KLUM: A SIMPLE MODEL OF GLOBAL AGRICULTURAL LAND USE AS A COUPLING TOOL OF ECONOMY AND VEGETATION

Working Paper FNU-65

KERSTIN RONNEBERGER
Research Unit Sustainability and Global Change, Hamburg University and Centre for Marine and Atmospheric Science, Hamburg, Germany
International Max Planck Research School of Earth System Modelling, Hamburg, Germany

RICHARD S.J. TOL
Research Unit Sustainability and Global Change, Hamburg University and Centre for Marine and Atmospheric Science, Hamburg, Germany
Institute for Environmental Studies, Vrije Universiteit, Amsterdam, The Netherlands
Engineering and Public Policy, Carnegie Mellon University, Pittsburgh, PA, USA

UWE A. SCHNEIDER
Research Unit Sustainability and Global Change, Hamburg University and Centre for Marine and Atmospheric Science, Hamburg, Germany
International Institute for Applied Systems Analysis, Laxenburg, Austria

May 24, 2005

Abstract. The *Kleines Land Use Model* (KLUM), is a global agricultural land-allocation model, developed as a tool to dynamically couple global state-of-the-art vegetation and economy models. The allocation process is based on profit maximisation, assuming risk aversion and decreasing returns to scales. The model is suited for long-term predictions, acknowledges spatial and biophysical diversity and enables the data exchange with common vegetation models. Finally, the effective simplicity of the mechanism facilitates online-coupling with larger models.

Simulations of future crop allocation under climate change suggest that cultivation of cereals would fall in favour of minor crops such as vegetables and fruits. Total revenue of crop production is predicted to increase for most parts of the world. The comparison with two reference scenarios, where solely prices or yields are changed show that the observed results are dominated by the induced price changes. Losses in revenue prevail and changes in area are more balanced over the world when only the much smaller yield changes are applied. Yet, the simple sum of price and yield effects on crop allocation can differ in magnitude and sign from the real dynamics, emphasising the importance of simultaneous inclusion of economic and biophysical aspects of land-use decisions.

Keywords: global land-use model, crop allocation, feed back loop, climate change

1. Introduction

Land-use constitutes one of the essential links between biosphere and anthroposhere. Large parts of the terrestrial land surface are used for agriculture, forestry, settlements and infrastructure. Changes in the land-use directly influence the natural environment. They influence the nutrient and water cycles. They govern a large part of greenhouse gas emissions. They determine landscape design, have an impact on biodiversity and may even alter the albedo. On the other hand, land-use changes also affect the social and economic environment. The use of land determines the economic revenue of land-intensive productions. Current as well as past land-use shapes the social and environmental surrounding of people. Finally, land-use decisions are triggered by environmental properties and motivated by socio-economic drivers, building a vital feedback loop of the interaction of human societies and the natural environment (Lambin et al., 2003).

Given the importance of this feedback loop, it is essential to understand the underlying motivations of land-use decisions and the resulting emergence of land-use patterns. Land-use models are needed to analyse the complex structure of linkages and feedbacks and to determine the relevance of drivers. They are used to project the magnitude, character and location of land allocation changes under different boundary conditions, supporting the analysis of drivers and processes as well as land-use and policy decisions.

Many important drivers and consequences of land-use change are of global extent. Land-use changes and environmental impacts are often spatially and temporally disjoint (Krausmann, 2004) and interlinked by means of international trade. For these reasons, some of the important impacts and processes of land-use changes need to be addressed on a global scale. However, for reasons of low data availability and since many important drivers of land-use decisions, such as land suitability are changing on a rather fine spatial scale, global approaches are still rare.

Current approaches to simulate global land-use changes still tend to over-emphasise either the geographic or the economic aspect, neglecting their interactions (Heistermann et al., submitted). Geographic models are commonly based on detailed biophysical characteristics of land. They focus on the dynamics of spatial patterns of land-use types by analysing land suitability and spatial interaction. Allocation decisions are based either on empirical-statistical evidence (as e.g. in the family of CLUE models (*Conversion of Land Use and its Effects*), see e.g. (Veldkamp and Fresco, 1995; Kok and Veldkamp, 2001)) or formulated as decision rules, based on case studies and common sense (as e.g. in *Syndromes* (Petschel-Held et al., 1999) and in the *dynamic simulation model of land-use changes in Sudano-sahelian countries of Africa* (SALU) (Stephenne and Lambin, 2001a; Stephenne and Lambin, 2001b)). In both cases the projections are based rather on observed behaviour than on underlying economic motivations. This limits their projection horizon and their capability to represent the impact of market interactions, such as economic competition among different land-intensive sectors (for more details on geographic land-use models see e.g. (Veldkamp and Lambin, 2001)).

In economic models, land is usually implemented as a constraint in the production of land-intensive commodities and the focus is more on market impacts and resulting emissions of land-use than on its allocation. The *International Model for Policy Analysis of Agricultural Commodities and Trade* (IMPACT) (Rosengrant et al., 2002), the *World Agricultural Trade Simulation Model* (WATSIM) (Kuhn, 2003) and the *Global Trade Analysis Project, Energy - Land* model (GTAPE-L) (Burniaux, 2002; Burniaux and Lee, 2003) are prominent examples. These models are based on economic motivations, qualifying them for long-term predictions and a dynamic representation of market impacts. Their limitation mainly manifests in the representation of land. Land is treated as homogeneous and space-less, ignoring biophysical characteristics and spatial interactions (for more details on economic land-use models see e.g. (Balkhausen and Banse, 2004; van Tongeren et al., 2001)).

There is a trend in both directions to improve their work by introducing the respectively missing aspect into their tools. Global economic models seek to improve their representation of land by dividing the land into different classes, based on geographic assessment. The *Future Agricultural Resources Model* (FARM) (Darwin et al., 1995; Darwin et al., 1996) was one of the first to use the so-called *Agro-Ecological Zone* methodology. According to the dominant climatic and biophysical characteristics, land is subdivided into different classes, reflecting the suitability for and productivity of different uses. Even though this improves the representation of environmental impacts on the economy, still the location of changes and the reverse effect on the environment are not simulated.

Global geographic approaches commonly aim to improve their economic rational by introducing economic properties such as demand as boundary conditions. In the *Integrated Model to Assess the Global Environment* (IMAGE) (Alcamo et al., 1994; Zuidema et al., 1994; RIVM, 2001) the *Land Cover Model*, an allocation tool based on cellular automata, allocates the commodity demands, as calculated by the *Agricultural Economy Model* (Strengers, 2001) according to land potential on a 0.5 × 0.5 grid. However, the economic demand module is theoretically weak as trade and market interactions are not dynamically represented. The EURURALIS project (van Meijl et al., submitted) aims at improving this weakness, by coupling the IMAGE model to GTAPEM (Hsin et al., 2004), a version of the standard GTAP model (Hertel, 1997), which has an extended agricultural sector. Crop yields and a feed conversion factor, determined by IMAGE are exchanged with production of food and animal products and a management factor (describing the degree of land intensification) as calculated by GTAPEM. The advantage of coupling the two comprehensive models lies in detail and comprehensiveness of process representation. Moreover, this is one of the few approaches, where a feedback between economy and vegetation is at least partly realized. Against these achievements stands the risk of producing redundancies and inconsistencies, since some processes, as for instance the allocation of land are implemented in both models.

The global agricultural land-use model *Kleines*[1] *Land Use Model* (KLUM) was developed to establish a link between biosphere and economy in a global integrated assessment model (IAM). We reduce the risk of redundancies and inconsistencies by *outsourcing* the allocation process from the larger models. At the same time we benefit from the comprehensive process representation of the specialized models by utilizing their output for the allocation process. Feeding back the allocation pattern to the larger models completes the feedback loop of economy and vegetation.

The *Agricultural and Land Use model* AgLU (Sands and Leimbach, 2003) and the *land-use choice module* (Tan et al., 2003) follow a similar approach. The AgLU model, a global partial equilibrium model, is used to provide a feedback between the climate and economic core models of the *Integrated Assessment of Climate Protection Strategies model* (ICLIPS) (Toth et al., 2003). Based on gross domestic product (GDP) and carbon price of the economic model, land is allocated according to proportional revenues of the possible uses. The resulting carbon emissions are calculated and fed back to the climate model. Biophysical characteristics of land are considered via a joint probability distribution, which determines the productivity of land. Still, this approach neither links land-use changes to specific geographic locations nor does the probabilistic representation of land productivities capture the true variability of land within a region or allows for a feedback to a vegetation model.

In KLUM we represent geographic location and biophysical heterogeneity of land by using spatially explicit potential productivities, as can be calculated by a vegetation model. The allocation is determined on the resolution of the biophysical input, which enables the direct utilisation of the results in the vegetation model.

The *land-use choice module* is a more geographically based approach to couple the global partial equilibrium model IFPSIM (*International food policy simulation model*) (Oga and Yanagishima, 1996) to the crop growth model EPIC (*Erosion Productivity Impact Calculator*) (Williams, 1995). Based on potential yields, as calculated by EPIC, and market prices as determined by IFPSIM, the utility of different land-use alternatives is calculated. From this, the land-use choice module chooses the set of alternatives with highest utility by means of logistic regression. The resulting allocation is calculated on a 0.1×0.1 grid resolution. Analogously to common geographic approaches, the regression technique allows for an easy inclusion of other than monetary factors influencing land-use patterns but the ad-hoc definition of utility limits the long term predictability.

We derive the allocation algorithm of KLUM from a maximization of profit. This explicit motivationally based approach ensures validity also for long-term predictions. The model replaces the internal allocation mechanism of the economy model that solely provides the equilibrium prices for the optimisation. The aggregated allocation can be fed back as production-specific land endowments to the economy model.

In the next section we present the model structure, outline the underlying assumptions and describe the implementation. We document the calibration and a thorough evaluation of the model performance by means of analytical as well as numerical analysis in section 3. Section 4 discusses the results for climate change on economic growth. Section 5 concludes.

2. The model

KLUM runs on an exchangeable spatial resolution and with 1 year time-steps. The model is designed for global coverage and a possible time horizon of several centuries. The allocation decision in each spatial unit is independent of adjacent units and preceding allocations. The size of the spatial units is flexible. Decisive parameters for the allocation process are crop prices and potential yields. Calibrated parameters are cost parameters and risk aversion. Currently, the model is calibrated according to data of FAOSTAT (FAO, 2004) and World Development Indicators (World Bank, 2003) to reproduce the allocation of 8 different crop aggregates (see table I) for 181 countries (see appendix table V).

Table I. Crop aggregation of KLUM, adopted from (GTAP, 2005).

Aggregate	Description
Paddy rice (pdr)	Paddy rice
Wheat (wht)	Wheat
Cereal grains nec (gro)	Maize(corn), Barley, Rye, Oats, Other cereals
Vegetables and fruits (vf)	vegetables, Roots and Tubers, Fruits, Nuts
Oil seeds (osd)	Oil seeds and oleaginous fruits
Sugar cane/beats (cb)	Plants used for sugar manufacturing
Plant-based fibres (pfb)	Raw vegetable materials used in textiles
Crops nec (ocr)	Flowers, vegetable-, fruit- and flower-seeds, spice crops etc.

2.1. Purpose and basic underlying assumptions

We design the model as an interface between biosphere and economy in a global integrated assessment model. Its objective is to reproduce the key-dynamics of land allocation to capture the characteristic trait of the feedback-loop between vegetation and economy. Thus, the focus lies on simplicity and efficiency in order to guarantee computational feasibility as well as to facilitate structural interpretation of model performance and results.

In the developed model the maximisation of achievable profit is assumed to be the driving motivation underlying the simulated land-use decisions. In each spatial unit we calculate and maximise the expected profit per hectare in order to determine the most profitable allocation in this unit. Thereby risk aversion as well as decreasing return to scale are assumed. The sum of these separately optimised allocations is equivalent to the global optimal allocation.

By using spatially explicit potential yields in the optimisation, the results account for geographic and biophysical heterogeneity of land and assure the spatial detail required for a data exchange with a global state-of-the-art vegetation model. Prices instead are defined on a regional level, to enable coupling to a state-of-the-art world trade model.

2.2. Implementation

We derive the allocation algorithm by maximising the achievable profit per hectare of each spatial unit. Profit per hectare π of one grid-cell is represented by:

$$\pi = \sum_{k=1}^{n} \left(p_k \alpha_k l_k - \tilde{c_k} \bar{L} l_k^2 \right) - \gamma \mathbb{V}\mathrm{ar} \left[\sum_{k=1}^{n} (p_k \alpha_k l_k - \tilde{c_k} \bar{L} l_k^2 \right] \tag{1}$$

The first part of the equation describes the expected profit, where p_k is the price per product unit, α_k is the productivity per area and l_k denotes the share of total area $\bar{L}$ allocated to crop $k \in \{1 \ldots n\}$ of n crops. $\tilde{c_k}$ is the cost parameter for crop k. Total costs are assumed to increase in land according to

$$\begin{aligned} C \quad &= \quad \sum_{k=1}^{n} \mathcal{C}_k(L_k) L_k \\ &\text{with} \quad \mathcal{C}_k(L_k) = \tilde{c_k} L_k, \forall k \in \{i \ldots n\} \\ \Rightarrow \quad C \quad &= \sum_{k=1}^{n} \tilde{c_k} L_k^2 \end{aligned} \tag{2}$$

where $L_k = l_k \bar{L}$ denotes the area allocated to crop k.

The second term of equation (1) represents the risk aversion of the representative land-owner and implicitly accounts for crop rotation considerations. To minimize the risk monoculture is avoided in favour of a crop mix. We quantify the perception of riskiness by the temporal variance of the expected profit, weighted by a risk aversion factor $0 < \gamma < 1$.

Maximising π under the constraint that the land shares need to add up to a total not greater than one, an explicit expression for the land-share l_i allocated to crop $i \in \{1 \ldots n\}$ can be derived:

$$\max[\pi] \qquad \text{s.t.} \textstyle\sum_{k=1}^{n} l_k \leq 1$$

$$\Rightarrow l_i = \frac{\frac{1}{2} \sum_k \frac{\beta_i - \beta_k}{c_k + \gamma \sigma_k^2} + 1}{\sum_k \frac{c_i + \gamma \sigma_i^2}{c_k + \gamma \sigma_k^2}} \tag{3}$$

where for convenience $\beta_k = p_k \alpha_k$ displaces the profitability of crop k, $\sigma_k^2 = \mathbb{V}\mathrm{ar}[\beta_k]$ displaces the respective variance; $c_k = \tilde{c_k} \bar{L}$. The temporal variability of total costs is assumed to be negligible compared to the variability of prices and productivities.

In the applied model, cost parameters and risk aversion factors for each spatial unit are determined by calibration. Variances are calculated from five preceding time-steps (initialised by the variance of the complete time-horizon). For the allocation decision of time t, prices and potential yields of time $t-1$ are assumed to be decisive. Prices are defined for world-regions in 5-year time-steps, reflecting the temporal and spatial structure of common state-of-the-art global trade models. Potential yields are defined on a finer spatial resolution and on a yearly basis, analogous to common state-of-the-art vegetation models. To account for memory effects, we calculate the decisive yield $\alpha(t)$ as the weighted mean of the actual yield $\widetilde{\alpha(t)}$ of the respective and the decisive yield of the preceding time-step $\alpha(t-1)$:

$$\alpha(t) = (1-m)\alpha(t-1) + m\tilde{\alpha}(t) \tag{4}$$

In current simulations, m is set to 0.3 since this gives a reasonable fit to the data. We apply the same relationship to the variance.

To avoid negative allocation, negative shares are set to zero and the allocation process is repeated for the remaining crops.

3. Calibration and validation

As emphasised we base the derived algorithm on the assumption that profit maximisation is a predominant driver of human induced land-use changes. Below, we assess the validity of this assumption as well as the suitability of the developed model for its purpose.

As a first step, we inspect the derived algorithm analytically concerning its mathematical dynamics to assure an accordance with intuitive logic. Secondly, we evaluate the model numerically to assess the performance and to identify potentials and limits. For this, we use the calibrated model to reproduce historical land-use changes and compare the results to observed data with respect to temporal and spatial accordance.

