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The Agricultural Economy Model in IMAGE 2.2

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Abstract

During the second Advisory Board Meeting on IMAGE 2.0 (originally, the Integrated Model to Assess the Greenhouse Effect, and now known as the Integrated Model to Assess the *Global Environment*) in June 1994, improvement of the Agricultural Economy Model (AEM) was discussed. It was decided to adopt a 'simple equilibrium relation between supply and demand' which resulted in a new version of the AEM as part of IMAGE 2.1. In this version, the AEM is part of the Terrestrial Environmental System (TES) and computes the food, feed crops and timber demands. The output of the AEM forms one of the inputs to the Land Cover Model (LCM), which simulates how land use and land cover will change in order to meet the demands of the AEM and those for biofuels and fuelwood, as determined by the Energy/Industry System (EIS). In this report, the focus will be on improvements in the AEM in IMAGE 2.2 compared to IMAGE 2.1. Why and how this part of the AEM has been improved in IMAGE 2.2 is outlined by first describing the IMAGE 2.1-version of the AEM and the related problems. This is followed by a discussion of how these problems could be tackled in IMAGE 2.2 and what steps are currently being considered to develop an integrated land-economy model that will cover all land-related products (food, feed, wood, biomass, etc.) into one economic model. This model will form part of a new version of IMAGE.

Contents

Summary

This report starts with a description of the basic concepts and the dynamic behaviour of the Agricultural Economy Model in IMAGE 2.1. Food products are associated with so-called *intensities*, which indicate the amount of land needed to supply 1 Kcal per day of the vegetative or animal product, taking into account the conversion from feed to meat. Because prices do not exist in the AEM, intensities are considered to be a proxy for prices. The 'heart' of the AEM consists of 13 regional utility functions, which return a utility-value for a given diet. The maximum value is achieved at the point where the demands are equal to the so-called *preference levels*. The overall shape and steepness of the utility function is determined by the values of the preference levels, and the so-called *weighing constants,* which indicate the eagerness to consume the food-products at their preferred levels. The basic idea of the AEM is to optimise the utility function, given a so-called *actual (*or *total) budget*, which is a function of intensities, income, average potential production and technology. The resulting general behaviour is that lower intensities (or 'prices') of one of the products result in a higher utility for the consumer given a certain income. However, there are a number of problems in the 2.1-version, of which the most prominent are:

- Because 12 food products are distinguished, the 13 regional utility functions are shaped by 156 preference levels, and 169 weighing constants, excluding 28 additional parameters. Next, FAO-data on intakes, incomes, and intensities from the period 1970-90 were used in a separate optimisation-module to determine optimal values for this set of 353 parameters. It turned out the data was too capricious for the optimisation module to generate a set of parameter values. The reason is the AEM assumes the existence of a relationship at the regional level between intensities and intake levels, which is not the case.
- A second problem is the observation that the general dynamic behaviour does not apply to all 'worlds'. In these cases, decreasing intensities can result in *lower* optimal utility values.
- In some regions cattle grazes on large areas while capital and labour inputs are very low and therefore prices are too. But in terms of intensities these products are very expensive. In IMAGE 2.1, this problem was 'solved' by setting an upper limit to the amount of grassland that can be assigned to cattle. In general, it can be stated that intensities alone cannot serve as an acceptable proxy for price.

To solve the problems it was examined whether a reduction in product aggregates, and therefore a reduction in the number of parameters, would result in a model for which parameter values can be computed by the optimisation module. Unfortunately, even if two aggregates are considered only, i.e. 'affluent' products (oil crops and all animal products) and 'basic' products, the picture is still rather chaotic at the regional level. To get a better global picture intake levels were compared with ratios of intensities to income per capita. The overall picture significantly improves, although some regions are still problematic. However, in that case we are almost back at the well-known relationship between income and consumption: intake levels of affluent products increase with increasing income and intake levels of basic products rise to a maximum with rising incomes after which they go down because they are replaced by affluent products. Based on observations above, a number of simplifications were made in order to have a feasible food demand model in which the original concepts were maintained as much as possible. Finally, the calibration and its result in terms of parameter-values for the utility functions are described followed by some concluding remarks how the development of an integrated agricultural economy model should proceed after the finalisation of IMAGE 2.2.

Samenvatting

Na een korte introductie worden in hoofdstuk 2 de basisconcepten en het dynamisch gedrag beschreven van het ‘Agricultural Economy Model’ (AEM) in IMAGE 2.1. Voedselprodukten zijn gekoppeld aan *intensiteiten*, die aangeven hoeveel land nodig is voor het produceren van 1 Kcal per dag van het betreffende plantaardige of dierlijke produkt, waarbij in het laatste geval op basis van een reeks aannamen een omrekening plaatsvindt van veevoer naar vlees. In het model worden de intensiteiten beschouwd als een benadering van prijzen. De kern van het AEM bestaat uit 13 regionale utiliteitsfuncties, die een nutswaarde berekenen op basis van een gegeven dieet. De maximumwaarde wordt bereikt op het punt waar de vraag gelijk is aan de zogenaamde *preferentie-niveaus*. De vorm van de utiliteits-functies worden bepaald door de waarden van de preferentie-niveaus en de zogenaamde gewichtsconstanten. Deze constanten geven aan hoe graag de consument een bepaald voedselprodukt wil consumeren op het gegeven preferentie-niveau. Het principe van het AEM bestaat uit het optimaliseren van de utiliteitsfunctie, gegeven een bepaald *actueel budget*, hetgeen een functie is van de intensiteiten, het inkomen, de gemiddelde potentiële produktie en de technologische ontwikkeling. Het resulterende algemene gedrag is dat lagere intensiteiten (of prijzen) van één van de voedselprodukten leiden tot een hogere nutswaarde voor de consument, gegeven een bepaald inkomen. In hoofdstuk 3 komen een aantal problemen in de 2.1-versie van het AEM aan de orde:

- Omdat 12 voedselprodukten worden onderscheiden, worden de 13 regionale utilititeitsfuncties beschreven door 156 preferentie niveaus en 169 gewichtsconstanten. Daarnaast zijn er nog 28 additionele parameters. Vervolgens zijn consumptiedata, inkomens, en intensiteiten uit de periode 1970-1990 gebruikt in een aparte optimaliseringmodule voor het bepalen van de waarden van de resulterende 353 parameters. Hierbij bleek dat het onmogelijk was om op basis van deze data een set parameter-waarden te bepalen. De reden is dat het uitgangspunt waarop het AEM is gebaseerd, nl. de aanname dat er op wereldregio-niveau een relatie bestaat tussen intensiteiten en consumptie-niveaus, onjuist is.
- Een tweede probleem is dat het eerder beschreven dynamische gedrag niet altijd blijkt op te treden: soms leiden *afnemende* intensiteiten leiden tot *lagere* nutswaarden.
- In sommige regio’s graast het vee op grote gebieden waarbij de inputs van kapitaal- en arbeid laag zijn evenals de resulterende vleesprijzen. Echter, in termen van intensiteiten zijn deze produkten erg duur. Dit is een voorbeeld van de algemene constatering dat intensiteiten alleen niet voldoende zijn als een benadering voor prijzen.

Ten einde deze problemen op te lossen, is gekeken of een reductie van het aantal voedselaggregaten zou resulteren in een model waarvoor de parameters wel berekend kunnen worden. Helaas bleek dat zelfs bij twee aggregaten, te weten ‘affluent’ (olie gewassen en dierlijke produkten) en ‘basic’ (granen, bonen, etc), het beeld nog steeds tamelijk chaotisch is. Als de consumptie-niveaus worden vergeleken met de ratio’s van intensiteiten en inkomen per capita verbetert het beeld significant, maar in dat geval zijn we bijna terug bij de veel gebruikte relatie tussen inkomen en voedselconsumptie: nl. dat consumptie-niveaus van ‘affluent’ produkten toenemen met toenemende inkomens en dat het consumptie-niveau van ‘basic’ produkten eerst stijgt naar een maximum en vervolgens daalt omdat ze worden vervangen door de ‘affluent’ produkten. Op basis van bovenstaande analyses, zijn vervolgens een aantal vereenvoudigingen doorgevoerd in het AEM zodanig dat een bruikbaar voedselvraagmodel ontstond waarin de oorspronkelijke concepten zo veel mogelijk werden gehandhaafd. Het laatste gedeelte van het rapport beschrijft de calibratie van dit model (incl. de bepaling van de parameter-waarden van de utiliteitsfuncties), gevolgd door een aantal con-

cluderende opmerkingen aangaande de verdere ontwikkeling van een geïntegreerd land-economisch model hetgeen zal plaatsvinden na de afronding van IMAGE 2.2.

1. Introduction

In IMAGE 2.0, historical consumption patterns of agricultural food products were extrapolated into the future by using semi-logarithmic functions with Gross Regional Product (GRP) per capita as the driving force. The consumption of all products was scaled down if overall consumption exceeded a threshold, which sometimes led to unrealistic shares of food products. Another disadvantage was that land scarcity was not taken into account. Therefore, during the second Advisory Board Meeting in June 1994 it was discussed to improve the Agricultural Economy Model (AEM) by adopting a 'simple equilibrium relation between supply and demand'. This resulted in a new version in IMAGE 2.1.

In IMAGE 2.1, the AEM is part of the Terrestrial Environmental System (TES) and computes the demands for food and feed crops and timber. The demand for food and feed are based on the demands for 7 vegetable and 5 animal food products, which cover about 70 to 80% of total food intake. For each region, the remaining part (including for example fish and fruit) is assumed to be a fixed fraction over time. In this report, the focus will be on the module that computes the demand for vegetable and animal food products because the computation of the demand for feed and timber was not updated since IMAGE 2.0.
The output of the AEM forms one of the inputs to the Land Cover Model (LCM), which determines how land use and land cover will change in order to meet the demands from the AEM and those for biofuels and fuelwood as determined by the Energy/Industry System (EIS).

The primary objective of the AEM is to supply information to the LCM in order to compute land use and land cover changes and the related emissions of greenhouse gasses, i.e. primarily CO_2 emissions due to deforestation and methane from livestock. Other sources, such as nitrous oxide from the use of fertilisers and methane from landfills, are covered by other parts of IMAGE. Although results of model runs allow to make some general statements on food-security, a detailed simulation of global food demand and supply is not a primary objective of the AEM (or TES). Nevertheless, improvements are needed, as will be discussed in this report.

Before going into details on why and how the AEM has been improved in IMAGE 2.2, it is useful to have a proper understanding of the IMAGE 2.1 version. Therefore, in chapter 2 the model is explained without going into details of the underlying formulas. If needed, a detailed description can be found in annex A. Then, in chapter 3, the problems of the IMAGE 2.1 version of the AEM will be discussed. Finally, in chapter 4 it is described how these problems are more or less tackled in IMAGE 2.2 and what steps are currently being discussed to develop a integrated land-economy-model that will cover all land related products (food, feed, wood, biomass, etc.) into one economic model. This model will be part of a next version of IMAGE.

2. Model description

2.1 Basic concepts

To understand the basic concepts of the AEM, it is sufficient to consider a simplified world with only one region and a demand for diet *d* consisting of only two hypothetical food products p_1 and p_2. The demands for these products, represented by d_1 and d_2 are, respectively, placed on the *x*-axis and the *y*-axis in *figure 2.1*.

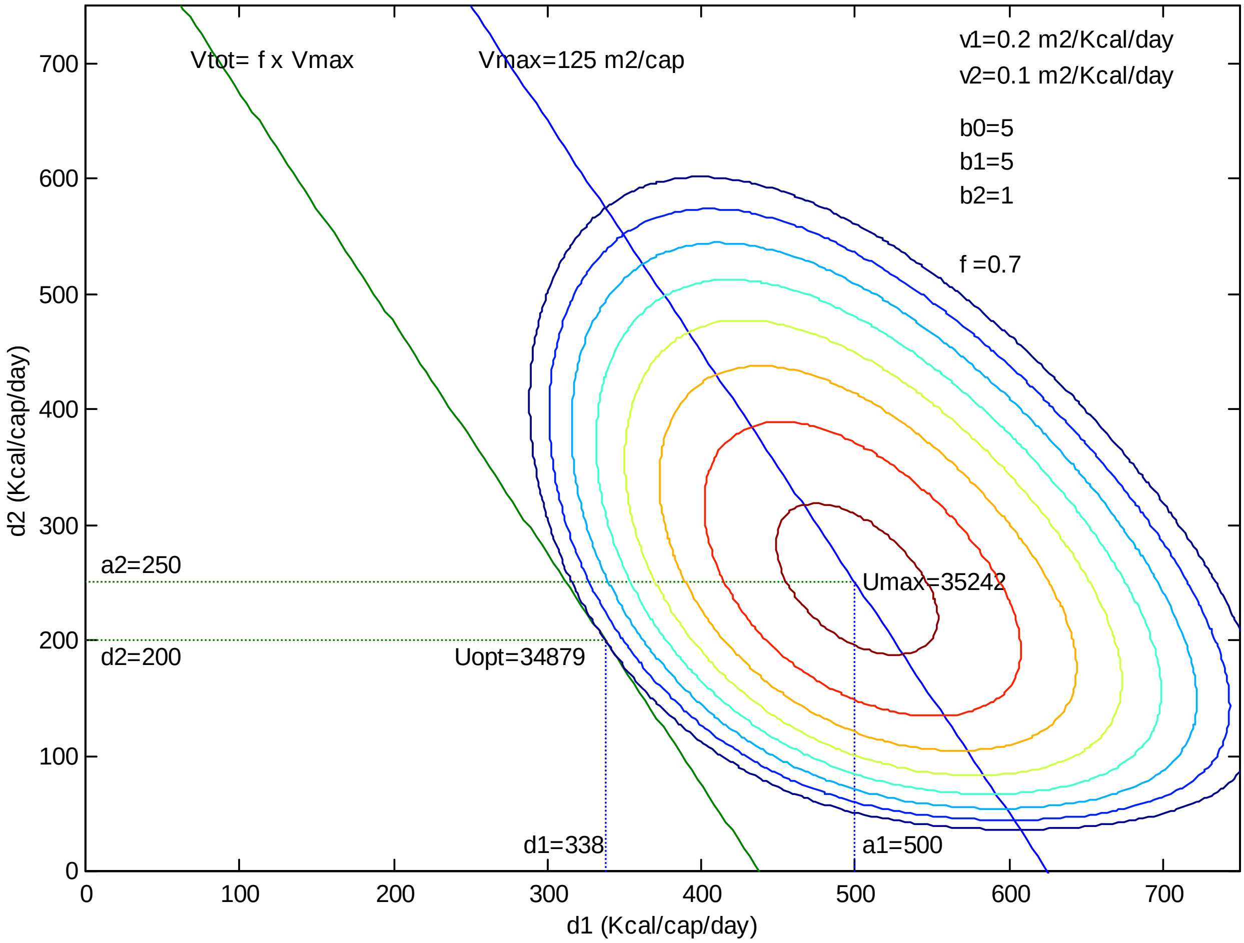


Figure 2.1 The basic concept of the AEM in a two-products-one-region world.

The animal and vegetative food products are associated with so-called *intensities* v_1 and v_2, which indicate the amount of pasture or land needed to supply 1 Kcal per day of the product, where the conversion from feed to meat is based on a series of assumptions (RIVM, 2001). In this example 0.2 m^2 is needed to produce one Kcal/day of p_1. Because prices do not exist in the AEM, intensities are considered to be a proxy for prices: higher intensities are interpreted as higher prices and should therefore result in lower shares in the eventual diet, if all other factors remain unchanged. We will come back to this later.
Obviously, if d_1 and v_1 are multiplied, then the outcome is equal to the amount of agricultural land per capita needed to produce the demanded amount of p_1. Consequently, the *x*-axis and

the y-axis can easily be converted into surfaces by multiplying with the intensities. In case of p_1, the x-axis would go from 0 to 750×0.2 = 150 m^2.

Next, there are *preference levels*, referred to in *figure 2.1* by a_1 and a_2. Their values (in Kcal/cap/day) are equal to the demands that would exist in the absence of any limits concerning for example land and income. Multiplying preference levels and intensities result in an amount of agricultural land that would be needed per capita to produce the preferred diet (i.e. where d_1=a_1 and d_2=a_2). In the AEM, this amount is defined as the 'maximum budget', referred to with the variable V_{max}. In our example, V_{max} is equal to 500×0.2 + 250×0.1 = 125 m^2/capita. Any point on the V_{max}-line drawn in *figure* 2.1, corresponds to a combination of d_1 and d_2 for which 125 m^2/cap of agricultural land would be needed to produce these demands.

The 'heart' of the AEM is the so-called utility function *U,* which returns the utility-value for a given diet (i.e. a combination of d_1 and d_2). Obviously, the maximum value of *U* is achieved at the point where the demands are equal to the preference levels, indicated by U_{max}. In *figure 2.1*, the hill-shaped utility function with its top at U_{max} is reflected by a number of more or less ellipse-shaped contour lines. As already indicated, the overall shape and steepness of the utility function is determined by the values of the preference levels, but also by the so-called *weighing constants* b_0, b_1 and b_2. The values of b_1 and b_2 indicate the eagerness or importance to the consumer to consume the products p_1 and p_2 at the preferred levels a_1 and a_2. The value of b_0 indicates the same for the sum of a_1 and a_2, i.e. the importance of consuming 500+250=750 Kcal/cap/day. In our example b_0=5, b_1=5 and b_2=1 indicating that it is far more important to consume p_1 at its preference level than it is for p_2 and also it is considered very important to consume the total preferred level of 750 Kcal/cap/day.

The basic idea of the AEM is to optimise the utility function, given a so-called *actual (*or *total) budget*, referred to by V_{tot}, which can be considered as the available amount of agricultural land per capita. This is not fully correct, but for the time being it is enough to interpret this variable as such. V_{tot} is always equal or less than the maximum budget V_{max}. In *figure 2.1*, the actual budget is equal to 0.7 times the maximum budget. In the implementation of the AEM this fraction *f* depends on income, average potential production and technology. If any of these factors increase, the fraction increases also (see *section 2.2* and annex A).

The optimal diet, i.e. the combination of d_1 and d_2 for which the utility function *U* has a maximum value given a certain budget, is at the point of tangency of the budget-line and a contour of *U*. In *figure 2.1*, this point is indicated by U_{opt}. In our example, a budget of 87.5 m^2/cap results in an optimal utility value of 34879 at d_1=338 and d_2=200 Kcal/cap/day.

