PROJECT N. 037033

EXIOPOL

A NEW ENVIRONMENTAL ACCOUNTING FRAMEWORK USING EXTERNALITY DATA AND INPUT-OUTPUT TOOLS FOR POLICY ANALYSIS

TECHNICAL REPORT: A World Trade Model Scenario Analysis

Can global demand for food be satisfied by changes in diets and farming technologies?

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Preamble

EXIOPOL ("A New Environmental Accounting Framework Using Externality Data and Input-Output Tools for Policy Analysis") is an Integrated Project set up by FEEM and TNO with funding from the EU's 7th Framework Program. It runs between March 2007 and 2011. The main project set-up is in three content clusters, one on externalities modelling (Cluster II), one on a SUT/IO accounting framework with environmental extensions (Cluster III), and one on using the combined result in modelling for decision support (Cluster IV). Furthermore, one overarching cluster is dedicated to keeping the scope of this conceptually complex project focused (Cluster I), one is reserved for management (Cluster VI), and a final one is for dissemination of results (Cluster V).

This technical report reflects the following Cluster IV Case study, named: A World Trade Model Scenario Analysis - Can global demand for food be satisfied by changes in diets and farming technologies?

Acknowledgments

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1 Overview

1.1 Objectives

Construction of the EXIOPOL database, an environmentally extended input-output database of the world economy drawing on many and diverse sources of information, has been an ambitious undertaking. The scenario analysis described in this report has two objectives. The first goal is to provide an evaluation of the EXIOPOL database by applying to it a model of the world economy, the World Trade Model (Duchin 2005), that makes use of virtually all of its components while requiring several types of logical consistency that could not otherwise be imposed upon the data. The second goal is to make use of the unprecedented scope and detail of the EXIOPOL database by using it to address ways of dealing with vital strategic challenges facing agriculture and food over the next several decades. The latter is intended to demonstrate the value of further investment of effort in improving and extending the reach of the database, with attention to areas where quality assurance is particularly important. Among the features of the World Trade Model (WTM) that make it uniquely suited for this purpose is that it treats quantities and unit prices as distinct but interdependent variables and is able to impose quantitative resource constraints, necessary to reveal shifts in the international division of labor under alternative scenario assumptions.

1.2 Scenarios

The WTM is used to analyze three scenarios, which we call E2000, E2050, and ETD. The first is a baseline calculation for the year 2000 using the EXIOPOL variables and parameters, intended to test the database by credibly reproducing the base year conditions and to serve as the reference point for comparison with the outcomes of the other two scenarios. The second, E2050, assumes growth in all components of demand over the next four decades, proportional to regional population growth projections, and it in particular assumes substantially improved diets in developing countries, increases both in caloric intake and especially in access to animal products. E2050 clearly puts increased stress on the global agriculture and food system, and we enlarge endowments in selected regions to reflect potentially available agricultural lands. The final scenario, ETD, is designed to examine to what extent these pressures can be alleviated by the adoption of less resource-intensive diets in the rich countries accompanied by improved management of water and less land-intensive livestock technologies in selected regions.

1.3 Prototype Scenario Analysis with the WTM Database

Due to delays in the delivery of EXIOPOL data, the three scenarios were initially analyzed by applying the World Trade Model (WTM) to a smaller prototype database developed by Duchin (2005) and expanded and analyzed in the course of subsequent empirical studies (Juliá and Duchin 2007; Strømman, Hertwich, and Duchin 2009). The prototype analysis provided the opportunity to identify the variables and parameters that would be needed for scenario formulation and obtain empirical results that serve as a reference point for comparing results obtained with the EXIOPOL database. Its smaller size also facilitated the task. However, the data are for 1990 rather than 2000, the money units are in dollars rather than Euros (there was no Euro in 1990), the regional and sectoral classifications differ, and the data content relied on many rule-of-thumb assumptions. The EXIOPOL database offers the opportunity to apply the WTM to a much larger database, and one assembled from documented sources and including environmental extensions.

1.4 Outcomes from Analyzing the EXIOPOL Database

The comparisons among numerical results for the different scenarios are presented later in this Report, and we believe that they provide insight into future prospects for global agriculture and for European agriculture in particular. However, they in the first instance proved invaluable for identifying weaknesses in the EXIOPOL database, also discussed in subsequent sections, which could not be detected by formal consistency checks and were not revealed, either, in the computation of the baseline scenario, E2000.

Major problems were discovered in the data for the residual region called the rest-of-world, projected to contain 45% of the world population in 2050. While it was known that its representation in the EXIOPOL database was in need of improvement, it turns out that this region – including almost all the countries in both Africa and Latin America, and numerous others besides – is crucial for understanding the future evolution of global agriculture.

We were able to identify – and to some extent rectify -- specific problems in the data for the rest-of-world region that should be useful in further data development for the larger database. Fortunately, we were able to draw some conclusions from these analyses, despite the data problems, by combining the numerical results with an interpretation of the more aggregate results for the prototype scenarios using the WTM database.

1.5 Contents of this Report

Section 2 contains the first stage of our evaluation of the EXIOPOL database, describes how we dealt with the problem issues, and offers recommendations for improving the EXIOPOL database over the longer term. Next we describe two important extensions made to the WTM in the course of this project, providing a choice among technologies to individual regions and tracking networks of resources. The former has been utilized for the analysis reported here. Section 4 describes assumptions underlying the three scenarios and identifies the sources for the supplementary data compiled by us. Section

5 reports the results about the stresses on agriculture in 2050, the ability of dietary changes and new technologies to relieve them, and the shifts in the global division of labor in agricultural production that can be anticipated. It also identifies critical problems with the EXIOPOL database that were discovered in comparing outcomes for scenarios E2050 and ETD.

The World Trade Model /EXIOPOL User Manual is included with the Report. That document provides instructions on how to use the WTM family of models as applied to the EXIOPOL (or another) database and includes code for implementing both the WTM and the new model extensions. Several papers have been published and others presented at professional meetings on the basis of this research; they are cited in the text and also distinguished in the list of references by an asterisk. The scenario results will appear in future scholarly presentations and publications in progress and comprise a portion of a forthcoming Ph.D. dissertation (Springer 2011).

2 "Stress Test" for the EXIOPOL Database: Computing the Baseline Scenario for 2000 (E2000)

The contents of the EXIOPOL database closely match the data requirements of the World Trade Model, as it is intended to provide nearly all the data required by the model while the model makes use of practically all the EXIOPOL data. In particular, the WTM utilizes EXIOPOL data in physical units to represent constraints on use of land, water, and other materials and that limit production. First we probe the database before applying the model. Then, applying the WTM to the EXIOPOL database provides a vital "stress test" to help identify the problem areas for the data by revealing both internal inconsistencies and discrepancies with external control totals. Of course a model necessarily introduces its own assumptions, particularly, in the case of the WTM, that specialization is based on comparative advantage. Policies that impact trade flows, like quotas, are not represented in the current analysis but could be accommodated by the model.

In this section we briefly describe the structure of the EXIOPOL database and the model requirements and then evaluate the data and describe the additional data work that was needed to amend and extend the database to prepare for WTM scenario analysis of the baseline data for scenario E2000.

2.1 Transforming the EXIOPOL Input-Output Tables, Satellite Accounts, and Environmental Extensions into a Database for the WTM

The EXIOPOL database includes for each of 43 regions the input-output table of intermediate product flows for 129 production sectors, including columns of domestic final demand and trade flows and rows of value-added payments. All the *input-output data* are in money values. However, a sector's output is the implicit product of some quantity and a unit price, with the latter expressed in the common unit price of year 2000 Euros. The *satellite accounts* provide complementary information, some measured in quantity units such as person-years or work hours of labor. The *environmental extensions* are exclusively in quantity units and record the use of resource inputs and wastes generated in each sector. For present purposes, we focus attention on the agricultural and food sectors and the factors of cropland and pastureland, rainwater and irrigation water.

The WTM requires two kinds of additional data that were planned for inclusion in the EXIOPOL database but that we knew from the outset would be challenging to quantify. These are estimates of endowments in physical units for all factors of production, including labor, built capital, land, water, and minerals, and the unit price for each factor, namely the wage rate, rate of return on capital, and royalties on resources. Quantifying these variables is a challenge because they are not (except for labor) – yet -- typically part of an economic database. Nonetheless, they are vital for investigations related to sustainable development, the endowments to set realistic limits on resource availability and the resource prices as a basis for allocating resources and computing scarcity rents, which can be expected to increase as demand for goods grows relative to resource supply. We also require data about distances among regions as a basis for determining bilateral trade flows.

Requirements for the WTM database can be succinctly described in terms of a small number of vectors of variables and matrices of parameters for each region. The matrices are A, the square matrix of intermediate input requirements per unit of output; F, the rectangular matrix of factor input requirements per unit of output; y, the vector of domestic final demand; f, the vector of factor endowments; and π, the vector of factor prices. If there is a feasible solution, the WTM determines the lowest-cost international division of labor that satisfies domestic demand in all regions subject to regional factor availability. The model also solves for prices of goods and scarcity rents on any factor endowments in a region that are fully utilized. For a description of the model, see (Duchin 2005; Strømman and Duchin 2006).

Table 1 associates the different parts of the EXIOPOL database with each WTM variable and parameter. Several simple manipulations were executed to express it in these terms. Only the problem areas are discussed in the next section.

2.2 Evaluation of the EXIOPOL Database and Construction of the WTM/EXIOPOL Database

It was fully to be anticipated that the ambitious EXIOPOL database would exhibit inconsistencies and incomplete coverage and require additional conceptual specifications. Spot checks for internal consistency and comparisons with external data from reliable sources revealed some of the problems, while others were discovered in the course of interpreting the results of model computations for the baseline scenario, E2000. (Still others are discussed in Section 5.) This section identifies problem areas in the EXIOPOL database and shows how they have been resolved. It then describes the major new data developments needed to provide a more detailed description of the use and availability of land and water. The result we call the WTM/EXIOPOL database. The starting point for its development is the EXIOPOL database, including symmetric input-output tables aggregated to 21 regions and 78 sectors: these classifications are shown in Tables 2 and 3, respectively. The regions include three groups of European economies: individual countries for the large EU economies of Western Europe, the group of Eastern European members of the EU, and a composite region for the remaining Western European countries (almost all EU); individual countries for other large, developed economies; individual countries for large, developing economies; and a large and diverse composite region called rest-of-world, which includes countries from Africa, Asia, Latin America, Middle East, Oceania, and the non-EU Eastern Europe. The aggregations of European countries reduce the number of regions from 43 to 21. The sector scheme in Table 3 shows the level of detail for agricultural and food products, retaining most of the detail of the full EXIOPOL database. After describing the discrepancies (illustrated by numerical examples at the WTM/EXIOPOL levels of aggregation), we report the development of supplementary data on land and water for agriculture, followed by our major recommendations.

2.2.1 Input-Output Data

Control totals that quantify sectoral production are needed in order to calculate inter-industry coefficients from flows. Initially we found that column totals and row totals, both in principle measuring the same value of sectoral output, did not in fact match. In some regions, column totals were actually negative for some sectors, due to negative operating surplus or negative taxes in value added. The EXIOPOL team resolved these problems, at least for the more aggregated input-output tables used for the WTM/EXIOPOL database.

Money Values and Physical Units

Incorporating physical constraints into a model of the economy requires that measurements in quantity and price units be consistent. Spot checks comparing output in money values in the EXIOPOL input-output tables for agricultural and resource extraction sectors with output in physical units from the satellite accounts or environmental extensions, or from external sources, revealed large discrepancies, evident in Table 4, which shows the comparison to external sources for agricultural products.

An extreme example provides insight into the likely major source of these discrepancies. The WTM computation for scenario E2000 showed Japan having a comparative advantage in grain! In investigating why, we saw that the EXIOPOL database has Japan producing about 10% of global cereals and fruits and vegetables in money values while in fact Japan accounts for about 1% of each in tonnes (Siebert and Döll 2010); see Table 4. The problem probably arises in the conversion of input-output data for countries with diverse currencies into a common money unit, here Yen into Euros. A single exchange rate, whether the market exchange rate or the average purchasing power parity, may work acceptably well for regions with relative prices close to those of the Euro zone. But if the high relative price of fruits and vegetables in Japan is underestimated, the quantity and in turn the Euro value of output will be overestimated. The vital consequence is the impact on the entries in the column of input coefficients (i.e., input per unit of grain output) for the grain sector in the conversion from Yen-per-Yen to Euro-per-Euro. If a single conversion factor is used, each coefficient will remain unchanged when converted to Euros, as the numerator and denominator are converted by the same exchange rate. But if the product in the denominator is relatively expensive in Japan, its apparent Euro value will be too high and the coefficient in Euros will be too low, resulting in erroneously low input coefficients that make Japan appear like a low-cost producer of all the agricultural products.