3.1. ALGORITHM DYNAMICS

The major drivers of land allocation in KLUM are profitability β and its variability σ^2 of each crop. In the following we study the impact of changes in a crop's β_i and σ_i^2 on its own land-share l_i and the remaining crop's land-shares $l_{j\neq i}$. Solving the respective derivatives of the allocation algorithm equation (3) yields:

$$\frac{\partial l_i}{\partial \beta_i} = \frac{1}{2}\frac{\sum_{k\neq i}\frac{1}{c_k+\gamma\sigma_k^2}}{\sum_k \frac{c_i+\gamma\sigma_i^2}{c_k+\gamma\sigma_k^2}} > 0 \tag{5}$$

$$\frac{\partial l_i}{\partial \sigma_i^2} = -l_i\gamma\frac{\sum_{k\neq i}\frac{1}{c_k+\gamma\sigma_k^2}}{\sum_k \frac{c_i+\gamma\sigma_i^2}{c_k+\gamma\sigma_k^2}} < 0 \tag{6}$$

$$\frac{\partial l_j}{\partial \beta_i} = -\frac{1}{2}\frac{\frac{1}{c_j+\gamma\sigma_j^2}}{\sum_k \frac{c_i+\gamma\sigma_i^2}{c_k+\gamma\sigma_k^2}} < 0 \quad (7)$$

$$\frac{\partial l_j}{\partial \sigma_i^2} = l_i\gamma\frac{\frac{1}{c_j+\gamma\sigma_j^2}}{\sum_k \frac{c_i+\gamma\sigma_i^2}{c_k+\gamma\sigma_k^2}} > 0 \quad (8)$$

The results are intuitive: an increase in a crop's profitability increases its own and decreases the remaining land-shares; an increase in a crop's riskiness decreases its own and increases the remaining land-shares. The total amount of changes naturally adds up to zero.

Furthermore, interpreting σ^2 as a measure of riskiness, the results show that the effect of riskiness depends on the allocated share. $\tilde{l} = \frac{1}{2\gamma}$ marks the share of land for which a change in riskiness and a change in profitability are valued equally; for shares greater than $\tilde{l}$, riskiness is valued higher than profitability whereas for shares lower than $\tilde{l}$, profitability is more influential than the risk. Restricting the risk aversion parameter to be $0 < \gamma < 1 \Rightarrow \tilde{l} \geq 0.5$ implies that at most riskiness dominates for crops planted at more than half of total cropland. Calibration exercises with unbound γ support the assumed restriction. Only for very few countries (mostly countries with problematic data) risk aversion exceeds the value of one. For calibration with bound γ for nearly all countries $\gamma < 0.5 \Rightarrow \tilde{l} > 1$, implying that in the respective country profitability always dominates risk (see appendix table VI).

3.2. Numerical assessment

For the numerical assessment we use the available data of FAOSTAT (FAO, 2004) for the time-period 1966-1997 on yield, prices and harvested area. We aggregate the data of 134 available crops to 8 aggregates[2] (as shown in table I). Prices are standardized to constant US dollars based on year 1995, by means of GDP data and inflation-rates as documented in the World Development Indicators (World Bank, 2003) [3]. Excluding countries with data for less than 6 years or 1 crop-aggregate leaves us with 163 countries for the validation exercise (see appendix table V). For the moment, we prefer the national resolution to a subnational grid-resolution as consistent data are readily available. Prices are aggregated to 16 regions (see table II) and averaged over 5 years in order to imitate the coupling situation in most IAMs, where economic trade models commonly operate on coarse spatial and temporal resolution. We assume the total available land $\bar{L}$ to stay constant during the simulation.

Table II. World regions in KLUM. The affiliation of countries is presented in the appendix table V

Acronym	Name
USA	USA
CAN	Canada
WEU	Western Europe
JPK	Japan and South Korea
ANZ	Australia and New Zealand
CEE	Central and Eastern Europe
FSU	Former Soviet Union
MDE	Middle East
CAM	Central America
SAM	South America
SAA	South Asia
SEA	Southeast Asia
CHI	China, North Korea & Mongolia
MAF	Mediterranean Africa
SSA	Subsaharan Africa
SIS	Small Island States

For every country we use the first half of the available time-period for calibrating risk-aversion and cost parameters. For this, we minimise the sum of mean-squared-errors of model results and observed data [4]. In the optimisation the cost parameters $\tilde{c}_{k\in\{1\ldots n\}}$ are restricted to be positive and in the same order of magnitude as the revenues $\beta_{k\in\{1\ldots n\}}L_{k\in\{1\ldots n\}}$ (notation as in preceding equations); risk aversion parameters are forced to satisfy $0 < \gamma < 1$. In order to study the performance of the calibrated model we use the data of the second half of the available time-period to calculate the evolving crop-pattern and we compare the results to the observed data on harvested area.

Figure 1 - 3 highlight different aspects of the model performance. In Figure 1 we compare the global pattern of prevailing crops for modelled and observed allocation. The prevailing crop is defined as the crop with the highest area-share, averaged over the validation time-period. Note that this does neither necessarily imply that the majority of the available land is allocated to the prevailing crop, nor that the crop has a predominant economic relevance in that country.

In order to evaluate the sub-national patterns, we depict the percentage deviation of simulated from observed means in figure 2 and the

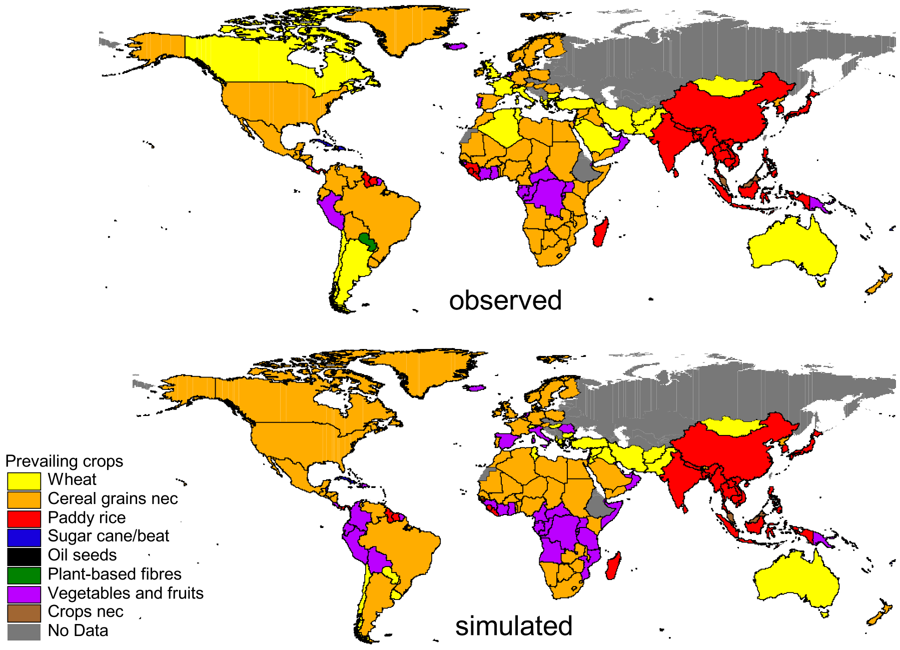

Figure 1. The pattern of prevailing crops for the validation period.

correlation of model results and observed data in figure 3. We do this for *wheat*, *rice* and *cereal grains nec*. The accordance of means reflect the spatial exactness of the simulated pattern, whereas the correlation quantifies the degree of temporal accuracy. As a measure of correlation we chose the Fisher-Z transformed correlation coefficient, since in its value it accounts for the amount of data points and, moreover, allows a direct comparison of different values. In order to emphasise units where the depicted crop exceeds a certain relevance with respect to the cultivated area share, we highlight countries with a respective land share $l \geq 0.1$.

All figures show a good accordance of model results and observed data. Only for 33 of the 163 countries the prevailing crops are falsely predicted. The number and percentage of countries with false predicted prevailing crop in each region and observed and simulated prevailing crop on the regional aggregation can be found in table III. Falsely predicted prevailing crops are often a result of similar price and/or yield structure for two crops (such as wheat and cereal grains nec for price and yield in Canada, or the price of cereal grains and vegetables and fruits in Subsaharan Africa). Similar profitabilities can lead to two dominant crops. The dominance of one over the other is a mat-

Table III. Number and percentage of false predicted prevailing crops per region. Observed and simulated prevailing crop on regional aggregation.

Region	false/total	%	observed	simulated
ANZ	0/2	0	wheat	wheat
CAM	0/8	0	cereal grains nec	cereal grains nec
CAN	1/1	100	wheat	cereal grains nec
CEE	2/5	40	cereal grains nec	cereal grains nec
CHI	0/3	0	paddy rice	paddy rice
JPK	0/2	0	paddy rice	paddy rice
MAF	1/5	20	wheat	cereal grains nec
MDE	3/14	~ 21	wheat	wheat
SAA	0/7	0	paddy rice	paddy rice
SAM	6/13	~ 46	cereal grains nec	cereal grains nec
SEA	1/11	~ 9	paddy rice	paddy rice
SIS	5/29	~ 17	Sugar cane/beats	Sugar cane/beats
SSA	7/43	~ 16	cereal grains nec	cereal grains nec
USA	0/1	0	cereal grains nec	cereal grains nec
WEU	7/19	~ 37	cereal grains nec	cereal grains nec

ter of habit or politics, which cannot be reproduced by the chosen mechanism. Even though the highest percentage of failure occurs in Canada, Western Europe and South America, only for Canada and Mediterranean Africa the prevailing crop has been falsely predicted on a regional aggregation of area and area shares.

The deviations of simulated and observed mean are in general rather low. For area shares of more than 10% of total cropland, the deviations of simulated and observed mean seldom exceed 20% and are even lower for most of these countries. The same goes for the correlation, which also tends to be better for crops with *relevant* area shares. Of the depicted crops, the results for *wheat* show the best correlation and the results for *cereal grains nec* are in greatest accordance with the observed mean. *Paddy rice* projections are weakest in correlation and mean, which can be interpreted as just another aspect of the fact that crops with high area shares are reproduced better. The overall picture shows that the model is weakest in Africa and strongest in Asia, except for *paddy rice*, which is weakest in China. The comparably bad reproduction of *paddy rice* in China results from a strong decrease in China's *paddy rice* production in favour of *oil seeds* and *other crops* which is not represented by the model in the validation period. This trend is not explainable by the profitability of the crops as it is not

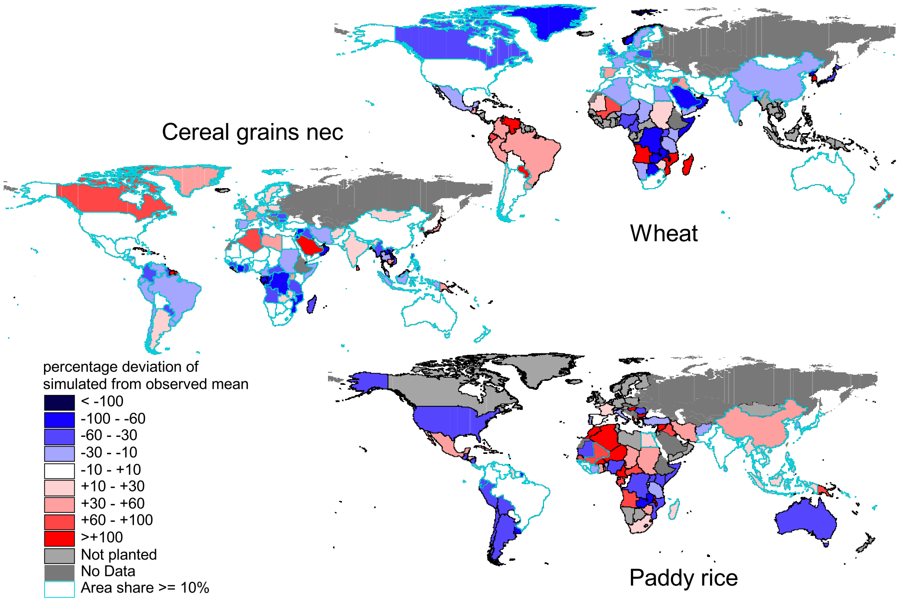

Figure 2. The percentage deviation of mean area share over the validation period for model results to observed data. For blue countries the model underestimates the changes, for red countries the changes are overestimated by the model

visible in price and yield data. Thus this change cannot be reproduced by the model.

4. Future scenarios

Tan and Shibasaki (2003) present estimates of changes in yield due to climate change of the major crops for several countries around the world. They utilise climate change data from the first version of the *Canadian Global Coupled Model* (CGCM1) [5] to quantify monthly minimum and maximum temperature and precipitation. Adaptation is taken into account by means of changing planting dates.

Based on their estimates for 2050 we determine potential yields under climate change of *wheat*, *paddy rice* and *cereal grains nec*, to simulate the effects of a changing climate on crop allocation. We use the predictions of yield changes in maize to adjust potential production of *cereal grains nec*, even though this is an aggregate of many different cereal crops weighted differently in different countries. However, in many countries maize is the dominant or one of the dominant aggregates, suggesting that this simplification is acceptable. Prices are

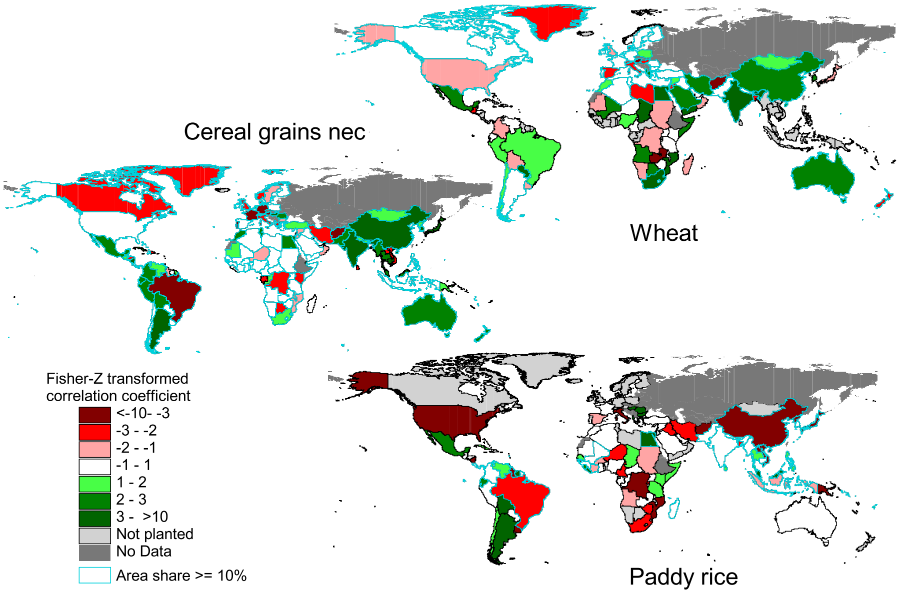

Figure 3. The Fisher-Z-transformed correlation coefficients over the validation period of model results and observed data. Green symbolizes good correlation, whereas red depicts negative correlation.

assumed to develop with a continued linear trend, as estimated from past years. For future simulations the model is calibrated with the complete dataset, which also includes countries with less than 6 years of data (see appendix table V). We determine the optimal allocation of the 8 crop aggregates for the 83 countries used in Tan and Shibasaki's study for 1997 and 2050. In the simulation the variances σ^2 are set to the temporal average of past variances. Potential productions of the remaining crop aggregates are assumed to continue on the level of 1997.