2.2 Dynamic behaviour

To understand the dynamic *behaviour* of the AEM, it is interesting to see what happens if the intensity v_1 (or 'price') of p_1 declines by, say, 50% while other factors remain equal. *Figure 2.2* shows how the overall picture will change. Because 1 Kcal of p_1 can be produced now on a much smaller surface, the maximum budget V_{max} has decreased by 50 m^2/cap (i.e. 42%).

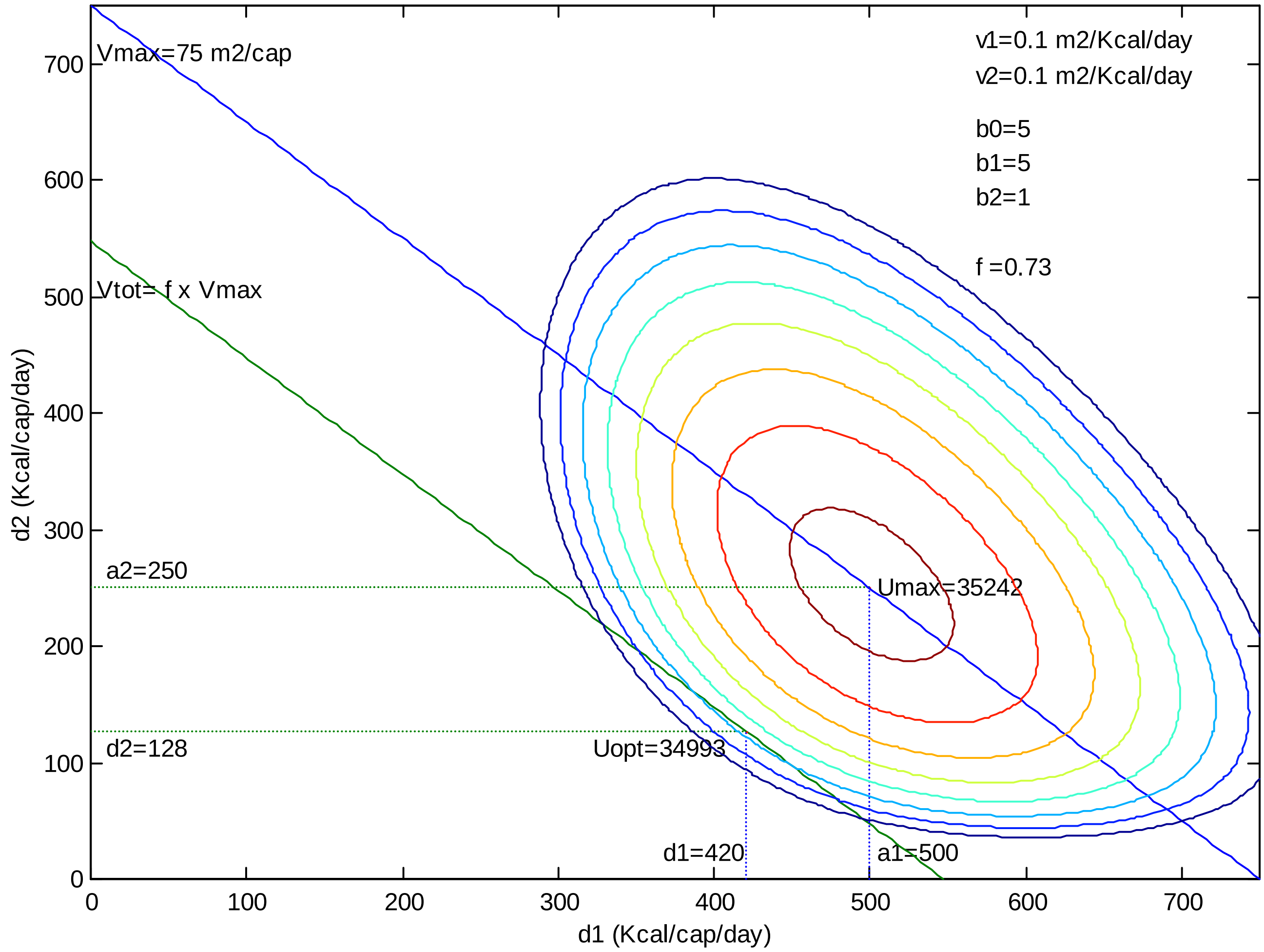


Figure 2.2 The dynamic behaviour of the AEM in a two-products-one-region world: the utility increases if intensities (or 'prices') go down.

The actual budget V_{tot} has increased from 0.7 to 0.73 times the maximum budget, although in absolute term it is a *decrease* of almost 33 m^2/cap (i.e. 37.4%). The fraction f increases because a decrease in v_1, which is the same as an increase of yields, is, in IMAGE 2.1, always caused by an improvement of the average potential productivity and/or an improvement in agricultural technology. Therefore, decreasing intensities make the actual budget line shift towards the maximum budget line, given that income does not decrease. In this example, the increase of f from 0.7 to 0.73 has been chosen more or less arbitrarily, but in the implementation of the AEM, the actual increase depends on the value of the parameters that determine the relationship between f and income, average potential production and technology.

The shape of the utility-function has not changed because its parameters on which it depends (b_0, b_1, b_2, a_1 and a_2) did not change either. The point of tangency of the budget-line is on a higher contour line than in *figure 2.1*, which goes with a higher demand for p_1 and a lower demand for p_2. To be precise, in the new situation the utility has increased to 34993 and d_1 to 420 Kcal/cap/day while d_2 has decreased to 128 Kcal/cap/day.

The general behaviour for this example is, as it should be, that lower intensities (or ‘prices’) of one of the products result in a higher utility for the consumer given a certain income.

2.3 Implementation of the AEM in IMAGE 2.1

The implementation of the AEM in IMAGE 2.1 describes a 12 products, 13 regions world in which every region has its own 12-products-utility function.
Although it would be rather complicated to represent graphically, the basic concepts and the dynamic behaviour of this AEM are identical to the description above. There are only two extensions related to food trade between regions and the actual regional availability of agricultural land.

In IMAGE 2.1, so-called ‘Self Sufficiency Ratios’ are time series that exogenously determine net food trade between the 13 world regions. Although it might be argued it would be essential to model trade more dynamically, the current approach is satisfactory in terms of correct behaviour of the AEM. In fact, the current approach boils down to exogenously assigning agricultural land in one region to produce food products for another, which reveals itself in the values of the intensities. For example, the intensity of rice in Canada would not be defined without trade. However, in the AEM, there is a Canadian intensity value for rice, which is equal to the weighted average of the rice intensities from importing regions.

The second aspect, the actual availability of land, is important because up to here it was assumed implicitly that the actual budget, as computed by the AEM, is also available according to the Land Cover Model (LCM) of IMAGE 2.1. However, in some cases it turns out that the actual budget cannot be met by the LCM. When this occurs, the actual budget of the AEM is reduced and the optimal diet is recomputed according to this lower budget.

3. Problems in the IMAGE 2.1 version of the AEM

3.1 The optimisation module

In the AEM of IMAGE 2.1, 12 food products and 13 regions are distinguished and therefore the 13 regional utility functions are shaped by 156 preference levels (a_1 through a_{12} for all 13 regions), and 169 weighing constants (b_0 through b_{12} for all 13 regions). On top of that there are 28 parameters in the functions that compute the actual budget (see annex A). In case of a 17-region version in IMAGE 2.2 these numbers would be 204, 221 and 36. In IMAGE 2.1, FAO-data on intakes, incomes, and intensities from the period 1970-1990 were used in a separate optimisation-module to determine optimal values for this set of 353 parameters.

Unfortunately, it turned out the data was too capricious for the optimisation module to generate a set of parameter values. To solve this problem, preference levels were made time-dependent, which basically means that U_{max} in *figures 2.1* and *2.2* moves in time from one point to another. Although the optimisation module tries to minimise changes in preference levels, these preference-level time series come close to intake-scenarios. From the figures of chapter 2 this can be understood easily: when the point U_{max} is moved around, it is obvious that U_{opt} will move in the same way at a more or less fixed distance on the actual budget line. Put in another way, it could be argued the necessary introduction of preference level time series indicate that the actual *existence* of preference levels (at least at the 12-products, 17-regions level) in the real world is questionable.

In general, it is not difficult to understand why the optimisation is problematic when looking at the underlying historical data. The AEM is based on the assumption that there is a relationship at the regional level between intensities and intake levels. However, an analysis for the period 1970-1995 in the 17 IMAGE 2.2 regions and for 12 products shows that clear relationships cannot be found for most food products, especially at the regional level. Only for oilcrops, a relationship can be found, i.e. intake levels increase when intensities (or 'prices') go down, but for the other products this is not the case (see annex B for figures).

3.2 General behaviour

Another problem is related to the question whether the general behaviour as described in *section 2.2*, applies to all 'worlds'. The answer is no, because if, for example, the value of the weighing constant b_1 is set to 1 in stead of 5, than the optimal utility goes *down* in case the intensity of p_1 is decreased by 50% (see *figures 3.1a* and *3.1b*).
The problem even gets worse if one realises that in the current implementation of the AEM in IMAGE 2.1 the optimisation has resulted in parameter-values that eliminate the dependence of f on changes in potential productivity (represented by the variable Q) and technology (represented by T). In other words, the value of f is a function of income only. If income per capita goes up, the budget line shifts towards the maximum budget. However, if income does not change, the fraction f does not change either. In terms of the example, it means the value of f in *figure 3.1b* would remain equal to 0.7 and the optimal utility would decrease even more than it already did.

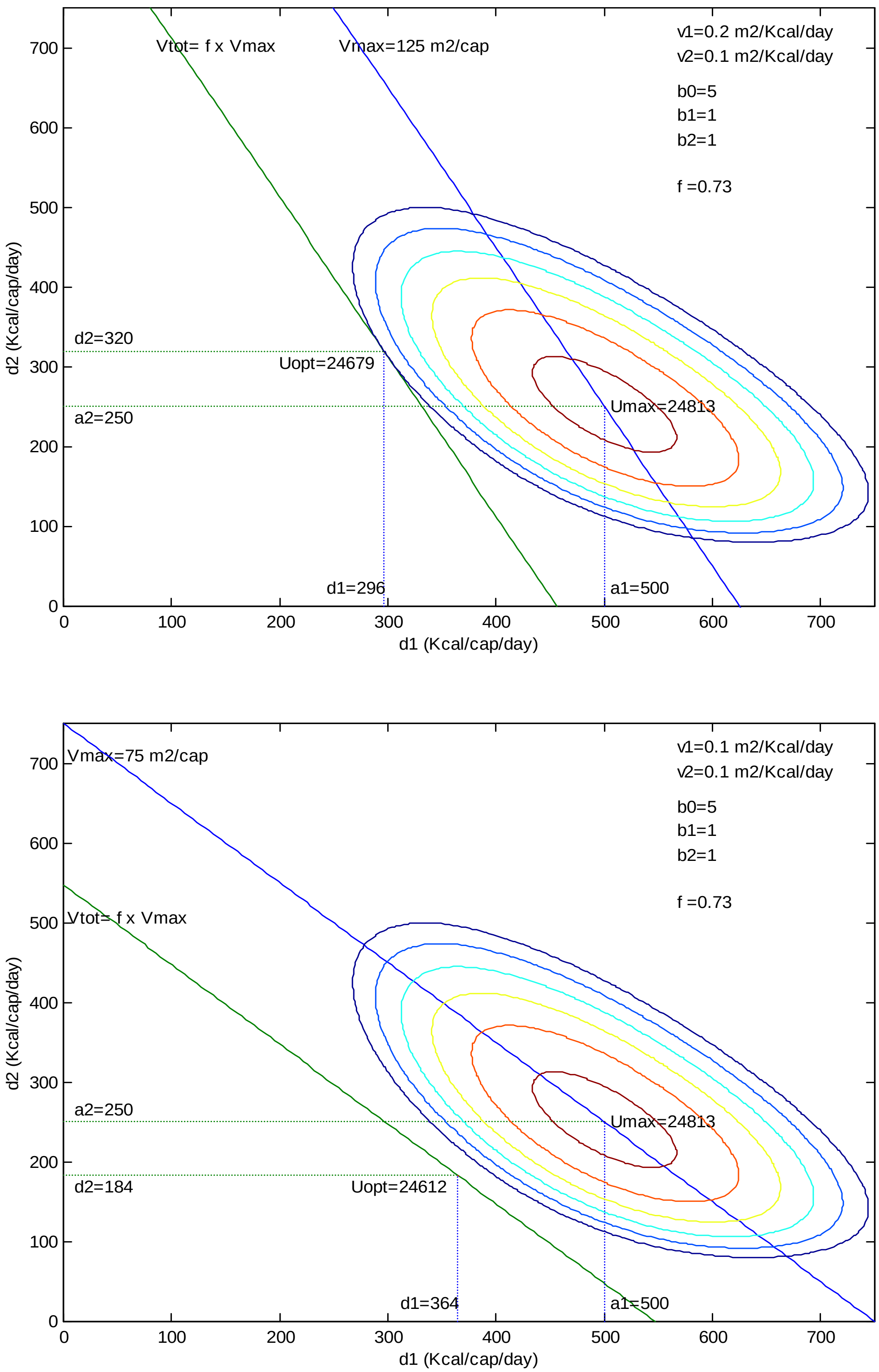


Figure 3.1a and b The behaviour of the AEM for a different set of weighing parameters: the utility ***decreases*** *if intensities go down.*

One could argue that the problem as sketched above will not occur because it is unrealistic to assume that one intensity decreases by 50% while the others remain equal. In general, it will be the case that all intensities go down or up simultaneously by more or less the same percentage. In terms of the figures as presented above it means that the maximum budget line remains in a more or less stable position (i.e., it will turn only slightly around the point U_{max}). In that case it is easy to see that any decrease of f will result in an increase of the utility value. However, the problem remains that in the current implementation the utility value will not increase if intensities go down, given a stable income per capita. And also, from a mathematical point of view, it should be clearly defined within what boundary conditions the model operates properly.

3.3 Animal product related intensities

Since the utility function needs some kind of scarcity indicator, and poor data-availability exclude the use of food prices, it was decided to use intensities as a proxy for scarcity and therefore as a proxy for price. The idea behind it is that if larger amounts of land are needed to produce 1 Kcal of a certain food product, then it will probably be more expensive because it implies an inefficient way of producing these products. However, in some regions such as South America, cattle grazes on large areas while capital and labour inputs are very low and therefore prices are too. But in terms of intensities, i.e. the amount of land needed to produce 1 Kcal of cattle meat, these products are very expensive (up too 1000 times more expensive than crop-products). In IMAGE 2.1, this problem is currently 'solved' by setting an upper limit to the amount of grassland that can be assigned to cattle. In the figures of annex B and C, intensities for cattle, sheep and goats have been adapted by converting the grassland area into crop-area that would be needed to produce the same amount of calories. The result of this conversion is that the ratio between animal related intensities and crop-related intensities is about equal to the conversion factor of feed to meat (i.e. the amount of feed-calories needed to produce one calorie of food), unless a large share of the animals are used for other purposes than food: for example sheep for wool in New Zealand or buffaloes for labour power in India. Because there is no data from which it can be derived it is almost impossible to derive acceptable intensities for those cases. In general, it can be stated that intensities alone cannot serve as an acceptable proxy for price.

3.4 The maximum budget

As described in chapter 2.1, a decrease in one of the intensities result in a decrease of the maximum budget V_{max} because less agricultural land is needed to produce the preferred diet. The consequence of this approach is that the actual budget V_{tot} also decreases by the same percentage; unless income per capita rises, but also in that case V_{tot} will generally decrease.
However, from the previous time-step it is known that, given a stable population size, the larger actual budget is available because the demands in that time-step were met. Therefore, there is no reason to lower the actual budget V_{tot}, except in case of population growth which, however, is not a variable in the AEM.
One could argue the variable V_{tot} should not be interpreted so strictly because it is only meant to be able to apply a macro-economic approach without having disposal of food prices, but

then one denies the inevitable direct link between the actual budget and the surface of agricultural land needed to produce the demanded amount of food.

4. Towards a new version of the AEM in IMAGE 2.2

4.1 On the relation between income, intensities and intake

To solve the problems described in chapter 3, it was examined whether a reduction in product aggregates, and therefore a reduction in the number of parameters, would result in a model for which parameter values can be computed by the optimisation module.
It was first tried to aggregate the twelve food products into six aggregate products because then it would still be reasonably possible to convert these aggregates back into the twelve food products, which are needed for the Land Cover Model. The six aggregates were: 1) cereals, 2) rice, 3) oilcrops, 4) pig meat, poultry, eggs and milk, 5) cattle, buffalo, sheep and goat meat, and 6) rest-products (roots, tubers, pulses and maize). The reasons to choose for these aggregates are described in annex C.
Unfortunately, as can be seen in the figures of annex C, the overall picture does not really improve when the intensities of these aggregates are compared with intake levels. Even if two aggregates are considered only, i.e. ‘affluent’ products (oil crops and all animal products) and ‘basic’ products, the picture is still rather chaotic at the regional level although the global picture gets slightly better (see *figures 4.1a* and *4.1b*). Oceania is not shown in *figure 4.1a* because intensities for affluent products are very high: between 125 and 350 km^2/Tcal at a rather constant intake level of about 1150 Kcal/cap/day.

To get a better global picture it makes sense to compare intake levels with ratios of intensities to income per capita. In that case proxies of ‘relative’ prices are compared with intake levels. As shown in *figure 4.2*, the overall picture significantly improves, although some regions are still problematic. However, in that case we are almost back at the often used relationship between income and consumption: intake levels of affluent products increase with increasing income and intake levels of basic products rise to a maximum with rising incomes after which they go down because they are replaced by affluent products.
This relationship is confirmed by *figure 4.3*, in which intake levels of affluent products and basic products have been directly plotted against income per capita. But also for this relationship holds: if it is tried to introduce a larger number of aggregates the relationship is lost. (See annex D for a detailed analysis of the relationship between income and intake.) It should be noted *figures 4.3a* and *4.3b* refer to ALL products, i.e. the aggregate ‘affluent products’ also includes the so called ‘other crops’ and ‘other meat’, where the latter includes fish.