The mining sectors reveal even larger discrepancies, shown in Table 5, where the tonnages reported in the EXIOPOL environmental extensions are compared to the values in Euros from the EXIOPOL input-output tables. These discrepancies probably reflect inconsistent definitions and conventions in collating information from different sources, although there are no doubt relative price differences as well. Striking examples include the cases of uranium, nickel, and aluminum. Spain is the world's third highest producer of uranium in tonnes; in monetary units, Spain produces none at all. Virtually no nickel endowment is reported for the U.S., yet the monetary value of production is high, while Indonesia shows high tonnage of output but a low money value. Canada, Other Western Europe, and EU Eastern Europe all show substantial tonnages of aluminum extraction yet very low money values of production, while Russia shows very low tonnage of production but high money values.

For the mining sectors, we adjusted the endowments, increasing them for regions known to have large reserves and thus permitting them to increase their output. This solution reduced the large discrepancies but was done in a cursory manner and requires more careful scrutiny. We paid closer attention to the region-specific problems for the agricultural sectors, increasing input coefficients for European regions as well as Japan and Korea, while decreasing cropland requirements for Russia and pastureland requirements for Australia.

Empty Columns and Rows

The input-output tables for a number of regions had empty columns and rows (i.e., zero intermediate inputs, value added, and final demand) for one or more sectors. One possible explanation is virtually no production and no use of the sector's output in that region (for example, cattle in India or pigs in Turkey). However, FAO data (FAO 2010) show considerable oil seed production in Brazil while no production is shown for this sector in the EXIOPOL database. In some cases the region in question was shown in the EXIOPOL database to import the product in question and therefore the row should quantify its use. Probably the dominant explanation for the empty columns and rows is that the sector in question was included as part of a more inclusive sector in the original data source utilized by EXIOPOL for that region. Being committed to having the same sectoral scheme for every region, the EXIOPOL database was filled with zeroes in the corresponding columns and rows. This poses a dilemma that is not unique to EXIOPOL and clearly requires new thinking. If empty columns and rows are selected as a temporary solution, it is vital at least to alert users to this fact so they can assume the responsibility of dealing with the consequences. Any formal model will consider a region with no input costs to have a strong comparative advantage in producing the corresponding product. One of our motivations for aggregating sectors from 129 to 78 was to suppress sectors that had columns of zeroes in any region. In cases where this was not desirable, like the cattle sector that was empty for India but important for the scenario analysis, we inserted large input coefficients for India – rather than zeroes -- to assure that it did not specialize in this sector.

Final Demand and Value Added

In some regions, the sectoral composition of final demand appeared implausible. Extreme cases are Mexico, where reported domestic final demand for precious ores is almost 60% of global demand, and the rest-of-world region, where the sector "electrical energy, gas, steam, and hot water" accounts for 12% of the money value of final demand compared to 0.5 – 3.5% in other regions. We were able to resolve this problem by excluding changes in inventories from domestic demand, as these numbers were often extremely large and hard to justify, being a residual category.

Value-added rows included negative figures for consumption of fixed capital and for remaining net operating surplus for some sectors in some regions and sometimes also for those taxes that are included in value-added. While it is hard to give them a reasonable interpretation, we made no corrections because the negative numbers were usually small and occurred for non-strategic sectors. (In addition, they were needed to assure that the starting tables had matching row and column totals.) However, these negatives obviously require closer scrutiny. The agriculture sectors in the rest-of-world region show large payments for resource royalties while these factor prices are zero in all other regions; these, too, we left in place.

Rest-of-World Region

The rest-of-world region includes almost all countries of Africa and Latin America as well as the Middle East, many countries in Asia and some in Europe. The region accounted for 34% of world population and (according to EXIOPOL data) 22% of world GDP in 2000, and it is projected to be home to 45% of the global population in 2050. Developing data for this region was especially difficult because it is a residual including many diverse countries, and in addition none of them uses the Euro as its currency. One example of the problems is that estimated production of most sectors in this region was initially far too high, both as a percentage of global production (as compared to EXIOPOL totals) and in particular as a percentage of agricultural production in tonnes of crop or livestock. This region is vital for the scenario analysis, since experts agree that agricultural production is likely to increase most in Latin America and Africa, based on vast potential for improved land and irrigation productivity. While the EXIOPOL team dealt with many of these problems, it will be seen that the scenario analysis described below revealed additional ones.

Satellite Accounts: Labor

The numbers of workers employed in India and the EU Eastern European region are much higher than ILO control totals (ILO 2009), no data on employment are provided for the rest-of-world region, and no information is provided on regional labor force totals. We adjusted the India and EU Eastern Europe labor coefficients using the ILO data and made rough estimates for the rest-of-world region, assuming its sectoral distribution of labor followed that given in the satellite accounts for Indonesia. The ILO data on the labor force include the unemployed as well as the employed, and we use this inclusive figure for the endowment of labor.

Satellite Accounts: Built Capital

Many conceptual challenges surround estimation of a region's stock of built capital and capital stock requirements per unit of a sector's output. Since this subject was not the main focus for EXIOPOL, we were not surprised that, while the EXIOPOL database contains some data for EU countries, taken from the EU-KLEMS database, in the satellite accounts, there is none at all for other regions. The WTM requires a measure of the fixed capital stock and sectoral stock requirements per unit of output, implying an implicit rate of capacity utilization. Our rough fix was to estimate sectoral capital stock by assuming the sector's operational surplus was the return on the stock at an average rate of return; we also assumed that the stock was fully utilized. It is of course clear that the stock is generally not fully utilized, and we increased this endowment judgmentally for several regions by about 10% and for the rest-of-world region by as much as 40%, in response to the binding capital constraints encountered in the initial results for scenario E2000.

2.2.2 Land and Water for Agriculture

EXIOPOL input-output tables distinguish several categories of agricultural production for both crops and livestock. However, in each case there is a single average production technology available to a region. A key scenario objective is to provide alternative production options, namely rainfed and irrigated agriculture for producing the same crop, pastoral and industrial options for raising cattle, and allowing the use of cropland as well as pastureland for grazing livestock. EXIOPOL environmental accounts provide data on the regional availability and sectoral use of cropland and pastureland and of water. However, we required not only disaggregating the single average technology into discrete alternatives but also distinguishing rainfed land from land equipped for irrigation and green water, available free of cost as soil moisture, from blue water which must be pumped and delivered for irrigation. (The modeling extension for accommodating alternative technologies is described in Section 3). Our team developed these data using external sources of information that are identified below. Reconciling more aggregated EXIOPOL data to these data revealed discrepancies that needed to be resolved.

The source for the EXIOPOL data on water is the highly-regarded LPJmL model resident at the Potsdam Institute for Climate Impact Research (PIK). We sought some "ground truth" and found that reported total blue and green water consumption by region does not match estimates by water experts (Shiklomanov 2000; de Fraiture et al. 2007; Siebert and Döll 2010). In some cases EXIOPOL estimates are so implausibly high as to exceed total regional rainfall. For example, Mexico's water consumption according to the EXIOPOL data is 1139 cubic km as contrasted to 83 cubic km according to Siebert and Döll (2010).

Some water-intensive sectors show zero water use in EXIOPOL environmental extensions. Illustrative examples are the sector producing primary vegetables, fruits and nuts and the sector providing water distribution services. EXIOPOL partners attribute this discrepancy to differences in the EXIOPOL and PIK sectoral classification schemes. For example, if there is not a sector for fruits, vegetables, and nuts in the LPJmL model, no water would be allocated to that sector in the EXIOPOL database. The problem of classification mismatch was identified earlier in the context of empty columns and rows and clearly needs attention.

EXIOPOL data for blue water inputs measure *consumptive use* but do not quantify water *withdrawals*. But it is for withdrawals that agriculture, industry, and municipalities compete over available water, and one key objective of improved water management is to reduce the loss between withdrawal and effective use. If fees are imposed on use of blue water, it is for withdrawals and not consumption. For all these reasons, priority must be given to measuring withdrawals. Another complication is that the percentage of water use attributed to electric power production in the EXIOPOL database is unrealistically low. This is probably because it is consumption rather than withdrawals that is measured here also, and power plants discharge (rather than "consuming") most of the water withdrawn -- albeit at much higher temperatures. Indeed the distinction between withdrawals and consumption is further complicated by the potential for subsequent reuse of water withdrawn but not consumed, provided it is not deteriorated for subsequent use. But these challenging problems need to be resolved step by step, and our attempt for now is to develop consistent estimates for sector level withdrawals of blue water.

Irrigated and Rainfed Arable Land

Sector-level use of total cropland is provided in the EXIOPOL environmental extensions. For the scenario analysis, we disaggregated arable land into rainfed land and land equipped for irrigation, using data from the Global Crop Water Model (GCWM) (see Siebert and Döll 2010), kindly provided by S. Siebert. This source distinguishes both land area harvested and tonnes of crops produced on irrigated vs. rainfed land. Although this output is from a model rather than direct measurement, reported global and regional totals compare well with estimates by other land and water experts. Fortunately, the GCWM database contains enough detail about crop types to allow straightforward aggregation of their classification to the EXIOPOL classification.

We disaggregated both columns and rows of the matrix of factor requirements per unit of output to distinguish two technological options for each crop-producing sector (resulting in two columns) and two types of arable land (two rows). Land in the GCWM is measured in harvested land (i.e., the percentage of the land used that is actually harvested). We convert harvested land to land required by means of harvest coefficients by region and land type provided by Bruinsma (2008) for rich and for developing countries; we used the latter for Brazil, China, India, Indonesia, and the rest-of-world region and the former for all other regions. This step provided the necessary data on quantities of irrigated and rainfed land requirements in all EXIOPOL regions.

The global land use totals derived in this way match closely to those in the EXIOPOL database. Perhaps not surprisingly, however, there are substantial regional discrepancies. To make full use of the EXIOPOL database, we decided to apply the percentage distribution between rainfed and irrigated land for each sector according to the GCWM database to the totals in the EXIOPOL database. A region's rainfed land availability, or endowment, was calculated by summing rainfed land use in all crop sectors. The same was done for irrigated land. The implicit assumption is full use of the endowment of arable land.

The unit price of arable land was derived from the payments for arable land reported in the EXIOPOL database. For lack of information, no distinction was made between payment per hectare for rainfed and irrigable land.

Pastureland

Total pastureland used in each region, and payments by the individual livestock sectors for use of the land, are provided in the EXIOPOL environmental extensions. The endowment was estimated to be the total amount of land in use. For the price per hectare we used land payments as reported in the EXIOPOL database. Since pastureland was not distinguished by livestock sector, and to our knowledge such estimates are not available, we assumed it was allocated among the individual livestock sectors in proportion to their payments for land, most of the total accounted for by the cattle sector.

Water

The challenges posed by the EXIOPOL water data, described earlier, and our need to distinguish green from blue water, led us to use three alternative sources to calculate water requirements per unit of sectoral output. The GCWM dataset provides data on rainwater consumption and on tonnes of crop produced, on both irrigated and rainfed land. We use the FAO Aquastat database (FAO 2011) for estimates of water withdrawals in all sectors, since the GCWM dataset is limited to blue water consumption in agricultural sectors only. The Aquastat database also provides figures for blue and green water availability. Finally, de Fraiture et al. (2007) provide data for quantifying water withdrawals for the electric power sector.

Green water consumption per unit of crop output was calculated by aggregating GCWM data to match the crop and regional detail of EXIOPOL. Rainwater is used on both irrigated and rainfed land, and this aggregation was done separately for each of the three crop categories (and crop technologies), resulting in six green water coefficients per region. Aquastat provides figures on the amounts of the green water available for evapotranspiration. No price is associated with green water (i.e., the unit price is zero).

Blue water withdrawals were derived mainly from Aquastat, which distinguishes agricultural, industrial, and municipal use. To provide detail for the three crop sectors, we used GCWM data on blue water consumption and assumed that the ratio of blue water consumed to withdrawn is the same for all crops in a given region, implicitly assuming comparable irrigation efficiencies. We then used Aquastat data on withdrawals to distribute blue water among the agricultural sectors. De Fraiture *et al.* (2007) provide the percentage of industrial withdrawals destined for thermo-electric cooling for the electric power sector. Other industrial withdrawals were distributed among the remaining sectors. Municipal withdrawals are from the public water supply and are delivered to industry and commerce as well as households and public sector use (Solley, Merk, and Pierce 1988; López 2010). They were distributed as follows: 40% to municipalities and other services, 20% to household consumption, and the remainder to industries. Availability of blue water is interpreted as the *sustainable blue water supply,* as defined by (Duchin and López-Morales 2011). It was calculated using data from Aquastat. No fee is imposed on the withdrawal of blue water.