In figure 4, we depict the resulting area changes for *wheat*, *paddy rice* and *cereal grains nec* (the complete set of results is summarized in the appendix table VII). They show a decline in area for all 3 depicted crops in nearly all countries. Especially the area in *cereal grain* production is reduced up to complete disappearance in countries of the Eastern Bloc. The greatest increase of area for *cereal grains nec* can be found in Bangladesh and Japan by 20–32% . For *wheat*, area increases in South America by up to 75% , in Canada by some 7% and in Eastern Europe and Japan by up to 55% . The greatest decrease of area for *wheat* takes place in Africa, where it partly vanishes to zero and South Asia/China, where the area is nearly halved. Also *paddy rice* cultivation tends to disappear in Africa and is strongly reduced in most other

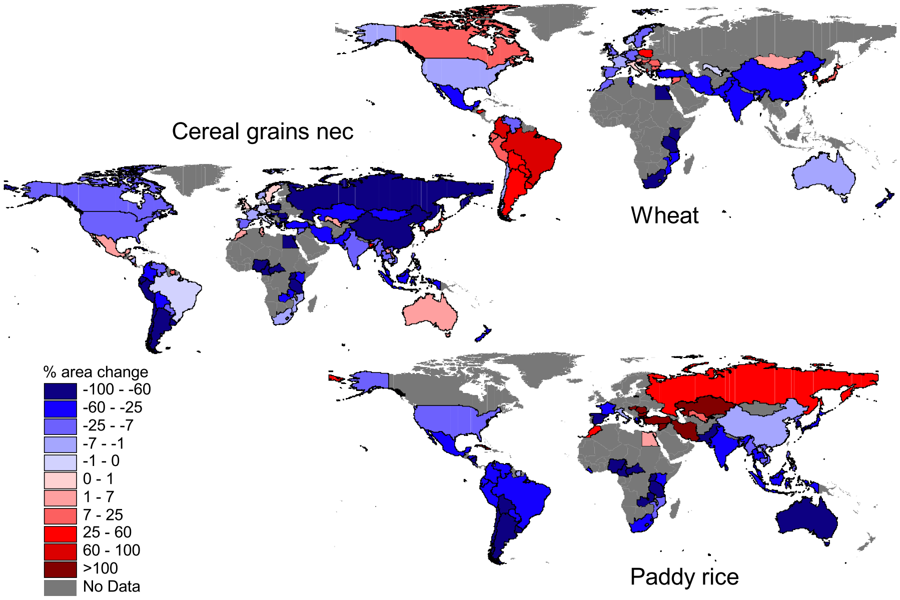

Figure 4. Percentage area changes 1997-2050 for *wheat*, *cereal grains nec* and *paddy rice* under climate change (scenario A). Blue depicts negative, red positive changes

countries. However, in the Former Soviet Union and the Middle East, the area share of *paddy rice* increases by up to 150–166% (Hungary and Kazakhstan). The area changes reflect a shift in total global crop production away from major crops, such as wheat, paddy rice, other cereal grains and also oil seeds towards minor crops, such as vegetables and fruits, sugar crops, plant based fibres and other crops (see table IV).

To quantify the impacts of climate change, figure 5 shows changes in total revenue from crop production from 1997 to 2050 (the respective results are summarized in the appendix table VIII). Strong gains govern the overall picture. Only North America, Sweden and Italy show losses in revenue. They range from -12% to -73% (USA and Italy). Greatest gains are achieved on the Asian continent where for many countries revenue is up to quintuple. Some African and South American countries double or even triple there revenue of crop production. Compared to this, the gains of about 2–50% obtained in Western Europe are modest.

To highlight the importance of land-use changes for these impact assessments, the lower graph of figure 5 presents percentage deviation of revenue changes calculated without area changes from the above depicted changes. For nearly all the simulated countries losses are overestimated whereas gains are underestimated, if area changes are not taken

Table IV. Percentage change of total global production 1997-2050 for all simulated crops.

Crop	Scenario A %	Scenario B %
Wheat	-12.84	+0.18
Paddy rice	-21.62	-0.12
Cereal grains nec	-39.95	-0.10
Vegetables and fruits	+78.41	+0.09
Sugar cane/beats	+54.66	-0.09
Plant-based fibres	+43.16	+0.09
Oil seeds	-9.74	-0.17
Crops nec	+44.60	+0.17

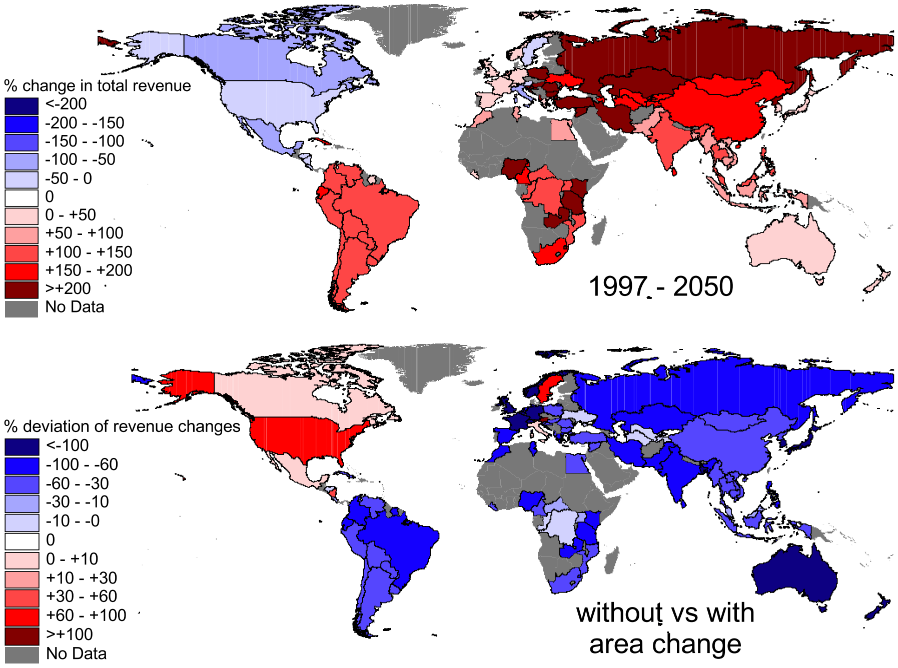

Figure 5. **Changes in revenue under climate change (scenario A).** The upper graph shows the percentage changes in revenue under consideration of the simulated area changes. The below picture shows the percentage deviation of revenue changes ignoring area changes from the above estimates.

into account. For a few, mainly wealthy countries, such as Switzerland, Germany, Japan and Australia, even the sign of predicted revenue change varies between the different estimates (depicted in dark blue). For all these countries estimates including area changes predict a gain in revenue, whereas the estimates ignoring area changes predict losses.

Besides the simulation of future allocation under climate change (scenario A), we run two diagnostic scenarios - one, in which only yields change and prices are kept constant (scenario B) and one, where prices change and yields are kept constant (scenario C). See appendix table VII for the results. The results of the diagnostic scenarios show that the projected effects of climate change on revenue and crop allocation are mainly a result of the assumed price changes. They exceed the applied yield changes by up to 2 orders of magnitude. Figure 6 shows the changes in area for scenario B as a reference for the impact of the yield changes. The pattern considerably differs from the predictions of scenario A in figure 4. Besides the fact that for all depicted crops area changes are naturally much lower than in scenario A, additionally the occurrence of decreases and increases is more balanced. However, decreases still dominate the picture. For *paddy rice*, we find most increases of area in the Asian countries but also in some South African and South and North American countries. Besides in Zambia, the decrease of area is largest in the Russian Federation, which stands in strong contrast to the predicted increase in area for this country in scenario A. For *wheat* the production in Europe and South America seems to move from the north to the south (Scandinavia is an exception). Whereas the greatest decrease in area for *wheat* can be seen in the south African countries, great increase can be observed in New Zealand and China. This again stands in contrast to the gains of these countries, predicted in scenario A. In contrast to *wheat*, for *cereal grains nec* the production seems to move from the south to the north (again Scandinavia is an exception). Among others, great increases in area are expected in Poland, which in scenario A is one of the countries where wheat production disappears. The decrease in area is greatest in Central Africa, which is in accordance with predictions of scenario A.

Also in scenario B we observe a shift of global crop production (table IV). However, the global production changes are smaller than in scenario A and the pattern is different. Paddy rice, other cereal grains and oil seeds production declines in favour of wheat, other crops, fruits and vegetables and plant-based fibres. The increase is highest for global wheat production, in contrast to the predicted decrease of wheat production in scenario A. For sugar crops the decline in global production in scenario B stands in contrast to the increase in scenario A.

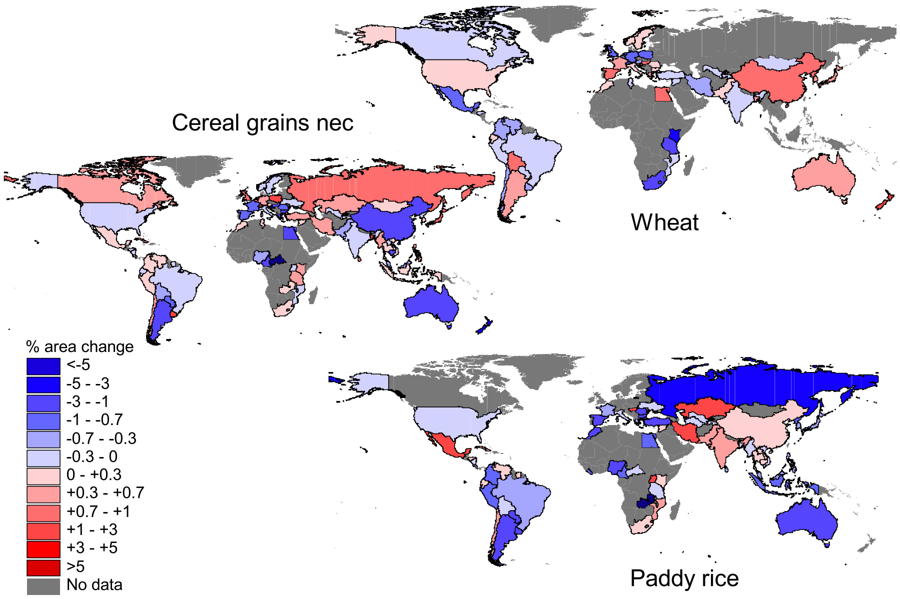

Figure 6. Percentage area changes 1997-2050 for *wheat*, *cereal grains nec* and *paddy rice* under climate change (scenario B). Blue depicts negative, red positive changes

The pattern of resulting revenue changes is notably different as well for scenario B compared to scenario A (see figure 7). In contrast to the prevailing gains in revenue of scenario A, in scenario B more countries experience a loss in revenue. Gains mainly occur in South Asia, South Africa and North Europe, but also Canada and Mexico and Kazakhstan strongly gain from climate change. Losses govern the rest of the global pattern.

The pattern of percentage deviations of revenue change without area changes to those with area changes is not as straight forward as for scenario A. For nearly all South American countries, for the USA, China and Australia and some African and European countries, losses are over- and gains are underestimated when ignoring area changes. But for larger parts of Eastern Europe and the former Soviet Union, gains are overestimated and losses are underestimated. In contrast to scenario A, in scenario B rather for poorer countries such as Cameroon, Uganda and Zambia the revenue-change predictions differ in sign if area changes are ignored.

The results of the different scenarios also show that the allocation change under simultaneous price and yield changes differ from the linear sum of allocation change under sole price and sole yield changes. In figure (8) the percentage deviation of the summed allocation change of

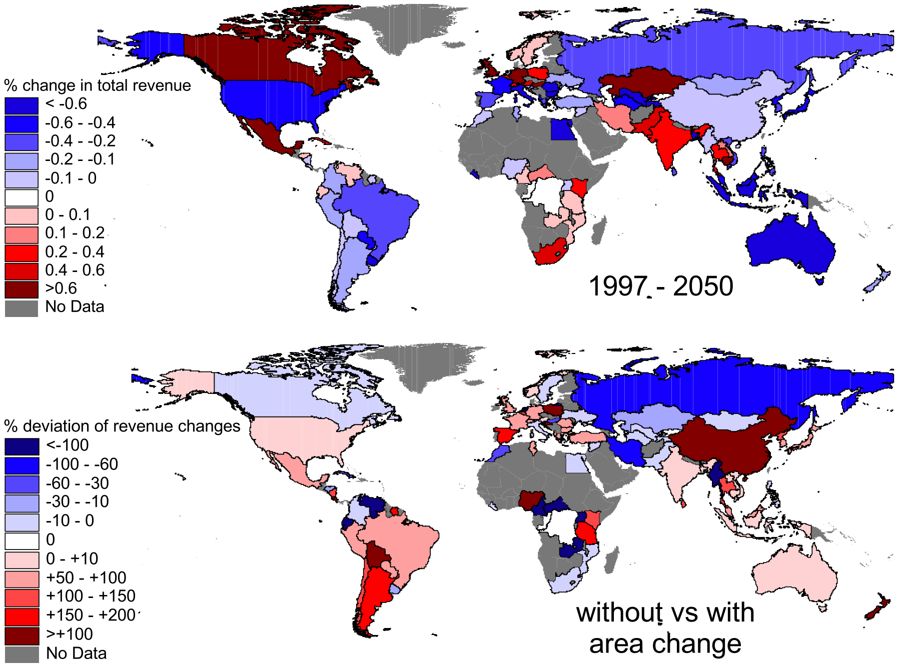

Figure 7. **Changes in revenue under climate change (scenario B).** The upper graph shows the percentage changes in revenue under consideration of the simulated area changes. The lower picture shows the percentage deviation from the above estimates of revenue changes ignoring area changes.

scenario B and C from the allocation change of scenario A are shown exemplary for *wheat*, *paddy rice* and *cereal grains nec*. We find that the deviation are highest for *cereal grains nec*. They range from +255% up to -142%, implying that some changes even differ in sign. However, most deviations are in the range of up to ±10%. For *paddy rice* area changes are overestimated by the simple sum of price and yield effected changes for large parts of the world. For *wheat* and *cereal grains nec* the picture is more diverse. However, it can be noted, that in many countries an overestimation of the change in area allocated to *wheat* comes along with an underestimation of the area change in *cereal grains nec*, and vice versa. This indicates that especially the representation of competition among similar crops is weak, if price and yield interactions are ignored.

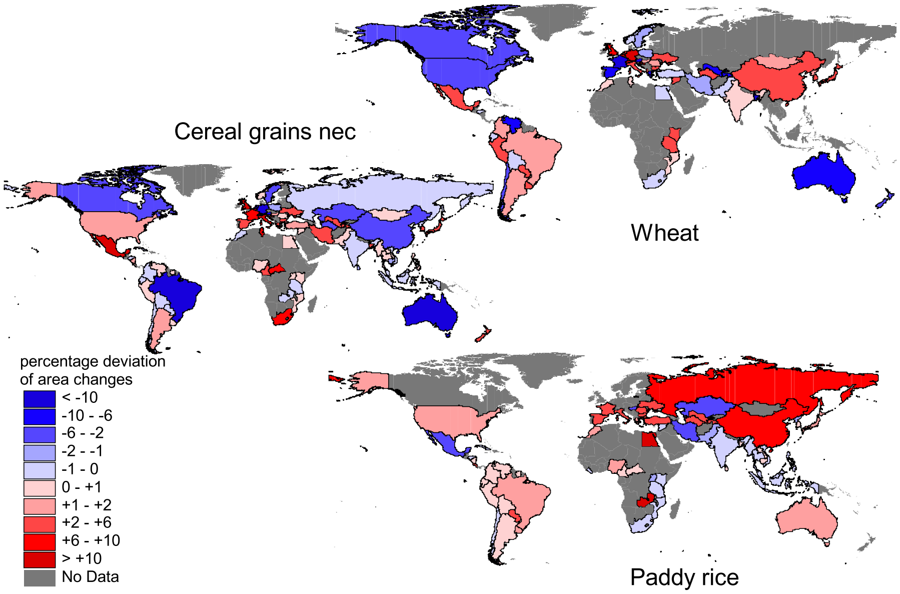

Figure 8. Percentage change of summed allocation-changes of scenario B and C from the allocation-changes under scenario A. For blue countries area changes are underestimates, for red countries the changes are overestimated if effects of price and yield are simply summed up.

5. Discussion and conclusion

Studying environmental impacts on the economy and vice versa requires an effective representation of land-use as the essential link of biosphere and economy. We present a global agricultural land-use model, made to dynamically couple global state-of-the-art vegetation and economy models. In order to capture the economic as well as the biophysical aspects of land-use decisions the model is motivated by profit maximisation, where potential production enters as a spatial explicit decision factor. The restriction to only the essential parameters as well as the motivationally based approach qualifies the model for long-term predictions and online coupling.