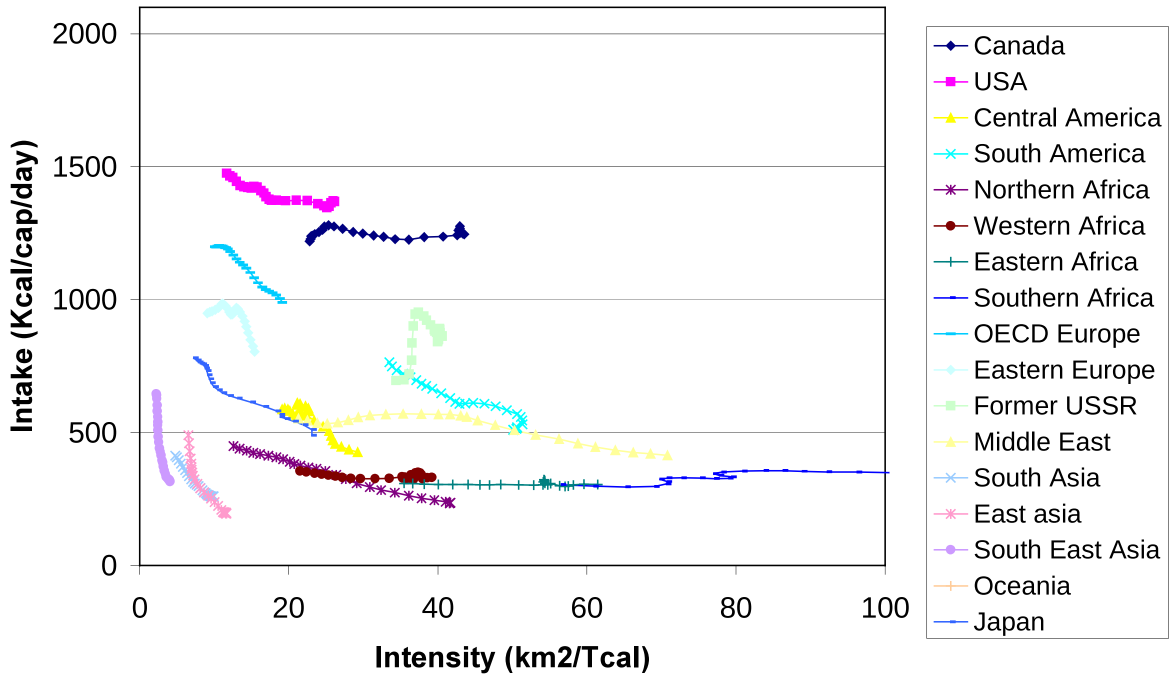


Figure 4.1a Intake levels versus intensities for affluent products (all animal products and oil crops) from 1970 to 1995.

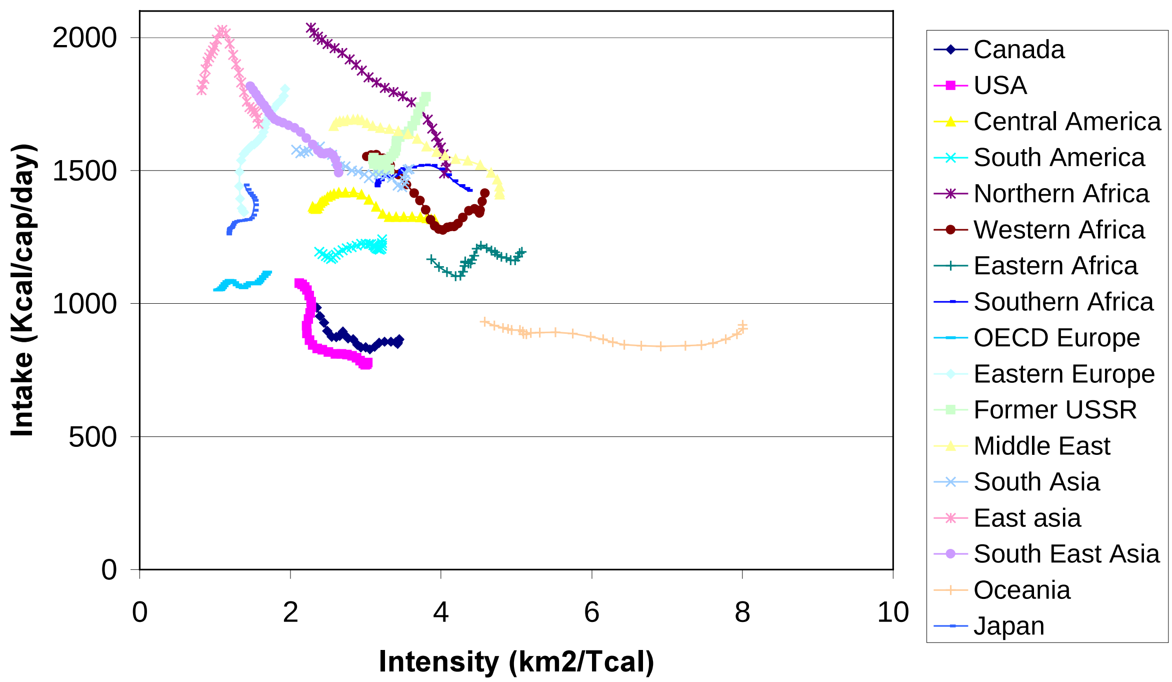


Figure 4.1b Intake levels versus intensities for basic products (all vegetable products excluding oil crops) from 1970 to 1995.

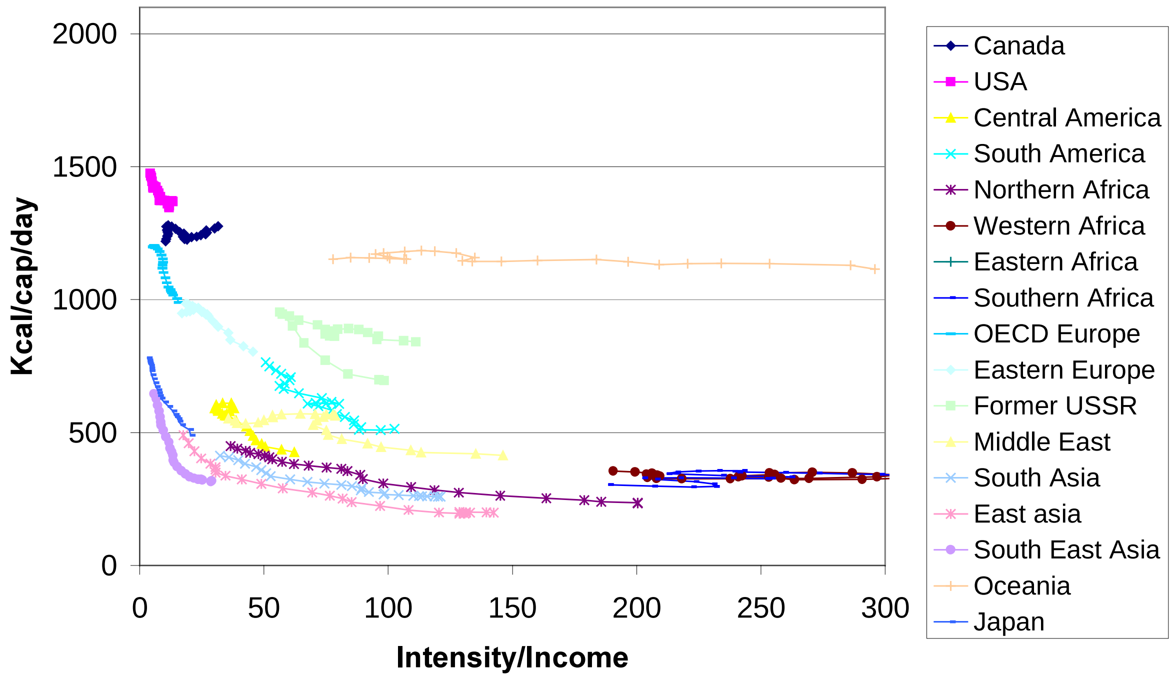


Figure 4.2a Intake levels versus relative intensities for affluent products (all animal products and oil crops) from 1970 to 1995.

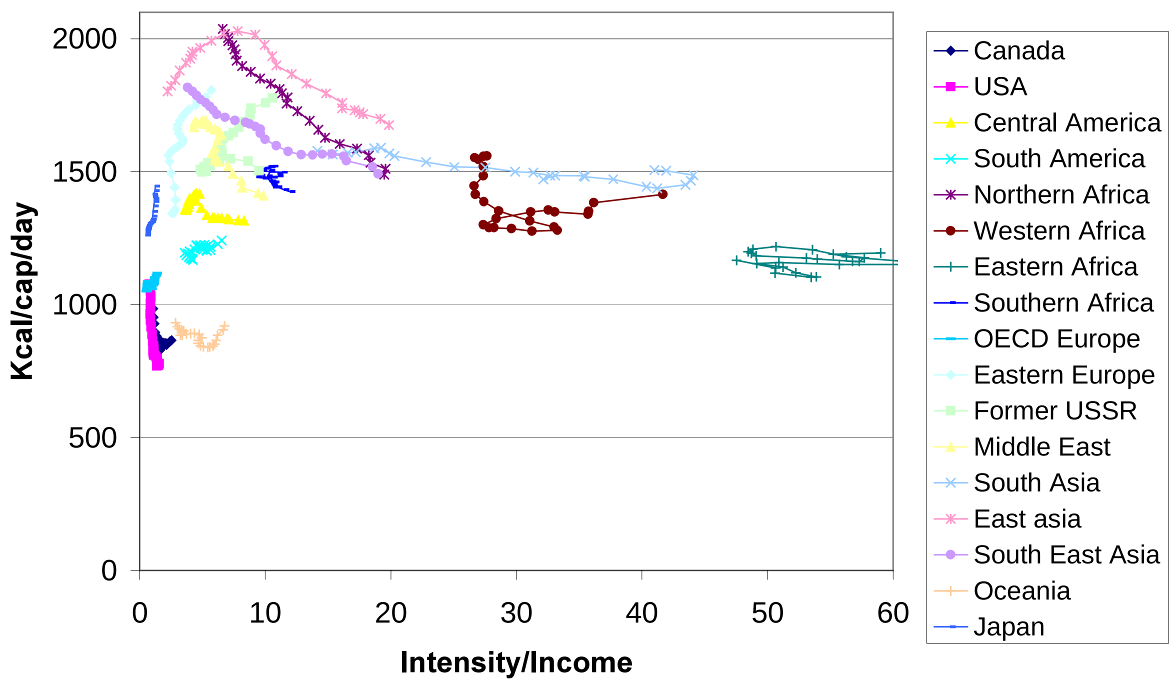
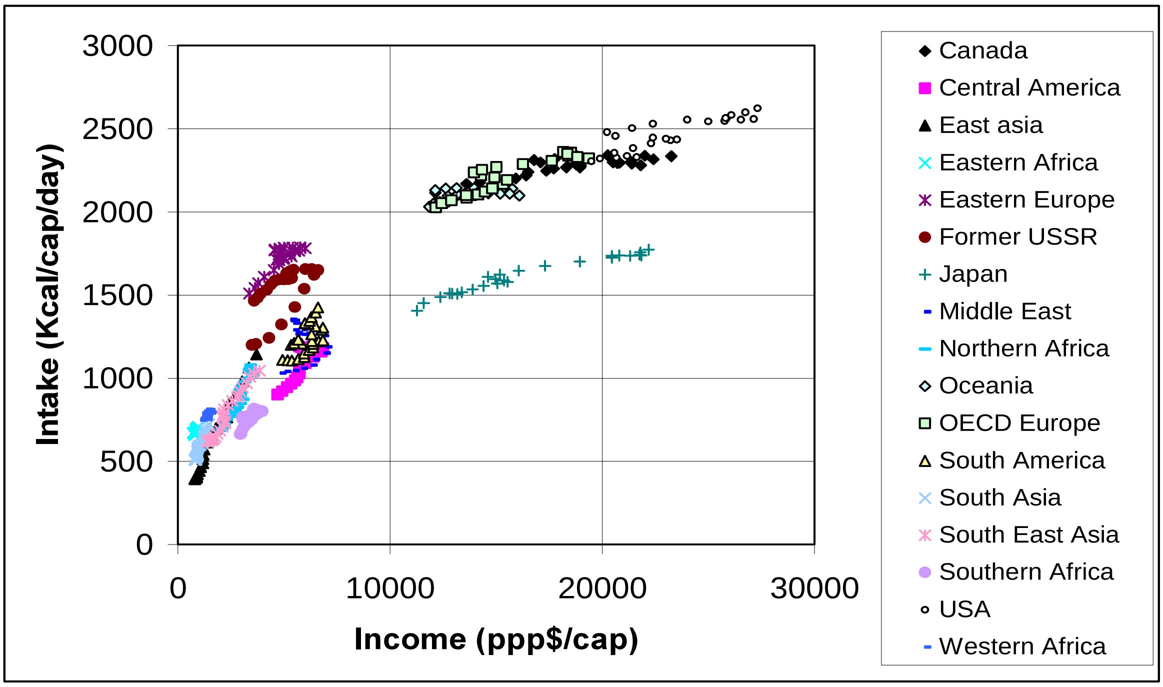


Figure 4.2b Intake levels versus relative intensities for basic products (all vegetable products excluding oil crops) from 1970 to 1995.

a.



b.

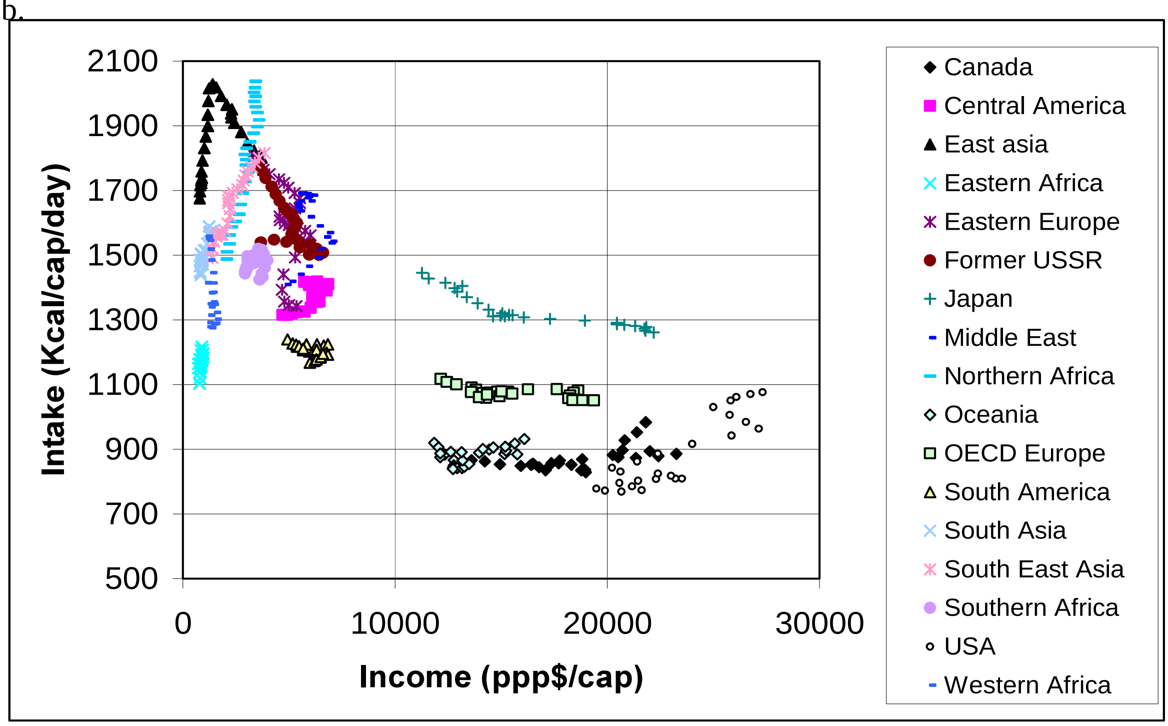


Figure 4.3a,b Income per capita versus intake levels (1970-1995) for a) affluent products (including other crops and other meat, a/o. fish) and b) basic products. Purchasing power parity dollars (ppp$) are used to have comparable dollars between regions. The use of 'normal' dollars would not change the essence of the overall picture. It would mainly shift the data points in the left part of the picture further to the left.

4.2 A simplified AEM

Based on the discussion in the previous chapters and *section 4.1*, the following simplifications were made in order to have a feasible food demand model in which the original concepts were maintained as much as possible:

1) Aggregation into two product types: ‘affluent’ products and ‘basic’ products. This aggregation is slightly different from the one described in *section 4.1*: the product ‘other crops’ is included in the aggregate ‘basic products’ instead of ‘affluent products’.
2) Deletion of the parameters Q and T.
3) Using constant preference levels in the calibration.
4) Deletion of weighing constant b_0 because it can be expressed in terms of the remaining weighing constants.
5) Solving the problem as discussed in *section 3.4*, which is part of the implementation in IMAGE 2.2 where the interaction with LCM takes place. It means that one should only switch to the actual budget as computed in the current time-step if it bigger than the budget of the *previous* time-step.

The simplifications as described above, result in the following formal definition of the AEM for each of the 17 regions.

$$\begin{aligned}&\max U(t) = \\ &b_{affl}(a_{affl} \times \ln d(t)_{affl} - d(t)_{affl}) + \\ &b_{bas}(a_{bas} \times \ln d(t)_{bas} - d(t)_{bas}) + \\ &(a_{tot} \times \ln d(t)_{tot} - d(t)_{tot})\end{aligned} \qquad [4.1]$$

$$(v(t)_{affl} \times d(t)_{affl}) + (v(t)_{bas} \times d(t)_{bas}) \le V(t)_{tot} \qquad [4.2]$$

$$V(t)_{tot} = \frac{V(t)_{\max}}{1 + \left(\dfrac{\alpha}{Y(t)}\right)^{\beta}} \qquad [4.3a]$$

$$V(t)_{\max} = (v(t)_{affl} \times a_{affl}) + (v(t)_{bas} \times a_{bas}) \qquad [4.3b]$$

where:

$d(t)_{affl}$, $d(t)_{bas}$	Demands for ‘affluent’ and ‘basic’ products in year *t* (kcal/cap/day)
$d(t)_{tot}$	Sum of $d(t)_{affl}$ and $d(t)_{bas}$
max$U(t)$	Maximum utility of the demanded diet ($d(t)_{affl}$, $d(t)_{bas}$) in year *t* (*t=1970,…,2100)* such that any other diet (given the actual budget) would result in a *lower* utility value.
a_{affl}, a_{bas}	Preference-levels for ‘affluent’ and ‘basic’ products (kcal/cap/day)
a_{tot}	Sum of a_{affl} and a_{bas} (kcal/cap/day)
b_{affl} , b_{bas}	Weighing constants (no dimension)
$v(t)_{affl}$, $v(t)_{bas}$	Intensities in year *t* (m^2/kcal/yr)
$V(t)_{tot}$	Actual budget for the utility function in year *t* (m^2/cap).