2.2.3 Other Data: Fossil Fuels, Minerals, and Transport Weights and Distances

In the sectoral aggregation for the WTM/EXIOPOL scenarios, oil and natural gas sectors were combined and extraction quantities provided in the environmental extensions were converted to tonnes of coal equivalent (TCE) using conversion factors from the IEA (IEA 2010). Because of the discrepancies between quantity and monetary estimates discussed earlier, infeasibilities were encountered in running the baseline scenario, E2000, as individual regions ran out of these raw materials. We dealt with this problem by increasing factor availability for regions and sectors where the EXIOPOL environmental extensions showed high amounts of production while the money value of production was low according to the EXIOPOL input-output tables. The reconciliation of energy and material quantities and values obviously requires close attention in future work.

For the WTM/EXIOPOL database, we distinguished two types of capital, agricultural and all other, and four types of labor used in the agricultural, mining, manufacturing, and service sectors. These distinctions made it possible to assume different rates of return on capital and different wage rates and to focus on impacts on agricultural factors in scenario results.

Finally, we had anticipated the production of matrices designating the distances between regions by different models of transport so as to permit the determination of not only imports to and exports from each region but also bilateral trade flows. Ultimately the

EXIOPOL database did not include this information, so it is the World Trade Model, and not the World Trade Model with Bilateral Trade, that is implemented for the scenario analysis.

The new data sources and the assumptions underlying the WTM/EXIOPOL database are shown in Table 6.

2.3 Recommendations for Improving the EXIOPOL Database

Different Classification Schemes

Conventions need to be established for combining data from sources with different classification schemes. Rough estimates at disaggregating a more aggregated classification to the common level of detail is probably a better strategy than inserting zeroes for a lacking category. When the problem is not only level of detail but also overlap of categories, one cannot hope to maintain all the data content.

Reflecting Differences in Relative Prices

At the current time, all empirically rich models of the world economy are based on inter-industry data for some set of countries or regions, with economic data measured in a single currency unit, the Euro in the case of EXIOPOL. A single exchange rate (the currency-exchange rate or the average purchasing power parity) is generally used to convert data originally in different currencies into the standard money unit. It would represent a big step forward to replace that single conversion factor by a vector of conversion factors, one for each of n sectors, to reflect differences in relative prices among regions. An easy way to do this is to start with a vector with n components all set to the single average exchange rate. For any region that is known to have substantially different relative prices, the exchange rate for selected sectors can be raised or lowered. For the longer term, research should focus on making relative prices endogenous to a model of the world economy. Then input-output data can be accommodated in the monetary units in which they were originally compiled.

Differences Among What Sound Like the Same Units

Definitions and conventions have to be established for quantity units. For example, water used in agriculture may be reported in different sources in the common unit of m^3, while referring to water withdrawals in one case and to water consumed in another. Hectares of agricultural land may refer to area required or area harvested, and so on. What is being measured, and not only the physical unit, needs to be made explicit when combining data from different sources.

Consistency between Monetary and Quantitative Units

It is vital to create formal checks for consistency between a variable's value measured in money units and the same variable measured in quantity units. Besides being sure they are defined so as to measure the same thing, it could be helpful to systematically divide the money value by the presumed quantity to be sure the implied price makes sense.

Rest-of-World Region and Other Residual Categories

This Report makes clear the problems introduced by a residual category that includes too many components, especially if they are very diverse in important characteristics. The most evident case in the EXIOPOL database is the rest-of-world region, which needs to be disaggregated into several more homogeneous regions. This problem would arise for analysis of other resources besides agricultural land and water, namely petroleum, which is concentrated in the Middle East, also included in the rest-of-world. Other residual categories are some of the problematic components of value-added and of final demand.

Capital Stocks and Endowments of Resources

All factor stocks, or endowments, require careful definition before quantification is plausible. Particularly challenging is the case of water: see the discussion in (Duchin and López-Morales, 2011). In the present study we use the environmentally sustainable stock, a definition that reflects substantial progress over the absence of any modifiers but is still subject to multiple interpretations and approaches to measurement.

Built capital is difficult for somewhat different reasons: it combines very heterogeneous items, such as bridges, buildings, and machines. Here one step forward is to quantify a vector of stocks by type and not a single number to represent the entire stock of built capital. (This is called a capital stock matrix in a dynamic input-output model.) Now that not only economists but also industrial ecologists have strong interest in quantifying the stock of built capital (to estimate the recoverable materials at the end of life in the latter case), future work should focus on improving these measurements by reconciling top-down estimates with bottom-up detail from direct surveys.

3 Extensions to the World Trade Model: The Choice-of-Technology Model and Resource Networks

Two conceptual extensions to the WTM were designed and implemented expressly for the analysis of EXIOPOL scenarios. The first we call the rectangular choice-of-technology, or RCOT, model to emphasize the fact that it utilizes rectangular matrices of intermediate and factor requirement coefficients, A^* and F^*, in place of the usual square variety, A and F. This model provides each region the opportunity to produce a given product using one of several alternative technologies, or any number of the options simultaneously. The second is the development of absorbing Markov chains (AMCs) that identify and quantify what we call *resource-specific networks* and *resource-end-use networks* to track a particular resource between origins in a given region and embodiment in products delivered to final consumers in other regions (Duchin and Levine 2010; Duchin and Levine 2011).

Both extensions to the WTM are fully incorporated into the logic of global comparative advantage and fully consistent with it. The WTM/EXIOPOL User's Manual includes these codes.

3.1 The Rectangular Choice-of-Technology Model

The RCOT model has been used in the scenario analyses reported here to represent the choice between rainfed and irrigated farming technologies for growing most crops. Which is the lower-cost option depends on the specific situation in the region, and in other regions. Furthermore and importantly, in many cases a region utilizes more than one option simultaneously when the lower-cost options run into factor constraints.

We also introduced a second option for raising cattle (beef cows) in the ETD scenario. Given the great surge in demand for animal products under the E2050 scenario, the new option provides the opportunity to raise animals using less land for grazing but substitutes purchased feed products for grasses. We also allowed for the option of competing with crop production for arable land (competing pastureland and cropland was also introduced in E2050, see Section 4 for details). These scenarios are the first implementation of the RCOT model with a global dataset. Other studies have used more roundabout representations of the choice among technologies in the WTM (Julia and Duchin 2007, Lopez-Morales 2010).

The implementation of the RCOT model in this study has demonstrated its value and we expect it will be appealing to other researchers as well. It has a simple and transparent logic, is easy to implement, and increases the power of the analysis in situations where alternative technologies for producing the same output differ significantly (consider the case of nuclear reactors and coal plants for generating electric power, for another important example). The additional data requirements are the minimum that would be needed to describe the differences among the alternative technologies. RCOT does, however, require suspending the traditional belief that input-output coefficient matrices need to be square so they can be inverted.

3.2 Resource-Specific Networks and Resource-End-Use Networks

Duchin and Levine (2010) first developed an absorbing Markov chain (AMC) to track the network of embodied flows of a given resource input through a single economy to its end uses and transcribed the well-established Markovian notation in terms of variables and parameters more familiar to input-output economists. Subsequently, they extended the framework by developing the AMC for tracking the network of flows of a given embodied resource through the global economy using as input the solution of the WTM with bilateral trade (Duchin and Levine 2011b). The objective in the context of the present study is to examine the flows through the global economy of one region's water endowment (its resource-specific network) or to identify and track the sources of water for, say, producing the food consumed in a particular region (the resource-end-use network).

As mentioned in Section 2, the World Trade Model with Bilateral Trade can determine not only a region's flows of exports and imports but also the destination regions for each exported good and the origin regions for each imported good. The underlying logic is consistent with comparative advantage in that an importing region favors those exporting regions from which the goods can be delivered to them at lowest cost (Strømman and Duchin 2006). To determine transport costs between any two regions one needs to know the mass of each good, the distance between the regions for each transport mode, and the input structure for each mode of transport. The first two types of information are compiled into what we call T matrices, and the last information comprises additional columns in the A and F matrices. At one point the plan was for this information to be developed as part of the EXIOPOL database, but unforeseeable events prevented the completion of this work. As a consequence, it has not been possible to compute these networks for the scenarios described in this report. However, the AMCs are now in the process of being applied to the results of scenario analysis using the prototype WTM database.

4 WTM EXIOPOL Scenarios: Assumptions, Data Requirements, and Sources

The scenario analyses are designed to reveal the physical requirements and costs of increased agricultural production over the next four decades and evaluate the capacity of various solution concepts to reduce these pressures. Scenario E2050 represents the consumption demand of increased regional populations and improved diets in developing countries, and it assumes the availability of additional land, not now used for agriculture, in selected regions to accommodate the need for more food. Scenario ETD introduces three measures for alleviating the pressures associated with E2050: less resource-intensive diets in rich countries, improved agricultural water management, and land-saving (but grain-using) livestock production technologies. The last two measures are assumed for developing countries, specifically Latin America and Africa, where many experts believe that payoffs for such improvements are most promising. This section describes scenarios E2050 and ETD in terms of changes in exogenous variables and parameters and identifies the data sources. This information is shown in Tables 7 and 8.

4.1 E2050: Population Growth and Developed Country Diets

This scenario projects global growth of consumption demand and improved diets in developing regions. Domestic final demand in each region is increased by the percent of population change anticipated for 2050 (UN 2010). Most of this increase is experienced in developing countries, particularly India and the rest-of-world region, both with large current populations and large projected growth rates.

Improved diets are represented by increased food caloric intake and a higher share of calories from animal products in the developing regions. The FAO estimates that undernourishment can be substantially reduced by diets raised to 3000 kcal/day of food calories with 20% of those calories coming from animal products before diminishing returns are encountered (Bruinsma 2003); we use these as the dietary objectives. ("Available food calories" are the total amount that need to be supplied in a given region and exceed the amounts actually ingested as the former includes amounts wasted.) Data on regional food availability (kcal/capita/day) are provided in the FAOSTAT database (FAO 2010), the standard source used in the literature (Rosegrant, Cai, and Cline 2002; Tukker *et al.* 2008; Popp, Lotze-Campen, and Bodirsky 2010). For individual countries, the data utilized are for cereals, vegetables and fruits, cattle, pigs, poultry, other livestock, milk, other animal products, seafood, and total caloric availability. Other crops, other animal livestock, and other animal products were treated as residual categories. For regions of more than one country, a weighted average of kcal/capita/day was taken for each food type. Percentage of total caloric intake from each food type was calculated for each region.

The following two-step procedure was implemented to achieve 3000 kcal/capita/day with 20% consumption of animal products. First, demand for all food types was scaled up by the percentage necessary to reach the desired total caloric availability. Second, availability for the seven animal types was scaled up to reach 20% of the total, offset by a compensating decrease in calories from other foods. This approach allowed for the structural change in regional diets towards more animal products while maintaining regional preferences for the mix of products. For example, regions with a relatively high consumption of fish under E2000 maintained this preference as they upgraded their diets. Finally, we limit the increase in animal product demand to twice E2000 levels, a limit that was binding for India, Indonesia, and the rest-of-world region and prevented unrealistically large percentage increases in consumption of animal products in these regions.

The percentage change in calories for each food type was assumed to be the same as a percentage change in money values, a reasonable assumption at this relatively disaggregate level of product detail. We also assumed comparable percent changes in primary agricultural products and related processed foods. For instance, if FAO caloric intake of cattle meat increased by 66%, then demand for both primary cattle products and processed beef were increased by that amount under E2050.

In addition to changes in consumption, we also increased the endowments of capital, labor, rainfed land, irrigated land, fossil fuels, and minerals. In the baseline scenario, E2000, many factor endowments were assumed to be the same as or close to total factor use in that year. In E2050, availability of most factors is assumed to increase, and we next discuss how these increases are projected.

Capital and Labor

We increased each region's E2000 labor force (endowment) by the projected percentage change in the economically active population in the region, defined as those of ages 20 – 60, using data from the UN Population Division (UN 2010).

Each region's capital availability was increased by at least the same percentage as its labor availability to maintain capital to labor ratios. As capital estimates were problematic for the reasons discussed in Section 2, detailed estimates of future capital availability would be even more problematic. Maintaining a non-declining capital/labor ratio assures that a moderate amount of additional capital will be available for production.

