An issue that presumably will be addressed in the visions as well as in the policy mix work within POLFREE up to now is not visible in $GINFORS_3$: the world wide (growing) demand for meat. As we know this is a driving force for the demand for fodder crops and should be included explicitly in the model.
- The environmental part of the WIOD database contains data for the domestic extraction (used and unused in tonnes) of five biomass categories: animals, feed, food, forestry and other biomass.[6] As this data perfectly follows the guidelines for the compilation of economy-wide material flow accounts, it is needed in the raw material module of $GINFORS_3$ for the calculation of resource productivity indicators. But to explain these material flows without further knowledge of the composition of agricultural demand and supply (see the previous both points) is not feasible. For example within the category "feed" the biomass grazed by livestock or mowed for livestock sustenance plays a significant role. On the one hand this process usually is not market-based and therefore is not covered by the monetary data of the model. On the other hand the driving force of these extractions clearly is known: the production of primary livestock. Though livestock (meat) data clearly should be considered.

Therefore the database of $GINFORS_3$ additionally uses data from FAOSTAT. The FAO data holds information for the use of crops and livestock as food, feed, seed and other utilities as well as for production and the trade balance in physical terms (tonnes). In addition the production is also given in monetary terms. This allows the explicit modeling of demand, domestic supply and production in physical terms for 10 crops and crop groups (rice, wheat, maize, other cereals, oilcrops, starchy roots, sugarcrops, vegetables, fruits, other crops) and for meat and other livestock products. The monetary data gives the information needed to model the backward links to the economic structure of model.

The structure of the information in physical terms that is given by the commodity balance sheets in FAOSTAT is shown in the following figure.

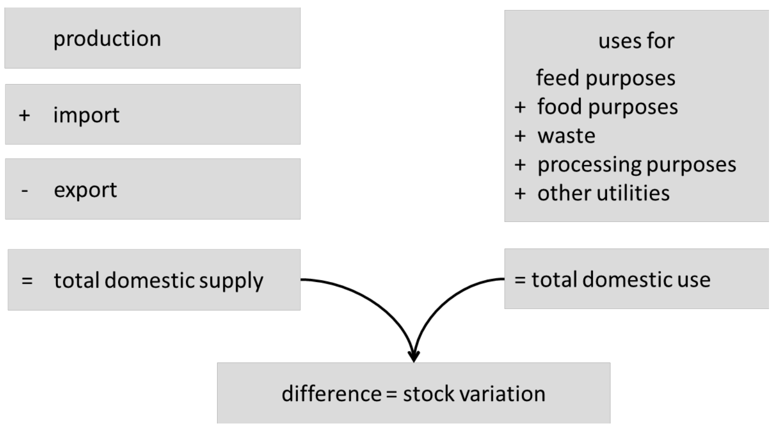

Figure 3: Agricultural commodities. Data structure for data in physical terms.

6 The sources for materials extraction data in the WIOD database include the database of material flows from SERI/Wuppertal Institute and the Material Flow Accounts (MFAs) from Eurostat.

Data on land use and on water demand

As data source for the historical development of land use in the 38 countries and rest or world in $GINFORS_3$ serves the WIOD database. In the WIOD documentation with regard to land use data it is stated that, “land use accounts include the agriculture and forestry use of land (in 1000 hectares) by land type. Note that land use by other sectors (chiefly built areas) could not be included due to data gaps. […] For agricultural and forestry land use, the main source used was FAOSTAT, the statistical system of the Food and Agriculture Organisation of the United Nations. […] Forest area includes an estimation of the area actually used for productive purposes […]. These figures have been extrapolated from the forest area used for production purposes reported by FAO.” (Timmer, M. P. (Ed.), 2012, pp. 45-51) The WIOD database distinguishes four types of land: arable area, pastures area, permanent crops area and forest area.

The following figure illustrates some findings for historical developments in this context. It shows the aggregated land use for agricultural purposes (arable area + pastures area + permanent crops area), the aggregated extraction of agricultural biomass (domestic extraction used for the biomass categories “feed” and “food”) and the population as indices (1995 = 100) for the whole world as well as for the EU27. For the worldwide developments we can see, that the agricultural land use is more or less stable. Although the worldwide extraction of agricultural biomass expanded by about 20 percent within 15 years. The curve for agricultural biomass extraction shows nearly the same development as the one for population and hereby hints at the interconnections between the nutrition needs of a rising population and the biomass use. In the EU27 the historical developments tell another story: Agricultural land use diminishes although at the end of the historical observations this development seems to slow maybe due to the need for energy crops. As for the worldwide observations the biomass extraction per hectare trends to grow, but we can see that as we become spatially more explicit this observation becomes more affected by good or bad weather conditions in some years.

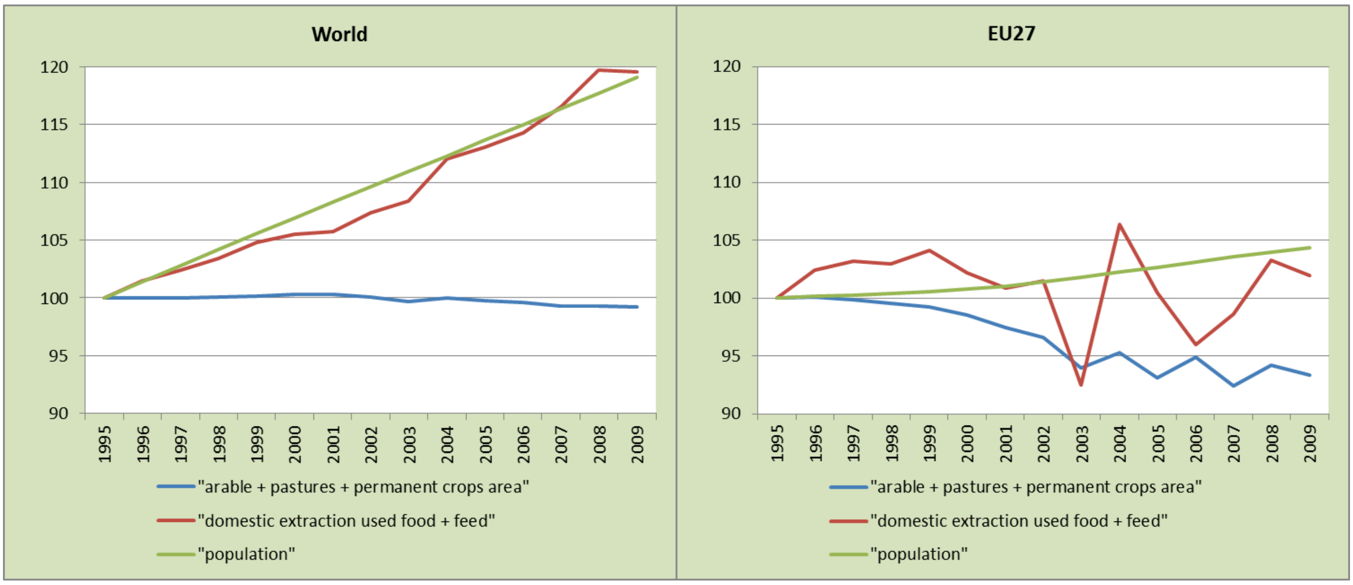

Figure 3. Historical observations with regard to agricultural land use

As will be shown later on for the purposes of modeling the land use the differentiation of only three categories (arable land and permanent crops area, pastures area and forestry area) is not feasible. Therefore the database of the model was supplemented by the observations for the "area harvested" from FAOSTAT for the ten crops and crop groups differed in the modeling. By doing so it is possible to consider the differences in level as well as in dynamic of yields among these crops and crop groups. The following figure illustrates these differences for the world average in the period from 1995 to 2009.

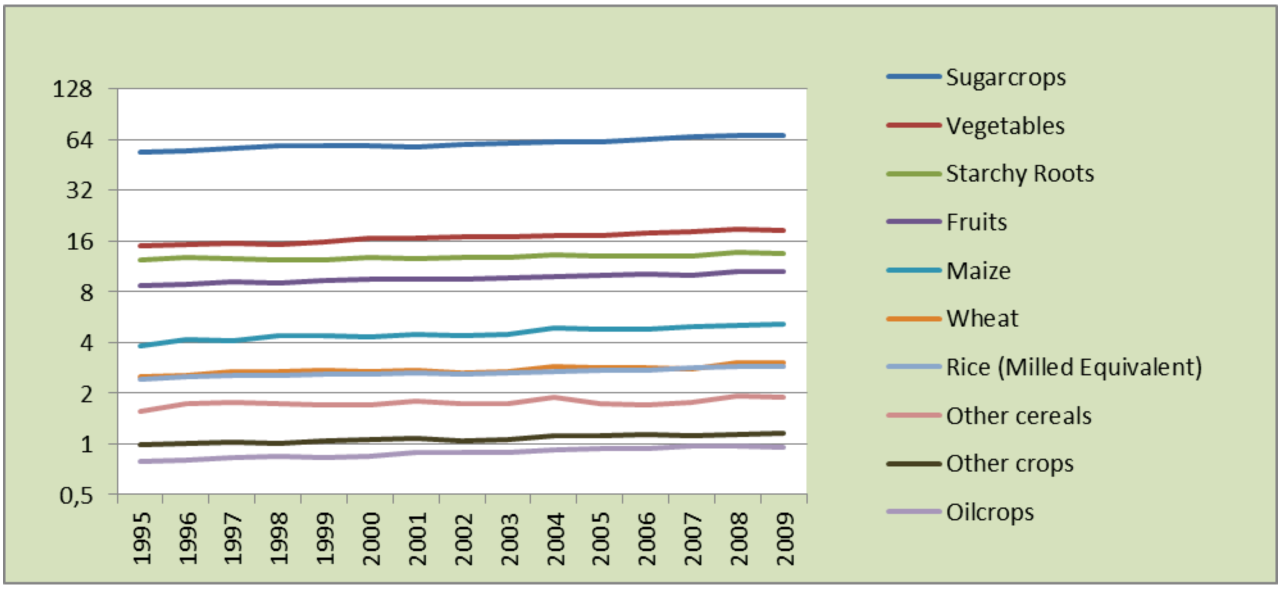

Figure 4. Historical observations with regard to yields. Datasource: FAOSTAT

With regard to water data Kohli et al. state that "the nomenclature surrounding water information is often confusing and gives rise to different interpretations and thus confusion. When discussing the way in which renewable water resources are utilized, the terms water use, usage, withdrawal, consumption, abstraction, extraction, utilization, supply and demand are often used without clearly stating what is meant." (Kohli et al., 2012, p.1) Later on a definition for the terms "water withdrawal" and "water use" is given: "Water flows from nature to society can be described on either side of the flow. On the nature side, i.e. "who is removing the water", this is called "withdrawal". On the society side, i.e. "who is using the water", it is called "use". The two flows are not the same because of leaks and because some entities that withdraw water do not use it themselves, but provide it to other entities." (Kohli et al., 2012, p.1)

The ambition is, to explain (and project) the amount of water that is available for irrigation in the agriculture. As has been shown in chapter 3.1 this is influenced by two sides: the total availability of water that can be withdrawn (supply side) and the amount of water that is withdrawn for the needs of industries and households (demand side).