$V(t)_{max}$	Amount of land (or maximum budget) in year t needed to produce the preferred diet.
$Y(t)$	Income in year t (US$/cap/yr)
α	Half-life (US$/cap/yr)
β	Income elasticity

4.3 Calibration

The calibration comes down to the determination of values for the preference levels (a_{affl} and a_{bas}), weighing constants (b_{affl} and b_{bas}), and the parameters α and β such that the maximisation of the Utility function (max$U(t)$) result in demand levels ($d(t)_{affl}$ and $d(t)_{bas}$) which are equal to the intake data from the FAO-database (period 1970-1995), given historical time series for intensities ($v(t)_{affl}$ and $v(t)_{bas}$) and incomes ($Y(t)$). The calibration has been performed with an optimisation program, written in MatLab (see annex E for more details). The optimisation program in GAMS was not used because GAMS is not supported by RIVM which means there is no recent version of GAMS, no documentation and no expertise how to use it. It turned out that re-programming in MatLab was the best way to go ahead.

Table 4.1. Result of the calibration based on the year 1995 only (for more details, see text).

	Region	b_{bas}	b_{affl}	a_{bas}	a_{affl}	a_{tot}	α	β
1	Canada	1.000	1.000	1930	1380	3310	2100	2.000
2	USA	1.000	1.000	2114	1620	3734	3914	1.724
3	Central America	1.000	1.000	1650	1559	3200	2900	1.000
4	South America	1.000	1.000	1530	1620	3150	3800	2.000
5	North Africa	0.293	0.196	2090	1444	3534	1231	0.900
6	West Africa	1.000	0.101	1506	1544	3050	867	0.700
7	East Africa	0.157	4.932	1613	1497	3110	1271	0.610
8	South Africa	1.000	1.000	1430	1620	3050	4950	0.773
9	OECD-Europe	0.200	0.200	1924	1521	3445	2815	1.116
10	Eastern Europe	0.987	1.000	1971	1603	3574	1830	1.636
11	Former USSR	1.000	1.000	1774	1620	3394	1651	0.956
12	Middle East	0.438	0.405	1892	1550	3442	3903	0.953
13	South Asia	6.901	3.999	2283	1343	3626	509	0.409
14	East Asia	0.045	0.520	1812	1578	3390	1322	0.932
15	South-East Asia	0.894	0.258	2064	1484	3548	807	1.326
16	Oceania	1.000	1.000	1750	1350	3100	2717	1.742
17	Japan	0.368	1.000	1872	1250	3122	10000	1.422

For the regions Central America, South America, East Africa, South Africa, South Asia, East Asia, South-East Asia, and Japan historical intake data are reproduced fairly well. For the remaining regions, it turned out to be impossible to reproduce the past (or even the trends) within acceptable limits. The most problematic regions are Canada, USA, West Africa, Middle East and Oceania. For the regions OECD-Europe, Eastern Europe and Former USSR it is impossible to reproduce the past for basic products. Therefore, it was decided not to simulate the past in IMAGE 2.2 but to use historical values for the period 1970-1995. After

1995 the simulation is activated ‘gradually’, i.e., in such a way that no shocks occur when going from the historical data towards the simulated values.
Unfortunately, even then the computed parameter setting still was unacceptable for many regions due to one or more of the following reasons: the parameter setting resulted in (very) unlikely future intake levels (i.e., unlikely values for a_{bas} and/or a_{affl}) and/or too large differences between simulated and real intake levels for 1995 that could not be solved by a gradual activation of the simulation after 1995 as described above.
After many simulation runs with IMAGE 2.2, it turned out these problems could be solved only if the calibration was limited to the year 1995. Only then it is possible to find parameter settings (see *Table 4.1*) that are within acceptable ranges and result in likely future intake levels. This ‘solution’ again raises the question whether the food demand model should be maintained in this form; a decision that will be part of the development of IMAGE 3.0.

4.4 The way ahead

In IMAGE 2.2, world food demand, land use and land cover change highly depend on exogenous time series such as the Management Factor, income per capita (derived from GDP and Population Growth), preference levels, and weighing constants. However, as indicated by many studies, there are numerous interdependent and complex processes that shape the agricultural sector and that should be taken into consideration when developing a new land-economy model in IMAGE 3.0.

For example, in the theories of Boserup (1965) and Bilsborrow and Okoth-Ogendo (1992) it is argued that an increasing demand for food as driven by population and income growth results in a situation of emerging food scarcity. This triggers a process of decreasing fallow cycles up to a level where the land cannot recover long enough to remain fertile. In response to that land ownership and agriculture have developed to its current form where large areas are reclaimed and additional inputs, such as (chemical) fertilisers, tractors, labour, irrigation, are needed to keep up and increase food production. In a later stage international food trade becomes an important factor.

Another interesting paper in this context has been written by G.K. Heilig of IIASA, called ‘Neglected Dimensions of Global Land-Use change: Reflections and Data’ (Heilig, 1994). He argues that current approaches often focus on agriculture-related alterations driven by population growth while other factors are far more important. For example, international markets, infrastructure that was built into remote areas for other (often military!) reasons, food preferences and life styles in affluent societies that trigger high demands of affluent food (i.e. meat) and especially *non*-food products (more than 22 percent of the arable land is cultivated for drugs, sugar beet, sugar cane, coffee, cocoa and tea), the explosion of world-wide tourism, and the scientific-technological revolution which is spreading to even the most remote areas in the world,

Also, one should take into account the dynamic differences between the major agricultural systems of the world and their interaction (Kamp, 1996). According to Grigg (1983), at least 9 major systems can be distinguished (1) Pastoral Nomadism, (2) Ranching, (3) Shifting cultivation, (4) Wet-rice cultivation, (5) Plantations, (6) Mediterranean agriculture, (7) Large-scale grain production, (8) Mixed farming, and (9) Dairying.

And finally, the following aspects should be considered when developing and implementing a dynamic land economy model (which covers both agricultural economics as land use and land cover change): a) income differences between cities and rural areas, b) the increase of the fraction of food products in feed (determined now by an exogenous time series), c) transport costs of trade, d) the use of agricultural products in industry (partly covered by IMAGE 2.1) and e) the impacts of policies such as raising imports, investments in research and development, subsidising land conversions and taxes on food products.

Since the last Advisory Board Meeting of 17-19 November 1999 (Tinker, 2000), several activities have been initiated which should lead to the appointment of a research assistant that should develop a dynamic land-economy model in collaboration with USDA/ESR (Roy Darwin, see annex F), WUR (Wageningen University Research), CESR (Centre for Environmental Systems Research, University of Kassel, Germany) and, off course, the IMAGE team. Furthermore, it is helpful to be aware of related models and research and to decide whether they can serve as a starting point for improving our land-related submodels. For example, i) IFPRIs (International Food Policy Research Institute) International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT) which has been used in ‘Global Food Projections to 2020’ (Rosegrant *et al.*, 1995), Polestar from the Stockholm Environment Institute and the related study from Gerald Leach (1995), but also the work of IIASA, where the Basic Link model (Fisher *et al.*, 1988) was an important development, should be considered.

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Annex A Description of the AEM in IMAGE 2.1

A.1 Introduction

The formulas that will be referred to in the sections below are:

$$\max U_r = \sum_f \left[b_{r,f} \left(a_{r,f} \times \ln d_{r,f} - d_{r,f} \right) \right] + b0_r \left(\sum_f a_{r,f} \times \ln \sum_f d_{r,f} - \sum_f d_{r,f} \right) \quad [A.1]$$

$$\sum_f \left(v_{r,f} \times d_{r,f} \right) \le Vtot_r \quad [A.2]$$

$$Vtot_r = \frac{V\max_r}{1 + \left(\frac{\alpha_r}{Y_r} \right)^{\beta} \times Q_r^{-\gamma} \times T_r^{-\delta}} \quad [A.3a]$$

$$V\max_r = \sum \left(v_{r,f} \times a_{r,f} \right) \quad [A.3b]$$

$$\sum_f \left(v_{r,f} \times d_{r,f} \right) \le Vtot_r \times SI_r \quad [A.4]$$

where:

f	Index for food product (f = 1,...,12)
r	Index for region (r = 1,...,13)
U	Utility of the diet
a	Preference-level (kcal/cap/yr)
$b0$, b	Weighing constants (more details in text)
d	Consumption-level (kcal/cap/yr)
v	Intensity (m^2/kcal)
$Vtot$	Available budget for the utility function, expressed in m^2/cap.
$Vmax$	Amount of land (or budget) that would be needed to produce the preferred diet.
Y	Income (US$/cap/yr)
Q	Average quality of agricultural land (based on the potential productivity)
T	Average level of technology to develop new agricultural land.
α	Half-life (more details in text)
β	Income elasticity
γ	Quality elasticity
δ	Technology elasticity

Formulae [A.2], [A.3] and [A.4] in the sections below have been copied from Alcamo *et. al.* (1998), Annex B, pg. 53 en 54, 's (B.2), (B.3) and (B.4) respectively. Formula (1) is equivalent to formula [3.15] in Huiberts (1997). The formula in Huiberts (1997) was better than the corresponding formula (B.1) in Alcamo *et. al.* (1998) because it contains essential details which were taken out in the Alcamo-version.

The modelled diet consists of 12 food products (f = 1,..,12): 7 crops and 5 animal products. There is a thirteenth product, which is an aggregate of low calorie products as vegetables, fruits and some other crops not covered by the other 12. The consumption of this 'low calorie' product is defined as a region-dependent fixed weight-related percentage of the other 12 products, based on historical data. Therefore, this product, which covers about 30% of the caloric intake, does not affect the value of the utility function.

A.2 General structure of the AEM

For each region a demanded diet is computed such that the utility function [A.1] is maximised within a given budget and based on set of *weighing constants* which indicate the preference of a food product compared to others (see §A.5). This budget, $Vtot_r$ in formula [A.3a], is expressed in terms of hectares per capita and is always lower than a maximum value $Vmax_r$ (see [A.3b]). This maximum is equal to the amount of land that would be needed per capita in case the consumption of all food products (i.e. the diet) would be equal to the *preference levels* (see §A.4). $Vtot_r$ is always less than $Vmax_r$ due to the fact that the nominator in formula [A.3a] is always greater than 1 (see §A.6), or equal to one in case the income per capita Y is infinite. Obviously, the value of $Vmax_r$ must be less than the actual availability of land in a region (determined by the LCM). If the this availability is exceeded, then the budget is lowered by a scarcity index, which becomes less than 1 in that situation, and the diet is recomputed such that the utility function obeys this lower budget resulting a shift away from affluent food products.
As shown in formula [A.2], the budget $Vtot_r$ is the upper limit for the 'spendings', defined as the amount of land per capita needed to produce the current consumption levels of food products. Spendings are computed by adding the multiplication of consumption levels ($d_{r,f}$) and *intensities* ($v_{r,f}$, see §A.3).
Figure A.1 is a schematic overview of the general structure of the AEM in IMAGE 2.1. Notice that the preference levels and weighing constants are referred to as an output of GAMS. It means they are exogenously determined by a calibration/optimisation module, which is implemented in the optimisation language called GAMS (see Huiberts (1997)), and see §A.8.

A.3 Intensities

For 13 regions and 12 products intensities ($v_{r,f}$) are computed, expressed in m^2/Kcal/yr, based on the amount of land needed to produce 1 Kcal per year of the product. Because prices do not exist in the AEM, intensities are considered to be a proxy for prices in the utility function [A.1]. Higher intensities are interpreted as higher prices and therefore result in lower shares in the eventual diet.

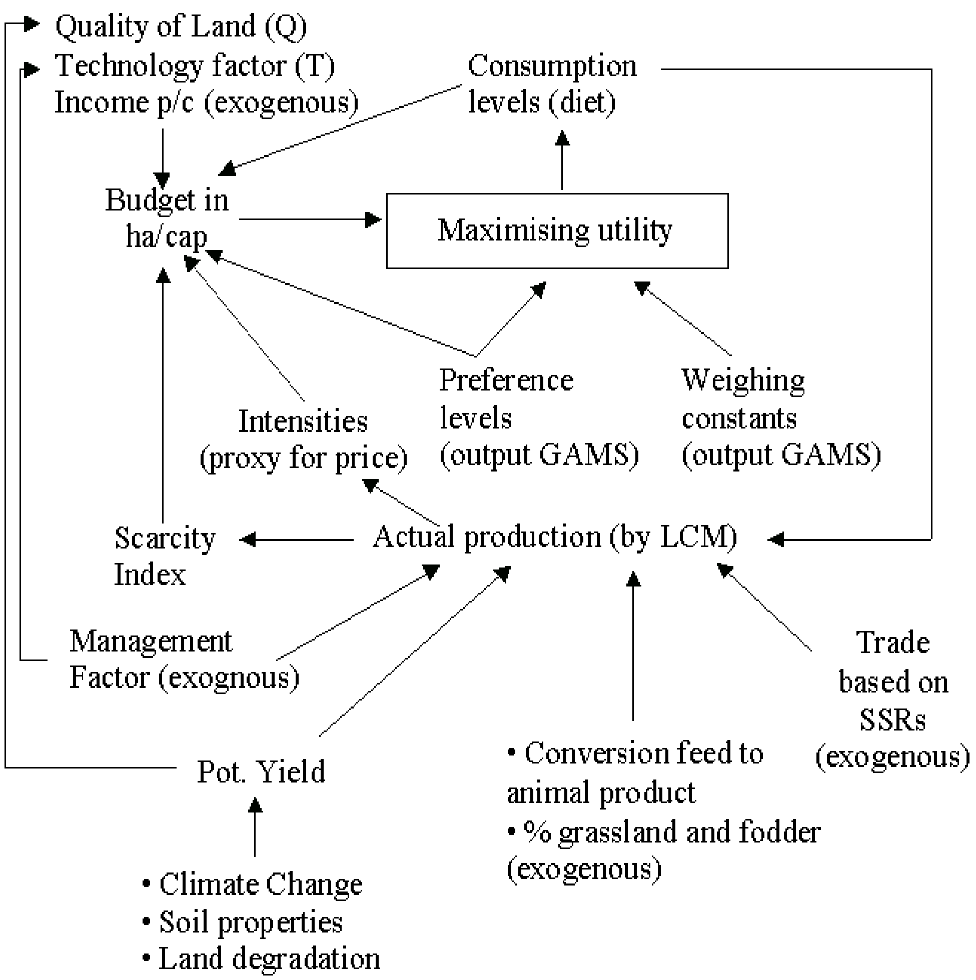

Figure A.1 Overview of the structure of AEM in IMAGE 2.1.

In the AEM it is accounted for that 1 Kcal of animal product needs (much) more than 1 Kcal of feed by applying conversion factors of feed to final animal product (see also *figure A.1*).
In the richer regions, such as OECD, about 85% of feed originate from grassland and crops that are suitable for animal consumption only (so called fodder crops such as green maize). About 15% originate from crops that are aslo suitable for human consumption (RIVM, 2001). In the poorer regions 90 to 95% originates from grassland and fodder. In the AEM these

percentages are exogenous time series where the percentages in the poorer regions converge to the values in the richer regions.
Next, intensities depend on the actual production of agricultural land in the concerning region and the actual production in other regions in case of imports (see *section A.7*). The actual production is determined at the grid-level by the Land Cover Model (LCM). As also indicated in *figure A.1*, the actual production is equal to the potential production multiplied by a Management Factor (MF). The potential production depends on climate, a number of soil characteristics and land degradation. In the current version of the AEM, irrigation is not accounted for explicitly. The surface of irrigated agricultural land remains equal to the surface as it was in the initial year 1970. In the period 1970 to 1990 the MF is based on the observed difference between the computed potential production and the historical actual production (based on FAO-data). For the future the MF is an exogenous time series. The changes (or in fact increase) of the MF represent all impacts of humans on yields, without being explicit how these changes are obtained. It is an implicit representation of the use of fertilisers, technological change, and irrigation as far as this irrigation is related to areas where agricultural production is possible without irrigation (for example Europe) or where irrigation was performed in 1970 already. Usually, the MF is smaller than 1, except for example in Japan where very intensive rice-production takes place. Therefore, in general, potential production can be interpreted as the theoretical maximum.
The actual use of fertilisers is an exogenous time series where it must be ensured manually that this series is consistent with the MF. In the model, the use of fertilisers as such does not affect the potential (and thus the actual) production. Because this might seem strange, we will come back to this point later.
From the description above it follows that any changes in climate, the MF, and/or soil characteristics and through land degradation, affect the actual agricultural production, and therefore the corresponding intensities.

A.4 Preference levels

Preference levels, referred to by $a_{r,f}$, are exogenous time series which are equal to the level of consumption of a certain product in a certain region in the absence of any limits concerning land or income. Leaving culture shocks aside, preference levels should not change too much over time. The calibration/optimisation module described in A.8 determines their values up to 2020. After 2020 it is assumed that the change in the period 1990-2020, linearly takes place again in the period 2020 to 2050 and again in the period from 2050 to 2100.

A.5 Weighing constants

In formula [A.1] two time-independent weighing constants can be distinguished[1]. The first type, $b0_r$, indicates for each region the relative importance (in terms of utility) to achieve the preferred level of all products combined. Clearly, there are 13 constants of this type. The second type, $b_{r,f}$, indicates the relative importance to achieve the preference level for a certain product in a certain region. There are 156 weighing constants of this type: 13 regions times 12 products.