Land and Water

Experts have different opinions about how much irrigated land will be in use globally by 2050. Some estimate increases relative to today as high as 30% (Fischer *et al.* 2007; Bruinsma 2008) while others believe there can be no increase at all (Alcamo, Flörke, and Märker 2007). The Aquastat database (2011) provides a global dataset with country-level estimates of land *potentially* available for irrigation, although unfortunately not for all regions; and several countries are shown to have less potential irrigated land in 2050 than in 2000, decreasing in some cases to zero. We used Aquastat projections but did not allow the endowment of potentially irrigated land to fall below that for E2000. Resulting global irrigable land is 120% above that assumed for E2000, with the largest increases in Brazil, India, Russia, and the rest-of-world region, where the countries included in the latter region are shown in Table 2. The land endowments are shown in Table 9.

Rainfed land endowments for E2050 were projected in a similar way using estimates of total potential arable land from the FAO (Bot, Nachtergaele, and Young 2000) and subtracting from them the estimated endowments of potential irrigated land. This procedure increases global availability of rainfed land to 180% above E2000, with the largest increases in Brazil and the rest-of-world region. Pastureland endowments were not changed, reflecting the opinion of land experts that expansion of pastureland, as a biome distinct from arable land, is no longer likely (Naylor 2009, Gibbs 2010). However, we introduced an additional technological option that allows cattle to use arable land as well as pastureland for grazing. Arable land is already used to graze cattle in some regions (Steinfeld, 2006).

We made no change to water endowments for E2050 since the sustainable supply assumed for E2000 is unlikely to increase. We adjusted availability of fossil fuels, ores, and other minerals by the same logic as for E2000, further increasing endowments for regions and factors where the EXIOPOL environmental extensions showed high quantities of production while the money value of production was low according to the EXIOPOL input-output tables.

4.2 ETD: Changes in Rich-Country Diets and in Agricultural Technologies

The ETD scenario introduces three measures for reducing the stresses imposed upon the global economy by the assumptions of E2050. The first measure shifts the composition of diets in developed regions away from the most resource-intensive foods, namely animal products. This was done using the same targets as for diet change in developing regions in E2050 (3000 kcal/capita/day availability with no more than 20% from animal products) with data from the same FAOSTAT database. The difference is that in developing regions, caloric intake was increased, as was the share of animal products, while caloric intake and share of animal products are reduced for developed countries under ETD.

The second and third measures introduce technological changes in farming methods to Brazil and the rest-of-world region. We focus on these two regions as the literature clearly identifies Africa and Latin America as the regions where the greatest benefits from technological upgrades can be expected. This is because today Latin America and Africa experience, on average, some of the lowest land yields and lowest water productivities of all world regions (Falkenmark and Rockström 2006; de Fraiture *et al.* 2007), and these regions include over half of global potential agricultural land and 65% of unused potential agricultural land (Bot 2000). In the prototype WTM scenarios, we are able to treat Latin America and Africa as distinct regions. For the WTM/EXIOPOL scenarios, however, we focus on Brazil and the rest-of-world region, as the latter regional category includes all Latin American and African countries except Brazil and South Africa.

<u>Improved Water Management in Brazil and the Rest-of-World Region</u>

Improved water management for both rainfed and irrigated agriculture has the potential to improve both "crop per drop" and land yields, for example by enabling denser planting or multiple crops per year, and further contribute to global reductions in land and water requirements by substituting for agricultural production in less efficient regions. We introduce assumptions about water management improvements for both rainfed and irrigated agriculture.

We represent improvements in irrigated agriculture by increasing the portion of blue water withdrawn that is productively consumed. Technologies such as sprinkler or drip irrigation can achieve this by more precise timing or placement of water, thereby improving irrigation efficiency by reducing the amount of water needed to be withdrawn to provide for the same water consumption. These methods also reduce the amount of consumptive water lost as evaporation, increasing productive water use as transpiration and improving yields (Falkenmark and Rockstrom 2006). To reflect these assumptions we lower both the blue water coefficients (m^3/tonne) and the irrigated land coefficients (ha /tonne). Withdrawal estimates from Aquastat (2010), and consumption estimates from Siebert and Döll (2010) are used to calculate the implicit baseline irrigation efficiencies for all EXIOPOL regions in 2000: calculated efficiencies are 0.23 for Brazil and 0.5 for the rest-of-world region. Both de Fraiture *et al.* (2007) and Calzadilla *et al.* (2008) estimate that efficiencies can be raised to 0.7 in these regions. We use this assumption to lower the water input coefficients accordingly for ETD (ignoring losses between withdrawal and application). We use yield improvements estimated by de Fraiture *et al.* (2007) to lower irrigated land coefficients.

We represent improved efficiency in rainfed agriculture by increasing the portion of green water uptake that is used productivity. Water management strategies - such as increasing green water retention through land leveling, terracing, soil fertility management, and tillage (de Fraiture et al. 2007 and Falkenmark and Rockström 2006) - increase the amount of green water available (cubic km/ha) and can shift to consumption for transpiration water that would have otherwise been evaporated. This improves yields (tonne/ha) and hence green water productivity (tonne/m3), particularly in regions where green water consumption is currently around 2000 – 3000 m3/tonne (such as Africa and Latin America) with much of it lost as non-productive evaporation with resulting low yields. Falkenmark and Rockström (2006) estimate that this vapor shift could achieve a doubling of cereal yields while keeping green water consumption constant, improving water productivity to tonne/1500 m3. These improvements lower both green water coefficients and rainfed land coefficients.

Technological Choice for Cattle Farming Systems in Brazil and the Rest-of-World Region

According to Naylor (2009), expansion of livestock production no longer utilizes pastoral systems, which are being displaced by industrial systems. The latter use much less pastureland, substituting processed feeds and fodder for grasses. With the largest tracts of potential arable land located in Latin America and Africa, and the most abundant pastureland in Africa, the ETD scenario provides industrial systems in both these regions as a technological option for raising cattle.

To represent this option, we further disaggregate each of the two cattle production sectors in Brazil and the rest-of-world that graze cattle – the one on pastureland and the other on cropland -- into two sectors. These two options under E2050 rely on no purchased feed. But now each may as an alternative employ the mixed/industrial technology: in this case, land requirements are substantially reduced and feed is purchased from the crop sectors and processed food sectors. Thus under ETD there are four options for raising cattle.

To calculate differences in land use (ha) and production (tonnes) for the two industrial farming systems, we use data from Bouwman *et al.* (2006) for three categories of countries: developing, transitional, and industrial countries. We calculate the percentage of total pastureland use and total production for both pastoral systems and mixed/industrial systems for developing countries and use these percentages with the figures from Bouwman *et al.* to disaggregate the coefficients in A and F, applying to the data in money values the percentage change in tonnes.

5 Comparisons of Scenario Outcomes

In this section we present the empirical results obtained for the scenarios, making use of two sets of analyses: the prototype WTM analysis and the significantly more detailed WTM/EXIOPOL database. We find that comparing the outcomes for the baseline scenario for 2000 (or 1990) with the growth assumptions and diet improvements of the scenario for 2050, and the latter with the dietary and technological moderating forces assumed for the final scenario, yields agreement on a certain number of important points. (See Table 10 for the regional and sectoral classification schemes for the prototype analysis.) While the EXIOPOL computations can in principle provide much greater regional and sectoral detail, additional problems with these data were discovered in the course of the scenario comparisons that compromise some of this potential, particularly for interpreting the last scenario. In what follows we report the basic conclusions with detail from each of the two sets of analyses while also identifying the data problems in the latter case. Numerical results are shown in Tables 11 through 17 and illustrated in Figures 1 through 11.

5.1 Prospects for Agriculture: Numerical Results

Since the 2050 scenario prescribes a near doubling of final demand for food products, it is not surprising that all crop and livestock outputs are about double those under the baseline, while agricultural use of land and water and other factors also increase globally but by somewhat smaller percentages, taking advantage of the additional land made available in both Brazil and the rest-of-world region. Nonetheless, food prices increase by 30 -100%. The largest expansion in food production is for livestock, and this takes place mainly in North America, Latin America and both Western and Eastern Europe. To accommodate this growth, livestock production takes advantage of the possibility of expanding onto not only pastureland but also arable land. Grain production continues to take place on both rainfed and irrigated lands and increases most in Latin America and Asia. Production of other crops increases mainly on irrigated land and mainly in Africa. Thus increased demand, especially for animal products, favors America and Europe for livestock production but the other continents for expansion of crop production.

The final scenario is characterized by reduced food demand, especially for livestock, in rich countries, improved crop productivity for both water and land use, and industrial livestock production in Latin America and Africa. These assumptions moderate the increases in agricultural production, use of land and water, and food prices relative to the last scenario. Prices of food products average only about 10% above the base year levels. In fact, prices of cereals and cattle prices are actually slightly below base year levels as they are now primarily produced in regions with improved technologies and expanded endowments of land (see Figures 1 and 2). Global production of livestock naturally falls (but unfortunately not for the EXIOPOL database) and remaining production shifts to Latin America and Africa. Crop production also falls (again, not true for the EXIOPOL database); this occurs mainly in China but also in Europe and North

America, where it had already fallen under the previous scenario. Global use of both rainfed land and irrigated land also declines. However, the use of blue water for irrigation increases. Irrigation is reserved for higher value crops, now produced mainly in regions where more water needs to be applied per unit of crop output than under the 2050 scenario. Cereal production is now concentrated largely in Africa and it is mainly rainfed; as a consequence the price of cereals falls to about baseline levels.

We conclude that it would be physically feasible to feed the populations anticipated for 2050 and at the same time substantially improve diets in developing countries by cultivating additional lands in Africa and Latin America that are considered, in the literatures cited, to be effectively available. However, this scenario incurs large increases in food prices. We find that with a shift to more plant-based diets in the rich countries accompanied by what are widely considered to be realistically attainable improvements in the productivities of water and land use in Africa and Latin America, the costs of doing so can be held down substantially. But these assumptions will lead to changes in relative cost structures for agriculture in favor of Latin America and Africa compared to Europe and North America. Enhancing comparative advantage agriculture in the latter regions would require concerted action, including selective investments in improved productivity in higher-value agricultural products.

5.2 More Detailed WTM/EXIOPOL Scenario Results

Globally, the portion of cereals grown on irrigated lands falls substantially under E2050 relative to E2000, as irrigation capacity is shifted to higher value crops. Growth in blue water withdrawals is almost double the increase in green water consumption. Global irrigated production increases about 150% for fruits, vegetables, and nuts and for other crops even though less land area is required. With large amounts of productive rainfed land availability in the United States and in the rest-of-world region, they are the major producers in 2050 of rainfed grain.

While crop production is relatively concentrated spatially, animal products are produced in a larger number of regions. The greatest increases in production are for pigs, poultry, and other meat animals (besides cattle), reflecting the mix of animal products that prevails in developing countries. Cattle production, which requires more land directly and indirectly per unit of output, increases the least of all the livestock sectors. However, most cattle production moves from pastureland to arable land, freeing up the pastureland for the expansion of the other livestock sectors.

Food commodity prices for all 19 categories of primary agricultural products, and all processed foods, rise between 30 and 100%, those of primary agricultural products, with the notable exception of grains, increasing more than those of the processed foods.

While these results are largely consistent with those of the prototype WTM analysis, EXIOPOL data problems become apparent when comparing the ETD scenario to E2050, as the former barely reduces global agricultural production and in fact production of some food products, namely cattle, actually increases. This outcome is inconsistent with the scenario assumptions: since global final demand for cattle falls under this scenario, the only reason for an increase in output must be intermediate demand for cattle. We calculated the shares of intermediate demand for cattle in all regions according to the EXIOPOL data for 2000: these figures are shown in Table 14, which reveals the problem. In most regions the vast majority of intermediate cattle output is delivered to the meat-processing sector, but in the rest-of-world region – which is the major producer of livestock under this scenario -- it is only 7%! (Other anomalies are large inputs of cattle into fish products in Indonesia and into primary crop production in Russia and Turkey.) Thus production of a number of unrelated products in the rest-of-world region products requires increased production of cattle. Considering this an isolated error, we redistributed cattle across intermediate users, following the distribution of cattle in Brazil. As a consequence, cattle production fell, as expected. However, this improvement in the cattle sector did not solve the problem, as overall livestock production now actually increased relative to the earlier EDT calculation, due mainly to an increase in pig production. The larger scope of the problem was confirmed when we looked in greater detail at the intermediate distribution of pigs: it showed similar problems to the cattle sector, particularly for the rest-of-world region, where for example 17% of intermediate production of pigs is delivered to the electric power sector. While a number of results of this scenario, such as reserving irrigation for higher value crops rather than grains, correspond to the results of the prototype analysis, it became clear that many of the numerical values could not be taken at face value.