Therefore the modeling task is based on data for water withdrawals/abstractions by different users. In the reasoning for this we follow the arguments of Alcamo et al.: "We compute water withdrawals rather than water consumption because (i) the quality of return water can be very poor, and therefore may hinder its re-use … (iii) More global data are currently available for withdrawals than for consumption." (Alcamo et al., 2000, p.11). Although the latter argument did change due to the publication of the WIOD-database, besides the still apparent first argument the footprint-concept of calculation water use data in the WIOD as well as concerns with regard to the consistency with other statistics from Eurostat, OECD and the FAO motivated this decision. Footprint data contains direct and indirect water use. To take this data for modeling is not feasible, because indirect effects should be one of the results of modeling and cannot be input. In so far footprint data is fine for ex- post statistical reporting, but not for modeling.

Data on biomass extraction

One of the objectives of modeling in GINFORS is to cover all data that is needed for the calculation of resource use and resource productivity indicators. With regard to the biomass part of these indicators the WIOD database holds all information needed. It reports about the domestic extraction used as well as about the unused extractions for five biomass categories: "animals", "feed", "food", "forestry" and "other".

5. The new features in $GINFORS_3$

After the discussion of the links between the global socio-economic developments, crop production, water and land availabilities in a very rough manner in chapter 3 and the discussion of data needs in chapter 4 in the following new model structures in $GINFORS_3$ should be discussed in a more detailed way.
We start with a concept for a new agriculture module, which depicts the agricultural products in a more detailed way. Objective of this agriculture module is on the one hand to integrate the physical information coming from the model LPJmL with regard to crop growth into the monetary information on agricultural demand and supply in GINFORS in a consistent manner. On the other hand the agricultural module should provide the biophysical model with the appropriate inputs: the demand and price driven changes in the need for the cultivation of crops and the evolution of the irrigated area.
The discussion of new features in GINFORS is completed by the explanation of agricultural and forestry land use and the explanation of water withdrawals. By doing so, we already present ideas about the modeling of the impacts of land and water constraints, a topic that will be discussed in more detail in the coming deliverable.[7]
The last aspect to be discussed is the explanation of biomass extractions as defined within the MFA concept.

5.1. Concept for a new farming module in GINFORS

As already said to cover the agricultural sector in a more detailed way is one aspect with high relevance for analyzing the questions arising with water and land use questions. The challenges in conceptualizing this new farming module are manifold. It should be able to:

- handle the results of the biophysical model with regard to worldwide crop growth (crop production),
- use the results of the input-output models with regard to different aspects of uses of agricultural products,
- explain the evolution of international trade with agricultural products,
- explain the evolution of prices for agricultural products,
- feed back the results of detailed modeling for agricultural products to the input-output models and
- provide the biophysical model with the proper information with regard to demand developments as well as with regard to the evolution of the irrigated area.

In the following we describe the structure of this circular flow module. Up to now this structure has the status of justified reasoning with regard to the questions to be analyzed as well as with regard to data availabilities. The conceptualization of new model features of GINFORS also has been subject of two internal workshops of the GWS/PIK/TNO. But whether these structures will

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be feasible in every detail can only be proved after the parametrization and implementation in the context of linking the models GINFORS and LPJmL.
The following figure depicts the circular flow concept in this farming module.[8]

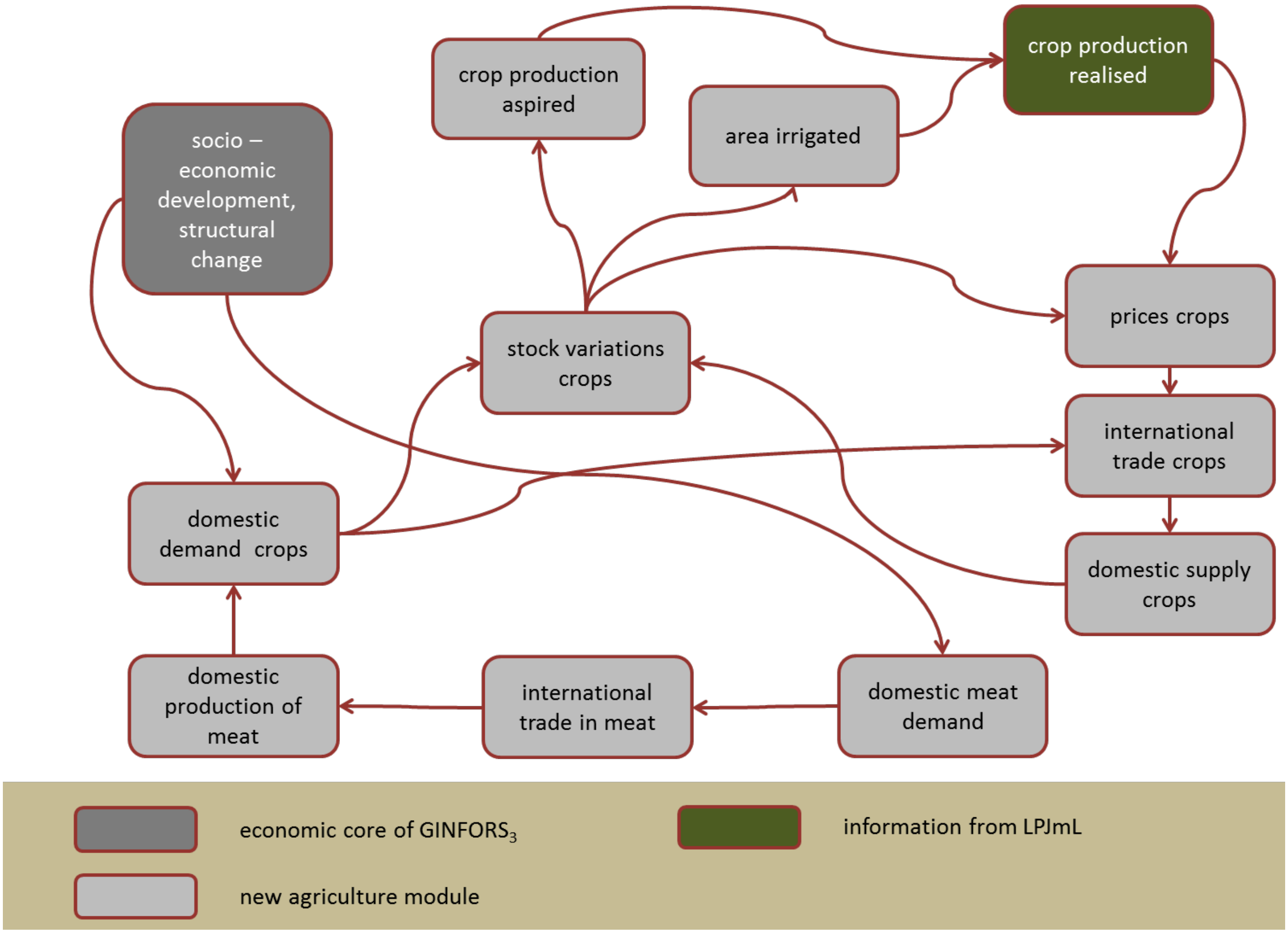

Figure 5. Structure of the agriculture module (concept)

We start the discussion of this concept with the information that is delivered by the biophysical model: the result of the harvest for different crops and countries (in tonnes). We can interpret this starting point as the beginning of one year. In the following the agricultural module which solves in an iterative process asks for the development of demand for agricultural products and for a solution to balance demand and supply. Important forces in achieving this balance are prices as well as modifications of international trade patterns. In doing so, the linkages with the whole economy have to be considered. At the end of this iterative process, which can be interpreted as the course of one year, there will still be some imbalances of supply and demand that are shown by the existence of stock variations for the different crops. In a last step these imbalances serve as input for the decisions of the farmers with regard to the aspired production in the next year. The description of the new farming closes with the explanation of the irrigated area. In the explanation of the concept we first assume a situation without constraints on land or

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[8] To prevent the figure from being confusing we disclaim plotting the information flows going from the different aspects of the farming module to the economic core of GINFORS although these information flows are of course considered in the concept of the module.

water availability. The modeling of impacts of such constraints on the crop supply and demand system is discussed in a separate chapter.

5.1.1. From crop growth to domestic supply of crops (quantities)

The result of the harvest or crop growth is given by the results of the biophysical model LPJmL. Let´s denote this variable $AGPRQ_{c,i}$. The index c stands for the 38 countries and rest of world that are differed in the model GINFORS and the index i for the 10 crops and crop groups (see table1) that might be differed in the agriculture module.[9]

Item nr.	Item
1	Rice
2	Wheat
3	Maize
4	Other cereals
5	Oilcrops (soyabeans, rape, etc.)
6	Starchy roots (potatoes, cassava, etc.)
7	Sugarcrops (sugar cane, sugar beet)
8	Vegetables (tomatoes, onions, etc.)
9	Fruits (appels, bananas, etc.)
10	Other crops (pulses, stimulants, cotton, rubber, etc.)