[1] The distinction can be found in Huiberts (1997) only. The limited description in Alcamo *et al* does not include this difference explicitly.

It should be emphasised the absolute values of these constants are meaningless. What counts are the ratios between them. If, for example, the values of the constants of the second type are equal to the values of the intensities and the constants of the second type are equal to zero, then the share of products in the diet linearly increases or decreases with income until the preference levels are achieved.
The values of the weighing constants are determined by a optimisation/calibration module as described in A.8.

A.6 Land availability or the budget of the utility function

An important boundary condition in maximising the utility function is the regional availability of agricultural land, which must be equal or more than the amount of land needed to produce the food products in the computed diet. Food and feed trade is accounted for indirectly because intensities are affected by it. Formula [A.3] computes the actual or total availability of land, referred to by $Vtot_r$, which is defined as the maximum amount of agricultural land (in m^2/cap) that would be needed if the preferred diet would be consumed, i.e. the numerator in formula [A.3], divided by a value indicating whether this area can actually be obtained, i.e. the denominator in formula [A.3]. Notice that the formulation of [A.3] implies that the intensities of the current agricultural land are representative for uncultivated land.
If the denominator of formula [A.3] is equal to the minimum value of 1, then the maximum amount of land that will ever be needed can, in principle, be obtained. However, there are limiting factors that reduce the maximum availability of agricultural land resulting in a denominator being less than 1. The limiting factors are represented by 7 variables: the state of the technology T_r , an index Q_r which indicates the regional average quality of agricultural land as compared to the world average, income per capita Y_r , the constant α_r defined as the income level for which the use of land per capita is 50% of the preferred level, given that Q_r and T_r are equal to 1 (in that case, the denominator is equal to 2). And finally, there are three elasticities related to the first three variables mentioned above: elasticity of technology δ, elasticity of land quality γ and an income elasticity β_r, where it should be noticed that $\delta$and γ are defined at the world level only.
Without going into detail formula [A.3] boils down to saying that more agricultural land can be reclaimed (with an upper limit as mentioned above) in case of (1) income growth, (2) an increase in the quality of current agricultural areas, and (3) the state of the technology. As also shown in *figure A.1*, regional incomes are exogenous time series. The other two factors are a (rather complex) function of intensities, actual production and the management factor (more details can be found in Huiberts (1997).

Clearly, the outcome of formula [A.3] should always be less than the surface of potential agricultural land[2] within a region (and other regions in case of trade). In that case, boundary condition [A.2] ensures that the maximisation of the utility function occurs within the limits of the maximum available agricultural land as defined by formula [A.3].
However, as also described in Alcamo *et al.* (1998), it turned out to be possible for formula [A.3] to be greater than the potential amount of land in a region. To overcome this problem, a

[2] In this context 'potential' indicates that, for example, rocky mountainous areas and deserts cannot be regarded as potential agricultural area.

Scarcity Index (SI) has been added to boundary condition [A.2] resulting in boundary condition [A.4]. The SI has a value between 0 and 1, where the procedure is as follows: during the simulation it turns out that the amount of land needed to produce the demanded amount of food products (as determined by the utility function) cannot be supplied by the region itself. In other words, the value of $Vtot_r$ is larger than ‘physically’ possible because non-existing land would be needed to satisfy the demand in the region under concern. In case of an exporting region, one could reduce food exports, but in the implementation of the AEM this is no option because export is exogenously (see A.7 on trade). For the same reason importing regions cannot increase their imports. Therefore, by assigning a value less than 1 to the SI, it is ensured in a next iteration, formula [A.1] generates which fits within the physical limits of land availability. It should be emphasised that the situation above hardly ever occurs. Only in Africa the SI is often less than 1.

A.7 Food trade

Food trade is modelled by exogenous ‘Self-Sufficiency-Ratios’ (SSRs). SSRs are defined for each region and each food product as the ratio between production and consumption. Through the LCM, SSRs can change intensities that affect the utility function and therefore the resulting food demand. For example, there is a value for the intensity of rice in Canada. Since rice-production fully takes place in other regions, the related SSR is zero.

The SSRs of exporting regions are dominant: if there is a strong growth of demand in an importing region (i.e. SSRs <<1) then this will only happen if the exporting regions are able to export the demanded amount (based on their SSRs which are greater than 1). If they are not able to do so, then the importing region will get less than asked for and the remaining amount must be produced in the region itself. Assuming that the region can produce the demanded amount of food products (i.e., boundary condition [A.2] is not violated, while the value of $Vtot_r$ remains within the physical limits for that region) then the food demand or diet is recomputed, based on an updated set of intensities which refer to the region itself to a larger extent now.

If the region is not able to produce the demanded amount of food products, then the SI (see A.6) will be adapted. In the ultimate case, especially when an importing region is not or hardly able to produce the product itself (as in case of rice in Canada), the AEM can be triggered to set an upper level on the consumption of the product under concern.

A.8 The calibration/optimisation module in GAMS

There is a separate calibration/optimisation module implemented in the optimisation language GAMS in order to determine a set of parameters, which are exogenous to the AEM in IMAGE 2.1.

Inputs to this module are GRPs (Gross Regional Products), intensities, consumption levels or intakes, and the values for Q (land quality) and T (technology). GRPs and consumption levels for the calibration period 1970-1990 are taken form historical FAO data. Intensities must be derived indirectly from historical data as will be discussed later. The values of Q and T are determined by IMAGE 2.1 in an iterative process between the calibration module and the IMAGE model, where they are defined in terms of the management factor, the actual

production, the food consumption and intensities (see Huiberts (1997), formulae [3.8] to [3.10] for more details).
Based on these inputs, the module generates time series for the calibration period 1970-1990 for the preference levels $a_{r,f}$, and fixed values for the time-independent weighing constants $b0_r$ and $b_{r,f}$ and the elasticities $\alpha_{r,}\beta_r$, $\gamma_,$ and δ such that the utility function is maximised and the historical diets are reproduced, based on FAO data. For the period 1990-2020 the same procedure is repeated given scenarios for GRP, intensities and consumption levels and resulting in preference levels up to 2020. As indicated earlier, for the period after 2020, it is assumed that the change in the period 1990-2020, linearly takes place again in the period 2020 to 2050 and again in the period from 2050 to 2100. The scenarios for consumption levels for the period 1990 to 2020 have been taken from the scenario of IFPRI (Rosegrant et al., 1995).

Annex B Intensities versus intake levels for 12 food products

This Annex contains 12 figures on the relation between intensities and intake (i.e. consumption level) for 12 aggregated food products as distinguished in IMAGE (for details, see main text). Differences between the ranges on the X- and Y-axes are due to large differences in intensity-and intake-values. It has been tried to keep those differences limited which sometimes causes that part of a timeseries falls outside the figure boundaries.