The EU share of global agricultural production is shown in Figure 9 to increase from the baseline to 2050, and Figure 10 shows that most of the growth is in livestock and higher value crops rather than cereals. However, with the reduced demand for food, especially for livestock, and improved resource productivities in both Africa and Latin America under the last scenario, global production falls but the prototype and EXIOPOL results for the EU diverge, with the former showing complete reliance on imports while the latter shows little change from 2050. Figures 11 and 12 distinguish the situations in the Western and Eastern parts of the EU, showing that under the 2050 and ETD scenarios the Western region can be a significant net exporter, and the Eastern region a small net exporter, of the higher value crops. However, taking also the prototype results for the PTD scenario into account, one could conclude that investments and policies for improving competitiveness in selected high-value crops might have a significant payoff.

6 Conclusions and Next Steps

We concluded Section 4 with recommendations for solving a number of the data problems in the EXIOPOL database. All of them constitute challenges that need to be resolved not only for the further development of the EXIOPOL database but also for building any detailed database of the world economy. These challenges have become much clearer to us as a result of the present exercise, and we ourselves will work on the resolution of some of them, starting buy relaxing the requirement that all regions have the same number of sectors in their input-output tables.

For the data challenges of which we became aware early enough, like the need for substantially more detailed data about water and land used in agriculture, we have identified and documented a body of research and data that are valuable additions for the EXIOPOL database and hope they will be integrated into it.

We are keenly aware of all the remaining challenges, both for data compilation and for modeling. At the present time interdisciplinary collaborations of economists and computational scientists with water and land scientists and agricultural experts of various sorts is intensifying, bringing diverse perspectives to bear on resolving the kinds of problems raised in this study. The challenges are great, but the possibility of making significant progress in understanding the prospects for various options for systemic change seems within reach

Tables and Figures

Table 1. WTM Variables and Parameters in Terms of the EXIOPOL Database

Parameter		Unit	Calcuation
A		€/€	Intermediate Production (1) / Total Production (1)
y		10^6 €	Domestic Final Demand (1)
F	-- Capital	10^6 €/10^6 €	Fixed capital stock used (2) / Total Production (1)
	-- Labor	workers/10^3 €	Workers (2) / Total Production (1)
	-- Arable Land	ha/€	Land Use (3) / Total Production (1)
	-- Pastureland	ha/€	Pastureland Use (3) /Total Production (1)
	-- Rainwater	10^3 m^3/ €	Rain water use (3) / Total Production (1)
	-- Blue water	10^3 m^3/ €	Blue water use (3) / Total Production (1)
	-- NPK	tonnes/€	Tonnes applied (3) /Total Production (1)
	-- Fossil fuels	tonnes/€	Tonnes extracted (3) / Total Production (1)
	-- Ores and minerals	tonnes/€	Tonnes extracted (3) / Total Production (1)
f	-- Capital	10^6 €	Fixed capital stock available (2)
	-- Labor	10^6 worker	Economically active population (2)
	-- Arable Land	10^6 ha	Arable land stock (3)
	-- Pastureland	10^6 ha	Pastureland stock (3)
	-- Blue water	10^9 m^3	Blue water stock (3)
	-- Rainwater	10^9 m^3	Rain water stock (3)
	-- NPK	10^6 tonnes	Fertilizer availability (3)
	-- Fossil fuels	10^6 tce	Fossil fuel stock (3)
	-- Ores and minerals	10^6 tonnes	Ores and minerals stock (3)
pi	-- Capital	10^6 €/10^6 €	Payments to fixed capital (1) / fixed capital use (2)
	-- Labor	10^3 €/worker	Compensation of employees (1) / worker (2)
	-- Arable Land	€/ha	Payments to arable land (1) / land use (3)
	-- Pastureland	€/ha	Payments to pastureland (1) / pastureland use (3)

Source: 1) Input-output tables 2) Satellite accounts 3) Environmental extensions

Table 2. Regional Classification for the WTM/EXIOPOL Database

EU Developed	Other Developed	Developing	Rest of World
France	Australia	Brazil	Africa (except S. Africa)
Germany	Canada	China	Asia (except Japan, S. Korea, China, India, Indonesia, and Turkey)
Italy	Japan	India	Middle East
Spain	South Korea	Indonesia	Other Eastern Europe
United Kingdom	United States	Mexico	Latin America (except Brazil)
Other Western EU		Russia	Oceania (except Australia)
Eastern EU		South Africa	
		Turkey	

Note: Other Western EU also included Norway and Switzerland.

Table 3. Sector Classification for the WTM/EXIOPOL Database

Food and Agriculture Sectors

Primary Crops	Primary Animal	Processed Food
Cereals	Cattle	Products of meat cattle
Vegetables, fruit, nuts	Pigs	Products of meat pigs
Other crops	Poultry	Products of meat poultry
	Meat animals nec	Other meat products
	Animal products nec	Products of vegetable oils
	Raw milk	Dairy products
	Fish	Other food products
		Sugar
		Beverages
		Fish products

Non-Agricultural Sectors

Manufacturing (except processed food)	Services	Mining
Tobacco products	Water collection and distribution	Coal, lignite, and peat
Textiles	Construction work	Crude petroleum and natural gas
Wearing apparel and furs	Sale, maintenance, repair of motor vehicles	Uranium and thorium ores
Leather and leather products	Wholesale and commission trade services	Iron ores
Wood and cork products	Retail trade services	Copper ores and concentrates
Pulp, paper and paper products	Hotel and restaurant services	Nickel ores and concentrates
Printed matter and recorded media	Transportation services	Aluminium ores
Coke, petroleum, and nuclear fuel products	Post and telecommunication services	Precious metal ores
Chemical products and man-made fibres	Financial intermediation services	Lead, zinc and tin ores
Rubber and plastic products	Insurance and pension funding services	Other non-ferrous metal ores
Other non-metallic mineral products	Services auxiliary to financial intermediation	Stone
Basic metals	Real estate services	Sand and clay
Fabricated metal products	Renting services of machinery and equipment	Chemical and fertilizer minerals
Office machinery and computers	Computer and related services	
Electrical machinery and apparatus	Research and development services	
Media and communication equipment	Other business services	
Medical, precision and optical instruments	Public administration and social services	
Motor vehicles, trailers and semi-trailers	Education services	
Other transport equipment	Health and social work services	
Furniture and other manufactured goods	Sewage and refuse disposal services	
	Membership organisation services	
	Recreational, cultural and sporting services	
	Other services	

Other Sectors
Forestry
Electrical energy, gas, steam and hot water

Table 4. Regional Shares of Global Agricultural Output in 2000: EXIOPOL Compared to External Control Totals

	Grains		**Vegetables**		**Other Crops**		**Livestock**	
	Euros	Tonnes	Euros	Tonnes	Euros	Tonnes	Euros	Tonnes
Australia	1.9	1.5	0.5	0.5	1.4	1.4	2.3	2.0
Brazil	1.9	2.3	0.3	3.0	7.0	9.1	3.2	5.0
Canada	1.7	2.1	0.9	0.7	0.9	2.5	2.6	1.8
China	15.0	24.6	20.4	20.8	9.1	5.9	13.9	19.7
Germany	2.3	1.7	1.3	3.3	2.4	2.1	3.8	4.7
Spain	1.7	0.9	1.6	2.3	2.7	1.0	2.5	<0.1
Other Western EU	2.6	1.5	3.3	2.7	4.6	3.4	7.6	5.6
Eastern EU	2.6	2.9	1.8	3.9	2.1	2.9	3.2	4.5
France	3.6	2.8	2.3	1.8	6.0	4.3	4.3	3.7
United Kingdom	1.4	1.0	1.3	0.3	1.9	1.7	2.2	2.1
Indonesia	2.3	2.9	2.5	2.3	1.7	2.2	0.9	0.9
India	13.7	10.9	3.2	9.5	14.5	9.5	5.6	2.3
Italy	2.0	0.9	2.1	2.5	2.9	1.5	3.1	2.6
Japan	9.7	0.6	10.4	1.2	2.1	1.0	4.5	2.3
South Korea	3.6	0.3	2.4	1.0	0.8	<0.1	1.2	0.6
Mexico	1.6	1.3	2.9	1.5	1.2	1.7	2.9	1.8
Russia	1.4	2.8	2.4	2.2	0.4	5.7	2.0	2.9
Turkey	1.9	1.4	4.9	2.4	1.6	0.8	2.3	0.8
United States	11.9	16.1	14.0	4.7	13.7	16.9	16.2	18.5
Rest of World	16.7	20.9	21.1	33.0	22.9	25.3	15.4	16.0
South Africa	0.5	0.5	0.5	0.4	0.3	1.0	0.4	2.2
World	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Source: Production in Euros from EXIOPOL database. Crop production in tonnes from Siebert and Doll (2010). Livestock production in tonnes from FAOSTAT (FAO 2010).
Note: Regions are ordered alphabetically by their two letter EXIOPOL code.

Table 5. Consistency of Monetary and Physical EXIOPOL Regional Shares of Global Mining Output

	Uranium		**Nickel**		**Bauxite**	
	Euros	Tonnes	Euros	Tonnes	Euros	Tonnes
Australia	1.5	21.3	0.2	4.9	9.1	24.4
Brazil	0.1	0.0	0.3	2.4	2.1	2.1
Canada	0.3	0.4	2.4	0.0	0.7	5.2
China	<0.1	1.4	<0.1	2.5	26.6	23.3
Germany	0.0	0.2	<0.1	0.0	0.0	0.0
Spain	<0.1	18.0	0.0	0.0	<0.1	1.9
Other Western EU	<0.1	2.3	0.2	0.3	0.2	5.8
Eastern EU	0.1	1.8	<0.1	0.0	<0.1	6.7
France	<0.1	0.0	<0.1	1.1	<0.1	0.0
United Kingdom	0.0	<0.1	0.0	<0.1	0.0	<0.1
Indonesia	0.0	0.0	0.4	43.8	0.3	0.0
India	0.0	0.6	0.0	0.0	<0.1	1.2
Italy	0.0	0.0	0.0	0.0	<0.1	<0.1
Japan	<0.1	0.0	0.0	0.0	0.0	0.3
South Korea	0.0	0.0	<0.1	1.1	0.0	<0.1
Mexico	<0.1	0.0	0.0	0.0	0.0	0.2
Russia	8.5	4.7	0.4	0.2	41.7	<0.1
Turkey	0.0	0.0	0.0	0.0	0.1	0.6
United States	0.3	4.3	5.9	0.0	<0.1	17.6
Rest of World	88.9	42.5	90.1	43.6	18.9	7.5
South Africa	0.1	2.4	<0.1	<0.1	0.0	2.8
World	100.0	100.0	100.0	100.0	100.0	100.0

Source: Production in Euros from EXIOPOL SIOT control totals. Production in tonnes from EXIOPOL environmental extensions.
Note: Regions are ordered alphabetically by their two letter EXIOPOL code.

Table 6. Additional Data Assumptions and Sources

Parameter		Unit		Calculation
F	-- Agricultural Capital	10^6 €/10^6 €		Agricultural capital stock (4) / Total Production (1)
	-- Other Capital	10^6 €/10^6 €		Other capital stock (4) / Total Production (1)
	-- Labor	workers / 10^3 €	India, EU2, ROW	Workers (4) / Total Production (1)
	-- Rainfed Land	ha/€		Rainfed Land Use (3,6,10) / Rainfed Production (1,6)
	-- Irrigated Land	ha/€		Irrigated Land Use (3,6,10) / Irrigated Production (1,6)
	-- Rainwater	10^3 m^3/ €		Rainwater consumption (6) / Total Production (1,6)
	-- Blue water	10^3 m^3/ €		Water Withdrawal (5,6,9) /Total Production (1,6)
	-- Fossil fuels	tce/€	Selected regions	Tonnes of Coal Equivalent (1,11) / Total Production (1)
f	-- Agricultural Capital	10^6 €		Agricultural capital stock (4)
	-- Other Capital	10^6 €		Other capital stock (4)
	-- Labor	10^6 worker		Economically available population (8)
	-- Rainfed Land	10^6 ha		Rainfed land used (3,6,10)
	-- Irrigated Land	10^6 ha		Irrigated land used (3,6,10)
	-- Blue water	10^9 m^3		Sustainable supply (4,5)
	-- Rainwater	10^9 m^3		Rainwater available (5)
	-- Fossil fuels	10^6 tonnes	Selected regions	Tonnes of coal equivalent extracted (4)
	-- Ores and minerals	10^6 tonnes	Selected regions	Tonnes extracted (4)
pi vector	-- Capital	10^6 €/10^6 €		Rate of return (4)
	-- Agricultural Labor	10^3 €/worker		Payments to agricultural labor (1) / agricultural workers (2)
	-- Mining Labor	10^3 €/worker		Payments to mining labor (1) / mining workers (2)
	-- Manufacturing Labor	10^3 €/worker		Payments to manufacturing labor (1) / manufacturing workers (2)
	-- Services Labor	10^3 €/worker		Payments to services labor (1) / services workers (2)
	-- Rainfed Land	€/ha		Payments to rainfed land (1,6) / rainfed land use (3,6,10)
	-- Irrigated Land	€/ha		Payments to irrigated land (1,6) / rainfed land use (3,6,10)

Source: (1) Input-output tables (2) Satellite accounts (3) Environmental extensions (4) Own estimates, see text (5) AQUASTAT 2011 (6) Siebert and Doll 2010 (7) USGS 2010 (8) ILO 2009 (9) de Fraiture *et al.* 2007 (10) Bruinsma 2008 (11) IEA 2010
Note: Applies to all regions except where noted.