The evaluation of the model shows that the derived algorithm is capable of reproducing essential dynamics of land-use decisions, theoretically as well as practically. The dynamics of the derived algorithm are in line with intuitive logic. Global, as well as national past allocation patterns can be reproduced with good accordance. False predictions are often a consequence of impacts that do not necessarily show up in price and yield data, such as political changes or local habits. A more flexible cost structure could improve the capability of the model to better adapt to extreme changes.

The partly weak temporal accordance of the model results with observation indicates that the causal timing of profitability impacts is not as straight forward as assumed in the model. It seems that the time-lag between a change in price or yield and its effect on the allocation can vary for crop, country and even in time. The good accordance of simulated and observed means, however, shows that only the exact timing of the impact is problematic whereas in average profitability changes have the expected effect on the crops allocation. The comparably poor performance of the model for the African continent can be interpreted in two ways; on the one hand the influence of existence farming in Africa is still much greater than in developed countries (Collier and Gunning, 1999), on the other hand data sources for Africa are often inconsistent and doubtful which makes a sound evaluation difficult.

Altogether the evaluation results suggest that despite the weaknesses the trends of global crop allocation are sufficiently reproduced for a global analysis or a data exchange with global economy and vegetation models, respectively.

Simulations of crop allocation under climate change project a large decline of major crops (such as wheat, paddy rice and other cereal grains) in favour of minor crops (such as vegetables and fruits, sugar crops and plant-based fibres) for most countries around the world. Increases are concentrated for wheat in South America and for paddy rice in the Former Soviet Union. KLUM predicts an increase of total revenue of crop production mainly everywhere, save North America. The increases are notably greater in developing than in developed countries. These predictions, however, are mainly determined by the price scenario, which dominates the much smaller yield changes. The pattern of only yield induced impacts looks fundamentally different: whereas positive and negative area changes are more balanced than in the first scenario, the changes in revenue are mainly negative. For some regions we find a shift of wheat production to the south and of other cereals to the north, indicating that wheat is replaced in northern countries by maize or other cereal grains.

The chosen linearly extrapolated price trends imply that minor crops, (such as vegetables and fruits, sugar crops and plant-based fibres) gain in price in comparison to major crops (such as wheat, paddy rice and other cereals). The prices of the minor crops have been increasing or slowly decreasing over the reference years, whereas for major crops prices have been declining more rapidly. In Asian countries and the eastern block, and to a lesser extent also in African countries, prices have been increasing in the reference period for all or at least most of the crops (again with the tendency to increase faster for minor crops). This directly explains the great gains on the Asian continent, in comparison to moderate gains or even losses of the developed world.

Assuming that the chosen price and yield projections are realistic, the results of the 3 different scenarios suggest that price changes will dominate or even outweigh the impacts of climate change. Yet, it should be noted, that the estimates of yield changes of Tan and Shibasaki are rather low, compared e.g. to changes of Rosenzweig et al. (1993), which are similar in sign but up to tenfold in magnitude. Our price extrapolations assume on the one hand, that prices are not affected by climate change and on the other hand, that they are independent of market development: according to these trends the majority of people would change their diet from common grains to fruits, vegetables, sugar crops and plant based fibres. Both implications are rather unlikely. So, the results emphasise once more the necessity to model the complete feedback loop of economy and environment, in order to capture feedbacks of prices and productivities as well as feedbacks and competition among different economic productions and sectors. This research is in progress. The importance of a proper inclusion of land-use changes in impact calculations is pointed up by the presented deviations of calculations with and without area changes. Monetary impacts can be underestimated by more than 200%, and even differ in sign, if land-use changes are ignored.

In a more balanced scenario of prices and yield changes not only the picture of changes would alter but also the effect on the decision of joint price and yield changes would increase. Even for the unbalanced scenario a strong non-linearity in the summed effect of price and yield changes can be detected; the effect is greatest for *cereal grains nec*, which is the crop with the greatest yield changes. Especially the representation of competition among similar crops suffers from an separate inclusion of price and yield effects on allocation. This emphasises the importance to include economic as well as biophysical aspects of land-use change decisions in a common framework, as done in KLUM.

All things considered, the developed model proves as a step in the right direction. Already the offline simulations allow for interesting dynamics and outline the importance of an appropriate inclusion of land-use changes into simulations of future development. To gain an insight into the dynamics of the feedbacks between economy, land-use changes and vegetation, the most important next step is to couple KLUM to a global economic trade model and a global vegetation model. Both couplings are in progress. An increase of the spatial resolution, as well as a change to a grid-pattern is planned, to match the spatial resolution of common vegetation models. Moreover, to allow for commonly not planted crops to conquered new regions, calibration-parameters for such crops need to be found. For the further future an extension of the agricultural sector to pasture and inclusion of other than agricultural land-uses is planned, as well as an explicit connection to water.

Acknowledgements

We like to thank Katrin Rehdanz for valuable discussions and Christine Röckmann for helpful comments. The Volkswagen Foundation and the Michael Otto Foundation provided welcome financial support.

Notes

[1] German for *small*, avoiding the acronym *SLUM*

[2] In the aggregation yields are weighted by the crop's area share and prices by the crop's production share

[3] For some countries WDI (2001) had to be used due to the local currencies choice in the FAOSTAT data

[4] The optimisation was done by means of the LSQNONLIN function of MATLAB 6.1

[5] Provided by the Intergovernmental Panel on Climate Change (IPCC)

References

Alcamo, J., G. J. J. Kreileman, M. Krol, and G. Zuidema: 1994, 'Modelling the Global Society-Biosphere-Climate System: Part 1: Model Description and Testing'. *Water, Air, and Soil Pollution* **76**, 1–35.

Balkhausen, O. and M. Banse: 2004, 'Modelling of Land Use and Land Markets in Partial and General Equilibrium Models: The Current State'. The Impact of decoupling and Modulation in the Enlarged Union: a sectoral and farm level assessment Workpackage 9, Deliverable No.3, IDEMA Project, Institute of Agricultural Economics, University of Göttingen, Göttingen.

Burniaux, J.-M.: 2002, 'Incorporating carbon sequestration into CGE models: a prototype GTAP model with land uses'. GTAP Resource 1144. Electronic version at http://www.gtap.agecon.purdue.edu/resources/res_display.asp?RecordID=1144 [Accessed May 2005].

Burniaux, J.-M. and H.-L. Lee: 2003, 'Modelling Land Use Changes in GTAP'. Conference paper, Sixth Annual Conference on Global Economic Analysis, The Hague, The Netherlands. Electronic version at http://www.gtap.agecon.purdue.edu/resources/res_display.asp?RecordID=1297 [Accessed May 2005].

Collier, P. and J. W. Gunning: 1999, 'Explaining African Economic Performance'. *Journal of Economic Literature* **37**, 64–111.

Darwin, R., M. Tsigas, J. Lewandrowski, and A. Raneses: 1995, 'World Agriculture and Climate Change: Economic Adaptations'. Agricultural Economic Report 703, Natural Resources and Environment Division, Economic Research Service, U.S. Department of Agriculture, Washington, D.C., USA.

Darwin, R., M. Tsigas, J. Lewandrowski, and A. Raneses: 1996, 'Land use and cover in ecological economics'. *Ecological Economics* **17**, 157–181.

FAO (Food and Agriculture Organization of the United Nations): 2004, 'FAOSTAT Database'. http://apps.fao.org.

GTAP (Global Trade Analysis Project): 2005, 'GTAP Database'. http://www.gtap.agecon.purdue.edu/.

Heistermann, M., C. Müller, and K. Ronneberger: submitted, 'Lost in Space? Achievements, Deficits and Potentials of Global Land-Use Models'. Electronic version at http://www.landuse-future.de/files/review_abstract.pdf [Accessed May 2005].

Hertel, T. W. (ed.): 1997, *Global trade analysis.* Cambridge.: Cambridge University Press.

Hsin, H., F. van Tongeren, J. Dewbre, and H. van Meijl: 2004, 'A New Representation of Agricultural Production Technology in GTAP'. Conference paper, 7th Annual Conference on Global Economic Analysis, Washington DC, United States. Electronic version at http://www.gtap.agecon.purdue.edu/resources/res_display.asp?RecordID=1504 [Accessed May 2005].

Kok, K. and T. A. Veldkamp: 2001, 'Evaluating impact of spatial scales on land use pattern analysis in Central America'. *Agriculture Ecosystems and Environment* **85**, 205–221.

Krausmann, F.: 2004, 'Milk, manure and muscle power. Livestock and the transformation of pre-industrial agriculture in Central Europe'. *Human Ecology* **32**, 735–772.

Kuhn, A.: 2003, 'From World Market to Trade Flow Modelling - The Re-Designed WATSIM Model -'. Final report, Institute of Agricultural Policy, Market Research and Economic Sociology, Bonn, Germany.

Lambin, E. F., H. J. Geist, and E. Lepers: 2003, 'Dynamics of land-use and land-cover change in tropical regions'. *Annual Review of Environment and Resources* **28**, 205–241.

Oga, K. and K. Yanagishima: 1996, 'International Food Policy and Agricultural Simulation Model'. JIRCAS Working Report 1, Japan International Research Center for Agricultural Sciences (JIRCAS), Ministry of Agriculture, Forestry and Fisheris, Tsukuba, Japan.

Petschel-Held, G., A. Block, M. Cassel-Gintz, J. Kropp, M. K. B. Lüdeke, O. Moldenhauer, F. Reusswig, and H. J. Schellnhuber: 1999, 'Syndromes of Global Change a qualitative modelling approach to assist global environmental management'. *Environmental Modeling and Assessment* **4**, 295–314.

RIVM: 2001, 'The IMAGE 2.2 model documentation'. Technical report, National Institute of Public Health and the Environment, Bilthoven, NL. Electronic version at http://arch.rivm.nl/image/ [Accessed Mar. 2005].

Rosengrant, M. W., S. Meijer, and S. A. Cline: 2002, 'International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT): Model Description'. Technical report, International Food

Policy Research Institute, Washington, DC. Electronic version at http://www.ifpri.org/themes/impact/impactmodel.pdf [Accessed May 2005].

Rosenzweig, C., M. L. Parry, G. Fischer, and K. Frohberg: 1993, ‘Climate Change and World Food Supply’. Research Report 3, Environmental Change Unit, University of Oxford, Oxford.

Sands, R. D. and M. Leimbach: 2003, ‘Modeling agriculture and land use in an integrated assessment framework’. *Climatic Change* **56**(1), 185–210.

Stephenne, N. and E. F. Lambin: 2001a, ‘Backward Land-Cover Change Projections for the Sudano-Sahelian Countries of Africa with a Dynamic Simulation Model of Land-Use Change (SALU)’. In: T. Matsuno and H. Kida (eds.): *Present and Future of Modeling Global Environmental Change: Toward Integrated Modeling.* TERRAPUB.

Stephenne, N. and E. F. Lambin: 2001b, ‘A dynamic simulation model of land-use changes in Sudano-sahelian countries of Africa (SALU)’. *Agriculture Ecosystems and Environment* **85**, 145–161.

Strengers, B. J.: 2001, ‘The Agricultural Economy Model in IMAGE 2.2’. RIVM report 481508015, RIVM, Bilthoven, Netherlands. Electronic version at http://www.rivm.nl/bibliotheek/rapporten/481508015.pdf [Accessed May 2005].

Tan, G. and R. Shibasaki: 2003, ‘Global estimation of crop productivity and the impacts of global warmings by GIS and EPIC integration’. *Ecological Modeling* **168**, 357–370.

Tan, G., R. Shibasaki, K. Matsumora, and K. S. Rajan: 2003, ‘Global research for integrated agricutural land use change modeling.’. In: *Asia GIS Conference 2003 Publications.* Wuhan Science and Technology Conference and Exhibition Center. Electronic version at http://www.hku.hk/cupem/asiagis/fall03/Full_Paper/Tan_Guoxin.pdf [Accessed May 2005].

Toth, F. L., T. Bruckner, H. M. Fuessel, M. Leimbach, and G. Petschel-Held: 2003, ‘Integrated assessment of long-term climate policies: Part1 - model presentation’. *Climatic Change* **56**, 37–56.

van Meijl, H., T. van Rheenen, A. Tabeau, and B. Eickhout: submitted, ‘The impact of different policy environments on land use in Europe’. *Agriculture Ecosystems and Environment.*

van Tongeren, F., H. van Meijl, and Y. Surry: 2001, ‘Global models applied to agricultural and trade policies: a review and assessment’. *Agricultural Economics* **26**, 149–172.

Veldkamp, T. A. and L. O. Fresco: 1995, ‘CLUE-CR: an integrated multi-scale model to simulate land use change scenarios in Costa Rica’. *Ecological Modelling* **91(1996)**, 231–248.

Veldkamp, T. A. and E. F. Lambin: 2001, ‘Predicting land-use change’. *Agriculture Ecosystems and Environment* **85**, 1–6.

Williams, J. R.: 1995, ‘The EPIC’. In: V. P. Singh (ed.): *Computer Models of Watershed Hydrology.* Water Resources Publications, book chapter 25, pp. 909–1000.

World Bank: 2003, ’World Development Indicators’. CD ROM.

Zuidema, G., G. J. van den Born, J. Alcamo, and G. J. J. Kreileman: 1994, ‘Simulating changes in global land-cover as affected by economic and climatic factors’. *Water, Air, and Soil Pollution* **76**, 163–198.

Appendix

A. Model parameters

Table V. Regional aggregation of simulated countries; Countries in italic letters are used only in the calibration for future scenarios

Region	Country	Region	Country	Region	Country
ANZ	Australia	SAA	Afghanistan	SSA	Angola
	New Zealand		Bangladesh		Benin
			Bhutan		Botswana
CAM	Belize		India		Burkina Faso
	Costa Rica		Nepal		Burundi
	El Salvador		Pakistan		Cameroon
	Guatemala		Sri Lanka		Cape Verde
	Honduras				Central African Republic
	Mexico	SAM	Argentina		Chad
	Nicaragua		Bolivia		Congo, Dem. Rep. of the
	Panama		Brazil		Congo, Rep. of the
			Chile		Cote d'Ivoire
CAN	Canada		Colombia		Djibouti
			Ecuador		Equatorial Guinea
CEE	Albania		French Guiana		Gabon
	Bosnia and Herzegovina		Guyana		Gambia, The
	Bulgaria		Paraguay		Ghana
	Croatia		Peru		Guinea
	Hungary		Suriname		Guinea-Bissau
	Macedonia, FYR		Uruguay		Kenya
	Poland		Venezuela		Lesotho
	Romania				Liberia
	Slovenia	SEA	Brunei Darussalam		Madagascar
			Cambodia		Malawi
CHI	China		Indonesia		Mali
	Korea, Dem. People's Rep.		Lao People's Dem. Rep.		Mauritania
	Mongolia		Malaysia		Mozambique
			Myanmar (Burma)		Namibia
FSU	*Azerbaijan*		Papua New Guinea		Niger
	Belarus		Philippines		Nigeria
	Estonia		Singapore		Rwanda
	Georgia		Thailand		Samoa
	Kazakhstan		Vietnam		Senegal
	Kyrgyzstan				Sierra Leone
	Latvia	SIS	Antigua and Barbuda		Somalia
	Lithuania		Bahamas		South Africa
	Moldova		Barbados		Sudan
	Russian Federation		Bermuda		Swaziland
	Tajikistan		Comoros		Tanzania, United Rep.
	Turkmenistan		Cuba		Togo
	Ukraine		Dominica		Uganda
	Uzbekistan		Dominican Republic		Zambia
			Fiji		Zimbabwe
JPK	Japan		French Polynesia		
	Korea, Rep.		Grenada	USA	United States
			Guadeloupe		
MAF	Algeria		Haiti	WEU	Austria
	Egypt		Jamaica		Belgium
	Libyan Arab Jamahiriya		Maldives		Cyprus
	Morocco		Martinique		Denmark
	Tunisia		Mauritius		Finland
			New Caledonia		France
MDE	Iran, Islamic Rep.		Puerto Rico		Germany
	Iraq		Reunion		Greece
	Israel		Sao Tome and Principe		Iceland
	Jordan		Seychelles		Ireland
	Kuwait		Solomon Islands		Italy
	Lebanon		St. Kitts and Nevis		Malta
	Oman		St. Lucia		Netherlands
	Qatar		St. Vincent & Grenadines		Norway
	Saudi Arabia		Tonga		Portugal
	Syrian Arab Rep.		Trinidad and Tobago		Spain
	Turkey		Vanuatu		Sweden
	United Arab Emirates				Switzerland
	West Bank and Gaza				United Kingdom
	Yemen				