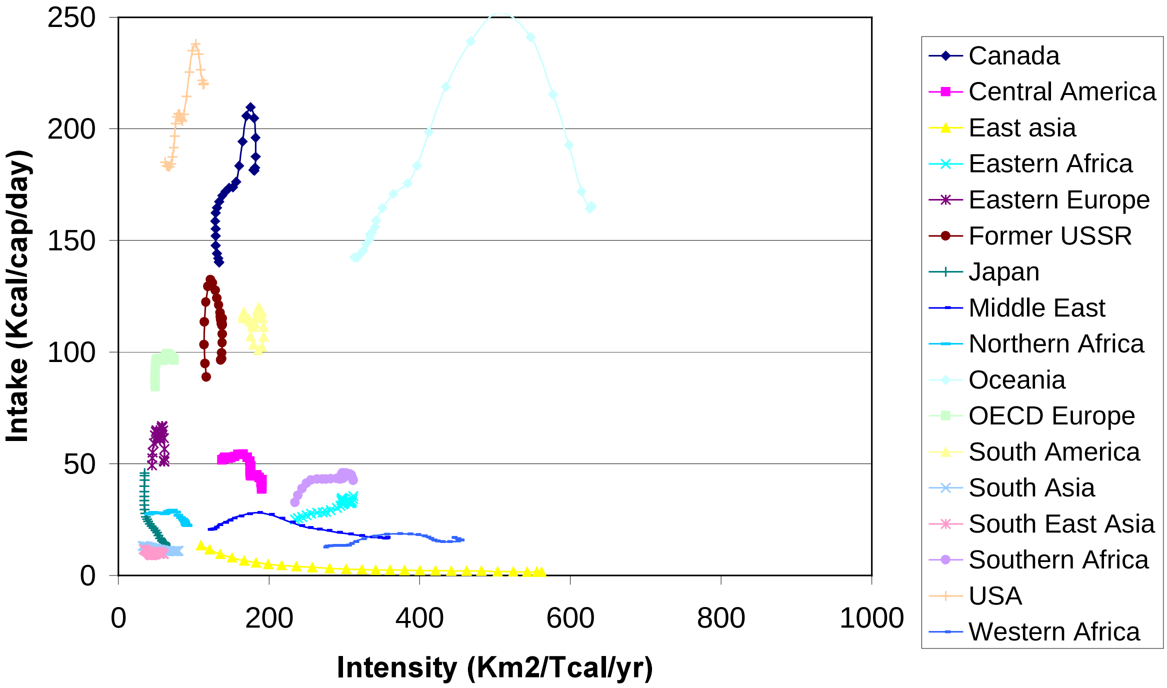

Figure B.1 Cattle meat intensities vs. intake from 1970 to 1995

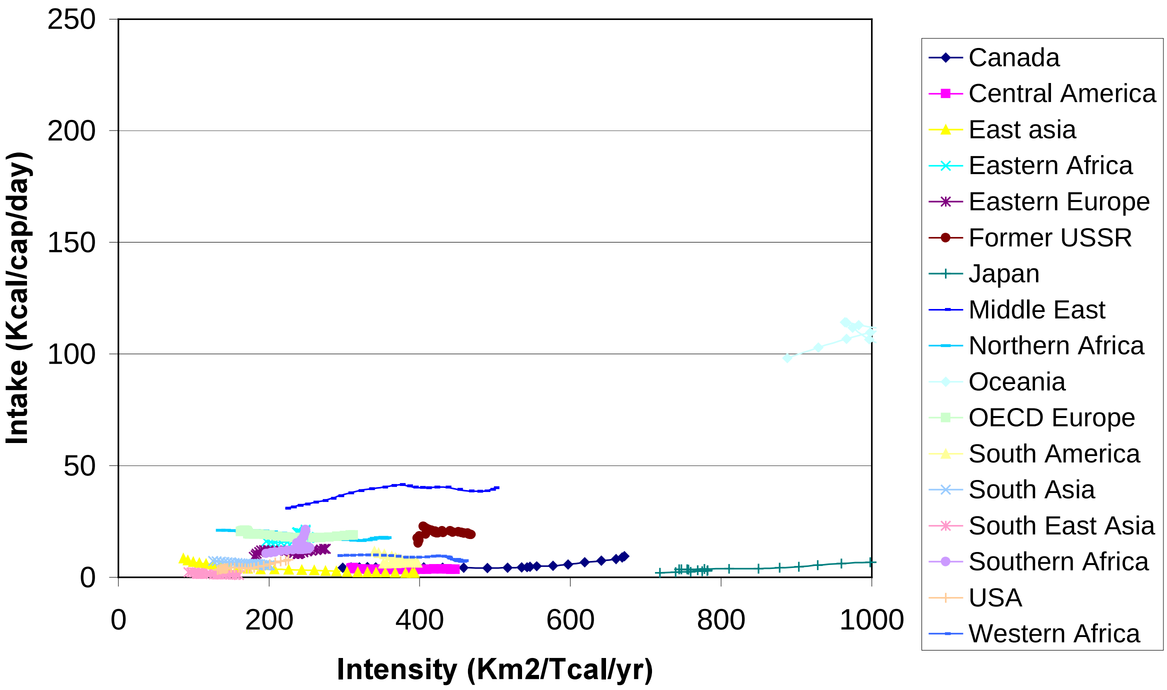

Figure B.2 Sheep and Goat meat intensities vs. intake from 1970 to 1995

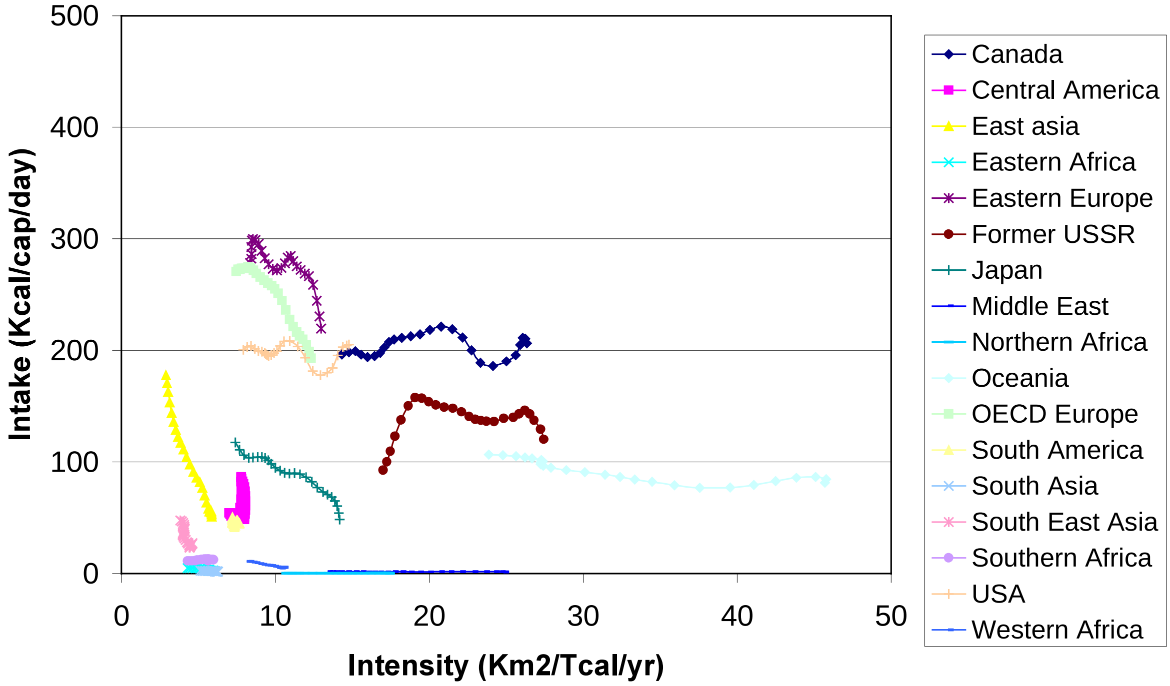

Figure B.3 Pig meat intensities vs. intake from 1970 to 1995

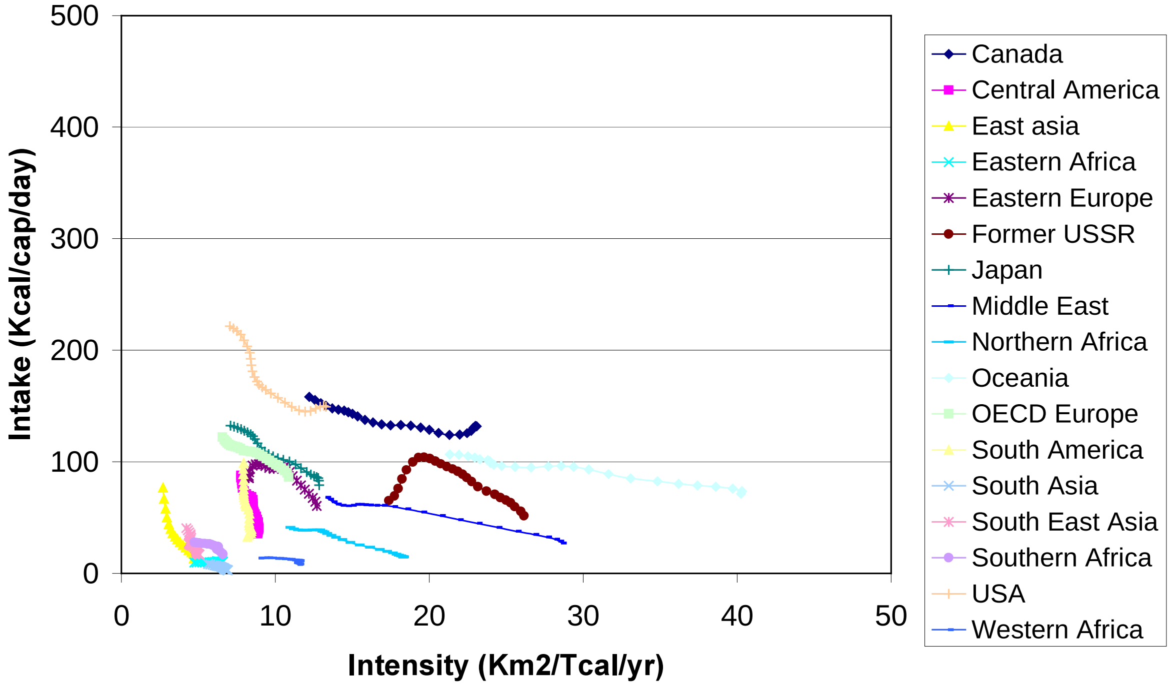

Figure B.4 Poultry meat and eggs intensities vs. intake from 1970 to 1995

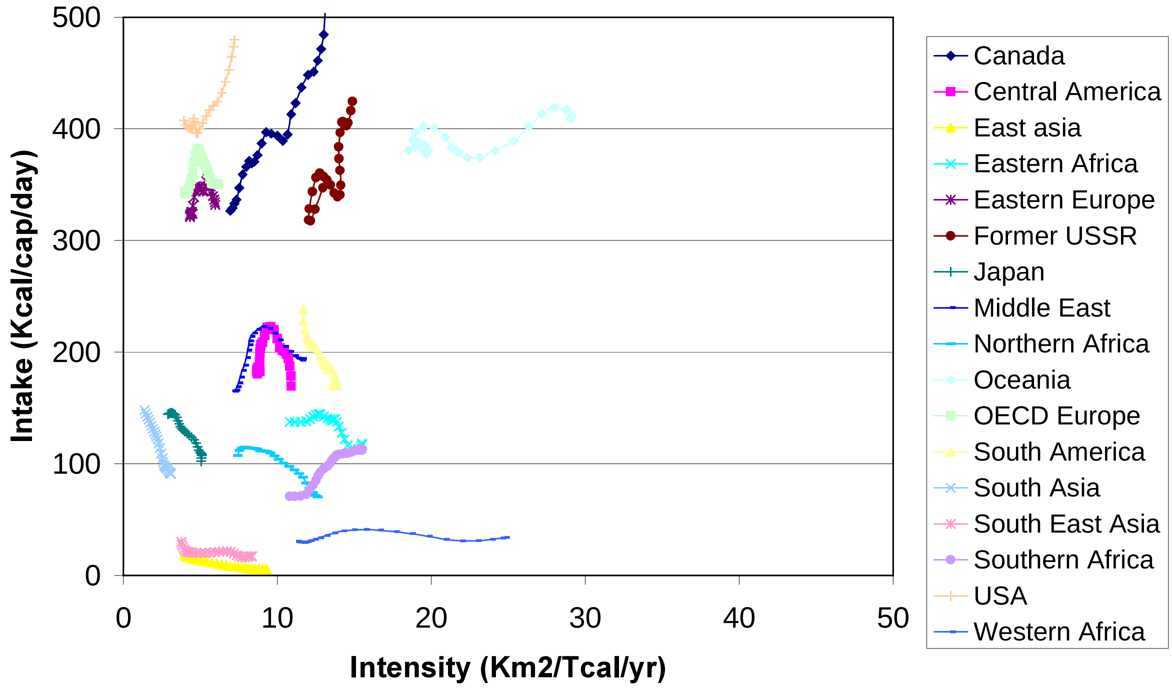

Figure B.5 Cattle milk intensities vs. intake from 1970 to 1995

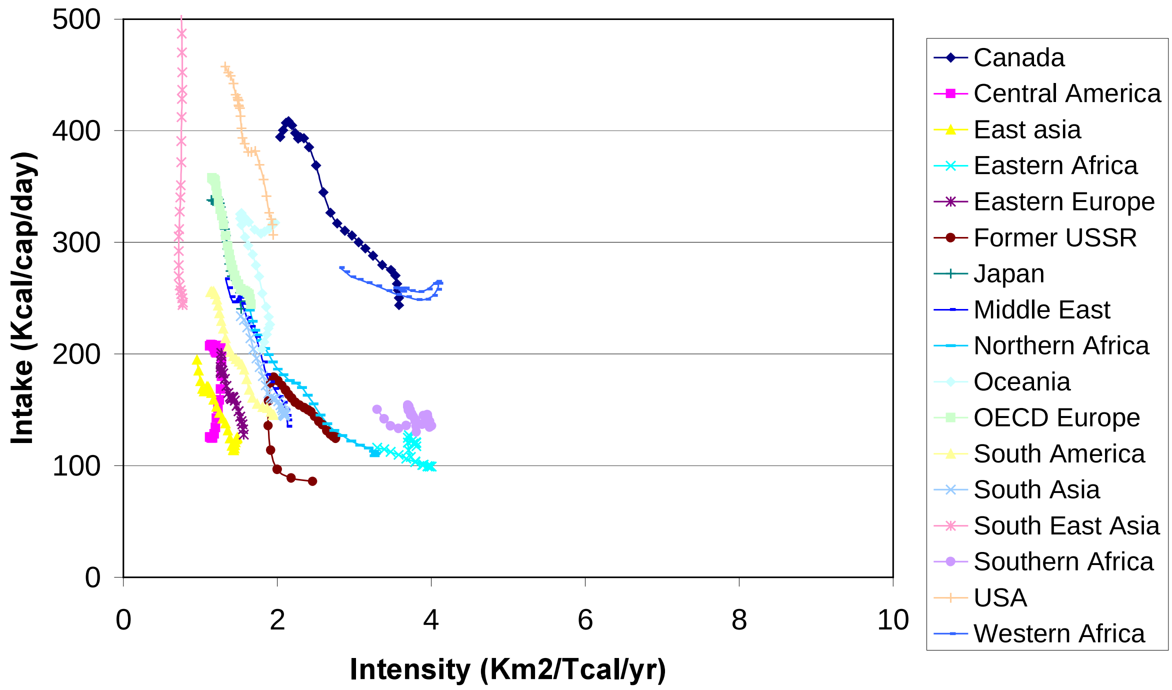

Figure B.6 Oilcrops intensities vs. intake from 1970 to 1995

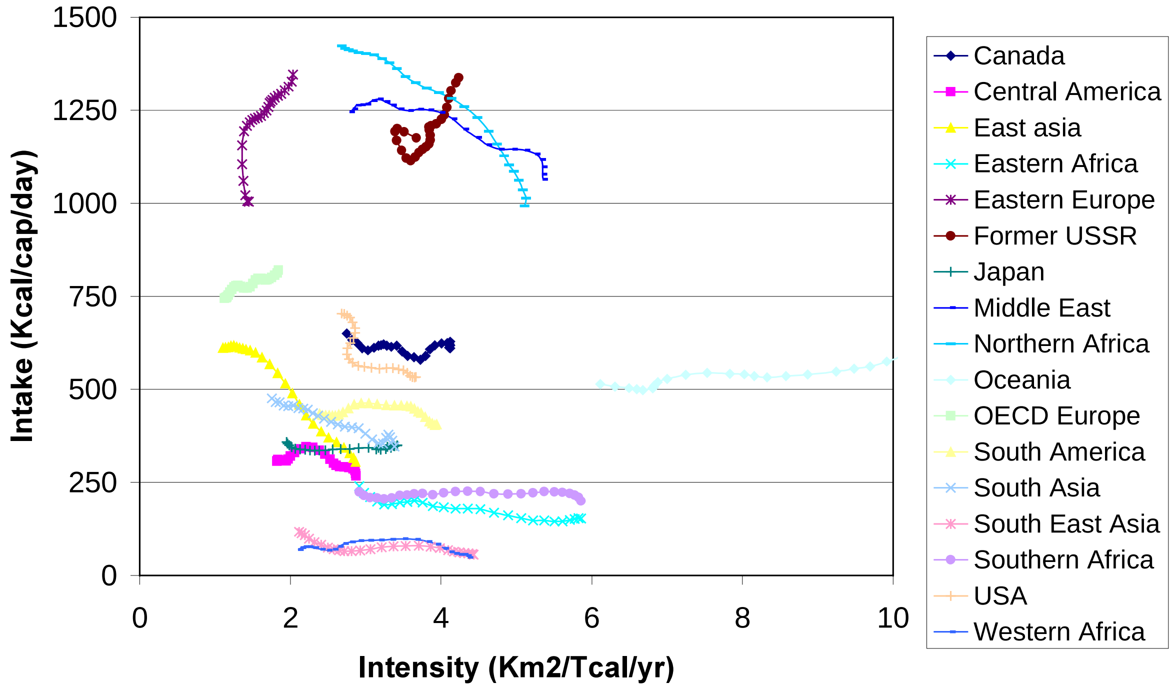

Figure B.7 Temperate cereals intensities vs. intake from 1970 to 1995

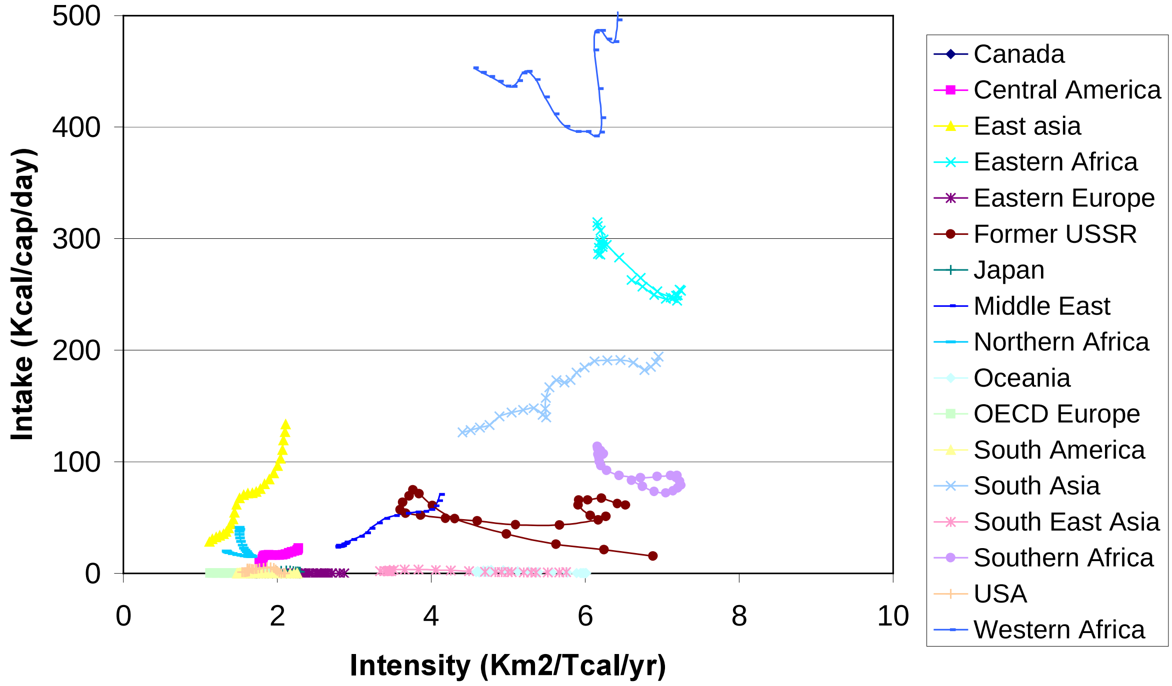

Figure B.8 Tropical cereals intensities vs. intake from 1970 to 1995

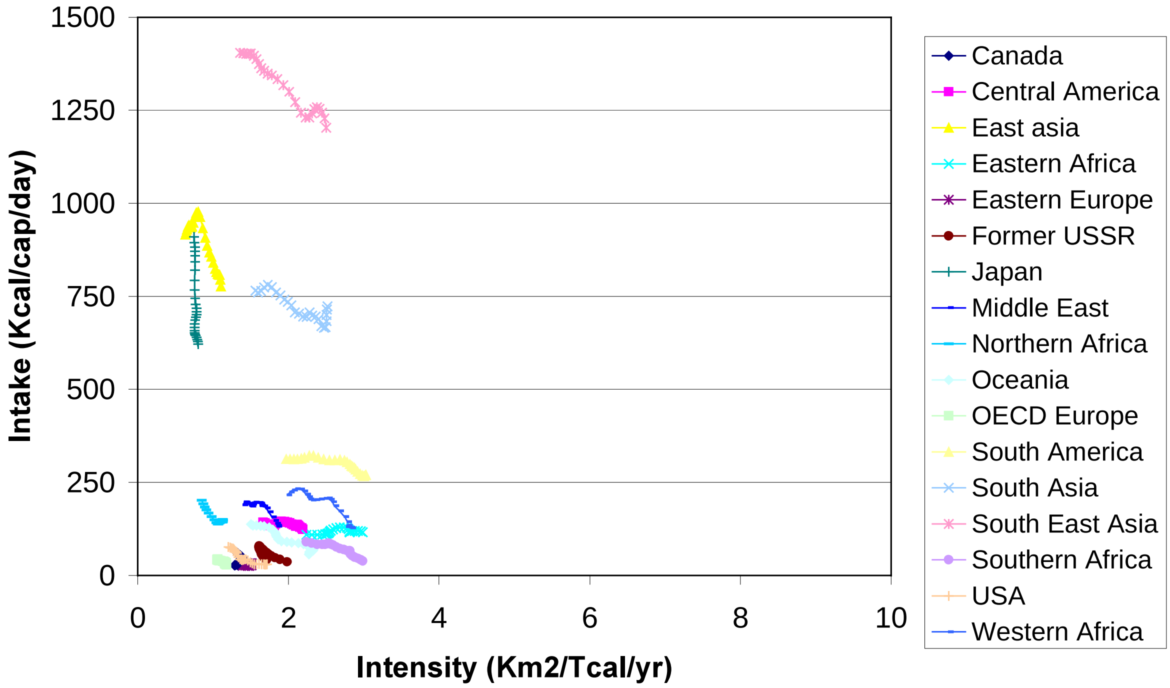

Figure B.9 Rice intensities vs. intake from 1970 to 1995

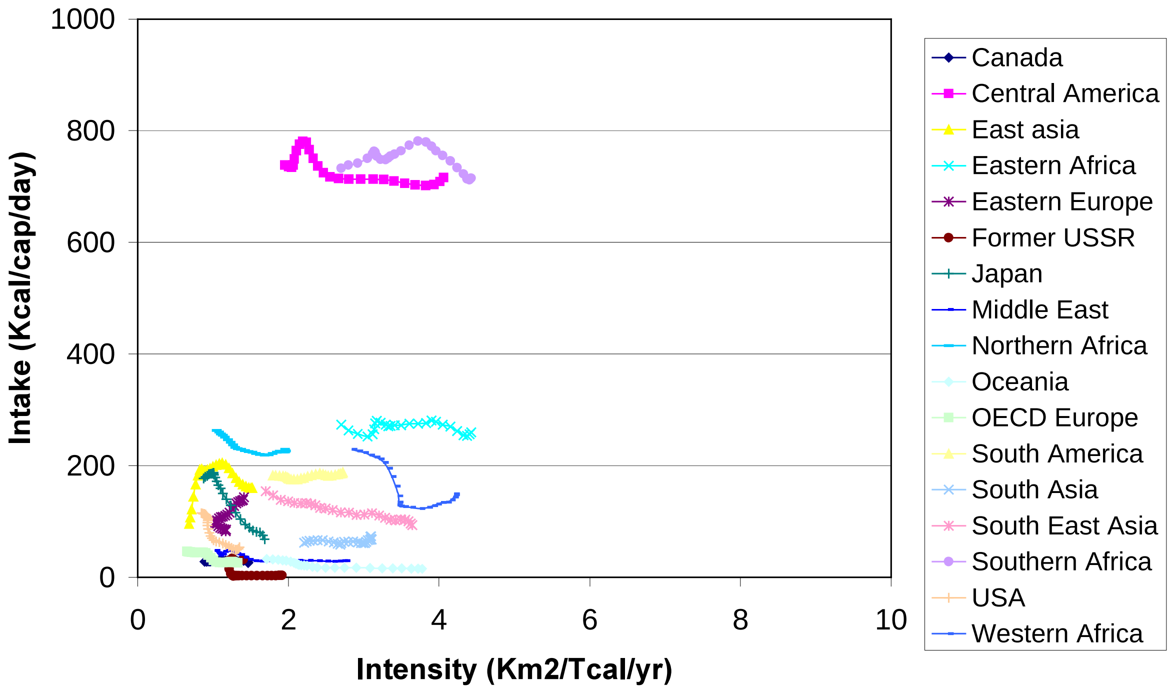

Figure B.10 Maize intensities vs. intake from 1970 to 1995

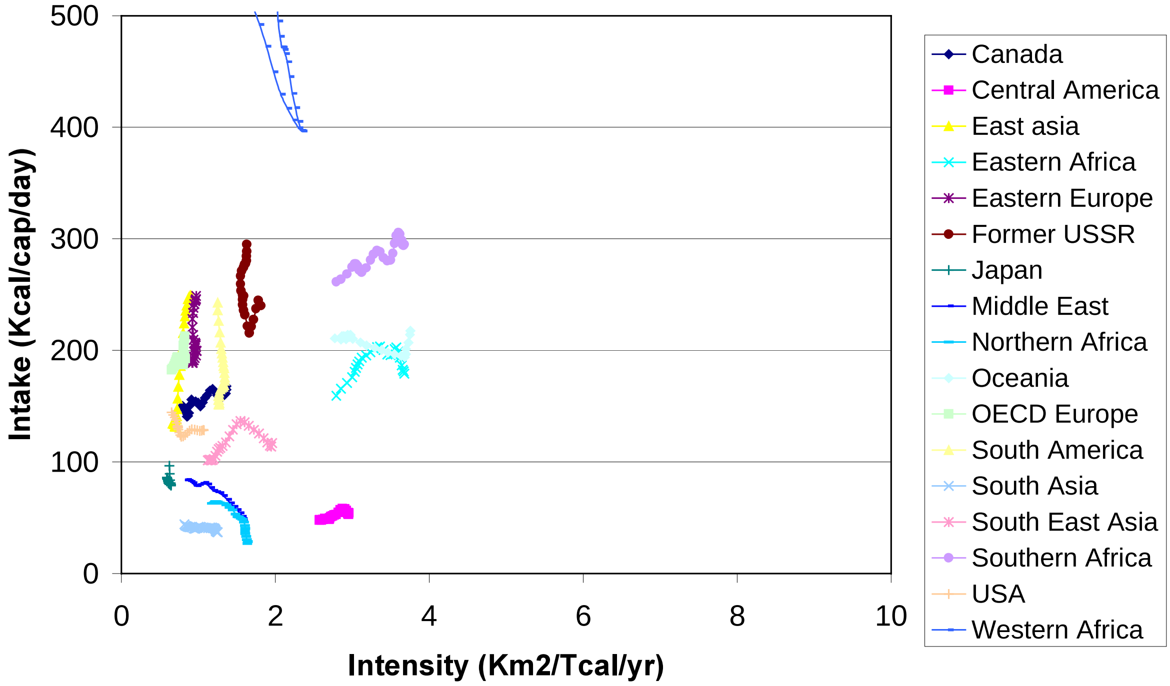

Figure B.11 Roots and tubers intensities vs. intake from 1970 to 1995

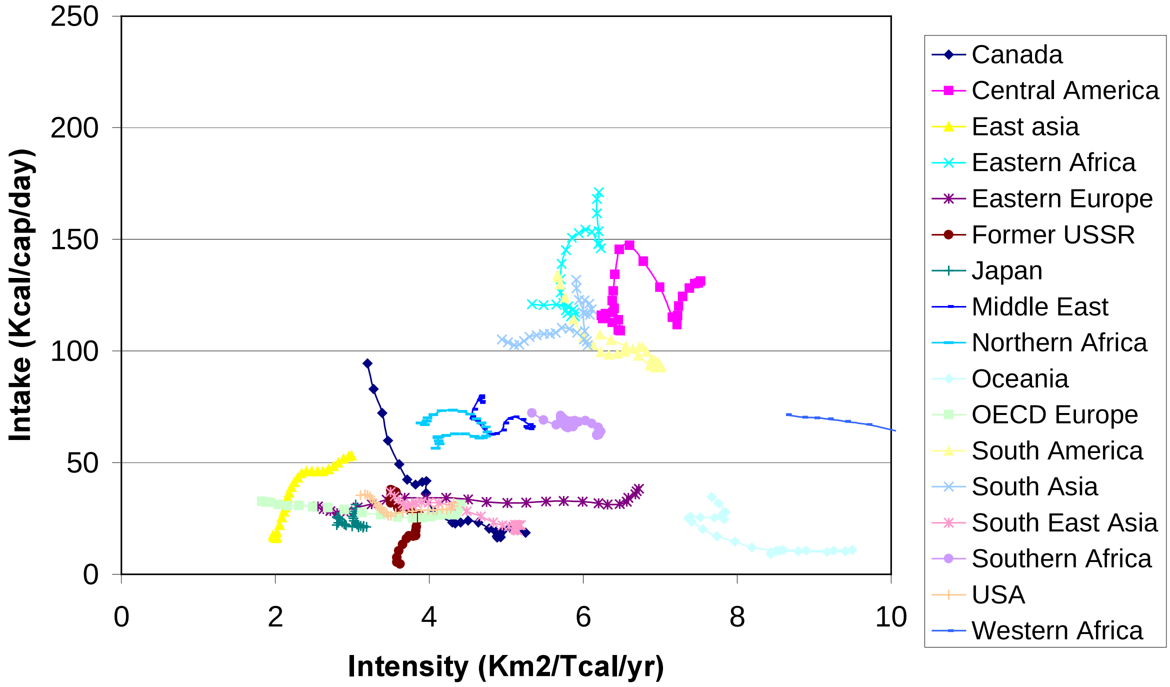

Figure B.12 Pulses intensities vs. intake from 1970 to 1995

Annex C Intensities versus intake levels for 6 food aggregates

The following aggregates have been defined:

1. Cattle, sheep and goat meat.
2. Pig and poultry meat, eggs and cattle milk
3. Temperate and tropical cereals.
4. Rice (figure in annex B only)
5. Oil crops (figure in annex B only)
6. Roots, tubers, pulses, and maize

The reasons the choose these aggregates were:
1. Both cattle and sheep and goat meat have high intensities (i.e. production methods are often extensive) and their is a slight global tendency that lower intensities are related with higher intake levels. It should be noticed that the consumption of sheep and goat meat is almost negligible compared to cattle meat.
2. For pig meat and poultry meat and eggs, the relation between intensities and intakes look similar: decreasing intensities go with increasing intake levels. Also, the range of intensity values and the share in the overall diet are similar for both products. The addition of milk to this aggregate, for which intensities does not seem to be related to income levels (see annex B), is because inclusion to any other aggregate would be illogical, unless it would be kept as a separate product.
3. The relation between intake levels and intensities are rather different for temperate and tropical cereals. However, in general, either temperate cereals or tropical cereals are consumed (which also make it easier to split the aggregate back into to the individual products).
4. Rice was kept as a separate product because it is major component is some regions. If it would be combined with other products it would become complicated to make the translation towards the individual products. In this annex, no figure for Rice is included because it can be found in annex B.
5. Oil crops is also kept separate because it shows the most pronounced relationship between intensities and intake levels, that would otherwise be lost.
6. These products show a very poor relationship between intensities and intake levels. Therefore, they are taken together in a ‘Rest group’.

Remark: Four figures follow: one for each aggregate, except rice and oilcrops that can be found in annex B, figures B.9 and B.6.

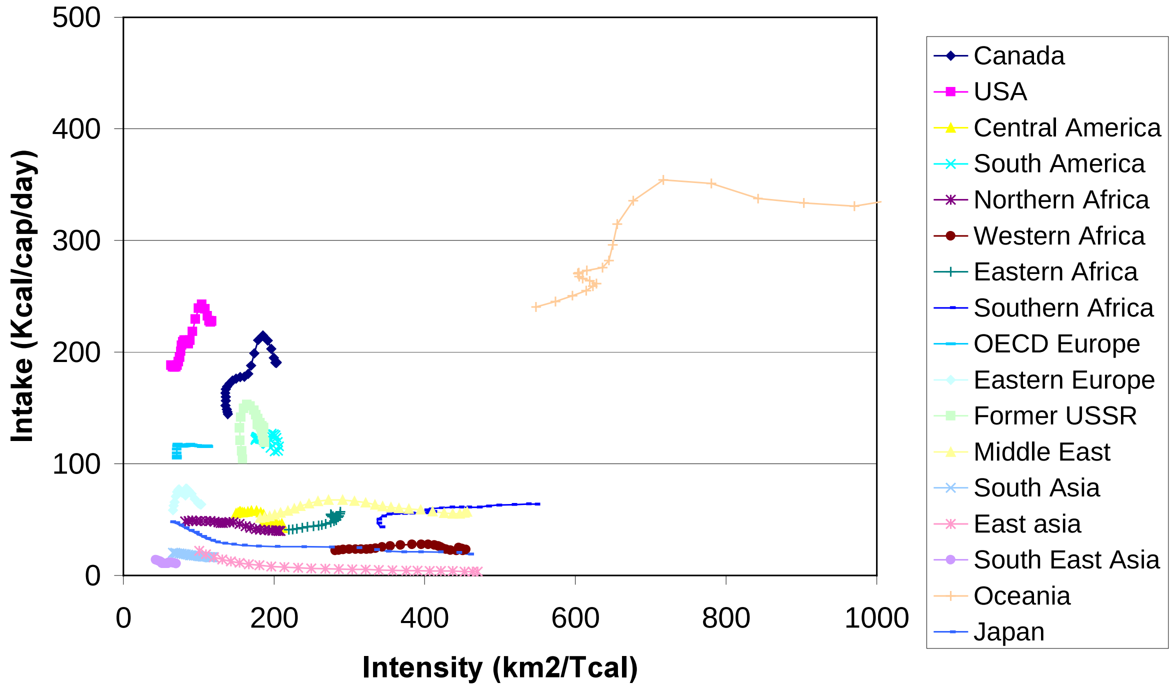

Figure C.1 Cattle, sheep and goat meat intensities vs. intake from 1970 to 1995

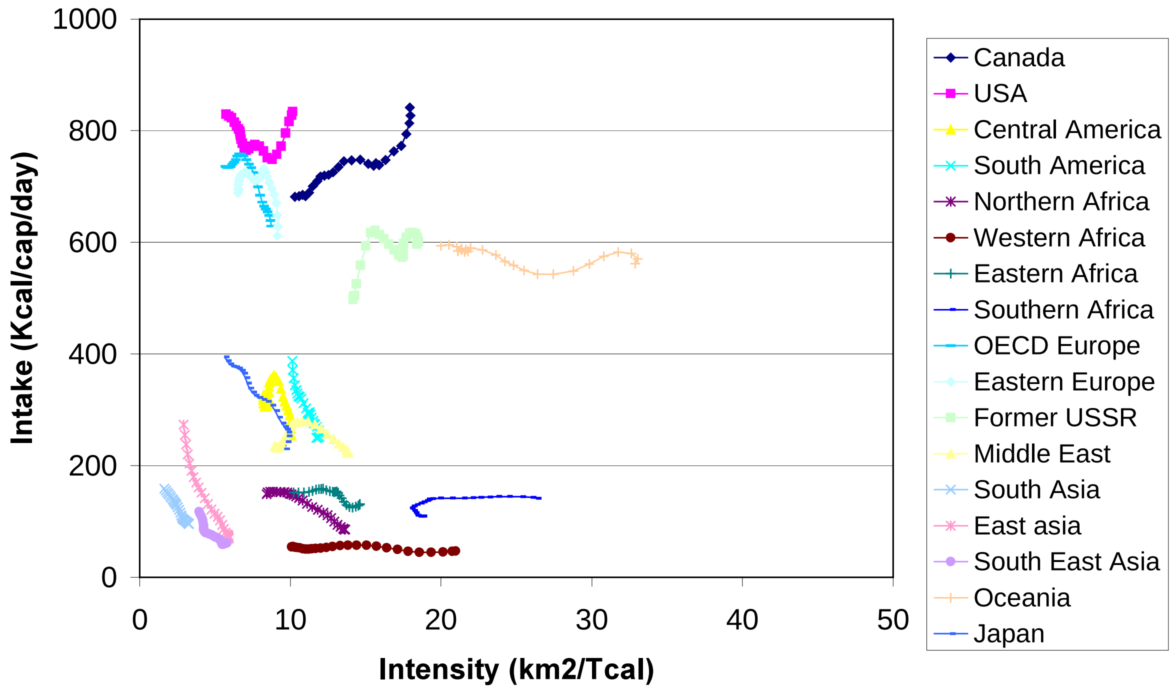

Figure C.2 Pig and poultry meat, eggs and cattle milk intensities vs. intake from 1970 to '95

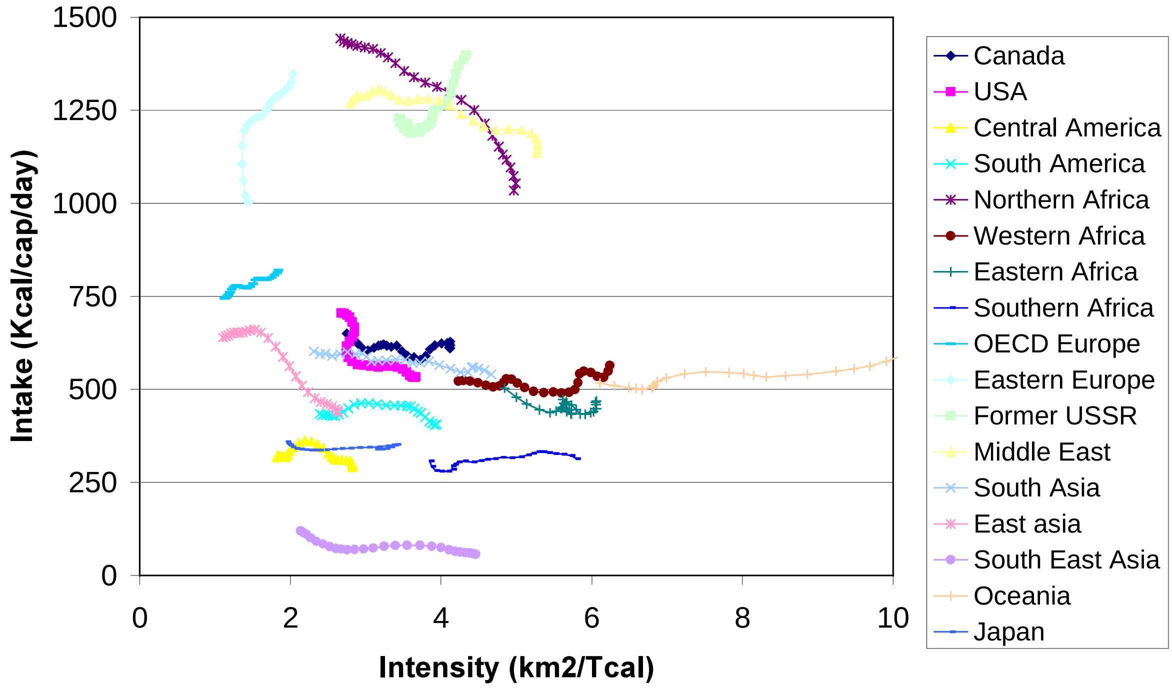

Figure C.3 Cereals intensities vs. intake from 1970 to '95.

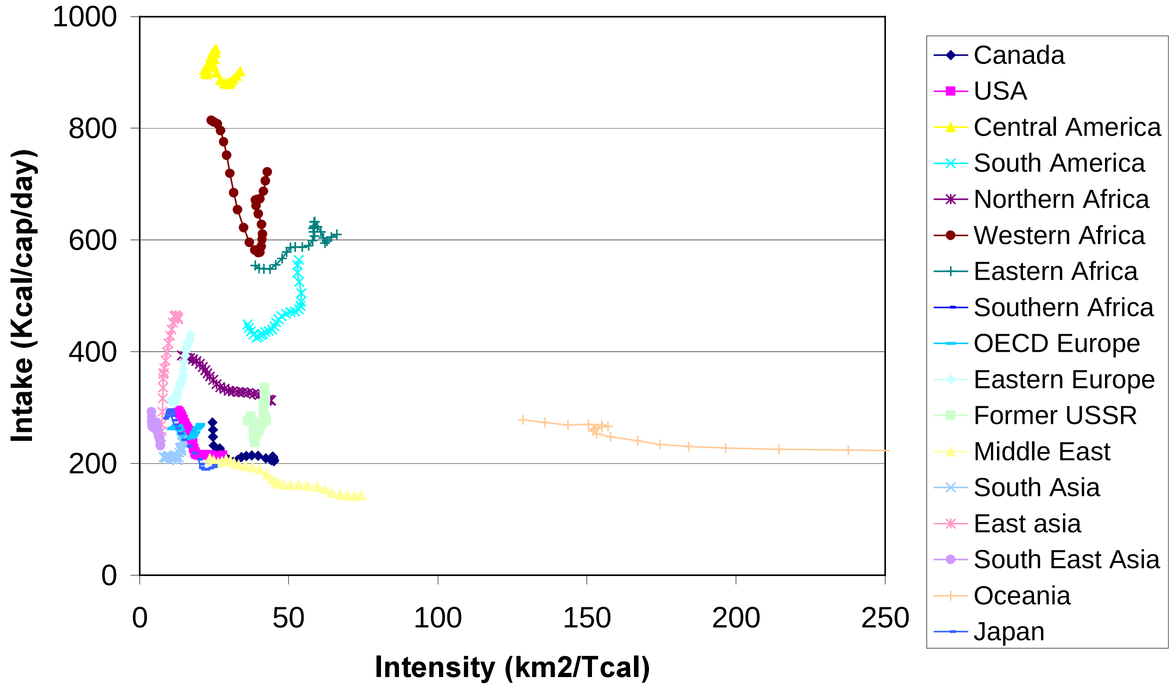

Figure C.4 Rest products (roots, tubers, pulses and maize) intensities vs. intake from 1970 to '95.

Annex D Correlation between income and intake

To analyse the correlation between income and food intake, income and intake data of 17 IMAGE regions and 14 aggregate products over the period 1970-1995 have been compared. Income has been expressed in term of purchasing power parity dollars (ppp$) because it results in a more pronounced correlation, if it exists. Ranges of incomes, especially in the developing regions, become larger where it should be realised that the results, in terms of 'normal' dollars will not significantly differ.

Table D.1 Correlation between income and intake (more details, see text).

→ product ↓ region	Other crops	Poul Eggs	oth ani	oil-crops	Milk	Rice	shee goat	root tub	catt buf.	pigs	temp cer	trop cer	puls	maize	Sum of +	Sum of -	Abs
E Asia	2	2	2	2	2	1	2	-2	2	2	2	-2	-2	0	19	-6	25
Japan	2	2	1	2	2	-2	-2	-1	2	2	0	0	-1	2	15	-6	21
SE Asia	2	2	1	2	2	2	1	-1	1	1	1	1	1	2	19	-1	20
S Asia	2	2	2	2	2	0	2	1	2	0	2	-2	-1	0	17	-3	20
N Africa	2	1	2	2	2	0	0	2	2	0	0	-2	2	0	15	-2	17
OECD EU	2	2	2	0	0	2	0	0	0	2	-1	0	0	1	11	-1	12
F USSR	1	2	1	1	0	2	0	-1	2	1	-1	0	0	0	10	-2	12
E Europe	1	2	0	1	0	0	-1	-1	0	2	-1	0	0	-1	6	-4	10
Canada	1	0	1	1	-1	1	-2	-1	0	0	0	0	1	0	5	-4	9
Oceania	0	0	1	0	-1	1	-1	0	0	1	-1	0	1	1	5	-3	8
C America	1	0	1	1	0	1	0	0	0	0	1	-2	0	0	5	-2	7
S Africa	-1	-1	0	0	1	-1	1	1	0	0	0	1	0	0	4	-3	7
S America	1	1	1	1		0	-1	-1	0	0	0	0	0	0	4	-2	6
USA	0	1	0	0	-1	1	-1	0	0	0	0	0	0	1	3	-2	5
W Africa	1	0	1	0	0	0	0	0	0	0	0	0	0	0	2	0	2
E Africa	1	0	1	0	0	0	0	0	0	0	0	0	0	0	2	0	2
M East	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sum of +	19	17	17	15	11	11	6	4	11	11	6	2	5	7			
Sum of -	-1	-1	0	0	-3	-3	-8	-8	0	0	-4	-8	-4	-1			
Abs	20	18	17	15	14	14	14	12	11	11	10	10	9	8			

The result is summarised in table D.1, where five correlation-classes are distinguished:

1. An obvious positive correlation between income and intake (more income results in higher intake levels) indicated by a value of +2;
2. A possibly positive correlation, indicated by +1;
3. Absolutely no correlation, indicated by 0.
4. A possibly negative correlation, indicated by -1.
5. An obvious negative correlation (more income results in lower intake levels, indicated by a value –2).

Notice that the values –2 to +2 do *not* refer to the absolute value of the correlation. They only indicate *whether* a correlation exist at all. Obviously, the correlation could be determined more precisely using R^2 values, but given the amount of work, it was decided not to compute those values. The objective of the analysis presented here is to get a first impression of the existence of a relationship between income and intake.(The spreadsheet in which this analysis has been performed is called ***income vs intake.xls***.)