Table 7. Description of Scenario E2050 (Relative to E2000)

Consumption (y)	Population	All regions: scaled proportional to population change (1)
	Diets	Developing regions: increased caloric per capita availability to 3000 calories with 20% from animal products (2)
Technologies (A, F)	Cattle grazed on pastureland	Same sector as E2000
	Cattle grazed on arable land	Same sector as E2000 except cattle uses arable land instead of pastureland (4)
Endowments (f)	Labor	Scaled proportional to change in working-age population (1)
	Built capital	Scaled to at least maintain K/L availability ratio
	Total arable land	Estimate from (2)
	Irrigated land	Estimate from (3)
	Rainfed land	Potential arable land minus potential irrigated land
	Pastureland	No change (4)
	Water	No change
	Fossil fuels and minerals	Own estimates

Source: (1) UN 2010 (2) Bot *et al.* 2000 (3) AQUASTAT 2011 (4) Gibbs *et al.* 2010

Table 8. Description of Scenario ETD (Relative to E2050)

Consumption (y)	Diets	Developed regions: reduced caloric per capita availability to 3000 calories with 20% from animal products (1)
Technologies (A, F)	Water management improvements	Improved green water productivity for rainfed cereals (2)
		Improved irrigation efficiency (cubic km consumed/withdrawn) for irrigated cereals (3)
		Improved rainfed and irrigated cereal yields (t/ha) (3)
	Pastoral system on pastureland	Increased pastureland requirements and no grain or processed feed inputs (4)
	Mixed industrial system on pastureland	Reduced pastureland requirements and uses all grain and processed feed inputs (4)
	Pastoral system on arable land	Increased arable land requirements and no grain or processed feed inputs (4)
	Mixed/industrial system on arable land	Reduced arable land requirements and increased grain and processed feed inputs (4)

Source: (1) FAOSTAT 2010 (2) Falkenmark and Rockström 2006 (3) de Fraiture *et al.* 2007 (4) Bouwman *et al.* 2006

Table 9. Rainfed and Irrigated Land Endowments (10^6 hectares)

	E2000		E2050 and ETD			
	Rainfed Land	Irrigated Land	Rainfed Land	% from E2000	Irrigated Land	% from E2000
Australia	44	4	121	178	4	0
Brazil	63	2	520	726	29	1195
Canada	51	1	125	143	1	23
China	92	56	138	50	64	13
Germany	12	0	28	139	0	0
Spain	15	3	21	41	3	0
Other Western EU	20	2	56	186	2	0
Eastern EU	28	0	72	158	6	1178
France	18	2	37	106	2	22
United Kingdom	6	0	16	175	0	0
Indonesia	28	6	60	117	11	86
India	121	49	67	-45	140	188
Italy	8	3	14	67	3	0
Japan	2	3	10	412	3	0
South Korea	1	1	3	157	1	0
Mexico	19	9	42	125	10	12
Russia	121	5	254	109	29	486
Turkey	22	5	17	-22	9	93
United States	153	25	329	115	25	0
Rest of World	433	76	1604	270	218	188
South Africa	13	3	27	109	3	0
EU	106	11	244	130	17	52
World	1269	255	3561	181	564	121

Source: Bot *et al.* 2000 and Aquastat 2011. See also Table 7.
Note: Regions are ordered alphabetically by their two letter EXIOPOL code.

10. Classifications for the Prototype Database

Regions	Sectors	Factors
North America	Coal	Rainfed land
Western Europe	Oil	Irrigated land
Other Europe	Gas	Pastureland
Former Soviet Union	Electricity	Blue water
Japan	Mining	Green water
China	Manufacturing	Ag labor
Rest of Asia	Services	Other labor
Latin America	Cereals	Ag capital
Africa	Livestock	Other capital
Australia/NZ	Other Crops	Coal
		Crude oil
		Natural gas

Table 11. Global Agricultural Production under Prototype Scenarios (1990 10^9 USD)

		P1990	P2050	PTD
Crops	Cereals	115	232	211
	- rainfed	64	138	211
	- irrigated	51	94	0
	Other Crops	468	801	791
	- rainfed	227	493	245
	- irrigated	240	308	546
Livestock	Livestock	353	747	661
	- arable	-	318	192
	- pastureland	-	429	469
Total	Crop	583	1,033	1,001
	Livestock	353	747	661

Source: Own computations.
Note: Totals in final block may contain some double counting.

Table 12. Global Factor Use under Prototype Scenarios (water in km^3, land in 10^6 ha)

	P1990	P2050	PTD
Blue Water	3,275	5,225	5,614
Green Water	4,960	10,575	8,681
Land for Crops	1,343	2,856	2,139
- rainfed	1,074	2,409	1,799
- irrigated	269	447	341
Land for Livestock	3,206	4,592	4,067
- arable	0	1,227	1,373
- pastureland	3,206	3,365	2,694
Total Agricultural Land	4,550	7,448	6,207

Source: Own computations.

Table 13. Global Agricultural Production under WTM/EXIOPOL Scenarios (2000 10^9 €)

		E2000	E2050	ETD
Crops	Cereals	349	518	495
	- rainfed	244	499	495
	- irrigated	105	19	0
	Fruits, Vegetables and Nuts	352	519	515
	- rainfed	211	197	229
	- irrigated	141	322	286
	Other Crops	328	592	619
	- rainfed	154	136	124
	- irrigated	174	455	495
Livestock	Cattle	165	212	172
	- arable	-	47	49
	- pastureland	-	165	123
	Other Livestock	608	925	970
Total	Crops	1,029	1,629	1,629
	Livestock	773	1,137	1,141

Source: Own computations.
Note: Totals in final block may contain some double counting.

Table 14. Global Factor Use under WTM/EXIOPOL Scenarios (water in km^3, land in 10^6 ha)

	Control	E2000	E2050	ETD
Blue Water	3,586	3,609	6,222	5,996
Green Water	5,509	6,150	8,513	8,117
Land for Crops	1,524	1,518	1,956	1,776
- rainfed	1,269	1,267	1,601	1,442
- irrigated	255	251	355	334
Land for Livestock	3,426	2,815	3,019	3,236
- arable	0	0	211	633
- pastureland	3,426	2,815	2,808	2,602
Total Agricultural Land	4,950	4,333	4,975	5,012

Source: Own computations.

Table 15. Distribution of Cattle Output in EXIOPOL Input-Output Tables

	Cereals	Veg, fruit, nuts	Other Crops	Cattle	Pigs	Poultry	Meat animals nec	Animal products nec	Raw milk	Products of meat cattle	Products of meat pigs	Products of meat poultry	Other meat products	Dairy products	Other food products	Fish products	Other Sectors	Total
Australia	0	0	0	<0.1	0	0	0	0	<0.1	66.3	0.4	3.0	9.3	0	10.7	5.6	3.9	100
Brazil	<0.1	<0.1	0.3	6.0	<0.1	<0.1	<0.1	1.1	1.8	76.9	0.2	0.3	<0.1	0.2	8.9	0.2	3.4	100
Canada	20.2	<0.1	3.3	22.9	9.4	<0.1	0.2	2.7	<0.1	38.0	0.5	0.1	0.1	0.2	0.5	<0.1	1.3	100
China	2.9	<0.1	<0.1	27.6	2.6	<0.1	0.3	<0.1	<0.1	47.2	5.9	<0.1	<0.1	0	6.9	0	6.4	100
Germany	0	0	0	<0.1	<0.1	0	<0.1	<0.1	<0.1	89.2	0	0	0	2.4	4.3	0	4.0	100
Spain	0	0	0	<0.1	0.3	0	<0.1	0.1	<0.1	90.5	0	0	0	3.5	2.8	0	2.6	100
EU1	<0.1	<0.1	<0.1	2.7	0.5	<0.1	<0.1	0.2	0.2	84.8	<0.1	<0.1	<0.1	2.8	5.4	<0.1	3.1	100
EU2	<0.1	<0.1	<0.1	<0.1	0.5	<0.1	<0.1	<0.1	<0.1	93.5	<0.1	<0.1	<0.1	0.8	3.2	<0.1	1.8	100
France	0	0	0	0.2	0.4	0	<0.1	<0.1	<0.1	90.5	0	0	0	3.9	2.5	0	2.4	100
UK	<0.1	<0.1	<0.1	<0.1	0.3	<0.1	0.1	<0.1	0.1	86.7	<0.1	<0.1	<0.1	4.3	4.8	0.2	3.3	100
Indonesia	4.0	6.0	7.3	<0.1	0.2	0	<0.1	0.1	<0.1	32.4	<0.1	10.1	0.2	6.8	<0.1	27.7	2.6	100
India	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Italy	0	0	0	<0.1	0.3	0	<0.1	<0.1	<0.1	87.0	0	0	0	1.1	2.1	0	9.5	100
Japan	3.7	4.2	0.9	6.2	3.2	0	<0.1	2.7	3.0	63.1	2.6	2.9	1.2	0	0	0	6.5	100
Korea	0.6	0.5	0.1	1.0	0.7	0	<0.1	0.3	0.3	83.8	1.8	0.5	0.6	6.1	0.3	0	3.2	100
Mexico	3.3	3.9	3.5	8.8	5.4	0.3	0.8	3.8	6.4	58.3	1.0	0.8	0.5	<0.1	0.3	<0.1	1.7	100
Russia	18.8	16.4	6.4	9.9	8.8	0	0.7	3.4	11.5	16.4	1.9	4.2	1.3	0	0	0	0.2	100
Turkey	15.5	9.9	14.1	4.0	0	0.1	5.2	3.5	5.0	23.9	0	0.5	14.4	0.4	0.3	0.2	3.1	100
USA	0.7	1.0	0.9	31.2	0.5	0.1	0.1	0.1	1.2	61.7	<0.1	<0.1	<0.1	0.1	0.4	<0.1	1.6	100
Rest of World	<0.1	0.5	<0.1	0.2	0.8	<0.1	<0.1	<0.1	<0.1	7.0	40.8	13.2	33.0	<0.1	1.9	0.2	1.3	100
South Africa	3.3	1.8	2.8	1.1	0.2	<0.1	0.7	0.4	0.7	70.2	0	10.2	0	0	7.6	0	0.6	100

Sources: Own computations. Intermediate production data from EXIOPOL base flows.
Notes: Highlighted cells are greater than 5% of total intermediate cattle production in the region. "Other sectors" is a sum of the remaining sectors not individually identified. Regions are ordered alphabetically by their two letter EXIOPOL code.

Table 16. EU Agricultural Production under WTM/EXIOPOL Scenarios (2000 10^9 €)

		E2000	E2050	ETD
Crops	Cereals	36	6	28
	- rainfed	36	6	28
	- irrigated	0	0	0
	Fruits, Vegetables and Nuts	90	174	142
	- rainfed	35	120	87
	- irrigated	55	55	55
	Other Crops	77	94	134
	- rainfed	66	83	124
	- irrigated	11	11	10
Livestock	Cattle	32	54	0
	- arable	-	22	0
	- pastureland	-	32	0
	Other Livestock	81	81	78
Total	Crops	202	275	305
	Livestock	113	135	78

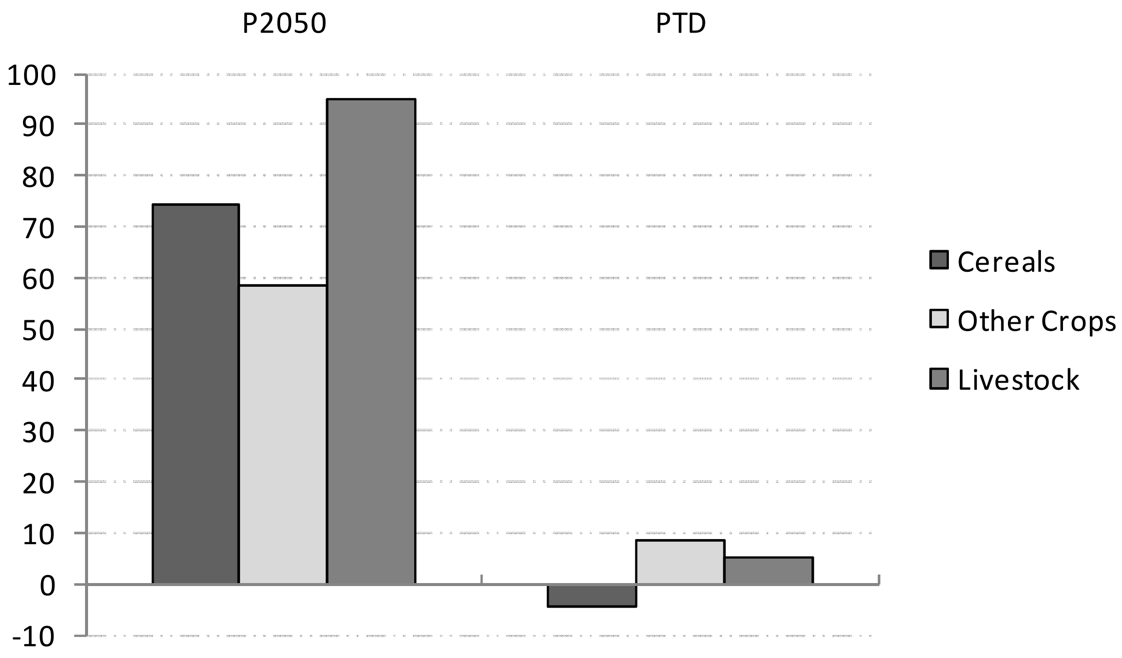
Source: Own computations.
Note: Totals in final block may contain some double counting.