Table 1. Preliminary classification of crops and crop groups

[1] $AGPRQ_{c,i}[t]$ = delivered by LPJmL $\quad c \in \{1,\ldots,39\},\ i \in \{1,\ldots,10\}$

To deduce from these figures to the domestic supply quantities we have to explain the evolution of external balances. For doing so we first have to deal with the evolution of production prices. They are defined as prices in local currency per kg ($AGPRQP_{c,i}$) and explained by the unit costs of the agricultural sector ($UNCOI_{c,1}$) as well as by the stock variations in relation to production quantity ($AGSVQ_{c,i}/AGPRQ_{c,i}$).[10] The explanation by the unit costs can be interpreted as a cost driven decision process. The amount of stock variations in relation to production indicates the market situation for the respective commodity/country. An increase in stocks indicates an excess supply and therefore should lead to a price reduction and vice versa.

[2] $AGPRQP_{c,i}[t] = f\,(UNCOI_{c,1}[t],\ AGSVQ_{c,i}[t]/AGPRQ_{c,i}[t]) \quad c \in \{1,\ldots,39\},\ i \in \{1,\ldots,10\}$

The production prices serve in a next step for the explanation of import shares. We denote the production prices in US-Dollar per kg as $AGPRQPD_{c,i}$ and the import quantities in relation to domestic use quantities as $AGIMQS_{c,i}$ and explain these shares by the evolution of the dollar based production price in the respective country in relation to the world market price.

[3] $AGIMQS_{c,i}[t] = f\,(AGPRQPD_{c,i}[t]\ /\ AGPRQPD_{40,i}[t]) \quad c \in \{1,\ldots,39\},\ i \in \{1,\ldots,10\}$

9 The classification of crops and crop groups used in this paper is insofar preliminary as it is not aligned to the potentials (technical and with regard to contents) of the model LPJmL yet.

10 The unit costs of the agricultural sector are determined in the input-output-core of $GINFORS_3$. They reflect the evolution of the different cost components (intermediate inputs, labour and capital inputs, taxes and subsidies on production) in relation to the (real) output.

To deduce from the shares to the import quantities ($AGIMQ_{c,i}$) is complicated by the fact that the domestic use quantities ($AGDUQ_{c,i}$) are not known yet.[11] But on the other hand GINFORS solves in an iterative process, so that this problem of sequence might not be crucial for the stability of the solution.[12]

[4] $AGIMQ_{c,i}[t] = AGIMQS_{c,i}[t] * AGDUQ_{c,i}[t]$ $c \in \{1,\dots,39\}, i \in \{1,\dots,10\}$

The worldwide import quantities are than given by definition:

[5] $AGIMQ_{40,i}[t] = \sum_c AGIMQ_{c,i}[t]$ $c \in \{1,\dots,39\}, I \in \{1,\dots,10\}$

We assume that the worldwide export quantities ($AGEXQ_{40,i}$) grow with the same rate as the import quantities.[13]

[6] $AGEXQ_{40,i}[t] = AGEXQ_{40,i}[t-1] * AGIMQ_{40,i}[t] / AGIMQ_{40,i}[t-1]$ $i \in \{1,\dots,10\}$

In a next step we ask for the evolution of the export quantities in the 38 countries and rest of world. Therefore we explain the shares of the respective country in the world exports ($AGEXQS_{c,i}$) by the relative prices that already served for the explanation of the import shares.

[7] $AGEXQS_{c,i}[t] = f (AGPRQPD_{c,i}[t] / AGPRQPD_{40,i}[t])$ $c \in \{1,\dots,39\}, i \in \{1,\dots,10\}$

Before calculating the export quantities ($AGEXQ_{c,i}$) on base of these explanations we have to assure that the sum of export shares for all commodities i equals 100%.

[8] $AGEXQ_{c,i}[t] = AGEXQS_{c,i}[t] * AGEXQ_{40,i}[t]$ $c \in \{1,\dots,39\}, i \in \{1,\dots,10\}$

In a last step of this part we can calculate the domestic supply quantities ($AGDSQ_{c,i}$) for all commodities and countries.

[9] $AGDSQ_{c,i}[t] = AGPRQ_{c,i}[t] + AGIMQ_{c,i}[t] - AGEXQ_{c,i}[t]$ $c \in \{1,\dots,39\}, i \in \{1,\dots,10\}$

Before we can model the implications of these developments on the production, imports and exports of agricultural products in the economic core of GINFORS we first have to deal with the supply and demand for agricultural products that are not covered by the biophysical model: the livestock products.

5.1.2. The explanation of livestock demand and supply (quantities)

The ambition of the modeling exercise with regard to livestock products is twofold: On the one hand the production of meat and the hereby induced demand for feed is one of the links that should be considered in the explanation of crop demand. On the other hand the explanation is needed to complete the agricultural sector variables already known only for the crop commodities for a consistent link with the product group “agricultural products” in the input-output-core of the model.
By doing so we differ two commodities:

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11 To explain and use import shares that show the import quantities in relation to the production quantities is not feasible as in some cases there is no production at all or the production is negligible in relation to the import quantities, let´s say for example in the case of rice in Germany.

12 If this hyothesis fails other orders of the solution procedere within the agriculture module will be tested. But to go into too much detail with regard to possible sequences and their advantages or disadvantages would overload the ambition of the deliverable at hand.

13 As the historical database shows the worldwide import and export quantities are not equal. With regard to this circumstance equation (5) might also be varied in that way that the inequality of worldwide import and export quantities diminishes over a certain period.

Item nr.	Item
11	Meat
12	Other primary livestock (milk, eggs, wool, honey)

Table 2. Primary livestock products

The explanation of the livestock part of the module starts with the use of livestock products for food uses.
The per capita domestic food use in country c ($AGFOQC_{c,i}$) in kg per year is explained by the per capita demand for agricultural products ($COHHRC_{c,1}$) and for food products and beverages valued at constant prices ($COHHRC_{c,9}$). The explanatory variable itself in $GINFORS_3$ is explained by the development of the disposable income of private households in constant prices as well as by the development of the purchasers' prices of food and beverage products in relation to the average consumption prices. Therefore the approach assures the consideration of important economic drivers of meat demand as well as the consideration of changes in population.

[10] $AGFOQC_{c,i}[t] = f(COHHRC_{c,1}[t] + COHHRC_{c,9}[t])$ $c \in \{1,\ldots,39\}, i \in \{11,12\}$

By multiplication of the per capita numbers with the exogenously given population figure ($populn_c$) we can derive the total domestic food use of livestock products ($AGFOQ_{c,i}$) in all 38 countries and rest of world in millions of tons.

[11] $AGFOQ_{c,i}[t] = AGFOQC_{c,i}[t] * populn_c[t]$ $c \in \{1,\ldots,39\}, i \in \{11,12\}$

With regard to meat, the use for food purposes is the only relevant part. But with regard to other primary livestock products we also have to explain the evolution of uses for processing purposes ($AGPGQ_{c,12}$). In each of the 38 countries and rest of world this is explained by the intermediate demand for agricultural products by the food and beverages industry (${}_cUSER_{1,3}$) valued at constant prices. The use of other primary livestock products for other purposes ($AGOTQ_{c,12}$) is explained by the intermediate demand for agricultural products by the textiles industry (${}_cUSER_{1,4}$) valued at constant prices.

[12] $AGPGQ_{c,12}[t] = f({}_cUSER_{1,3}[t])$ $c \in \{1,\ldots,39\}$

[13] $AGOTQ_{c,12}[t] = f({}_cUSER_{1,4}[t])$ $c \in \{1,\ldots,39\}$

In a next step these explicitly explained uses are used to forecast the total domestic use quantities ($AGDUQ_{c,i}$).[14]

[14a] $AGDUQ_{c,11}[t] = AGDUQ_{c,11}[t-1] * AGFOQ_{c,11}[t] / AGFOQ_{c,11}[t-1]$ $c \in \{1,\ldots,39\}$

[14b] $$AGDUQ_{c,12}[t] = AGDUQ_{c,12}[t-1] * \frac{AGFOQ_{c,12}[t] + AGPGQ_{c,12}[t] + AGOTQ_{c,12}[t]}{AGFOQ_{c,12}[t-1] + AGPGQ_{c,12}[t-1] + AGOTQ_{c,12}[t-1]}$$ $c \in \{1,\ldots,39\}$

The explanation of the production prices in local currency per kg is carried out by the evolution of the unit costs of the agricultural sector.

[15] $AGPRQP_{c,i}[t] = f(UNCOI_{c,1}[t])$ $c \in \{1,\ldots,39\}, i \in \{11,12\}$

14 Hereby we assume that the shares of other uses (feed, seed, waste, processing, other utilities for meat and feed, seed, waste for other primary livestock products) in the domestic use do not change in time. As we can see from the historical data these five uses together account only for about 1% of the total domestic use of meat.

The modeling of import and export quantities follows the same logic as the one of for the crops and crop groups in the equations 2 to 7. In a last step of this part we can calculate the production quantities ($AGPRQ_{c,i}$) for the both livestock commodities and countries. In contrast to the modeling approach for the crops and crops groups we do not model an explicit adjustment of supply and demand via the stock variations. Instead of doing so we assume, that the stock variations ($AGSVQ_{c,i}$) diminish in the future.[15]

[15] $AGPRQ_{c,i}[t] = AGDUQ_{c,i}[t] - AGIMQ_{c,i}[t] + AGEXQ_{c,i}[t] + \alpha * AGSVQ_{c,i}[t-1]$

$c \in \{1,\dots,39\}, i \in \{11,12\}$

5.1.3. Bottom-up agricultural information as feed-in to the economic core of the model

The input-output module of $GINFORS_3$ differs 59 product groups, one of them is "products of agriculture, hunting and related services". In the two previous chapters many information with regard to the development of quantities as well as of prices have been derived in a very detailed bottom-up modelling approach. Therefore the next challenge is to aggregate and feed-in this information into the economic monetary system for the respective variables for "products of agriculture, hunting and related services". By doing so, we achieve two goals: On the one hand we ensure consistency between the different modules of the system. On the other hand especially the price developments due to imbalances of supply and demand for crops feed back into the economic decisions mapped in the economic core.