Table VI. The risk aversion parameter γ as calculated in the full calibration run with restricted γ

Country	γ	Country	γ	Country	γ
Australia	9.87E-06	Bhutan	2.25E-14	Botswana	0.00141
New Zealand	2.54E-05	India	5.40E-05	Burkina Faso	3.79E-05
Belize	4.83E-05	Nepal	2.22E-14	Burundi	2.22E-14
Costa Rica	2.22E-14	Pakistan	5.85E-05	Cameroon	3.56E-14
El Salvador	2.23E-14	Sri Lanka	2.22E-14	Cape Verde	2.22E-14
Guatemala	0.000127	Argentina	2.94E-05	Central African Republic	2.34E-14
Honduras	2.22E-14	Bolivia	2.43E-14	Chad	0.000266
Mexico	1.12E-11	Brazil	3.07E-05	Congo, Dem. Rep. of the	3.01E-14
Nicaragua	2.22E-14	Chile	2.22E-14	Congo, Rep. of the	2.23E-14
Panama	3.55E-06	Colombia	2.73E-14	Cote d'Ivoire	2.22E-14
Canada	5.15E-05	Ecuador	3.29E-14	Djibouti	3.00E-07
Albania	9.51E-08	French Guiana	2.22E-14	Equatorial Guinea	1.39E-09
Bosnia and Herzegovina	6.68E-07	Guyana	4.02E-05	Gabon	2.22E-14
Bulgaria	2.23E-14	Paraguay	2.30E-14	Gambia, The	2.73E-14
Croatia	5.19E-07	Peru	2.22E-14	Ghana	2.22E-14
Hungary	2.22E-14	Suriname	2.38E-14	Guinea	0.00136
Macedonia, FYR	6.19E-07	Uruguay	2.22E-14	Guinea-Bissau	3.63E-06
Poland	2.15E-07	Venezuela	2.22E-14	Kenya	3.62E-06
Romania	1.54E-07	Brunei Darussalam	1.13E-05	Lesotho	2.22E-14
Slovenia	5.95E-07	Cambodia	2.22E-14	Liberia	2.23E-14
China	1.88E-13	Indonesia	2.26E-14	Madagascar	3.96E-14
Korea, Dem. People's Rep.	1.75E-05	Lao People's Dem. Rep.	7.38E-11	Malawi	4.02E-05
Mongolia	2.22E-14	Malaysia	2.22E-14	Mali	2.22E-14
Azerbaijan	2.68E-09	Myanmar (Burma)	2.23E-14	Mauritania	0.00018
Belarus	1	Papua New Guinea	1.14E-06	Mozambique	0.00122
Estonia	1.38E-05	Philippines	2.62E-14	Namibia	2.39E-14
Georgia	6.34E-10	Singapore	1.63E-05	Niger	2.42E-08
Kazakhstan	1.51E-07	Thailand	1.95E-05	Nigeria	9.65E-07
Kyrgyzstan	9.61E-10	Vietnam	2.71E-14	Rwanda	2.39E-14
Latvia	2.53E-08	Antigua and Barbuda	0.0383	Samoa	5.82E-14
Lithuania	3.91E-08	Bahamas	2.22E-14	Senegal	2.43E-14
Moldova	0.999	Barbados	2.23E-14	Sierra Leone	2.23E-14
Russian Federation	6.50E-08	Bermuda	0.1	Somalia	3.52E-14
Tajikistan	0.1	Comoros	2.33E-06	South Africa	3.05E-14
Turkmenistan	0.999	Cuba	3.23E-06	Sudan	2.54E-12
Ukraine	0.992	Dominica	0.121	Swaziland	2.22E-14
Uzbekistan	7.05E-05	Dominican Republic	2.22E-14	Tanzania, United Rep.	2.22E-14
Japan	2.22E-14	Fiji	3.03E-05	Togo	7.51E-05
Korea, Rep.	5.55E-07	French Polynesia	1	Uganda	7.84E-06
Algeria	2.78E-05	Grenada	2.22E-14	Zambia	1.68E-08
Egypt	4.00E-06	Guadeloupe	7.23E-06	Zimbabwe	4.22E-14
Libyan Arab Jamahiriya	1.18E-05	Haiti	2.22E-14	United States	0.000591
Morocco	8.66E-06	Jamaica	2.00E-07	Austria	2.23E-14
Tunisia	2.22E-14	Maldives	2.56E-06	Belgium	6.20E-06
Iran, Islamic Rep.	2.61E-14	Martinique	3.57E-05	Cyprus	2.22E-14
Iraq	5.71E-06	Mauritius	2.25E-14	Denmark	4.27E-14
Israel	2.22E-14	New Caledonia	9.58E-07	Finland	1.34E-05
Jordan	2.22E-14	Puerto Rico	0.0916	France	2.22E-14
Kuwait	2.22E-14	Reunion	6.08E-07	Germany	4.14E-14
Lebanon	2.47E-14	Sao Tome and Principe	2.24E-14	Greece	2.60E-14
Oman	2.22E-14	Seychelles	6.50E-06	Iceland	0.1
Qatar	3.55E-14	Solomon Islands	2.22E-14	Ireland	2.46E-14
Saudi Arabia	6.05E-06	St. Kitts and Nevis	4.46E-06	Italy	0.00221
Syrian Arab Rep.	0.00106	St. Lucia	4.55E-06	Malta	4.08E-08
Turkey	2.29E-14	St. Vincent & Grenadines	2.22E-14	Netherlands	1.01E-06
United Arab Emirates	7.05E-06	Tonga	2.22E-14	Norway	3.50E-14
West Bank and Gaza	4.98E-07	Trinidad and Tobago	4.14E-06	Portugal	0.00145
Yemen	8.89E-06	Vanuatu	2.24E-14	Spain	4.32E-14
Afghanistan	2.51E-13	Angola	2.22E-14	Sweden	2.22E-14
Bangladesh	2.22E-14	Benin	2.55E-14	Switzerland	1.41E-07
				United Kingdom	2.22E-14

B. Results

Table VII.: Simulated %-changes in allocated area: 1997 - 2050

Region	country	crop	scenario A %	scenario B %	scenario C %
ANZ	Australia	cb	-89.051	0.281	-89.054
ANZ	Australia	gro	3.068	-1.181	3.086
ANZ	Australia	ocr	258.820	5.989	258.740
ANZ	Australia	osd	-18.390	2.745	-18.427
ANZ	Australia	pdr	-85.309	-1.553	-85.297
ANZ	Australia	pfb	182.880	0.292	182.880
ANZ	Australia	vf	-3.134	0.070	-3.135
ANZ	Australia	wht	-6.807	0.561	-6.816
ANZ	New-Zealand	gro	-58.936	-3.090	-58.894
ANZ	New-Zealand	ocr	318.970	14.733	318.770
ANZ	New-Zealand	osd	-10.807	8.979	-10.929
ANZ	New-Zealand	pfb	361.170	4.732	361.100
ANZ	New-Zealand	vf	-1.905	0.200	-1.908
ANZ	New-Zealand	wht	-63.561	2.122	-63.591
CAM	Costa-Rica	cb	25.270	0.186	25.267
CAM	Costa-Rica	gro	21.692	0.025	21.685
CAM	Costa-Rica	ocr	-79.566	0.076	-79.567
CAM	Costa-Rica	osd	40.841	0.647	40.832
CAM	Costa-Rica	pdr	-15.643	-0.382	-15.630
CAM	Costa-Rica	pfb	32.353	0.408	32.347
CAM	Costa-Rica	vf	-15.201	0.072	-15.202
CAM	Honduras	cb	17.107	-0.001	17.107
CAM	Honduras	gro	0.799	-0.005	0.799
CAM	Honduras	ocr	-24.422	-0.004	-24.422
CAM	Honduras	osd	-15.578	-0.004	-15.578
CAM	Honduras	pdr	-34.791	0.154	-34.795
CAM	Honduras	pfb	8.824	-0.003	8.824
CAM	Honduras	vf	-17.955	-0.001	-17.955
CAM	Honduras	wht	28.092	-0.007	28.092
CAM	Mexico	cb	24.030	-0.295	24.030
CAM	Mexico	gro	1.660	0.175	1.660
CAM	Mexico	ocr	-54.276	-0.334	-54.276
CAM	Mexico	osd	2.560	-0.805	2.561
CAM	Mexico	pdr	-29.412	1.197	-29.454
CAM	Mexico	pfb	25.426	-0.597	25.427
CAM	Mexico	vf	-10.925	-0.181	-10.925
CAM	Mexico	wht	-26.385	-0.827	-26.383
CAM	Nicaragua	cb	18.494	0.048	18.494
CAM	Nicaragua	gro	-3.184	-0.053	-3.185
CAM	Nicaragua	ocr	-67.609	0.117	-67.609
CAM	Nicaragua	osd	99.844	0.828	99.842
CAM	Nicaragua	pdr	-66.434	-0.269	-66.424
CAM	Nicaragua	pfb	17.580	0.158	17.580
CAM	Nicaragua	vf	-14.660	0.046	-14.660
CAN	Canada	cb	-62.144	-0.232	-62.140
CAN	Canada	gro	-9.455	0.537	-9.456
CAN	Canada	ocr	-71.060	-0.040	-71.060
CAN	Canada	osd	0.712	-0.571	0.720
CAN	Canada	pfb	-14.072	-0.145	-14.070
CAN	Canada	vf	15.376	-0.087	15.377
CAN	Canada	wht	7.577	-0.262	7.575
CEE	Albania	cb	-100.000	6.247	-100.000
CEE	Albania	gro	-100.000	-0.442	-100.000
CEE	Albania	ocr	151.410	0.283	150.810
CEE	Albania	osd	30.387	1.480	27.249
CEE	Albania	pfb	-100.000	2.842	-100.000
CEE	Albania	vf	131.270	0.481	130.250
CEE	Albania	wht	57.833	-0.581	60.240
CEE	Bulgaria	cb	0.000	0.000	0.000
CEE	Bulgaria	gro	-100.000	-2.240	-100.000
CEE	Bulgaria	ocr	163.940	0.147	163.600
CEE	Bulgaria	osd	-100.000	3.776	-100.000
CEE	Bulgaria	pdr	142.170	-1.974	147.820
CEE	Bulgaria	pfb	-100.000	16.478	-100.000
CEE	Bulgaria	vf	91.935	0.804	90.057
CEE	Bulgaria	wht	11.483	0.015	12.133
CEE	Croatia	cb	0.000	0.000	0.000
CEE	Croatia	gro	-100.000	-3.305	-100.000
CEE	Croatia	ocr	165.040	0.181	164.880
CEE	Croatia	osd	-68.189	3.015	-70.785

continued on next page

Simulated %-changes in allocated area: 1997 - 2050, continued

Region	country	crop	scenario A %	scneario B %	scenario C %
CEE	Croatia	pfb	-100.000	7.806	-100.000
CEE	Croatia	vf	59.323	1.465	58.062
CEE	Croatia	wht	14.639	0.880	15.987
CEE	Hungary	cb	0.000	0.000	0.000
CEE	Hungary	gro	-100.000	-1.310	-100.000
CEE	Hungary	ocr	171.600	-0.012	171.730
CEE	Hungary	osd	-100.000	-0.781	-100.000
CEE	Hungary	pdr	151.950	2.912	144.210
CEE	Hungary	pfb	64.805	-0.170	66.556
CEE	Hungary	vf	90.308	-0.132	91.673
CEE	Hungary	wht	25.025	0.761	24.647
CEE	Poland	cb	-100.000	-28.780	-100.000
CEE	Poland	gro	-100.000	1.241	-100.000
CEE	Poland	ocr	162.440	-0.124	162.490
CEE	Poland	osd	23.893	-1.107	24.337
CEE	Poland	pfb	-100.000	-2.702	-100.000
CEE	Poland	vf	139.710	-0.285	139.830
CEE	Poland	wht	55.229	-0.710	55.090
CEE	Romania	cb	0.000	0.000	0.000
CEE	Romania	gro	-100.000	-0.793	-100.000
CEE	Romania	ocr	158.130	0.157	157.760
CEE	Romania	osd	-100.000	2.697	-100.000
CEE	Romania	pdr	141.090	-2.505	148.190
CEE	Romania	pfb	138.390	0.296	137.690
CEE	Romania	vf	109.520	0.505	108.320
CEE	Romania	wht	24.822	0.062	25.110
CEE	Slovenia	cb	0.000	0.000	0.000
CEE	Slovenia	gro	-100.000	0.793	-100.000
CEE	Slovenia	ocr	163.780	-0.017	163.780
CEE	Slovenia	osd	-100.000	-0.716	-100.000
CEE	Slovenia	vf	55.125	-0.132	55.125
CEE	Slovenia	wht	-63.321	-0.256	-63.321
CHI	China	cb	65.555	0.173	65.185
CHI	China	gro	-82.222	-2.002	-77.872
CHI	China	ocr	12.862	0.282	12.259
CHI	China	osd	-19.264	0.630	-20.611
CHI	China	pdr	-2.672	0.078	-2.928
CHI	China	pfb	49.846	0.318	49.167
CHI	China	vf	87.952	0.212	87.499
CHI	China	wht	-33.174	0.958	-35.161
CHI	Korea,-Dem.-People's-Rep.	gro	-54.765	-0.153	-54.203
CHI	Korea,-Dem.-People's-Rep.	ocr	35.482	0.459	34.559
CHI	Korea,-Dem.-People's-Rep.	pdr	-20.876	-0.756	-19.751
CHI	Korea,-Dem.-People's-Rep.	pfb	40.243	0.724	38.788
CHI	Korea,-Dem.-People's-Rep.	vf	83.423	0.437	82.545
CHI	Korea,-Dem.-People's-Rep.	wht	-58.774	0.989	-60.775
CHI	Mongolia	gro	-39.882	0.227	-40.334
CHI	Mongolia	vf	120.560	0.018	120.530
CHI	Mongolia	wht	4.763	-0.051	4.865
FSU	Azerbaijan	gro	0.000	0.000	0.000
FSU	Azerbaijan	ocr	0.000	0.000	0.000
FSU	Azerbaijan	pdr	0.000	0.000	0.000
FSU	Azerbaijan	pfb	0.000	0.000	0.000
FSU	Azerbaijan	vf	0.000	0.000	0.000
FSU	Azerbaijan	wht	0.000	0.000	0.000
FSU	Kazakhstan	cb	148.560	-0.875	151.230
FSU	Kazakhstan	gro	-35.471	0.362	-34.838
FSU	Kazakhstan	ocr	135.310	-1.244	139.110
FSU	Kazakhstan	osd	-100.000	-59.859	-100.000
FSU	Kazakhstan	pdr	166.920	2.218	160.860
FSU	Kazakhstan	pfb	0.000	0.000	0.000
FSU	Kazakhstan	vf	172.820	-0.200	173.430
FSU	Kazakhstan	wht	0.000	0.000	0.000
FSU	Kyrgyzstan	cb	0.000	0.000	0.000
FSU	Kyrgyzstan	gro	0.000	0.000	0.000
FSU	Kyrgyzstan	ocr	0.000	0.000	0.000
FSU	Kyrgyzstan	pdr	0.000	0.000	0.000
FSU	Kyrgyzstan	pfb	0.000	0.000	0.000
FSU	Kyrgyzstan	vf	0.000	0.000	0.000
FSU	Kyrgyzstan	wht	0.000	0.000	0.000
FSU	Russian-Federation	cb	111.790	-0.130	109.760
FSU	Russian-Federation	gro	-100.000	0.702	-100.000
FSU	Russian-Federation	ocr	-100.000	-0.597	-100.000
FSU	Russian-Federation	osd	0.000	0.000	0.000
FSU	Russian-Federation	pdr	56.159	-4.223	64.027