Table 17. EU Factor Use under WTM/EXIOPOL Scenarios (water in km^3, land in 10^6 ha)

	Control	E2000	E2050	ETD
Blue Water	253	208	244	262
Green Water	437	433	398	602
Land for Crops	117	117	158	197
- rainfed	106	107	148	187
- irrigated	11	10	10	10
Land for Livestock	104	101	122	62
- arable	0	0	22	0
- pastureland	104	101	101	62
Total Agricultural Land	221	218	281	258

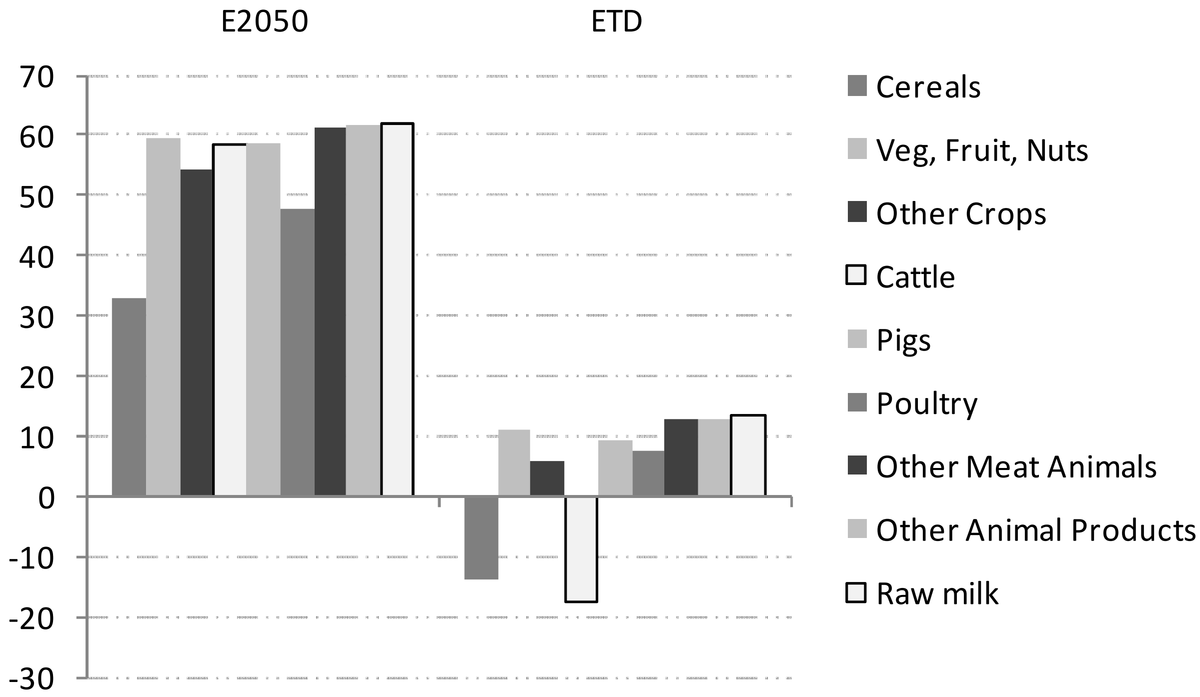
Source: Own computations.
Note: Water in cubic kilometers and land in million hectares.

Figure 1. Percentage Change in Agricultural Commodity Prices under Prototype Scenarios (Relative to P1990)



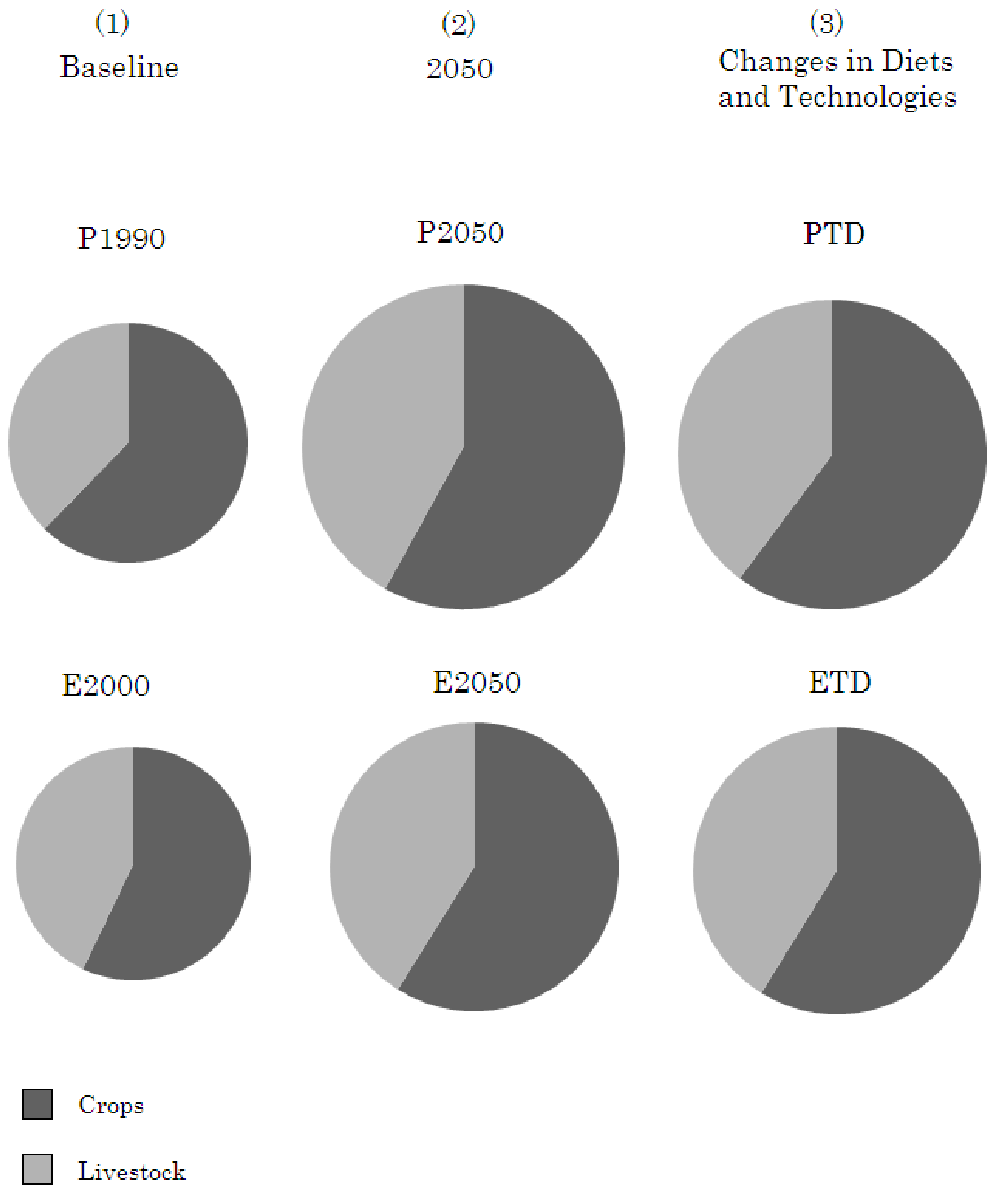
Source: Own computations.

Figure 2. Percentage Change in Agricultural Commodity Prices under WTM/EXIOPOL Scenarios (Relative to E2000)



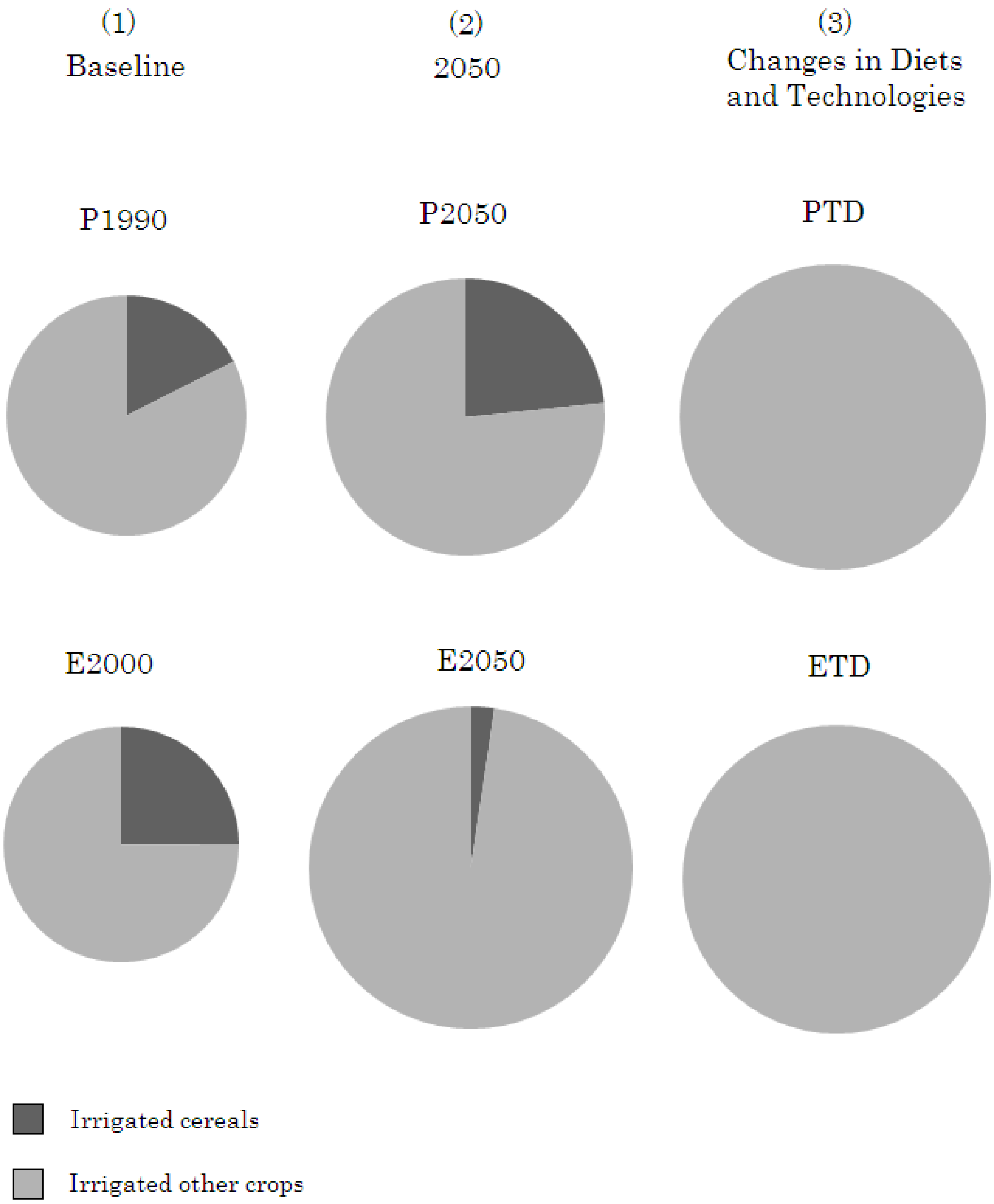
Source: Own computations.