Let´s denote the total production of agricultural products in local currency at current prices that can be derived by summing up the production quantities valued with the production prices in local currency per kg for all 12 commodities as $agprvt_c$. This variable serves in the economic core to forecast the gross output of "products of agriculture, hunting and related services" at basic prices ($GOUTB_{c,1}$).

[16] $agprvt_c[t] = \sum_i AGPRQ_{c,i}[t] * AGPRQP_{c,i}[t]$ $c \in \{1,\dots,39\}, i \in \{1,\dots,12\}$

[17] $GOUTB_{c,1}[t] = GOUTB_{c,1}[t-1] * agprvt_c[t] / agprvt_c[t-1]$ $c \in \{1,\dots,39\}$

In a next step we calculate the weighted average production prices ($agprpa_c$) for all 38 countries and rest of world as follows:

[18] $agprpa_c[t] = \sum_i (AGPRQ_{c,i}[t] * AGPRQP_{c,i}[t] / agprvt_c[t]) * AGPRQP_{c,i}[t]$

$c \in \{1,\dots,39\}, i \in \{1,\dots,12\}$

This price development on base of detailed information for the different commodities serves for the extrapolation of the price index (1995 = 100) of gross output in GINFORS ($GOUTBP_{c,1}$).

[19] $GOUTBP_{c,1}[t] = GOUTBP_{c,1}[t-1] * agprpa_c[t] / agprpa_c[t-1]$ $c \in \{1,\dots,39\}$

The same calculations as for the gross output at basic prices also can be executed for the exports at basic prices ($EXPOB_{c,1}$) and the corresponding price index ($EXPOBP_{c,1}$). Hereby we assume that the development of export prices for the single commodities do not differ from the development of production prices. We denote the total exports at current prices derived from the bottom-up information as $agexvt_c$ and the weighted average export price as $agexpa_c$.

[20] $agexvt_c[t] = \sum_i AGEXQ_{c,i}[t] * AGPRQP_{c,i}[t]$ $c \in \{1,\dots,39\}, i \in \{1,\dots,12\}$

15 In contrast to the FAOSTAT database we define a net increase in stock as a positive value and a net decrease from stock with a negative sign. This means that a net increase in stock shows a excess supply and a net decrease in stock a excess demand.

[21] $EXPOB_{c,1}[t] = EXPOB_{c,1}[t-1] * agexvt_c[t] / agexvt_c[t-1]$ $c \in \{1,\ldots,39\}$

[22] $agexpa_c[t] = \sum_i (AGEXQ_{c,i}[t] * AGPRQP_{c,i}[t] / agexvt_c[t]) * AGPRQP_{c,i}[t]$

$c \in \{1,\ldots,39\}, i \in \{1,\ldots,12\}$

[23] $EXPOBP_{c,1}[t] = EXPOBP_{c,1}[t-1] * agexpa_c[t] / agexpa_c[t-1]$ $c \in \{1,\ldots,39\}$

Our last concern with regard to the feed-in of bottom-up information into the economic core goes to the imports of agricultural products. To do so we first calculate the world market prices ($agwmpd_i$) for the 12 agricultural commodities in US-Dollar per kg as weighted averages of the dollar based production prices of exporting countries.

[24] $agwmpd_i[t] = \sum_c AGEXQS_{c,i}[t] * AGPRQPD_{c,i}[t]$ $c \in \{1,\ldots,39\}, i \in \{1,\ldots,12\}$

In a next step we calculate the imports of agricultural products in current local currency ($agimvt_c$) as the sum of quantities valued with the world market prices. This variable serves in the economic core to forecast the imports of “products of agriculture, hunting and related services” in local currency ($IMPO_{c,1}$).

[25] $agimvt_c[t] = \sum_i AGIMQ_{c,i}[t] * agwmpd_i[t] / usdex_c[t]$ $c \in \{1,\ldots,39\}, i \in \{1,\ldots,12\}$

[26] $IMPO_{c,1}[t] = IMPO_{c,1}[t-1] * agimvt_c[t] / agimvt_c[t-1]$ $c \in \{1,\ldots,39\}$

The evolution of the import prices again is deduced from the weighted averages of import prices ($agimpa_c$) for all 38 countries and rest of world as follows:

[27] $agimpa_c[t] = \sum_i (AGIMQ_{c,i}[t] * (agwmpd_i[t] / usdex_c[t]) / agimvt_c[t]) * agwmpd_i[t] / usdex_c[t]$

$c \in \{1,\ldots,39\}, i \in \{1,\ldots,12\}$

Again the price development on base of detailed information for the different commodities serves for the extrapolation of the price index (1995 = 100) of imports in GINFORS ($IMPOP_{c,1}$).

[28] $IMPOP_{c,1}[t] = IMPOP_{c,1}[t-1] * agimpa_c[t] / agimpa_c[t-1]$ $c \in \{1,\ldots,39\}$

The last variables in the economic core of GINFORS that have to be regarded are the import shares for agricultural products. The variable $IMIDS_{c,1}$ shows the share of imports in the total intermediate use of agricultural products, the variable $IMFDS_{c,1}$ the share of imports in total final inlands use of agricultural products. As we do not know from the bottom-up information about the use as intermediate input or as final use we extrapolate both variables with the same approach.

[29a] $$IMIDS_{c,1}[t] = IMIDS_{c,1}[t-1] * \frac{agimvtc[t] / (agprvt_c[t] + agimvt_c[t] - agexvt_c[t])}{agimvtc[t-1] / (agprvt_c[t-1] + agimvt_c[t-1] - agexvt_c[t-1])}$$

[29b] $$IMFDS_{c,1}[t] = IMFIDS_{c,1}[t-1] * \frac{agimvtc[t] / (agprvt_c[t] + agimvt_c[t] - agexvt_c[t])}{agimvtc[t-1] / (agprvt_c[t-1] + agimvt_c[t-1] - agexvt_c[t-1])}$$

$c \in \{1,\ldots,39\}$

On base of the information that is now given to the input-output core of the model many economic reactions are caused. The next topic of the circular flow module to be discussed is the implications of these economic information given in the structures of GINFORS as well as the implications of the above determined meat production on the demand for crops (in physical terms).

5.1.4. The explanation of crop demand (quantities)

This next topic to be discussed is quite the same as the one for the livestock side. In a first step the domestic demand for crops has to be explained. In a next step the global trade issues have to be considered to receive the figures for the production needed. The comparison of the production needed with the actual production allows the calculation of stock variations. These serve on the one hand as an input for the balancing of demand and supply in the iterative solution procedure. But at the end of the solution procedure there might be still some stock variations that could not be disposed due to price adjustments. In this case the stock variations will serve as information for decisions of the farmers with regard to the harvested area in the next period (year), which is one of the essential information that serves as an input for the model LPJmL. We will come back to this point in the next and last chapter upon the concept for the agriculture module.

In comparison to livestock demand with regard to crop demand we have to consider two additional aspects. On the one hand a further differentiation of utilities in the domestic demand for crops which allows an as precise as possible consideration of the “right” drivers. On the other hand a more detailed differentiation of different crops or crop groups. Since most crops generally can be used for nearly all purposes (feed, food, processing or other purposes), it does not make sense to differentiate the purposes already in international trade.

The modeling starts with the explanation of total domestic crop demand (in tonnes) for the different utilities:

- The total domestic crop demand for feed purposes ($agfecq_c$) in tonnes in each of the 38 countries and rest of world is explained by the production of meat in the country ($AGPRQ_{c,11}$).

  [30] $agfecq_c[t] = f(AGPRQ_{c,11}[t])$ $\qquad c \in \{1,\dots,39\}$

- The total domestic crop demand for food purposes ($agfocq_c$) in each of the 38 countries and rest of world is explained by the sum of the intermediate demand for agricultural products by the food and beverages industry (${}_cUSER_{1,3}$) and the hotels and restaurants sector (${}_cUSER_{1,22}$) and the final demand of private households for agricultural products ($COHHR_{c,1}$) valued at constant prices.

  [31] $agfocq_c[t] = f({}_cUSER_{1,3}[t] + {}_cUSER_{1,22}[t] + COHHR_{c,1}[t])$ $\qquad c \in \{1,\dots,39\}$

- The total domestic crop demand for processing purposes ($agpgcq_c$) in each of the 38 countries and rest of world is explained by the the intermediate demand for agricultural products by the food and beverages industry (${}_cUSER_{1,3}$) valued at constant prices.

  [32] $agpgcq_c[t] = f({}_cUSER_{1,3}[t])$ $\qquad c \in \{1,\dots,39\}$

- The total domestic crop demand for other purposes ($agotcq_c$) in each of the 38 countries and rest of world is explained by the sum of the intermediate demand for agricultural products ($INTCR_{c,1}$) – except those by the food and beverages industry (${}_cUSER_{1,3}$), the agricultural sector itself (${}_cUSER_{1,1}$) and the hotels and restaurant sector (${}_cUSER_{1,22}$) - valued at constant prices.

  [33] $agotcq_c[t] = f(INTCR_{c,1}[t] - {}_cUSER_{1,1}[t] - {}_cUSER_{1,3}[t] - {}_cUSER_{1,22}[t])$ $\qquad c \in \{1,\dots,39\}$

After these explanations the next ambition is to explain and extrapolate the domestic demand (in tonnes) for different crops and crop groups for all 38 countries and rest of world. For doing so we define share matrices for each of the four utilities differed above ($AGFECS_{c,i}$, $AGFOCS_{c,i}$, $AGPGCS_{c,i}$, $AGOTCS_{c,i}$). They show the shares in the total domestic crop demand for the purpose at hand for 10 different crops and crop groups (see table 1). I.e. the variable

$AGFOCS_{27,9}$ shows the share of fruits [i=9] (in tonnes) in the total domestic crop demand for food purposes (in tonnes) in the United Kingdom [c=27].