continued on next page

Simulated %-changes in allocated area: 1997 - 2050, continued

Region	country	crop	scenario A %	scneario B %	scenario C %
FSU	Russian-Federation	pfb	0.000	0.000	0.000
FSU	Russian-Federation	vf	163.780	-0.031	163.300
FSU	Russian-Federation	wht	0.000	0.000	0.000
FSU	Tajikistan	gro	0.007	0.000	0.007
FSU	Tajikistan	ocr	0.021	0.000	0.021
FSU	Tajikistan	pdr	0.034	-0.001	0.035
FSU	Tajikistan	pfb	-0.001	0.000	-0.001
FSU	Tajikistan	vf	0.076	0.000	0.076
FSU	Tajikistan	wht	0.000	0.000	0.000
FSU	Turkmenistan	gro	0.000	0.000	0.000
FSU	Turkmenistan	ocr	0.002	0.000	0.002
FSU	Turkmenistan	pdr	0.001	0.000	0.001
FSU	Turkmenistan	pfb	0.000	0.000	0.000
FSU	Turkmenistan	vf	0.007	0.000	0.007
FSU	Turkmenistan	wht	0.000	0.000	0.000
FSU	Ukraine	cb	0.003	0.000	0.003
FSU	Ukraine	gro	0.001	0.000	0.001
FSU	Ukraine	ocr	0.003	0.000	0.003
FSU	Ukraine	osd	0.001	0.000	0.001
FSU	Ukraine	pdr	0.003	0.000	0.003
FSU	Ukraine	pfb	0.000	0.000	0.000
FSU	Ukraine	vf	0.012	0.000	0.012
FSU	Ukraine	wht	0.000	0.000	0.000
FSU	Uzbekistan	cb	10.816	0.011	10.784
FSU	Uzbekistan	gro	1.611	-0.050	1.751
FSU	Uzbekistan	ocr	10.698	0.011	10.667
FSU	Uzbekistan	osd	2.497	0.012	2.464
FSU	Uzbekistan	pdr	12.055	-0.192	12.594
FSU	Uzbekistan	pfb	-1.460	0.012	-1.494
FSU	Uzbekistan	vf	62.157	0.008	62.135
FSU	Uzbekistan	wht	-0.292	-0.014	-0.253
JPK	Japan	cb	-4.440	0.608	-4.466
JPK	Japan	gro	23.366	0.874	23.402
JPK	Japan	ocr	32.879	0.263	32.868
JPK	Japan	osd	79.005	0.629	78.978
JPK	Japan	pdr	-39.238	-0.376	-39.257
JPK	Japan	pfb	0.000	0.000	0.000
JPK	Japan	vf	46.281	0.271	46.269
JPK	Japan	wht	23.975	0.525	24.209
JPK	Korea,-Rep.	gro	15.424	0.076	15.733
JPK	Korea,-Rep.	ocr	35.636	0.228	35.596
JPK	Korea,-Rep.	osd	108.130	1.180	107.920
JPK	Korea,-Rep.	pdr	-63.303	-0.385	-63.391
JPK	Korea,-Rep.	pfb	0.000	0.000	0.000
JPK	Korea,-Rep.	vf	51.521	0.254	51.476
JPK	Korea,-Rep.	wht	26.568	0.581	26.718
MAF	Egypt	cb	36.051	0.379	35.590
MAF	Egypt	gro	-81.411	-1.338	-80.532
MAF	Egypt	ocr	8.733	2.162	6.104
MAF	Egypt	osd	-49.030	1.704	-51.101
MAF	Egypt	pdr	1.184	-0.745	2.291
MAF	Egypt	pfb	166.600	1.674	164.570
MAF	Egypt	vf	44.417	0.256	44.106
MAF	Egypt	wht	-100.000	0.980	-100.000
MAF	Morocco	cb	44.535	0.001	44.534
MAF	Morocco	gro	4.818	0.003	4.814
MAF	Morocco	ocr	62.633	0.001	62.631
MAF	Morocco	osd	23.381	0.002	23.379
MAF	Morocco	pdr	26.918	-1.148	28.475
MAF	Morocco	pfb	125.840	0.001	125.840
MAF	Morocco	vf	49.231	0.001	49.230
MAF	Morocco	wht	-21.087	0.003	-21.091
MAF	Tunisia	cb	48.596	0.020	48.591
MAF	Tunisia	gro	1.786	0.174	1.742
MAF	Tunisia	ocr	56.020	0.085	55.998
MAF	Tunisia	osd	24.169	0.080	24.148
MAF	Tunisia	pfb	121.650	0.081	121.630
MAF	Tunisia	vf	46.444	0.043	46.433
MAF	Tunisia	wht	-32.477	-0.129	-32.444
MDE	Iran,-Islamic-Rep.	cb	123.290	0.036	123.200
MDE	Iran,-Islamic-Rep.	gro	-32.110	0.561	-33.567
MDE	Iran,-Islamic-Rep.	ocr	110.850	0.042	110.740
MDE	Iran,-Islamic-Rep.	osd	-100.000	0.193	-100.000
MDE	Iran,-Islamic-Rep.	pdr	135.450	2.028	129.810
MDE	Iran,-Islamic-Rep.	pfb	-72.689	0.156	-73.107

continued on next page

Simulated %-changes in allocated area: 1997 - 2050, continued

Region	country	crop	scenario A %	scneario B %	scenario C %
MDE	Iran,-Islamic-Rep.	vf	148.860	0.016	148.820
MDE	Iran,-Islamic-Rep.	wht	-52.323	-0.374	-51.330
MDE	Syrian-Arab-Rep.	cb	108.250	0.006	108.230
MDE	Syrian-Arab-Rep.	gro	-14.513	0.018	-14.560
MDE	Syrian-Arab-Rep.	ocr	55.912	0.011	55.883
MDE	Syrian-Arab-Rep.	osd	9.094	0.015	9.053
MDE	Syrian-Arab-Rep.	pdr	109.100	0.006	109.080
MDE	Syrian-Arab-Rep.	pfb	46.979	0.011	46.949
MDE	Syrian-Arab-Rep.	vf	124.290	0.005	124.280
MDE	Syrian-Arab-Rep.	wht	13.492	-0.188	13.993
MDE	Turkey	cb	110.420	0.100	110.150
MDE	Turkey	gro	-43.793	0.311	-44.622
MDE	Turkey	ocr	66.779	0.161	66.350
MDE	Turkey	osd	16.057	0.236	15.428
MDE	Turkey	pdr	110.100	-2.105	115.970
MDE	Turkey	pfb	-1.815	0.247	-2.474
MDE	Turkey	vf	141.380	0.047	141.260
MDE	Turkey	wht	-46.735	-0.233	-46.116
SAA	Bangladesh	cb	42.935	0.235	42.929
SAA	Bangladesh	gro	32.707	1.084	32.678
SAA	Bangladesh	ocr	100.600	0.286	100.600
SAA	Bangladesh	osd	6.475	0.653	6.458
SAA	Bangladesh	pdr	-23.381	-0.135	-23.377
SAA	Bangladesh	pfb	133.230	0.320	133.220
SAA	Bangladesh	vf	109.770	0.181	109.770
SAA	Bangladesh	wht	-5.411	0.562	-5.426
SAA	India	cb	38.796	-0.073	38.800
SAA	India	gro	-13.020	-0.040	-12.977
SAA	India	ocr	107.470	-0.130	107.470
SAA	India	osd	-15.913	-0.388	-15.889
SAA	India	pdr	-56.658	0.436	-56.657
SAA	India	pfb	164.290	-0.610	164.320
SAA	India	vf	113.850	-0.058	113.850
SAA	India	wht	-33.903	-0.027	-33.978
SAA	Pakistan	cb	36.685	-0.165	36.732
SAA	Pakistan	gro	-35.765	-0.487	-35.464
SAA	Pakistan	ocr	100.700	-0.137	100.740
SAA	Pakistan	osd	-31.384	-0.511	-31.236
SAA	Pakistan	pdr	-66.004	0.571	-65.883
SAA	Pakistan	pfb	132.130	-0.670	132.330
SAA	Pakistan	vf	110.650	-0.095	110.680
SAA	Pakistan	wht	-37.225	0.271	-37.382
SAA	Sri-Lanka	cb	19.360	0.211	19.354
SAA	Sri-Lanka	gro	-57.739	0.838	-57.761
SAA	Sri-Lanka	ocr	59.145	0.331	59.136
SAA	Sri-Lanka	osd	-47.872	0.682	-47.890
SAA	Sri-Lanka	pdr	-71.452	-0.511	-71.439
SAA	Sri-Lanka	pfb	0.000	0.000	0.000
SAA	Sri-Lanka	vf	80.192	0.229	80.186
SAM	Argentina	cb	-100.000	0.627	-100.000
SAM	Argentina	gro	-100.000	-1.524	-100.000
SAM	Argentina	ocr	-83.432	0.654	-83.563
SAM	Argentina	osd	13.154	0.620	13.030
SAM	Argentina	pdr	-92.975	-1.208	-92.106
SAM	Argentina	pfb	0.000	0.000	0.000
SAM	Argentina	vf	57.028	0.094	57.010
SAM	Argentina	wht	57.300	0.696	57.361
SAM	Bolivia	cb	-100.000	0.491	-100.000
SAM	Bolivia	gro	-46.409	-0.549	-45.746
SAM	Bolivia	ocr	-20.710	0.232	-21.000
SAM	Bolivia	osd	26.264	0.616	25.496
SAM	Bolivia	pdr	-68.543	-0.248	-68.784
SAM	Bolivia	pfb	-100.000	2.207	-100.000
SAM	Bolivia	vf	53.526	0.170	53.314
SAM	Bolivia	wht	35.180	0.990	33.945
SAM	Brazil	cb	-76.059	0.428	-76.573
SAM	Brazil	gro	-0.064	-0.193	0.205
SAM	Brazil	ocr	-12.275	0.395	-12.749
SAM	Brazil	osd	36.290	0.862	35.256
SAM	Brazil	pdr	-40.477	-0.354	-40.619
SAM	Brazil	pfb	-52.912	1.700	-54.951
SAM	Brazil	vf	61.474	0.122	61.328
SAM	Brazil	wht	75.847	-0.293	77.324
SAM	Chile	cb	-100.000	0.544	-100.000
SAM	Chile	gro	-100.000	0.695	-100.000

continued on next page

Simulated %-changes in allocated area: 1997 - 2050, continued

Region	country	crop	scenario A %	scneario B %	scenario C %
SAM	Chile	ocr	-100.000	0.508	-100.000
SAM	Chile	osd	-50.853	0.415	-52.177
SAM	Chile	pdr	-100.000	0.543	-100.000
SAM	Chile	pfb	-100.000	3.762	-100.000
SAM	Chile	vf	39.654	0.089	39.371
SAM	Chile	wht	-1.665	-0.341	-1.277
SAM	Colombia	cb	-85.551	0.135	-85.677
SAM	Colombia	gro	-27.168	0.205	-27.284
SAM	Colombia	ocr	-23.671	0.195	-23.853
SAM	Colombia	osd	14.666	0.374	14.317
SAM	Colombia	pdr	-49.247	-0.876	-48.785
SAM	Colombia	pfb	-91.823	0.636	-92.416
SAM	Colombia	vf	58.868	0.050	58.821
SAM	Colombia	wht	72.296	-0.501	73.779
SAM	Ecuador	cb	-97.433	0.065	-97.516
SAM	Ecuador	gro	-64.671	-0.099	-64.559
SAM	Ecuador	ocr	-40.272	0.096	-40.395
SAM	Ecuador	osd	25.525	0.101	25.396
SAM	Ecuador	pdr	-58.014	0.060	-58.091
SAM	Ecuador	pfb	-100.000	0.233	-100.000
SAM	Ecuador	vf	61.931	0.010	61.919
SAM	Ecuador	wht	22.270	0.181	22.038
SAM	Paraguay	cb	-72.691	0.657	-73.553
SAM	Paraguay	gro	-14.842	-0.800	-13.931
SAM	Paraguay	ocr	-18.082	0.478	-18.709
SAM	Paraguay	osd	23.722	0.799	22.673
SAM	Paraguay	pdr	-44.834	-1.519	-44.345
SAM	Paraguay	pfb	-55.611	1.657	-57.786
SAM	Paraguay	vf	57.344	0.154	57.143
SAM	Paraguay	wht	33.646	-0.104	34.854
SAM	Peru	cb	-93.979	0.143	-94.171
SAM	Peru	gro	-67.655	0.043	-67.783
SAM	Peru	ocr	-51.866	0.384	-52.383
SAM	Peru	osd	-1.399	0.455	-2.012
SAM	Peru	pdr	-56.246	-0.702	-55.952
SAM	Peru	pfb	-100.000	1.038	-100.000
SAM	Peru	vf	54.159	0.076	54.056
SAM	Peru	wht	17.854	-0.183	18.773
SAM	Suriname	cb	-14.190	0.001	-14.191
SAM	Suriname	gro	14.863	-0.103	14.990
SAM	Suriname	pdr	-6.756	0.001	-6.757
SAM	Suriname	vf	53.811	0.000	53.811
SAM	Uruguay	cb	-100.000	0.440	-100.000
SAM	Uruguay	gro	-82.845	1.225	-84.807
SAM	Uruguay	ocr	-28.098	0.249	-28.497
SAM	Uruguay	osd	16.420	0.608	15.446
SAM	Uruguay	pdr	-61.214	-2.340	-60.089
SAM	Uruguay	pfb	0.000	0.000	0.000
SAM	Uruguay	vf	55.801	0.113	55.619
SAM	Uruguay	wht	56.000	-0.582	57.768
SAM	Venezuela	cb	-90.645	0.002	-90.649
SAM	Venezuela	gro	-18.291	0.004	-18.300
SAM	Venezuela	ocr	-24.965	0.002	-24.970
SAM	Venezuela	osd	21.123	0.004	21.114
SAM	Venezuela	pdr	-50.673	0.002	-50.677
SAM	Venezuela	pfb	-100.000	0.009	-100.000
SAM	Venezuela	vf	60.888	0.000	60.887
SAM	Venezuela	wht	-11.129	-0.555	-9.866
SEA	Cambodia	cb	-70.384	-0.761	-69.596
SEA	Cambodia	gro	-3.133	-1.742	-1.330
SEA	Cambodia	ocr	112.360	-0.672	113.050
SEA	Cambodia	osd	-8.880	-3.191	-5.576
SEA	Cambodia	pdr	-9.260	0.135	-9.400
SEA	Cambodia	pfb	39.722	-0.438	40.176
SEA	Cambodia	vf	76.667	-0.456	77.139
SEA	Indonesia	cb	-81.710	0.404	-82.138
SEA	Indonesia	gro	-34.801	0.183	-34.859
SEA	Indonesia	ocr	75.189	1.363	73.745
SEA	Indonesia	pdr	-33.096	-0.744	-32.350
SEA	Indonesia	pfb	-93.325	3.953	-97.511
SEA	Indonesia	vf	67.151	0.496	66.626
SEA	Lao-People's-Dem.-Rep.	cb	-62.919	-0.095	-62.821
SEA	Lao-People's-Dem.-Rep.	gro	2.243	-0.145	2.394
SEA	Lao-People's-Dem.-Rep.	ocr	115.260	-0.043	115.300
SEA	Lao-People's-Dem.-Rep.	osd	11.341	-0.170	11.517