Based on table D.1, the following conclusions can be drawn:

1. For only four regions there is a clear correlation between income per capita and intake for more than half of all food products. In order of the number of correlated products these regions are East Asia (12), South Asia (9), North Africa (8) and Japan (8). Also, for South East Asia there is some correlation for most products. So, in general, it can be said that Asian regions score relatively well.
2. In the remaining twelve regions, there is little or no correlation between income and intake. In the USA, West Africa, East Africa and the Middle East almost no correlation could be found at all!
3. For all but a few products, correlations – if they exist - are positive. In other words, rising incomes usually result in an increase of intake levels. A predominantly negative correlation can be found only for tropical cereals, roots and tubers and sheep and goats meat. It leads to the conclusion that it is hard to distinguish between affluent products and basic products, but it clearly shows that rising incomes result in eating more.
4. For those regions where strong positive correlations were found, it mainly applied to poultry and eggs, other crops, oil crops, milk, cattle and buffaloes meat, other animal’s meat en pig meat.
5. Although preference levels (at the product level) are dominant variables in the AEM, their actual existence was not confirmed by the data.
6. Aggregation of products in affluent products (sum of oil crops, other crops, cattle and buffaloes meat, pig meat, sheep and goat meat, other meat, poultry and egg products, and milk products), and basic products (= sum of temperate cereals, tropical cereals, rice, maize, pulses, and roots and tubers) suggest that:

a. rising incomes result in an increase of the intake of affluent products, where the data also suggest an overall preference level of 2600 Kcal/cap/day except for Japan where it might be around 1700 Kcal/cap/day (see *figure 4.3a*).
b. although less evident, intake levels of basic products first seem to rise to a maximum level of about 2000 Kcal/cap/day at 200-400 ppp$/cap after which intake levels seem to converge to lower values between 800 and 1300 Kcal/cap/day (see *figure 4.3b*).

In summary, the conclusions 1 through 4 support the more general conclusion that no relation exist between income and consumption levels at the level of 14 separate food products. If food products are aggregated in two product types (affluent vs. basic) then the results clearly improve.

Annex E The calibration/optimisation module in MatLab

The calibration/optimisation module was previously written in GAMS (see annex A.8). Because many error messages were generated when we tried to adapt the GAMS module, and there was no expertise available, it was decided to rewrite the calibration/optimisation module in MatLab (with the help of Peter Heuberger).
This annex describes the files (see table E.1) which are needed to run the optimisation tool and it is described in short how it should be used.

Table E.1. All files of the calibration/optimisation module.

Filename	Description of functionality
Beep.m	Sound the computer's speaker.
Callbimage.m	Call-back function for image optimisation user interface
Findroot.m	Finds a diet in a given year with the maximum utility value, given a set of weighing parameters, preference levels, intensities, income, historical intake, and an actual budget.
Guiimage.m	Graphical user interface (more details in text).
Imageopt4gui.m	Main program for calibration/optimisation module
Imageopt.ini	Initialisation file. Variables that can be set are: 1) input-file (*setdata.m*), 2) outputfile (*testresult.dat*), 3) number of parameters (6, see table 4.1, excl. a_{tot}), 4) the parameter names, 5) the number of regions (17), 6) the region names (Canada, USA, etc.), and then for each of the 17 regions: 7) the lower bounds, upper bounds and initial values of the 6 parameters, 8) the result of the last time the parameters were determined, and 9) a set of four constraints (see text)
Runopt.m	This function tries to find the best set of parameters as mentioned in table 4.1 such that the historical data is reproduced as close as possible. It uses *testopt.m*.
Setdata.m	Contains all input-data, copied from *MatLabInput7095.xls*, worksheet 'matlab input 6'.
Startup.m	Start-up function
Testopt.m	Finds a diet for a time period (in this case 1970 through 1995, divided in 6 time steps: 1970, 1975, …, 1995) using *Findroot.m*.
Testresult.dat	Contains the result of the calibration/optimisation, i.e.: 1) region number (1 refers to the first region in field 4 of *Imageopt.ini*), 2) date and time of last update, 3) lower bounds, upper bounds and initial values of the 6 parameters of table 4.1. in the main text 4) a set of constraints (see text), 5) the optimal values of the 6 parameters (as can be found in table 4.1 of the main text), which will be in between the lower and the upper bounds, 6) historical X-values, i.e., intakes of basic products in 1970, 1975, …, 1995, expressed Kcal/cap/day.

	7) historical Y-values, i.e., intakes of affluent products in 1970, 1975, …, 1995, expressed in Kcal/cap/day. 8) reconstructed optimal X-values (i.e., having the highest utility), based on the optimal parameter values of field 5) and income per capita in 1970, 1975, …, 1995. 9) reconstructed optimal Y-values in 1970, 1975, …, 1995.
Writeini.m	Writes current setting to file imageopt.ini while creating a backup file *imageopt.ini.N*, with N=1,2,…

To start the optimisation module, one should start MatLab (version 5.3 or higher, including the optimisation library) from the directory where the files of table E.1 can be found. At the time of writing this document this directory is: P:\projekt\image_plus\aem\opt\ver02. Then type: 'guiimage'. The window shown in *figure E.1* will appear. Most buttons and values will speak for themselves, but some need some extra explanation.

First of all, the unit of p_basic (the preference level of basic products) and p_affl (the preference level of affluent products) is Kcal/cap/day $\times$ *1000*. The unit of alpha is \$/cap/year$\times$ *1000.*.

The constraints in the lower part of the window can be activated by setting a 'v' sign in the field that precedes each of the constraints. The first constraint indicates that a solution of parameter values should be found such that the weight of the intake of basic products (w_basic) should be less than the weight of the intake of affluent products (w_affl). The idea behind this constraint is that people will generally value affluent products higher than basic products. However, during the optimisation process it turned out that this constraint is too strict (see table 4.1) and therefore it has been de-activated for all regions.
The second constraint is comparable to the first, but refers to the preference levels. Again, this constraint turned out to be too strict and was de-activated for all regions.
The third constraint indicates that the sum of the two preference levels should be more than 2800 Kcal/cap/day (2.8 $\times$ 1000 Kcal/cap/day). Another value could be entered, but as will be noticed, this value has been used for all regions.
The last constraint indicates the sum of the two preference levels should not exceed 4300 Kcal/cap/day (which is very high). If needed this maximum was set to a value such that the sum of the preference levels were more or less comparable to other the regions.

To run the actual optimisation one should 'press' on the Run-button. After some time the result of the optimisation will appear in the column 'Last Result'. By clicking on the entry below 'Continue?' the Last Result will be copied to the Initial Value, which means that the next run will start from this point. The last results can be saved by clicking on 'Save settings'. Notice that the last results for *all* regions will be saved. If you want to return to the parameter values as they were when you saved the results for the last time, one should click on 'Reset'.

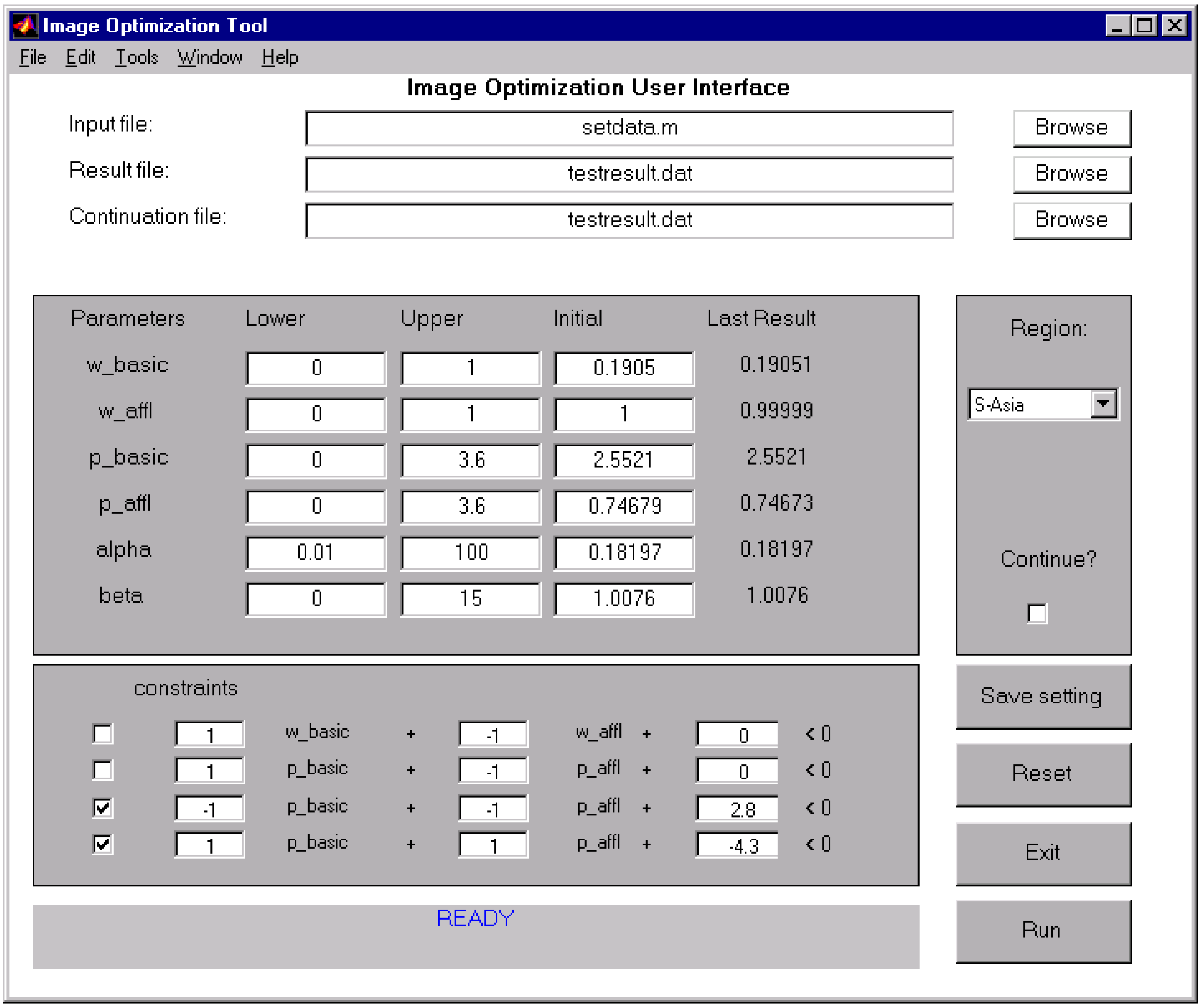

Figure E.1 The Graphical User Interface of the optimisation module.

At the end of each run, two windows like the ones shown in *figure E.2* will appear. The two graphs in the window 'Reconstructing S-Asia' indicate how well the computed optimal intake values of basic and affluent products (Hist Basic and Hist Affl) reproduce the historical intake levels, given the set of parameter values as shown in the column Last Result. The Y-axis represents the time steps: 1=1970, 2=1975, …, 6=1995.
The second window shows the shape of the utility function, with income per capita on the Y-axis (in $/cap/year) and optimal intake levels on the X-axis (in Kcal/cap/day). Remember (from chapter 2) that the outcome of the utility function also depends on the value of the intensities (i.e., 'prices' of food products). For the graph shown, these values are fixed on the lowest value in the historical time series, which is equal to the value in 1995 in most cases.

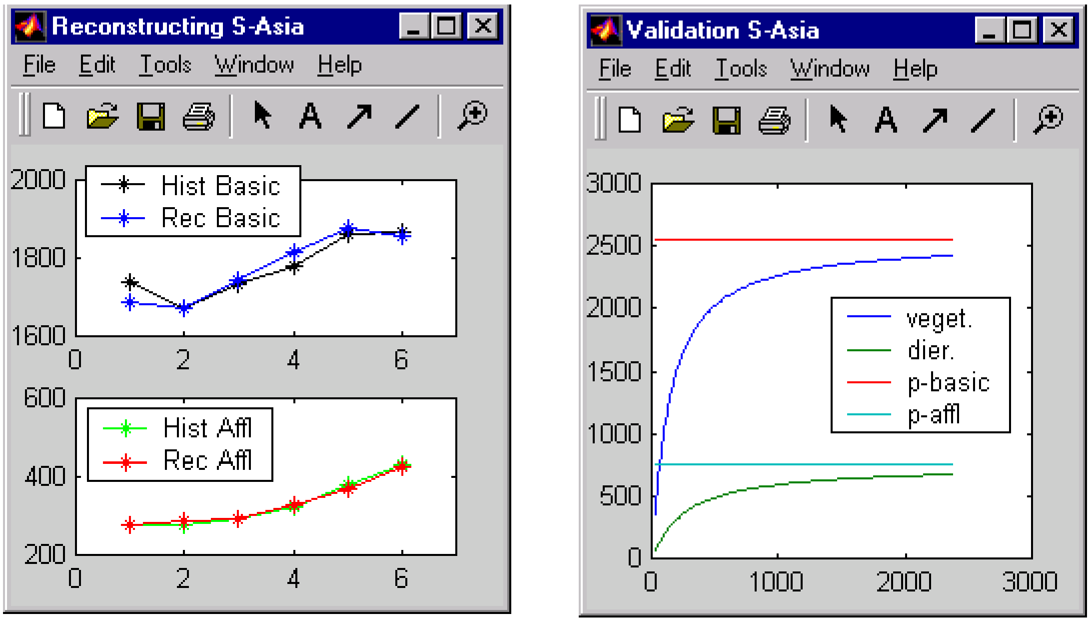

Figure E.2 Result windows

Annex F Developing an Economically Based Global Land-Use-and-Cover Model for IMAGE

A recommendation by Roy Darwin, USDA/ERS, 27/01/2000

Recommendation

The agricultural and energy components of IMAGE 2 should be integrated in one economic framework. This economic framework also should be able to simulate competition for land and water resources by the agricultural, forestry, bioenergy, and other sectors. This would help to eliminate inconsistencies in calculating changes in terrestrial land use, greenhouse gas emissions, and other entities. It would also facilitate policy analyses by providing the means for simulating taxes or subsidies and reporting results in terms of economic costs and benefits as well as in terms of physical units.

Annotation

Presentations and discussions at the Ad-Hoc Advisory Board Meeting indicated that personnel involved with IMAGE 2 and at RIVM in general know what problems need to be resolved regarding the Agricultural Economy Model (recently called the Land Demand Model). Land intensities are poor proxies for food prices, international trade in agricultural commodities is treated as a residual, and biofuel production is given priority over food production when determining land use. They also indicated that IMAGE 2 and RIVM personnel have focused on the key scientific issues that IMAGE 2 needs to address when evaluating policies pertaining to global economic and environmental changes—climate and weather variability, irrigation and competing uses of water resources, and land degradation. A number of steps have been taken toward incorporating these phenomena into IMAGE 2 while recognizing that alternative models (or the institutions that house them) could be helpful in resolving the economic problems. IMAGE 2 personnel also recognize the need to maintain consistency with WorldScan.

Nevertheless, there is a sense that IMAGE 2 plans to resolve economic issues in the agricultural sectors separately from those in the energy sector. A better approach would be to integrate the agricultural and energy sectors within one economic model. This would enable simultaneous global simulations of production, trade, and consumption of energy and agricultural commodities. The economic model also should be able to simulate competition for land and water resources by the agricultural, forestry, bioenergy, and other sectors.

One way to proceed is to incorporate an existing economic database and modeling framework like that provided by the Global Trade Analysis Project (GTAP) at Purdue University (see www.agecon.purdue.edu/gtap/). This would enable IMAGE 2 to conduct analyses in both physical and monetary units while retaining consistency with WorldScan. Because WorldScan is founded on GTAP databases, it would be relatively easy to utilize WorldScan monetary results as the main economic drivers of a GTAP-based economic model within IMAGE 2. IMAGE 2 could also conduct independent economic analyses. An early version of GTAP also forms the basis for USDA/ERS's FARM land-use-and-cover change modeling framework. ERS is currently developing land and water resources databases that will be compatible with the current and next version of GTAP. These databases will be made available to GTAP users. This will enable simultaneous solution of the impacts of commodity production on land and water use. An added benefit for IMAGE 2 would be greater flexibility in regional disaggregation. The current version of GTAP, for example, has separate data for 45 regions that can be aggregated to IMAGE 2 regions or alternative combinations.

Some of GTAP's features are as follows. An energy version of the GTAP database and model tracks fuels (coal, oil, and gas) in terms of physical units. Agricultural commodities in GTAP are relatively disaggregated (wheat, paddy rice, other grains, vegetables-fruit-nuts, oilseed crops, plant fiber crops, sugar crops, other crops, cattle, raw milk, wool, other animal products. The land and water resources database will provide ways to track these crop and livestock aggregates in physical units. GTAP has the potential to simulate resource stocks in natural resource sectors (e.g., fisheries, forestry, coal, oil, gas, and minerals). Policy levers such as taxes and subsidies can be simulated. GTAP output provides standard economic measures of welfare, expenditures, costs, and benefits. GTAP databases and models well documented so that transparency is increased. Dynamic versions of GTAP and FARM will be available soon as well.

Existing IMAGE 2 components can be modified to link with GTAP databases and model output by either 0.5° grid and/or region. Like many other global energy modeling groups (e.g., Massachusetts Institute of Technology, Australian Bureau of Agricultural and Resource Economics, Charles River Associates) that rely on GTAP data and modeling structures, IMAGE 2 could take advantage of its engineering approach to energy and emission modeling when working with GTAP products. These groups also are working to solve some of the energy modeling issues raised during the IMAGE 2 Advisory Board Meeting, e.g., technological innovation and technological evolution, tracking nuclear and renewable energy (e.g., solar, wind) separately from fossil fuel energy, simulating capital turnover rates in energy production, and capturing post-combustion capture of carbon emissions by emerging technologies. It would be easier to collaborate with these groups when everyone is trying to improve the same basic data sets.

Most importantly, however, IMAGE 2 could take advantage of its strengths in simulating grid-level land-use/cover changes, land degradation, water resources, livestock production, residue management, and knowledge about the energy content of food when working with GTAP products. Issues that could be resolved include 1) simulating agricultural production and trade with prices rather than land intensities, 2) realistically simulating international trade in agricultural and energy commodities, 3) simulating competition for land by agriculture and other sectors (especially forestry and bioenergy), 4) simulating competition for water by irrigators and other users of water resources, and 5) simulating land degradation. These effects could be simulated both with and without weather variability.

The first step in incorporating a GTAP-based, FARM-like economic model into IMAGE 2 would be to collaborate with USDA/ERS, the Netherlands Agricultural Economics Research Institute (LEI), and others to develop a land and water resources database consistent with current and future GTAP databases during 2000. Collaboration would take the form of sharing data and/or having RIVM personnel spend time at ERS. The second step would be for IMAGE 2's newly hired economist to enrol in the basic GTAP courses in 2000. The third step (once the land and water resources database is available) would be to purchase the appropriate GTAP database and related software. The cost would be approximately $12,000 for the second two steps.