As the historical data indicates these shares differ tremendously between the four utilities as well as between the countries but do not show as big changes in time. The following figure illustrates this finding for three example countries: Germany, China and USA. Therefore in a first modeling attempt we assume these shares to be constant in time.

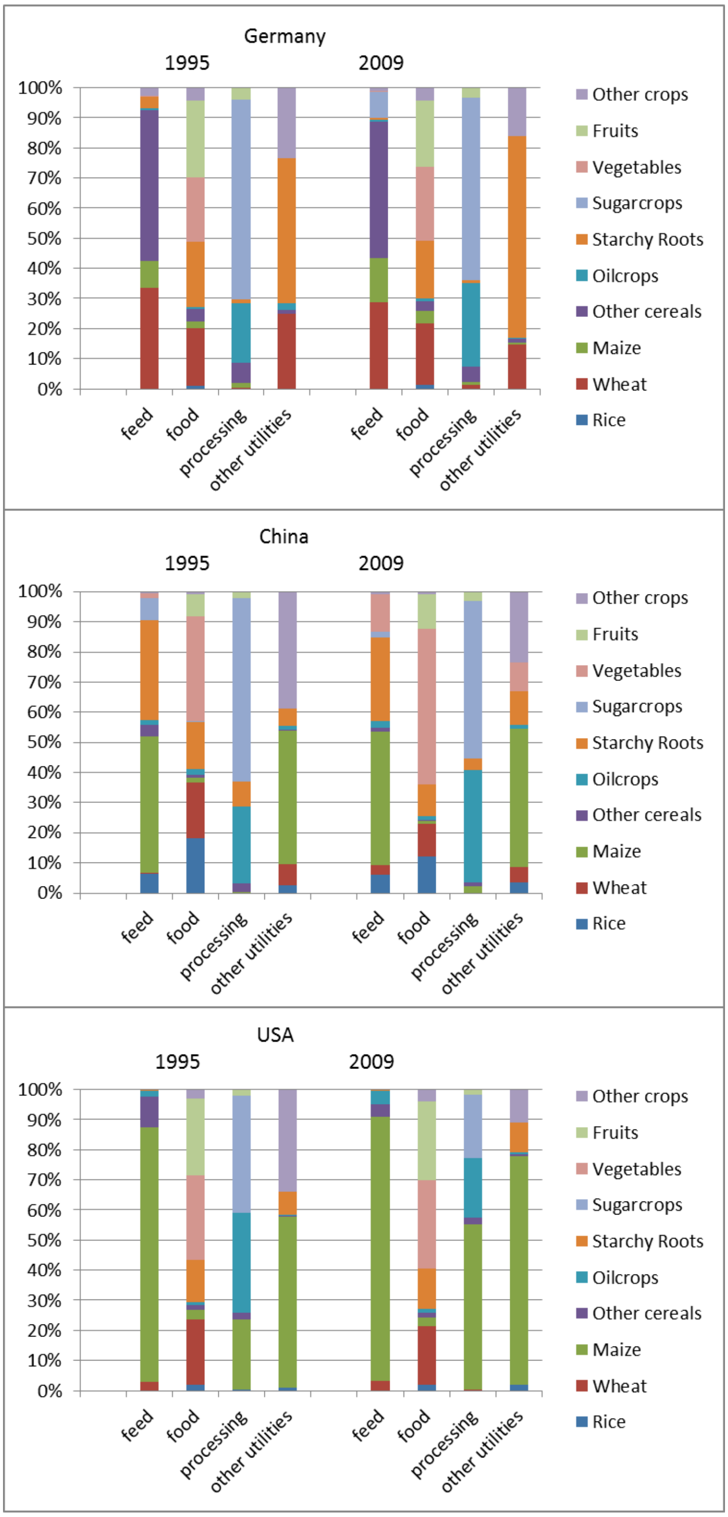

Figure 7. Examples for the crop composition of different utilities. Own calculations on base of data from FAOSTAT.

The modeling of the domestic crop demand for seed purposes differs from the logic for the other purposes. Crucial for this purpose is rather any special economic driver than the production of the different crops and crop groups needed to fulfill the other demands. We assume that there is a fixed relation between the production of crop i in country c ($AGPRQ_{c,i}$) and the domestic crop demand for seed purposes of crop i in country c ($AGSEQ_{c,i}$).

[34] $AGSEQ_{c,i}[t] = AGSEQ_{c,i}[t-1] * AGPRQ_{c,i}[t] / AGPRQ_{c,i}[t-1]$ $c \in \{1,\dots,39\}, i \in \{1,\dots,10\}$

In a next step we can calculate the total domestic crop demand for 10 crops and crop groups ($AGDUQ_{c,i}$) for all 38 countries and rest of world. The extrapolation in equation (35) does not simply add up the results for five purposes but uses the growth rates of these sums. Background for this is that we did not explicitly model the purpose "waste". By using the growth rates of the other five purposes we implicitly assume constant waste quotas.

[35] $AGDUQ_{c,i}[t] = AGDUQ_{c,i}[t-1]$

$* (AGSEQ_{c,i}[t] + AGFECS_{c,i}[t] * agfecq_c[t] + AGFOCS_{c,i}[t] * agfocq_c[t] + AGPGCS_{c,i}[t] * agpgcq_c[t] + AGOTCS_{c,i}[t] * agotcq_c[t])$

$/ (AGSEQ_{c,i}[t-1] + AGFECS_{c,i}[t-1] * agfecq_c[t-1] + AGFOCS_{c,i}[t-1] * agfocq_c[t-1] + AGPGCS_{c,i}[t-1] * agpgcq_c[t-1] + AGOTCS_{c,i}[t-1] * agotcq_c[t-1])$

$c \in \{1,\dots,39\}, i \in \{1,\dots,10\}$

The domestic supply for the different crops and crop groups in all 38 countries and rest of world are already known by equation (8). So in a last step we can determine the imbalance of supply and demand that are defined as the stock variations in tonnes ($AGSVQ_{c,i}$).

[36] $AGSVQ_{c,i}[t] = AGDSQ_{c,i}[t] - AGDUQ_{c,i}[t]$ $c \in \{1,\dots,39\}, i \in \{1,\dots,10\}$

As the stock variations serve as explanatory variables for the evolution of production prices the results of equation (36) will give the crucial impulses in the iterative solution procedure for balancing supply and demand on the international markets as well as via effects on the domestic demand figures. But of course it is not probable that this process will lead to a perfect alignment of demand and supply. Therefore we define a variable production aspired ($AGPRAQ_{c,i}$) which is the difference between the (actual) production and the stock variation. The production aspired is one of the crucial information that serves as an input from GINFORS to the biophysical model LPJmL.

By conceptualizing the new features of GINFORS we already have to bear in mind the technical limitations of a hard link between the two models. In a perfect world without technical limitations after each iteration loop of GINFORS the results for the production aspired would be calculated and reported to the model LPJmL and the (actual) production would be calculated within the model LPJmL and reported to the model GINFORS. But as the model GINFORS solves with a demanding number of iterations and the solution procedure of the model LPJmL although using very powerful hardware is quite time-consuming a hard link like this would result in interlinked model solution procedures that last for rather some days than some minutes or hours, which is not feasible.

The consideration of these (technical) limitations of a hard link between the two models leads to the following concept in the extrapolation of the crop production aspired.

5.1.5. The extrapolation of the crop production aspired

For the extrapolation of the aspired crop production the stock variations after finishing the iterative solution serves as an input for the decision about the aspired harvested area in the next period. If the farmers remark an increase in stocks (= excess supply) that could not be eliminated by price variations the hypothesis to be tested in the farming module is, that they will diminish the harvested area in the next period. The other way round they will try to expand the harvested area in cases of excess demand. We denote the aspired area harvested for the different crops and crop groups in country c as $AGAHA_{c,i}$.[16]

$$[37]\ AGAHA_{c,i}[t+1] = AGAH_{c,i}[t] + \alpha * (AGPRQ_{c,i}[t] - AGSVQ_{c,i}[t]) / AGPRQ_{c,i}[t] \qquad c \in \{1,\ldots,39\},\ i \in \{1,\ldots,10\}$$

The missing link between the aspired area harvested from equation (37) and the aspired production quantities is the question about the evolution of the expected yields for the different crops and crop groups (= production quantity per harvested area) in the 38 countries and rest of world. We denote the expected yield as $AGYIE_{c,i}$ and assume that the farmers expect that the yields will grow with the average growth rate of the last five years.[17]

$$[38]\ AGYIE_{c,i}[t+1] = AGYI_{c,i}[t] * AGYI_{c,i}[t] / AGYI_{c,i}[t-5] \qquad c \in \{1,\ldots,39\},\ i \in \{1,\ldots,10\}$$

By doing so, we can calculate the production quantities aspired ($AGPRAQ_{c,i}$) in the next period as starting point for the next iterative solution procedure as the product of the expected yields and the aspired harvested area.

$$[39]\ AGPRAQ_{c,i}[t+1] = AGYIE_{c,i}[t+1] * AGAHA_{c,i}[t+1] \qquad c \in \{1,\ldots,39\},\ i \in \{1,\ldots,10\}$$

If the expected yields differ from the realized yields that are modeled in LPJmL this imposes a difference between the aspired production and the realized production (in the next period) and leads to modifications of prices as well as demand and international trade patterns. The same logic holds for the modeling of land and water constraint impacts on crop supply and use. We will come back to this issue in chapter 5.2. But before doing so, we have to address the explanation of additional information needed by the biophysical model: the evolution of the irrigated area.