continued on next page

Simulated %-changes in allocated area: 1997 - 2050, continued

Region	country	crop	scenario A %	scneario B %	scenario C %
SEA	Lao-People's-Dem.-Rep.	pdr	-5.874	0.022	-5.898
SEA	Lao-People's-Dem.-Rep.	pfb	28.535	-0.113	28.652
SEA	Lao-People's-Dem.-Rep.	vf	70.951	-0.063	71.016
SEA	Malaysia	cb	-70.615	0.163	-70.784
SEA	Malaysia	gro	-42.606	-0.328	-42.174
SEA	Malaysia	ocr	21.733	0.325	21.396
SEA	Malaysia	osd	-26.724	0.348	-27.085
SEA	Malaysia	pdr	-41.143	-0.631	-40.490
SEA	Malaysia	pfb	0.000	0.000	0.000
SEA	Malaysia	vf	47.633	0.147	47.481
SEA	Myanmar-(Burma)	cb	-76.410	-0.007	-76.402
SEA	Myanmar-(Burma)	gro	-24.223	0.622	-24.947
SEA	Myanmar-(Burma)	ocr	116.840	-0.018	116.860
SEA	Myanmar-(Burma)	osd	-6.530	-0.049	-6.472
SEA	Myanmar-(Burma)	pdr	-12.396	-0.019	-12.374
SEA	Myanmar-(Burma)	pfb	-8.726	-0.068	-8.647
SEA	Myanmar-(Burma)	vf	80.994	-0.006	81.001
SEA	Philippines	cb	-73.336	0.067	-73.402
SEA	Philippines	gro	-20.019	0.641	-20.700
SEA	Philippines	ocr	106.450	0.141	106.310
SEA	Philippines	osd	-16.591	0.463	-17.048
SEA	Philippines	pdr	-21.088	-0.688	-20.363
SEA	Philippines	pfb	4.275	0.362	3.917
SEA	Philippines	vf	74.453	0.082	74.373
SEA	Thailand	cb	-72.769	-0.190	-72.568
SEA	Thailand	gro	-17.732	0.153	-17.955
SEA	Thailand	ocr	84.052	-0.249	84.315
SEA	Thailand	osd	-27.154	-0.601	-26.520
SEA	Thailand	pdr	-35.225	0.111	-35.329
SEA	Thailand	pfb	8.129	-0.341	8.488
SEA	Thailand	vf	65.975	-0.136	66.119
SEA	Vietnam	cb	-72.705	0.236	-72.950
SEA	Vietnam	gro	-10.749	0.268	-10.996
SEA	Vietnam	ocr	82.920	0.452	82.450
SEA	Vietnam	osd	-9.253	0.731	-10.014
SEA	Vietnam	pdr	-16.178	-0.085	-16.092
SEA	Vietnam	pfb	33.043	0.204	32.830
SEA	Vietnam	vf	69.479	0.196	69.275
SIS	Cuba	cb	-6.979	-0.079	-6.782
SIS	Cuba	gro	-100.000	0.547	-100.000
SIS	Cuba	ocr	-100.000	-0.116	-100.000
SIS	Cuba	pdr	126.090	0.652	124.360
SIS	Cuba	pfb	-100.000	-0.321	-100.000
SIS	Cuba	vf	-16.701	-0.078	-16.508
SSA	Cameroon	cb	-93.443	1.131	-93.443
SSA	Cameroon	gro	-100.000	-2.015	-100.000
SSA	Cameroon	ocr	-100.000	1.391	-100.000
SSA	Cameroon	osd	-100.000	4.695	-100.000
SSA	Cameroon	pdr	-100.000	-0.752	-100.000
SSA	Cameroon	pfb	-100.000	13.404	-100.000
SSA	Cameroon	vf	55.146	0.315	55.146
SSA	Cameroon	wht	0.000	0.000	0.000
SSA	Central-African-Republic	cb	-100.000	0.744	-100.000
SSA	Central-African-Republic	gro	-100.000	-7.718	-100.000
SSA	Central-African-Republic	ocr	-100.000	0.922	-100.000
SSA	Central-African-Republic	osd	-100.000	1.184	-100.000
SSA	Central-African-Republic	pdr	-100.000	-0.089	-100.000
SSA	Central-African-Republic	pfb	-100.000	31.982	-100.000
SSA	Central-African-Republic	vf	22.454	0.254	22.454
SSA	Congo,-Dem.-Rep.-of-the	cb	31.335	0.000	31.335
SSA	Congo,-Dem.-Rep.-of-the	gro	0.000	0.000	0.000
SSA	Congo,-Dem.-Rep.-of-the	ocr	0.000	0.000	0.000
SSA	Congo,-Dem.-Rep.-of-the	osd	0.000	0.000	0.000
SSA	Congo,-Dem.-Rep.-of-the	pdr	0.000	0.000	0.000
SSA	Congo,-Dem.-Rep.-of-the	pfb	0.000	0.000	0.000
SSA	Congo,-Dem.-Rep.-of-the	vf	-6.710	0.000	-6.710
SSA	Congo,-Dem.-Rep.-of-the	wht	0.000	0.000	0.000
SSA	Congo,-Rep.-of-the	cb	-100.000	0.000	-100.000
SSA	Congo,-Rep.-of-the	gro	0.000	0.000	0.000
SSA	Congo,-Rep.-of-the	ocr	0.000	0.000	0.000
SSA	Congo,-Rep.-of-the	osd	0.000	0.000	0.000
SSA	Congo,-Rep.-of-the	pdr	0.000	0.000	0.000
SSA	Congo,-Rep.-of-the	vf	3.467	0.000	3.467
SSA	Kenya	cb	90.098	-0.081	90.217
SSA	Kenya	gro	-37.290	0.323	-37.656

continued on next page

Simulated %-changes in allocated area: 1997 - 2050, continued

Region	country	crop	scenario A %	scneario B %	scenario C %
SSA	Kenya	ocr	-100.000	-0.465	-100.000
SSA	Kenya	osd	-32.864	-1.570	-30.557
SSA	Kenya	pdr	-40.897	0.148	-40.699
SSA	Kenya	pfb	-68.065	-1.741	-65.507
SSA	Kenya	vf	92.434	-0.201	92.730
SSA	Kenya	wht	-100.000	-4.772	-100.000
SSA	Liberia	cb	replanted	0.000	replanted
SSA	Liberia	ocr	0.000	0.000	0.000
SSA	Liberia	pdr	-33.968	-0.969	-32.816
SSA	Liberia	vf	169.150	4.912	164.590
SSA	Mozambique	cb	65.239	-0.016	65.255
SSA	Mozambique	gro	-4.219	-0.042	-4.178
SSA	Mozambique	ocr	-75.682	-0.024	-75.658
SSA	Mozambique	osd	18.827	-0.036	18.863
SSA	Mozambique	pdr	-17.590	0.672	-18.258
SSA	Mozambique	pfb	-19.676	-0.057	-19.620
SSA	Mozambique	vf	88.043	-0.009	88.052
SSA	Mozambique	wht	-30.972	-0.065	-30.908
SSA	Nigeria	cb	68.974	0.117	68.974
SSA	Nigeria	gro	-100.000	-0.323	-100.000
SSA	Nigeria	ocr	-100.000	1.193	-100.000
SSA	Nigeria	osd	-100.000	0.793	-100.000
SSA	Nigeria	pdr	-100.000	-1.091	-100.000
SSA	Nigeria	pfb	-100.000	6.646	-100.000
SSA	Nigeria	vf	86.378	0.093	86.378
SSA	Nigeria	wht	0.000	0.000	0.000
SSA	South-Africa	cb	87.581	-0.088	87.704
SSA	South-Africa	gro	-1.971	0.296	-2.387
SSA	South-Africa	ocr	-97.050	-0.576	-96.246
SSA	South-Africa	osd	15.457	-0.714	16.455
SSA	South-Africa	pdr	-32.789	0.180	-32.680
SSA	South-Africa	pfb	-50.593	-1.366	-48.683
SSA	South-Africa	vf	99.305	-0.081	99.418
SSA	South-Africa	wht	-85.139	-1.778	-82.637
SSA	Swaziland	cb	90.351	0.012	90.328
SSA	Swaziland	gro	-92.963	-0.140	-92.900
SSA	Swaziland	ocr	-100.000	0.191	-100.000
SSA	Swaziland	pdr	-46.384	1.467	-47.924
SSA	Swaziland	pfb	-100.000	3.466	-100.000
SSA	Swaziland	vf	89.093	0.040	89.017
SSA	Swaziland	wht	0.000	0.000	0.000
SSA	Tanzania,-United-Rep.	cb	90.407	-0.039	90.480
SSA	Tanzania,-United-Rep.	gro	-69.415	0.582	-69.843
SSA	Tanzania,-United-Rep.	ocr	-100.000	-0.528	-100.000
SSA	Tanzania,-United-Rep.	osd	-73.231	-1.093	-71.218
SSA	Tanzania,-United-Rep.	pdr	-96.995	-0.057	-96.232
SSA	Tanzania,-United-Rep.	pfb	-100.000	-1.899	-100.000
SSA	Tanzania,-United-Rep.	vf	91.110	-0.113	91.317
SSA	Tanzania,-United-Rep.	wht	-100.000	-2.842	-100.000
SSA	Uganda	cb	-82.034	-0.005	-82.034
SSA	Uganda	gro	-100.000	-0.033	-100.000
SSA	Uganda	ocr	-100.000	-0.011	-100.000
SSA	Uganda	osd	-100.000	-0.071	-100.000
SSA	Uganda	pdr	-100.000	1.753	-100.000
SSA	Uganda	pfb	0.000	0.000	0.000
SSA	Uganda	vf	16.329	-0.003	16.329
SSA	Uganda	wht	0.000	0.000	0.000
SSA	Zambia	cb	96.121	0.000	96.121
SSA	Zambia	gro	-47.221	0.023	-47.221
SSA	Zambia	ocr	-100.000	0.009	-100.000
SSA	Zambia	osd	0.000	0.000	0.000
SSA	Zambia	pdr	-100.000	-26.881	-100.000
SSA	Zambia	pfb	0.000	0.000	0.000
SSA	Zambia	vf	109.010	0.001	109.010
SSA	Zambia	wht	0.000	0.000	0.000
USA	United-States	cb	-26.579	0.086	-26.579
USA	United-States	gro	-10.936	-0.188	-10.934
USA	United-States	ocr	-70.303	0.036	-70.304
USA	United-States	osd	-3.844	0.120	-3.845
USA	United-States	pdr	-24.040	-0.282	-24.039
USA	United-States	pfb	32.932	0.113	32.931
USA	United-States	vf	5.532	0.039	5.532
USA	United-States	wht	-3.006	0.072	-3.006
WEU	Austria	cb	-43.315	-0.201	-43.310
WEU	Austria	gro	-3.481	0.227	-3.489

continued on next page

Simulated %-changes in allocated area: 1997 - 2050, continued

Region	country	crop	scenario A %	scneario B %	scenario C %
WEU	Austria	ocr	1.155	-0.193	1.160
WEU	Austria	osd	10.782	-0.392	10.793
WEU	Austria	vf	31.679	-0.097	31.681
WEU	Austria	wht	1.140	-0.449	1.158
WEU	Belgium	cb	-45.363	-0.482	-45.344
WEU	Belgium	gro	3.907	0.872	3.886
WEU	Belgium	ocr	-2.167	-0.355	-2.153
WEU	Belgium	osd	28.757	-1.138	28.801
WEU	Belgium	pfb	21.463	-0.789	21.494
WEU	Belgium	vf	32.201	-0.110	32.205
WEU	Belgium	wht	-2.713	-0.474	-2.708
WEU	France	cb	-51.131	0.243	-51.137
WEU	France	gro	-6.929	-0.713	-6.904
WEU	France	ocr	-5.889	0.187	-5.893
WEU	France	osd	4.409	0.520	4.396
WEU	France	pdr	-29.879	-0.683	-29.869
WEU	France	pfb	15.235	0.436	15.224
WEU	France	vf	32.492	0.150	32.489
WEU	France	wht	-4.614	0.628	-4.638
WEU	Germany	cb	-39.752	-0.729	-39.727
WEU	Germany	gro	-0.432	0.635	-0.449
WEU	Germany	ocr	2.973	-0.662	2.995
WEU	Germany	osd	4.725	-1.261	4.768
WEU	Germany	pfb	0.000	0.000	0.000
WEU	Germany	vf	32.025	-0.227	32.033
WEU	Germany	wht	-7.514	-0.878	-7.493
WEU	Greece	cb	-63.022	0.322	-63.035
WEU	Greece	gro	-26.213	-1.285	-26.179
WEU	Greece	ocr	-11.597	0.252	-11.607
WEU	Greece	osd	-1.239	0.865	-1.274
WEU	Greece	pdr	-58.694	-0.611	-58.691
WEU	Greece	pfb	3.066	0.617	3.041
WEU	Greece	vf	29.644	0.147	29.639
WEU	Greece	wht	-0.728	0.521	-0.737
WEU	Italy	cb	-4.523	0.041	-4.524
WEU	Italy	gro	-0.862	-0.101	-0.859
WEU	Italy	ocr	-0.966	0.039	-0.967
WEU	Italy	osd	0.928	0.044	0.927
WEU	Italy	pdr	-3.894	-0.125	-3.892
WEU	Italy	pfb	2.176	0.044	2.175
WEU	Italy	vf	7.134	0.037	7.132
WEU	Italy	wht	1.035	0.038	1.034
WEU	Netherlands	cb	-54.865	-0.168	-54.863
WEU	Netherlands	gro	-10.144	0.994	-10.182
WEU	Netherlands	ocr	0.756	-0.165	0.758
WEU	Netherlands	osd	20.167	-0.447	20.172
WEU	Netherlands	pfb	-12.529	-0.098	-12.528
WEU	Netherlands	vf	31.510	-0.029	31.511
WEU	Netherlands	wht	-15.041	-0.760	-15.003
WEU	Norway	gro	-2.817	-0.005	-2.817
WEU	Norway	osd	2.276	-0.005	2.276
WEU	Norway	vf	29.708	-0.001	29.708
WEU	Norway	wht	-6.393	0.057	-6.397
WEU	Spain	cb	-71.466	0.330	-71.478
WEU	Spain	gro	-17.851	-0.835	-17.829
WEU	Spain	ocr	-5.697	0.533	-5.716
WEU	Spain	osd	-10.385	1.043	-10.422
WEU	Spain	pdr	-67.511	-1.735	-67.486
WEU	Spain	pfb	-4.747	0.637	-4.770
WEU	Spain	vf	29.104	0.204	29.097
WEU	Spain	wht	-11.383	0.709	-11.396
WEU	Sweden	cb	-37.887	-0.018	-37.885
WEU	Sweden	gro	0.882	-0.029	0.885
WEU	Sweden	ocr	-8.522	-0.009	-8.521
WEU	Sweden	osd	8.164	-0.031	8.166
WEU	Sweden	vf	30.751	-0.005	30.751
WEU	Sweden	wht	-9.369	0.142	-9.380
WEU	Switzerland	cb	-43.155	-0.255	-43.150
WEU	Switzerland	gro	-6.120	0.884	-6.153
WEU	Switzerland	ocr	1.310	-0.254	1.315
WEU	Switzerland	osd	-0.471	-0.445	-0.462
WEU	Switzerland	vf	30.839	-0.104	30.841
WEU	Switzerland	wht	-2.496	-0.708	-2.467
WEU	United-Kingdom	cb	-42.678	-0.591	-42.658
WEU	United-Kingdom	gro	0.301	0.791	0.278

continued on next page

Simulated %-changes in allocated area: 1997 - 2050, continued

Region	country	crop	scenario A %	scneario B %	scenario C %
WEU	United-Kingdom	ocr	3.018	-0.578	3.038
WEU	United-Kingdom	osd	3.658	-1.064	3.694
WEU	United-Kingdom	pfb	11.094	-0.802	11.121
WEU	United-Kingdom	vf	31.287	-0.154	31.292
WEU	United-Kingdom	wht	-8.115	-0.763	-8.096