5.1.6. The extrapolation of the irrigated area

In conceptualizing the farming module we first assume that the farmers try to hold the share of irrigated area.[18] We denote these shares that are historically known from the LPJmL database as $AGIRS_{c,s}$ and the aspired irrigated area as $AGIRA_{c,s}$.

$$[40]\ AGIRS_{c,i}[t+1] = AGIRS_{c,i}[t] \qquad c \in \{1,\ldots,39\},\ i \in \{1,\ldots,10\}$$

$$[41]\ AGIRA_{c,i}[t+1] = AGIRS_{c,i}[t+1] * AGAHA_{c,i}[t+1] \qquad c \in \{1,\ldots,39\},\ i \in \{1,\ldots,10\}$$

On base of these figures the total aspired irrigated area ($agirat_c$) can be calculated. If this sum is higher than the total irrigated area ($agirt_c$) in the previous year there is a need for investments in additional irrigation technology. Hitherto investigations with regard to data on investment costs in irrigation[19] show that there might be a need for some simple rules of thumb in defining the

16 The actual area harvested ($AGAH_{c,i}$) due to land constraints might differ from the aspired area harvested (see chapter 5.2).

17 The actual yield per hectar harvested area is calculated in the biophysical model LPJmL.

18 The setting of assumptions with regard to the evolution of shares of irrigated area is rather a task of scenario formulation than of conceptualising the farming module.

19 See the FAO aquastat "Database on investment costs in irrigation" (www.fao.org/nr/water/aquastat/investment/index.stm)

average cost per hectare in constant local currency for all 39 countries and regions differed in GINFORS. The total investment in irrigation in constant local currency ($aggfir_c$) is than given by multiplication of the investment costs ($agicir_c$) and the aspired expansion of the total irrigated area.

if $agirat_c[t+1] > agirt_c[t]$

$$[42]\ aggfir_{c,i}[t+1] = (agirat_c[t+1] - agirt_c[t]) * agicir_c[t] \qquad c \in \{1,\dots,39\},\ i \in \{1,\dots,10\}$$

As these investment decisions effect an increase in capital costs and hereby in the unit costs of the agricultural sector the implications on prices, supply and demand are automatically covered by the model GINFORS. Besides this the implications of the irrigated area on yields and crop production are covered by the biophysical model LPJmL. This too has consequences on the quantities and prices in the farming module of GINFORS.

Up to now the report on new features of GINFORS to model the links between the global socio-economic developments, crop production, water and land availabilities focused on fitting the model for the exchange of information/data with the biophysical model LPJmL. By doing so we first assumed the absence of land or water constraints. But as will be shown in this chapter the concept of the farming module needs only some extensions for the endogenous explanation of implications of land or water constraints.

5.2. Modeling of land use and impacts of land use constraints

In the explanation of land use we differ three land use categories: arable land and permanent crops area ($LAND_{c,1}$), permanent meadows and pastures area ($LAND_{c,2}$) and forestry area ($LAND_{c,3}$). With regard to the arable land and permanent crops area the conceptual differences to the total harvested area should be mentioned first:

Definitions according to the FAOSTAT-Glossary

"Arable land is the land under temporary agricultural crops (multiple-cropped areas are counted only once), temporary meadows for mowing or pasture, land under market and kitchen gardens and land temporarily fallow (less than five years). The abandoned land resulting from shifting cultivation is not included in this category. Data for "Arable land" are not meant to indicate the amount of land that is potentially cultivable."

"Permanent crops is the land cultivated with long-term crops which do not have to be replanted for several years (such as cocoa and coffee); land under trees and shrubs producing flowers, such as roses and jasmine; and nurseries (except those for forest trees, which should be classified under "forest")."

"Area harvested: Data refer to the area from which a crop is gathered. Area harvested, therefore, excludes the area from which, although sown or planted, there was no harvest due to damage, failure, etc. It is usually net for temporary crops and sometimes gross for permanent crops. Net area differs from gross area insofar as the latter includes uncultivated patches, footpaths, ditches, headlands, shoulders, shelterbelts, etc. If the crop under consideration is harvested more than once during the year as a consequence of successive cropping (i.e. the same crop is sown or planted more than once in the same field during the year), the area is counted as many times as harvested. On the contrary, area harvested will be recorded only once in the case of successive gathering of the crop during the year from the same standing crops."

Due to these conceptual differences a comparison of the historical figures shows that in some countries like China or India the numbers for the total area harvested due to successive cropping are bigger than the ones for the arable land and permanent crops area. In other countries like the USA or in European countries the total harvested areas are smaller than the figures for the arable land and permanent crops areas. But to model these conceptual differences would go far beyond the mission.

Of special interest for dealing with questions of (limited) land availabilities are not the developments of the harvested area for the single crops and crop groups as they can go in different directions due to changes in the use patterns but the sums over all crops and crop groups. We denote the actual total area harvested as $agaht_c$ and the aspired total area harvested as $agahat_c$.

[43] $agaht_c[t] = \sum_i AGAH_{c,i}[t]$ $c \in \{1,\ldots,39\}, i \in \{1,\ldots,10\}$

[44] $agahat_c[t+1] = \sum_i AGAHA_{c,i}[t+1]$ $c \in \{1,\ldots,39\}, i \in \{1,\ldots,10\}$

The growth of the total area harvested in a next step explains the total aspired use of arable land and permanent crops area ($LANDA_{c,1}$) in all 38 countries and rest of world.

[45] $LANDA_{c,1}[t+1] = LAND_{c,1}[t] * agahat_c[t+1] / agaht_c[t]$ $c \in \{1,\ldots,39\}$

If the availability of arable land is limited due to either the availability of fertile soil or by policy goals or competing land uses the expansion of the total harvested area might be restricted. In these cases the model will adjust the land expansion to maximum permitted value ($LANDM_{c,1}$).

if $LANDA_{c,1}[t+1] > LANDM_{c,1}[t+1]$

[46] $LAND_{c,1}[t+1] = LANDM_{c,1}[t+1]$ $c \in \{1,\ldots,39\}$

This constraint leads to an imbalance between the aspired harvested areas and the realized harvested areas.

[47] $AGAH_{c,i}[t+1] = AGAHA_{c,i}[t+1] * LAND_{c,1}[t+1] / LANDA_{c,1}[t+1]$ $c \in \{1,\ldots,39\}, i \in \{1,\ldots,10\}$

Within the farming module at first this implies an imbalance of demand and supply for crops (negative stock variations) in those countries with operative land constraints. But within the iterative solution procedure of the farming module this imposes an increase in prices and the respective implications on domestic demand as well as on the international trade patterns.

Before leaving the field of land use modeling the explanation of the other two land use categories should be mentioned. The purpose of this modeling is rather the analysis of implications of land constraints than the provision of information for the calculation of land use indicators.

For the explanation of the development of the permanent meadows and pasture area ($LAND_{c,2}$) the above described modeling of farming also provides the information needed. In regressions the dependency of this land use category on the evolution of meat production (in tonnes) is determined:

[48] $LAND_{c,2}[t] = f(AGPRQ_{c,11}[t])$ $c \in \{1,\ldots,39\}$

The explanation of the forest area ($LAND_{c,3}$) is based on the results for the evolution of production of “products of forestry, logging and related services” in monetary terms at constant prices ($GOUTBR_{c,2}$) from the economic core of the model:

[49] $LAND_{c,3}[t] = f(GOUTBR_{c,2}[t])$ $c \in \{1,\ldots,39\}$

5.3. Modeling of water withdrawals and impacts of water constraints

In this chapter we describe the modeling of abstraction of ground and surface water for the sectors public water supply, manufacturing, electricity production and agriculture. Water abstraction of the manufacturing sector is only self-supplied water (Kohli et al., 2012). This means that manufacturing may also use water distributed by the public water supply.

In the explanation of water withdrawals of the single sectors besides the below characterized explanatory variables with regard to contents a time trend is considered. By doing so the approach follows the concept of the WaterGAP model (Alcamo et al., 2000).

The aspired self-supplied water abstraction in cbm for industrial production of the manufacturing sector ($WAABA_{c,2}$) is explained by gross production of manufacturing in local currency and constant prices.

[50] $WAABA_{c,2}[t] = f(\sum_s GOUTBRI_{c,s}[t], Trend)$ $c \in \{1,\dots,39\}, s \in \{2,\dots,16\}$

The aspired self-supplied water abstraction for electricity production ($WAABA_{c,3}$) is referring only to cooling activities. Electricity production based on hard coal, brown coal, coke and nuclear are the relevant drivers. The water abstraction in cbm for cooling is explained by gross energy use in TJ in the electricity supply sector (${}_cGEU_{e,17}$) for the sum of these energy carriers.

[51] $WAABA_{c,3}[t] = f ({}_cGEU_{1,17}[t] + {}_cGEU_{2,17}[t] + {}_cGEU_{3,17}[t] + {}_cGEU_{28,17}[t], Trend)$ $c \in \{1,\dots,39\}$

Public water supply delivers water to all sectors of the economy and to private households. The monetary equivalent to water abstraction in the model GINFORS is gross production of the product group 33 (collected and purified water, distribution services of water) in local currency at constant prices. We therefor explain the aspired water abstraction by public water supply ($WAABA_{c,4}$) with its monetary equivalent:

[52] $WAABA_{c,4}[t] = f(GOUTBR_{c,33}[t], Trend)$ $c \in \{1,\dots,39\}$

In the explanation of the aspired self-supplied water abstraction by agriculture ($WAABA_{c,1}$) we use information about the evolution of the total irrigated area (see above).

[53] $WAABA_{c,1}[t] = f(agirt_c[t], Trend)$ $c \in \{1,\dots,39\}$

Total aspired water abstraction ($waabat_c$) is then defined as:

[54] $waabat_c[t] = \sum_i WAABA_{c,i}[t]$ $c \in \{1,\dots,39\}, i \in \{1,\dots,4\}$

The modeling of impacts of water constraints faces two main challenges: the definition of the water constraint and the knowledge about costs for investments in the efficiency of water supply systems.

To get an idea about the existence of water constraints we first calculate the share of total aspired water abstraction in the total freshwater resources ($watfr_c$) that are explained in the biophysical model due to climate change and denote this variable as $waabts_c$.

[55] $waabts_c[t] = waabat_c[t] / watfr_c[t]$ $c \in \{1,\dots,39\}$

To define the maximum sustainable share of water abstractions ($waabtsm_c$) for all 38 countries and rest of world will be one of the tasks of scenario formulation. By doing so it has to be considered that GINFORS is a national scale model and is not able to consider regional differences within these countries or within the rest of world region. A rather simple assumption as starting point might be that the shares of total water abstraction are not allowed to increase above the historical values. Then the actual total water abstraction ($waabt_c$) has to be aligned to this share.

if $waabts_c[t] > waabtsm_c[t]$

[56] $waabts_c[t] = waabtsm_c[t]$ $c \in \{1,\dots,39\}$

[57] $waabt_c[t] = watabts_c[t] * watfr_c[t]$ $c \in \{1,\dots,39\}$

The next question that arises in case of water constraints is the allocation of water use adjustments to the different sectors. This is rather a task of scenario formulation than of (endogenous) model explanation. In any case the actual water abstraction ($WAAB_{c,i}$) of the different sectors has to be lower than the aspired one.

The concept of modeling the impacts of water constraints uses the difference between the aspired water abstraction and the actual (at most acceptable) water abstraction. By doing so the concept is different for the impacts on the agricultural sector and the three other sectors.

With regard to the agricultural sector the impact modeling is nearly the same as already discussed in the context of land constraints. But this time the constraint leads to a reduction of the irrigated area and not of the harvested area.

[58] $AGIRA_{c,i}[t] = AGIRA_{c,i}[t] * WAAB_{c,1}[t] / WAABA_{c,1}[t]$ $c \in \{1,\dots,39\}, i \in \{1,\dots,10\}$

Again within the farming module this implies an imbalance of demand and supply for crops (negative stock variations) in those countries with operative water constraints. But within the iterative solution procedure of the farming module this imposes an increase in prices and the respective implications on domestic demand as well as on the international trade patterns.

With regard to the impacts of water constraints on the other sectors the conceptualization is a lot more difficult. Although there is a brought consensus that there is a high potential for improvements in water efficiency in public water supply as well as in industry and in the cooling of electricity plants (see e.g. Ecologic, 2007a, Ecologic, 2007b) investigations with regard to empirical findings for the investment costs needed to achieve efficiency gains up to now did not lead to satisfactory results. To achieve an as best as possible empirical foundation for an educated guess of the investment needed to achieve efficiency gains of water use for the three sectors at hand therefore is one of the coming challenges in modeling the impacts of water constraints.

5.4. Explanation of biomass extraction

The main objective of modelling the domestic extraction used of biomass is to enable the system for calculating and reporting about resource productivity indicators like RMC. The explanation and forecasting is carried out for five subgroups of biomass: animals, feed, food, forestry and other. For further purposes unused extractions can be calculated.

For the explanation of three of these subgroups the farming module in principle delivers the information needed. But by doing so, the conceptual differences between the production (harvest) of crops and the extraction of biomass have to be considered (see SERI, 2013):

- The material flow data do not only account for the harvest, but also for the by-products of harvest (crop residues used as fodder and as straw).
- The production of crops in the agriculture module in addition does not include biomass grazed by livestock or mowed for livestock sustenance that is part of the biomass extraction subcategory feed.
- The MFA subcategory “other biomass” should not be confounded with the use of crops for other purposes in the FAO commodity balances. The extraction of other biomass accounts for only 0.1% of total biomass extraction and reports about the categories honey, gathering of mushrooms and berries, and aquatic plants.

- Although the agriculture module (based on FAO data) gives information about the different uses of crops, this information is only available for the place of use and not for the place of production.

The remaining two subgroups “animals”[20] and “forestry” are directly explained by the production at constant prices of the respective product group explained in the input-output modules.

6. Conclusions and outlook

The economic environmental model GINFORS will be hard linked with the biogeochemical model LPJmL for a globally consistent simulation of biomass, land and water use in deep country, sector and crop disaggregation. The report at hand discussed the need and concept of new features of GINFORS to facilitate this hard link. As has been shown the reasoning about links between global socio-economic developments, crop production, water and land availabilities led to the finding that these new features by no means cover only some additional behavioral equations with regard to land and water demand as the title of the deliverable might have supposed. Instead the ambition is to integrate a complex farming module that depicts the interaction of food (and feed) demand and supply. By conceptualizing the new features already two topics have been recognized that will be subject of the upcoming task of implementing the hard link between the two models: the need for a modular modeling approach with the exchange of data between the models which allows for the year by year isolated solution of the models and a concept for modeling the impacts of land or water constraints. Especially these two points but also experiences with regard to the empirical verification of the concepts discussed as well as technical aspects of the hard link will be subject of the coming deliverable “Report about the linking of GINFORS and LPJmL” (D 3.4).

20 As the materialflows data for the subcategory „animals“ due to data availabilities does not account for hunting and therefore is restricted to fishing the proper driver for this material flow is the product group “Fish and other fishing products; services incidental of fishing”.

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8. Appendix

The General Structure of GINFORS$_3$

From a logical perspective, four interdependently linked modules can be distinguished: The economy module, the bilateral trade module, the energy-emissions module and the resource use module. The following paragraphs provide introductory insights into the respective modelling approaches. Please note that summary information with regards to country coverage, underlying classification schemes and the full set of endogenised environmental pressure variables have also been tabulated in the appendix of this paper.

The economy module

For 38 national economies and a Rest of World region the economic relationships are modelled by individual **economy modules** with market clearing mechanisms. Suppliers set mark-up prices with regards to local currency denominated unit costs and demanders take these prices as one determinant of their decisions. Suppliers produce the demanded volumes. This structure ensures a balanced influence of supply and demand on the solution of the model avoiding the supply dominance of neoclassical modelling. All macro variables like GDP and its components as well as aggregate price indices or employment are calculated by explicit aggregation from the sectoral variables. In this sense the model has a bottom up structure.

As regards the **supply side,** the following modelling scheme applies for any of the 35 industries of a given national economy:[21] Input coefficients for intermediate inputs are modelled as price dependent variables. In the case of energy inputs these coefficients are driven by the inputs of related energy carriers (which are predetermined in physical units by the energy module). The capital stock is calculated from gross investment and the depreciation rate by definition. Gross investment is explained by gross production and the interest rate. Labour input in hours depends on gross production and sectorial real wage rates which are influenced by an average macroeconomic wage rate (Phillips curve approach). Compensation of employees is given by definition; the number of persons engaged can be derived from the average working time per person and the employment in hours. Unit costs are given by definition. Basic prices for sectors agriculture as well as mining and quarrying are calculated by definition from the aggregation of 8 exogenous product prices for fossil fuels, minerals and agricultural products. For all other 33 industry prices, unit costs and prices of competing import goods represent the relevant drivers. Domestic prices for 51 product groups are disaggregated from the industry prices via the make matrix. Basic prices for the 59 product groups are defined as weighted averages of import prices and domestic prices. Purchasers' prices for the 59 product groups are derived from basic prices adding tax rates and transport and trade margins. For all 35 industries value added can be calculated subtracting the sum of intermediate inputs from gross production. For 59 product groups total use is defined as the sum of intermediate and final demand. Import shares depend on the relation of import prices to basic prices. Gross output for the 59 product groups can be calculated subtracting imports from total use. The imports in local currency are converted into dollars and given to the bilateral trade model.

With regards to the **demand side,** the following impacts are explicitly captured by our modelling scheme: Intermediate demand of 59 product groups for 35 industries is implicitly given by the

[21] The Rest of World region is exhibits a slightly less complex modelling scheme.

inputs of intermediate demand in the 35 industries. Final demand for each of the 59 product groups is sub-divided to private consumption, public consumption, gross fixed capital formation, inventory investments and exports. For each product group of private consumption real consumption per capita is explained by real disposable income per capita and relative prices. Special attention is given to private mobility in relation to mobility services, which are separated for land, water and air traffic. Energy product groups are explained in the energy module. Water demand is driven by physical water demand estimated in the resource use module. Real public consumption per capita is explained by the real sum of disposable income and net lending of the government and by relative prices of the product group. Gross fixed capital formation for 59 product groups can be calculated using the vector of gross fixed capital formation for 35 industries (see above) and a capital transformation matrix. Inventory investment is estimated by the change of gross output of the 59 product groups. Exports are given by the bilateral trade module.

The internally consistent bottom-up presentation of the flows of goods and services within the economy as well as the use of primary inputs within the production process inside the Input-Output system is completely embedded in the **sequence of accounts and balancing items** for the institutional sectors for 36 countries in units of local currency. Missing countries are Malta, Turkey and Rest of the World. This second major data set provides an internally consistent synthesis of all institutional sector accounts. It shows the amounts of uses and resources of each institutional sector for all transactions. Thus, policy relevant variables like disposable income of households or net lending / net borrowing of general government are pictured by this accounting module.

The bilateral trade module

The **bilateral trade module** takes for 59 product groups the export prices and the import values from the country models and converts them from local currency into dollars. For each product group, import shares of receiving countries depend on the relation between the respective export prices and an aggregated product-specific import price of the receiving country. Multiplying these trade shares with imports and summing up over importing countries gives the exports by definition. The import prices are calculated as a weighted average of export prices with the trade shares as weights.

The energy and emissions module

For each country the demand of 35 industries and private households for 28 energy carriers in physical terms (TJ) is explained by the **energy and emissions module**. In a first stage total energy demand of an industry is explained by gross production of the sector and the aggregated energy price in relation to the basic price of the industry. In the second stage the shares of the different carriers in total energy demand are determined by the relation of the price of the carrier in relation to the aggregated energy price of the industry. Energy demand for private households is in the first stage separated for the three purposes heating and cooling, mobility and household appliances. The energy intensity for heating and cooling is defined as the gross energy use per real capital stock of the real estate services industry. It´s evolvement is tested for dependency on relative price developments and time trends. Multiplication of the energy intensity with the real capital stock gives energy demand. Energy for mobility is explained by real disposable income of private households and the relation between the aggregated energy mobility price and the aggregated price for mobility services. Energy demand for household appliances depends from real disposable income and the relation between the household's electricity price and the price for aggregated private consumption. In the second stage in each purpose the relative prices of the energy carriers determine the structure of demand. At his point, energy demand and it´s structure have been determined for private households and all 35 industries except the electricity supply industry. Therefore, the structure of electricity and heat production has to be explained in a subsequent step. The corresponding calculations feature an explicit distinction between energy generated by renewable technologies and energy generated by nuclear energy plants. For seven renewable technologies the decision to install new capacities is modelled in dependency from investment and operating & maintenance costs, feed-in tariffs, the carbon price and market prices for electricity and heat. Installation as well as permanent shut-down of nuclear capacities is treated as an exogenous policy variable. Given these installations, the total amount of electricity and heat that has to be produced from conventional (fossil) energy carriers can then be calculated straightforwardly with allowances for efficiency and the conversion losses. The structure of energy carriers within this are again determined by relative prices.