Table VIII.: Simulated %-changes in total revenue: 1997 - 2050

Region	country	scenario A %	scenario B %	scenario C %
ANZ	Australia	8.961	-0.924	8.972
ANZ	New-Zealand	0.447	-0.166	0.444
CAM	Costa-Rica	-33.842	-0.042	-33.841
CAM	Honduras	-30.630	0.005	-30.630
CAM	Mexico	-53.717	0.658	-53.717
CAM	Nicaragua	-22.989	-0.099	-22.989
CAN	Canada	-67.847	1.182	-67.863
CEE	Albania	428.650	-0.753	429.310
CEE	Bulgaria	315.750	-0.738	317.210
CEE	Croatia	275.060	-0.167	275.610
CEE	Hungary	306.090	0.673	304.310
CEE	Poland	409.790	0.239	409.660
CEE	Romania	319.820	-0.642	321.600
CEE	Slovenia	308.800	-0.040	308.800
CHI	China	155.930	-0.059	155.540
CHI	Korea,-Dem.-People's-Rep.	211.440	-0.592	211.370
CHI	Mongolia	151.470	-0.135	151.760
FSU	Azerbaijan	180.000	0.000	180.000
FSU	Kazakhstan	486.120	2.199	476.880
FSU	Kyrgyzstan	180.000	0.000	180.000
FSU	Russian-Federation	453.840	-0.279	453.530
FSU	Tajikistan	177.790	-0.794	180.010
FSU	Turkmenistan	178.810	-0.427	180.000
FSU	Ukraine	179.660	-0.123	180.010
FSU	Uzbekistan	186.110	-0.604	187.850
JPK	Japan	42.108	-0.417	42.117
JPK	Korea,-Rep.	46.174	-0.361	46.179
MAF	Egypt	94.531	-0.615	94.575
MAF	Morocco	50.818	-0.017	50.851
MAF	Tunisia	78.428	-0.109	78.436
MDE	Iran,-Islamic-Rep.	445.560	0.178	443.910
MDE	Syrian-Arab-Rep.	286.830	-0.075	287.080
MDE	Turkey	417.840	-0.117	417.880
SAA	Bangladesh	75.885	-0.608	75.893
SAA	India	135.000	0.212	134.980
SAA	Pakistan	93.705	0.453	93.658
SAA	Sri-Lanka	156.640	-0.338	156.630
SAM	Argentina	135.060	-0.185	135.120
SAM	Bolivia	125.480	-0.096	125.310
SAM	Brazil	104.650	-0.382	105.190
SAM	Chile	120.130	-0.085	120.170
SAM	Colombia	123.800	-0.129	123.840
SAM	Ecuador	153.910	0.004	153.890
SAM	Paraguay	132.150	-0.406	132.570
SAM	Peru	125.810	-0.111	125.760
SAM	Suriname	38.110	-0.001	38.111
SAM	Uruguay	112.280	-0.925	113.500
SAM	Venezuela	124.570	0.000	124.570
SEA	Cambodia	66.228	1.311	65.142
SEA	Indonesia	93.320	-0.808	93.574
SEA	Lao-People's-Dem.-Rep.	34.725	0.164	34.576
SEA	Malaysia	111.580	-0.515	111.630
SEA	Myanmar-(Burma)	62.964	-0.001	62.970
SEA	Philippines	100.710	-0.230	100.850
SEA	Thailand	137.400	0.241	137.360
SEA	Vietnam	65.128	-0.358	65.370
SIS	Cuba	188.250	0.268	186.450
SSA	Cameroon	196.440	0.087	196.440
SSA	Central-African-Republic	141.500	0.130	141.500
SSA	Congo,-Dem.-Rep.-of-the	109.700	0.000	109.700
SSA	Congo,-Rep.-of-the	109.960	0.000	109.960
SSA	Kenya	228.970	0.223	229.040
SSA	Liberia	27.790	-2.287	28.818

continued on next page

Simulated %-changes in total revenue: 1997 - 2050, continued

Region	country	scenario A %	scneario B %	scenario C %
SSA	Mozambique	141.300	0.086	141.250
SSA	Nigeria	259.100	-0.010	259.100
SSA	South-Africa	185.340	0.593	184.540
SSA	Swaziland	252.320	-0.008	252.270
SSA	Tanzania,-United-Rep.	260.530	0.090	260.820
SSA	Uganda	135.190	-0.002	135.190
SSA	Zambia	254.240	0.002	254.240
USA	United-States	-12.165	-0.430	-12.162
WEU	Austria	-15.493	0.506	-15.506
WEU	Belgium	27.760	0.273	27.749
WEU	France	1.646	-0.448	1.655
WEU	Germany	9.338	0.905	9.308
WEU	Greece	34.783	-0.342	34.789
WEU	Italy	-72.651	-1.438	-72.608
WEU	Netherlands	55.890	-0.003	55.890
WEU	Norway	12.879	0.007	12.879
WEU	Spain	43.882	-0.248	43.885
WEU	Sweden	-23.564	0.059	-23.568
WEU	Switzerland	14.930	0.369	14.924
WEU	United-Kingdom	13.052	0.724	13.028

Working Papers
Research Unit Sustainability and Global Change
Hamburg University and Centre for Marine and Atmospheric Science

Ronneberger, K., R.S.J. Tol and U.A. Schneider (2005), *KLUM: A simple model of global agricultural land use as a coupling tool of economy and vegetation*, **FNU-65** (submitted)

Tol, R.S.J. (2005), *The Benefits of Greenhouse Gas Emission Reduction: An Application of FUND*, **FNU-64** (submitted)

Röckmann, C., M.A. St.John, F.W. Köster, F.W. and R.S.J. Tol (2005), *Testing the implications of a marine reserve on the population dynamics of Eastern Baltic cod under varying environmental conditions*, **FNU-63** (submitted)

Letsoalo, A., J. Blignaut, T. de Wet, M. de Wit, S. Hess, R.S.J. Tol and J. van Heerden (2005), *Triple Dividends of Water Consumption Charges in South Africa*, **FNU-62** (submitted)

Zandersen, M., Termansen, M., Jensen,F.S. (2005), *Benefit Transfer over Time of Ecosystem Values: the Case of Forest Recreation*, **FNU-61** (submitted)

Rehdanz, K., Jung, M., Tol, R.S.J. and Wetzel, P. (2005), *Ocean Carbon Sinks and International Climate Policy*, **FNU-60** (submitted)

Schwoon, M. (2005), *Simulating The Adoption of Fuel Cell Vehicles*, **FNU-59** (submitted)

Bigano, A., J.M. Hamilton and R.S.J. Tol (2005), *The Impact of Climate Change on Domestic and International Tourism: A Simulation Study*, **FNU-58** (submitted)

Bosello, F., R. Roson and R.S.J. Tol (2004), *Economy-wide estimates of the implications of climate change: Human health*, **FNU-57** (submitted, *Ecological Economics*)

Hamilton, J.M. and M.A. Lau (2004) *The role of climate information in tourist destination choice decision-making*, **FNU-56** (forthcoming, Gössling, S. and C.M. Hall (eds.), Tourism and Global Environmental Change. London: Routledge)

Bigano, A., J.M. Hamilton and R.S.J. Tol (2004), *The impact of climate on holiday destination choice*, **FNU-55** (submitted, *Climatic Change*)

Bigano, A., J.M. Hamilton, M. Lau, R.S.J. Tol and Y. Zhou (2004), *A global database of domestic and international tourist numbers at national and subnational level*, **FNU-54** (submitted)

Susandi, A. and R.S.J. Tol (2004), *Impact of international emission reduction on energy and forestry sector of Indonesia*, **FNU-53** (submitted)

Hamilton, J.M. and R.S.J. Tol (2004), *The Impact of Climate Change on Tourism and Recreation*, **FNU-52** (submitted)

Schneider, U.A. (2004), *Land Use Decision Modelling with Soil Status Dependent Emission Rates*, **FNU-51** (submitted)

Link, P.M., U.A. Schneider and R.S.J. Tol (2004), *Economic impacts of changes in fish population dynamics: the role of the fishermen's harvesting strategies*, **FNU-50** (submitted)

Berritella, M., A. Bigano, R. Roson and R.S.J. Tol (2004), *A General Equilibrium Analysis of Climate Change Impacts on Tourism*, **FNU-49** (submitted, *Tourism Management*)

Tol, R.S.J. (2004), *The Double Trade-Off between Adaptation and Mitigation for Sea Level Rise: An Application of FUND*, **FNU-48** (submitted, *Mitigation and Adaptation Strategies for Global Change*)

Erdil, Erkan and Yetkiner, I. Hakan (2004), *A Panel Data Approach for Income-Health Causality*, **FNU-47**

Tol, R.S.J. (2004), *Multi-Gas Emission Reduction for Climate Change Policy: An Application of FUND*, **FNU-46** (forthcoming, *Energy Journal*)

Tol, R.S.J. (2004), *Exchange Rates and Climate Change: An Application of FUND*, **FNU-45** (submitted, *Climatic Change*)

Gaitan, B., Tol, R.S.J, and Yetkiner, I. Hakan (2004), *The Hotelling's Rule Revisited in a Dynamic General Equilibrium Model*, **FNU-44** (submitted)

Rehdanz, K. and Tol, R.S.J (2004), *On Multi-Period Allocation of Tradable Emission Permits*, **FNU-43** (submitted)

Link, P.M. and Tol, R.S.J. (2004), *Possible Economic Impacts of a Shutdown of the Thermohaline Circulation: An Application of FUND*, **FNU-42** (*Portuguese Economic Journal*, **3**, 99-114)

Zhou, Y. and Tol, R.S.J. (2004), *Evaluating the costs of desalination and water transport*, **FNU-41** (forthcoming, *Water Resources Research*)

Lau, M. (2004), *Küstenzonenmanagement in der Volksrepublik China und Anpassungsstrategien an den Meeresspiegelanstieg*, **FNU-40** (submitted, *Coastline Reports*)

Rehdanz, K. and Maddison, D. (2004), *The Amenity Value of Climate to German Households*, **FNU-39** (submitted)

Bosello, F., Lazzarin, M., Roson, R. and Tol, R.S.J. (2004), *Economy-wide Estimates of the Implications of Climate Change: Sea Level Rise*, **FNU-38** (submitted)

Schwoon, M. and Tol, R.S.J. (2004), *Optimal CO2-abatement with socio-economic inertia and induced technological change*, **FNU-37** (submitted)

Hamilton, J.M., Maddison, D.J. and Tol, R.S.J. (2004), *The Effects of Climate Change on International Tourism*, **FNU-36** (submitted)

Hansen, O. and R.S.J. Tol (2003), *A Refined Inglehart Index of Materialism and Postmaterialism*, **FNU-35** (submitted)

Heinzow, T. and R.S.J. Tol (2003), *Prediction of Crop Yields across four Climate Zones in Germany: An Artificial Neural Network Approach*, **FNU-34** (submitted, *Climate Research*)

Tol, R.S.J. (2003), *Adaptation and Mitigation: Trade-offs in Substance and Methods*, **FNU-33** (submitted, *Environmental Science and Policy*)

Tol, R.S.J. and T. Heinzow (2003), *Estimates of the External and Sustainability Costs of Climate Change*, **FNU-32** (submitted)

Hamilton, J.M., Maddison, D.J. and Tol, R.S.J. (2003), *Climate change and international tourism: a simulation study*, **FNU-31** (forthcoming, *Global Environmental Change*)

Link, P.M. and R.S.J. Tol (2003), *Economic impacts of changes in population dynamics of fish on the fisheries in the Barents Sea*, **FNU-30** (submitted)

Link, P.M. (2003), *Auswirkungen populationsdynamischer Veränderungen in Fischbeständen auf die Fischereiwirtschaft in der Barentssee*, **FNU-29** (*Essener Geographische Arbeiten*, **35**, 179-202)

Lau, M. (2003), *Coastal Zone Management in the People's Republic of China - An Assessment of Structural Impacts on Decision-making Processes*, **FNU-28** (submitted)

Lau, M. (2003), *Coastal Zone Management in the People's Republic of China - A Unique Approach?*, **FNU-27** (*China Environment Series*, Issue 6, pp. 120-124; http://www.wilsoncenter.org/topics/pubs/7-commentaries.pdf)

Roson, R. and R.S.J. Tol (2003), *An Integrated Assessment Model of Economy-Energy-Climate - The Model Wiagem: A Comment*, **FNU-26** (forthcoming, *Integrated Assessment*)

Yetkiner, I.H. (2003), *Is There An Indispensable Role For Government During Recovery From An Earthquake? A Theoretical Elaboration*, **FNU-25**

Yetkiner, I.H. (2003), *A Short Note On The Solution Procedure Of Barro And Sala-i-Martin for Restoring Constancy Conditions*, **FNU-24**

Schneider, U.A. and B.A. McCarl (2003), *Measuring Abatement Potentials When Multiple Change is Present: The Case of Greenhouse Gas Mitigation in U.S. Agriculture and Forestry*, **FNU-23** (submitted)

Zhou, Y. and Tol, R.S.J. (2003), *The Implications of Desalination to Water Resources in China - an Economic Perspective*, **FNU-22** (*Desalination*, **163** (4), 225-240)

Yetkiner, I.H., de Vaal, A., and van Zon, A. (2003), *The Cyclical Advancement of Drastic Technologies*, **FNU-21**

Rehdanz, K. and Maddison, D. (2003) *Climate and Happiness*, **FNU-20** (*Ecological Economics*, **52** 111-125)

Tol, R.S.J., (2003), *The Marginal Costs of Carbon Dioxide Emissions: An Assessment of the Uncertainties*, **FNU-19** (*Energy Policy*, **33** (16), 2064-2074)

Lee, H.C., B.A. McCarl, U.A. Schneider, and C.C. Chen (2003), *Leakage and Comparative Advantage Implications of Agricultural Participation in Greenhouse Gas Emission Mitigation*, **FNU-18** (submitted)

Schneider, U.A. and B.A. McCarl (2003), *Implications of a Carbon Based Energy Tax for U.S. Agriculture*, **FNU-17** (submitted)

Tol, R.S.J. (2002), *Climate, Development, and Malaria: An Application of FUND*, **FNU-16** (forthcoming, *Climatic Change*)

Hamilton, J.M. (2003), *Climate and the Destination Choice of German Tourists*, **FNU-15** (revised and submitted)

Tol, R.S.J. (2002), *Technology Protocols for Climate Change: An Application of FUND*, **FNU-14** (forthcoming, *Climate Policy*)

Rehdanz, K (2002), *Hedonic Pricing of Climate Change Impacts to Households in Great Britain*, **FNU-13** (forthcoming, *Climatic Change*)

Tol, R.S.J. (2002), *Emission Abatement Versus Development As Strategies To Reduce Vulnerability To Climate Change: An Application Of FUND*, **FNU-12** (forthcoming, *Environment and Development Economics*)

Rehdanz, K. and Tol, R.S.J. (2002), *On National and International Trade in Greenhouse Gas Emission Permits*, **FNU-11** (forthcoming, *Ecological Economics*)

Fankhauser, S. and Tol, R.S.J. (2001), *On Climate Change and Growth*, **FNU-10** (*Resource and Energy Economics*, **27**, 1-17)

Tol, R.S.J.and Verheyen, R. (2001), *Liability and Compensation for Climate Change Damages - A Legal and Economic Assessment*, **FNU-9** (*Energy Policy*, **32** (9), 1109-1130)

Yohe, G. and R.S.J. Tol (2001), *Indicators for Social and Economic Coping Capacity - Moving Toward a Working Definition of Adaptive Capacity*, **FNU-8** (*Global Environmental Change*, **12** (1), 25-40)

Kemfert, C., W. Lise and R.S.J. Tol (2001), *Games of Climate Change with International Trade*, **FNU-7** (*Environmental and Resource Economics*, **28**, 209-232)

Tol, R.S.J., W. Lise, B. Morel and B.C.C. van der Zwaan (2001), *Technology Development and Diffusion and Incentives to Abate Greenhouse Gas Emissions*, **FNU-6** (submitted, *International Environmental Agreements*)

Kemfert, C. and R.S.J. Tol (2001), *Equity, International Trade and Climate Policy*, **FNU-5** (*International Environmental Agreements*, **2**, 23-48)

Tol, R.S.J., Downing T.E., Fankhauser S., Richels R.G. and Smith J.B. (2001), *Progress in Estimating the Marginal Costs of Greenhouse Gas Emissions*, **FNU-4**. (*Pollution Atmosphrique - Numro Spcial: Combien Vaut l'Air Propre?*, 155-179)

Tol, R.S.J. (2000), *How Large is the Uncertainty about Climate Change?*, **FNU-3** (*Climatic Change*, **56** (3), 265-289)

Tol, R.S.J., S. Fankhauser, R.G. Richels and J.B. Smith (2000), *How Much Damage Will Climate Change Do? Recent Estimates*, **FNU-2** (*World Economics*, **1** (4), 179-206)

Lise, W. and R.S.J. Tol (2000), *Impact of Climate on Tourism Demand*, **FNU-1** (*Climatic Change*, **55** (4), 429-449)