Energy demand in physical terms feeds back into the economic module as has been shown for intermediate and final demand. The gross energy used is transformed into CO_2-emissions for 35 industries (and private households) and 14 energy carriers assuming constant emission factors as well as constant relations between gross energy uses and emission relevant energy uses. Last but not least the module explains the emissions for 7 further air pollutants (N2O, NOx, SOx, NMVOC, NH3, CH4) in 35 industries and private households using the information from the energy use side as well as from the economy and the resource use module.

The resource use module

For each country the **resource use module** explains material extractions for 12 kinds of material in tons, agricultural land use for three types in hectares and freshwater abstraction in cubic meter. The modelling approaches for land use and freshwater abstraction as well as for biomass extraction are discussed in detail in the main part of this paper. The general approach for the modelling of the extraction of materials other than biomass is that first an intensity in relation to the production of the respective product by the mining industry in local currency and constant prices is defined, which can be observed historically. With regard to the fit between material categories and the products of the mining industries the new GINFORS version constitutes a considerable advance. Whilst in older model versions a differentiation was given only for mining and quarrying energy and mining and quarrying non-energy. Due to the new database and structure of the model the model now differs five mining products. In the forecast the multiplication of this driver with its corresponding trend dependent intensity gives the extraction in physical terms. In those cases where the product differentiation is still not detailed enough the model explains the extractions in a two stage process. First the total extraction of construction and industrial minerals as well as the total extraction of oil and gas is explained. In a second step the breakdown into the components results on base of information from the other modules. Due to the global coverage of $GINFORS_3$ it is possible to calculate not only the domestic part of the resource use indicators but also the indirect uses due to imports of semi-finished and finished products.

Classifications

n	Name of country / region	Code
1	Austria	AUT
2	Belgium	BEL
3	Cyprus	CYP
4	Estonia	EST
5	Finland	FIN
6	France	FRA
7	Germany	DEU
8	Greece	GRC
9	Ireland	IRL
10	Italy	ITA
11	Luxembourg	LUX
12	Malta	MLT
13	Netherlands	NLD
14	Portugal	PRT
15	Slovak Republic	SVK
16	Slovenia	SVN
17	Spain	ESP
18	Bulgaria	BGR
19	Czech Republic	CZE
20	Denmark	DNK
21	Hungary	HUN
22	Latvia	LVA
23	Lithuania	LTU
24	Poland	POL
25	Romania	ROU
26	Sweden	SWE
27	United Kingdom	GBR
28	Russia	RUS
29	Turkey	TUR
30	Brazil	BRA
31	Canada	CAN
32	Mexico	MEX
33	United States	USA
34	China	CHN
35	India	IND
36	Japan	JPN
37	Korea	KOR
38	Australia	AUS
39	Rest of World	ROW

n	Name of product	Code
1	Products of agriculture, hunting and related services	1
2	Products of forestry, logging and related services	2
3	Fish and other fishing products; services incidental of fishing	5
4	Coal and lignite; peat	10
5	Crude petroleum and natural gas; services incidental to oil and gas extraction excluding surveying	11
6	Uranium and thorium ores	12
7	Metal ores	13
8	Other mining and quarrying products	14
9	Food products and beverages	15

10	Tobacco products	16
11	Textiles	17
12	Wearing apparel; furs	18
13	Leather and leather products	19
14	Wood and products of wood and cork (except furniture); articles of straw and plaiting materials	20
15	Pulp, paper and paper products	21
16	Printed matter and recorded media	22
17	Coke, refined petroleum products and nuclear fuels	23
18	Chemicals, chemical products and man-made fibres	24
19	Rubber and plastic products	25
20	Other non-metallic mineral products	26
21	Basic metals	27
22	Fabricated metal products, except machinery and equipment	28
23	Machinery and equipment n.e.c.	29
24	Office machinery and computers	30
25	Electrical machinery and apparatus n.e.c.	31
26	Radio, television and communication equipment and apparatus	32
27	Medical, precision and optical instruments, watches and clocks	33
28	Motor vehicles, trailers and semi-trailers	34
29	Other transport equipment	35
30	Furniture; other manufactured goods n.e.c.	36
31	Secondary raw materials	37
32	Electrical energy, gas, steam and hot water	40
33	Collected and purified water, distribution services of water	41
34	Construction work	45
35	Trade, maintenance and repair services of motor vehicles and motorcycles; retail sale of automotive fuel	50
36	Wholesale trade and commission trade services, except of motor vehicles and motorcycles	51
37	Retail trade services, except of motor vehicles and motorcycles; repair services of personal and household goods	52
38	Hotel and restaurant services	55
39	Land transport; transport via pipeline services	60
40	Water transport services	61
41	Air transport services	62
42	Supporting and auxiliary transport services; travel agency services	63
43	Post and telecommunication services	64
44	Financial intermediation services, except insurance and pension funding services	65
45	Insurance and pension funding services, except compulsory social security services	66
46	Services auxiliary to financial intermediation	67
47	Real estate services	70
48	Renting services of machinery and equipment without operator and of personal and household goods	71
49	Computer and related services	72
50	Research and development services	73
51	Other business services	74
52	Public administration and defence services; compulsory social security services	75
53	Education services	80
54	Health and social work services	85
55	Sewage and refuse disposal services, sanitation and similar services	90
56	Membership organisation services n.e.c.	91
57	Recreational, cultural and sporting services	92
58	Other services	93
59	Private households with employed persons	95

n	Name of production sector	Code
1	Agriculture, Hunting, Forestry and Fishing	AtB
2	Mining and Quarrying	C
3	Food, Beverages and Tobacco	15t16

4	Textiles and Textile Products	17t18
5	Leather, Leather and Footwear	19
6	Wood and Products of Wood and Cork	20
7	Pulp, Paper, Paper , Printing and Publishing	21t22
8	Coke, Refined Petroleum and Nuclear Fuel	23
9	Chemicals and Chemical Products	24
10	Rubber and Plastics	25
11	Other Non-Metallic Mineral	26
12	Basic Metals and Fabricated Metal	27t28
13	Machinery, Nec	29
14	Electrical and Optical Equipment	30t33
15	Transport Equipment	34t35
16	Manufacturing, Nec; Recycling	36t37
17	Electricity, Gas and Water Supply	E
18	Construction	F
19	Sale, Maintenance and Repair of Motor Vehicles and Motorcycles; Retail Sale of Fuel	50
20	Wholesale Trade and Commission Trade, Except of Motor Vehicles and Motorcycles	51
21	Retail Trade, Except of Motor Vehicles and Motorcycles; Repair of Household Goods	52
22	Hotels and Restaurants	H
23	Inland Transport	60
24	Water Transport	61
25	Air Transport	62
26	Other Supporting and Auxiliary Transport Activities; Activities of Travel Agencies	63
27	Post and Telecommunications	64
28	Financial Intermediation	J
29	Real Estate Activities	70
30	Renting of M&Eq and Other Business Activities	71t74
31	Public Admin and Defence; Compulsory Social Security	L
32	Education	M
33	Health and Social Work	N
34	Other Community, Social and Personal Services	O
35	Private Households with Employed Persons	P

n	Name of energy carrier	Code
1	Hard coal and derivatives	HCOAL
2	Lignite and derivatives	BCOAL
3	Coke	COKE
4	Crude oil, NGL and feedstocks	CRUDE
5	Diesel oil for road transport	DIESEL
6	Motor gasoline	GASOLINE
7	Jet fuel (kerosene and gasoline)	JETFUEL
8	Light Fuel oil	LFO
9	Heavy fuel oil	HFO
10	Naphta	NAPHTA
11	Other petroleum products	OTHPETRO
12	Natural gas	NATGAS
13	Derived gas	OTHGAS
14	Industrial and municipal waste	WASTE
15	Biogasoline also including hydrated ethanol	BIOGASOL
16	Biodiesel	BIODIESEL
17	Other combustible renewables	OTHRENEW
18	Electricity	ELECTR
19	Heat	HEATPROD
20	Electricity for e-mobility	EMOB

21	Biogas	BIOGAS
22	Hydroelectric	HYDRO
23	Geothermal	GEOTHERM
24	Photovoltaic	PV
25	Solarthermal heat	SOLAR HEAT
26	Solarthermal electricity	CSP
27	Wind power	WIND
28	Nuclear	NUCLEAR

n	Name of emission	Code
1	CO_2	CH4
2	methane	N2O
3	nitrous oxide	NOX
4	nitrogen oxides	SOX
5	sulphur oxides	CO
6	carbon monoxide	NMVOC
7	non-methane volatile organic compounds	NH3
8	ammonia	CH4

n	Name of material (domestic extraction used, unused domestic extraction)
1	biomass animals
2	biomass feed
3	biomass food
4	biomass forestry
5	biomass other
6	fossil coal
7	fossil gas
8	fossil oil
9	fossil other
10	construction minerals
11	industrial minerals
12	ores

n	Name of land use category
1	arable land and permanent crops area
2	pastures area
3	forestry area

n	Name of water abstraction category
1	freshwater abstraction by agriculture
2	freshwater abstraction by industry
3	freshwater abstraction for electricity production (cooling only)
4	freshwater abstraction by public water supply