Figure 3. Global Production of Crops and Livestock (€)



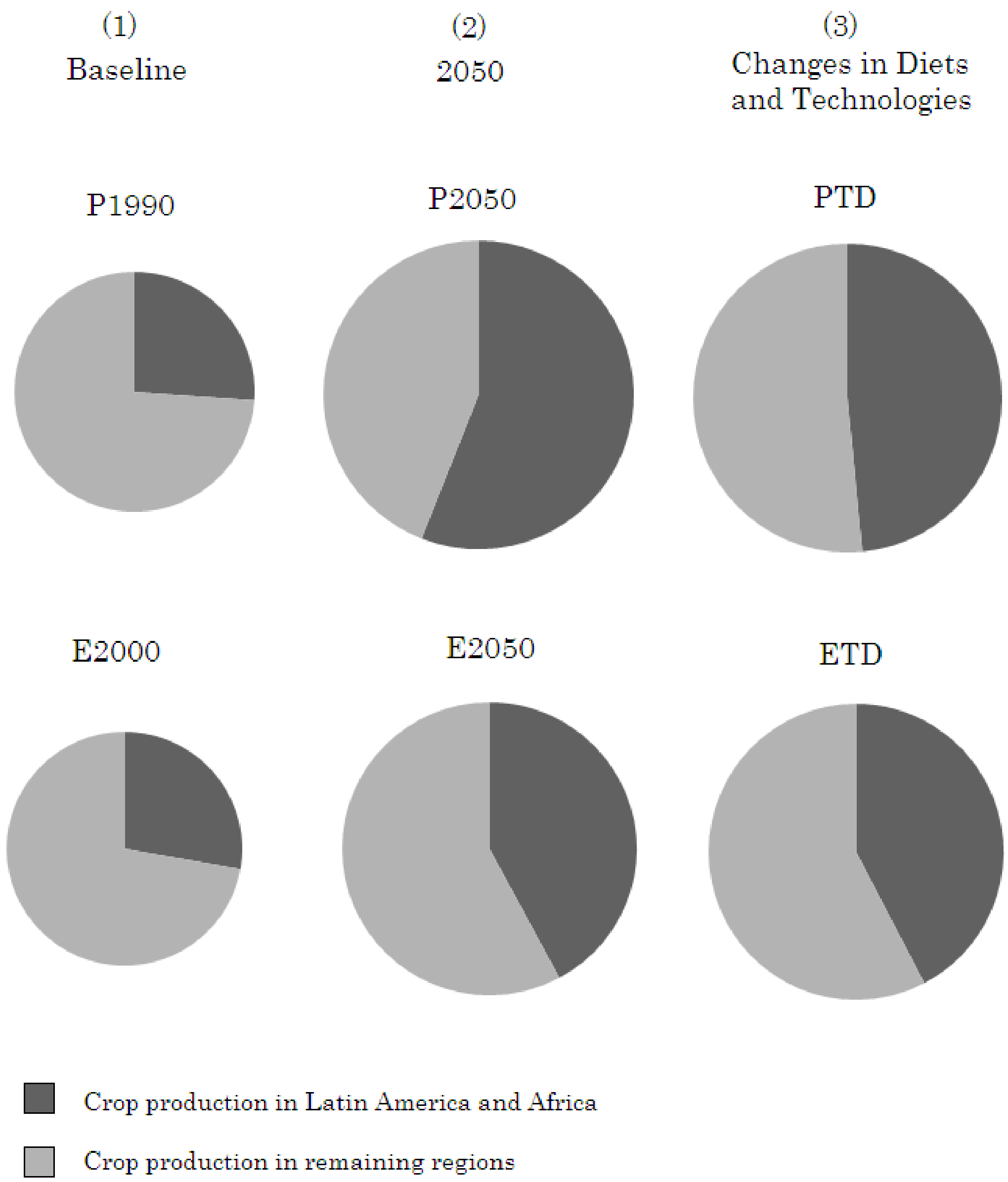
Source: Own computations.
Notes: Pie chart areas in columns (2) and (3) reflect changes in volumes relative to the baseline in column 1. See discussion in text.

Figure 4. Global Production of Irrigated Cereals and Other Crops (€)



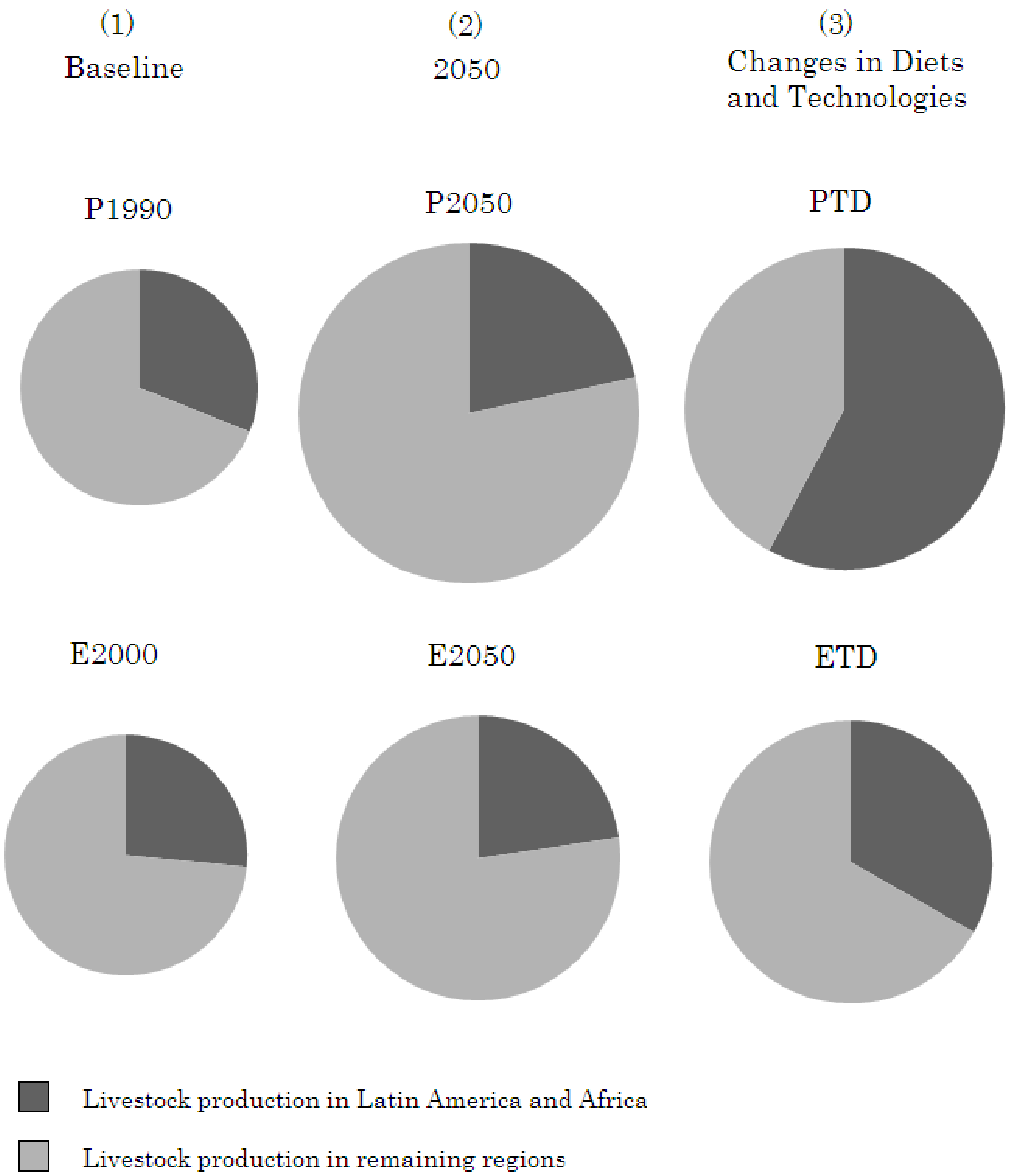
Source: Own computations.
Notes: Pie chart areas in columns (2) and (3) reflect changes in volumes relative to the baseline in column 1. See discussion in text.

Figure 5. Crop Production in Latin America and Africa as a Share of Global Production (€)



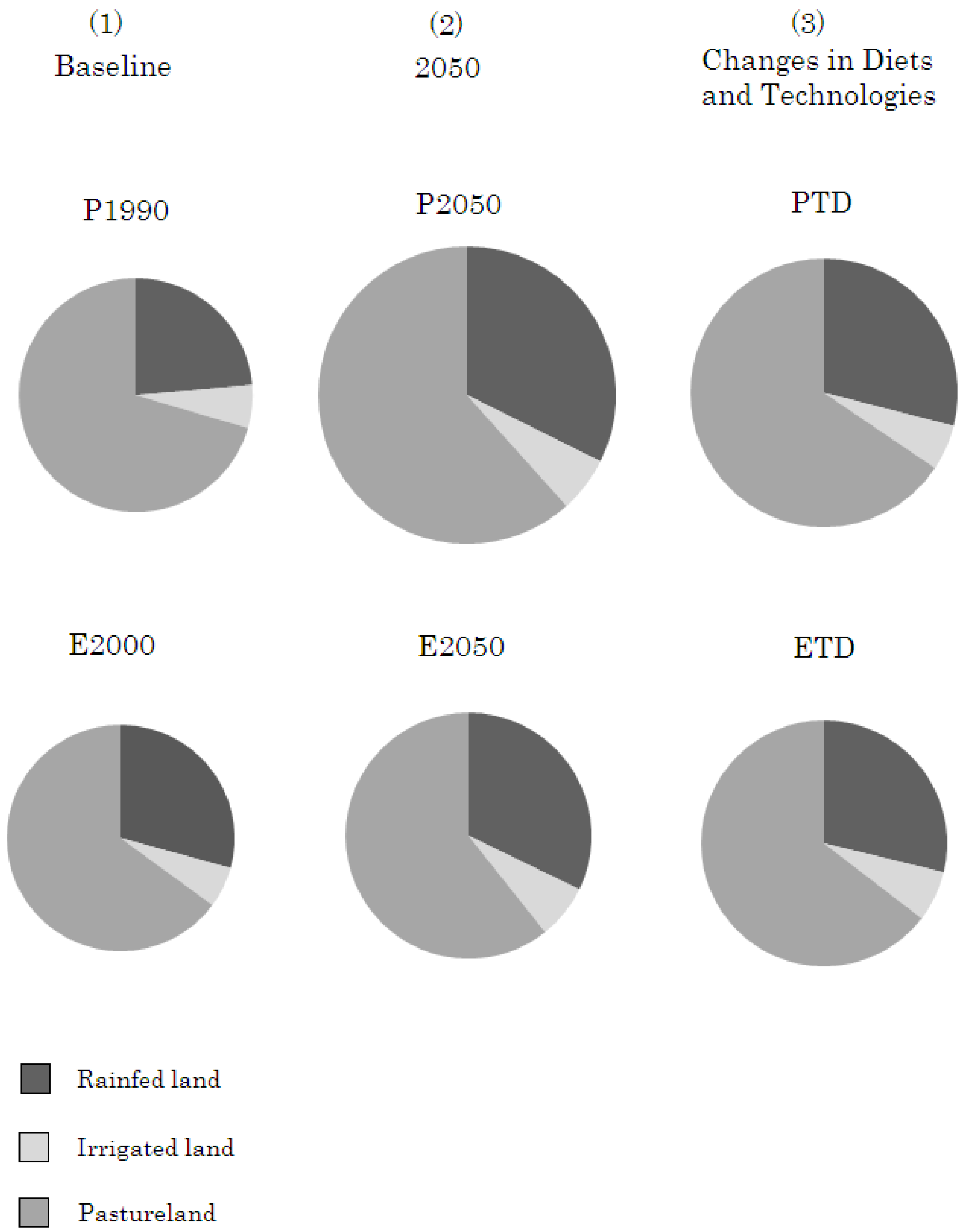
Source: Own computations.
Notes: Pie chart areas in columns (2) and (3) reflect changes in volumes relative to the baseline in column 1. The two regions distinguished in pie charts are defined differently in two databases, with the EXIOPOL rest-of-world region including countries beyond Latin America and Africa. See discussion in text and Table 2 and Table 10 for classification differences.

Figure 6. Livestock Production in Latin America and Africa as a Share of Global Production (€)



Source: Own computations.
Notes: Pie chart areas in columns (2) and (3) reflect changes in volumes relative to the baseline in column 1. The two regions distinguished in pie charts are defined differently in two databases, with the EXIOPOL rest-of-world region including countries beyond Latin America and Africa. See discussion in text and Table 2 and Table 10 for classification differences.

Figure 7. Global Use of Rainfed Land, Irrigated Land, and Pastureland for Agriculture (hectares)

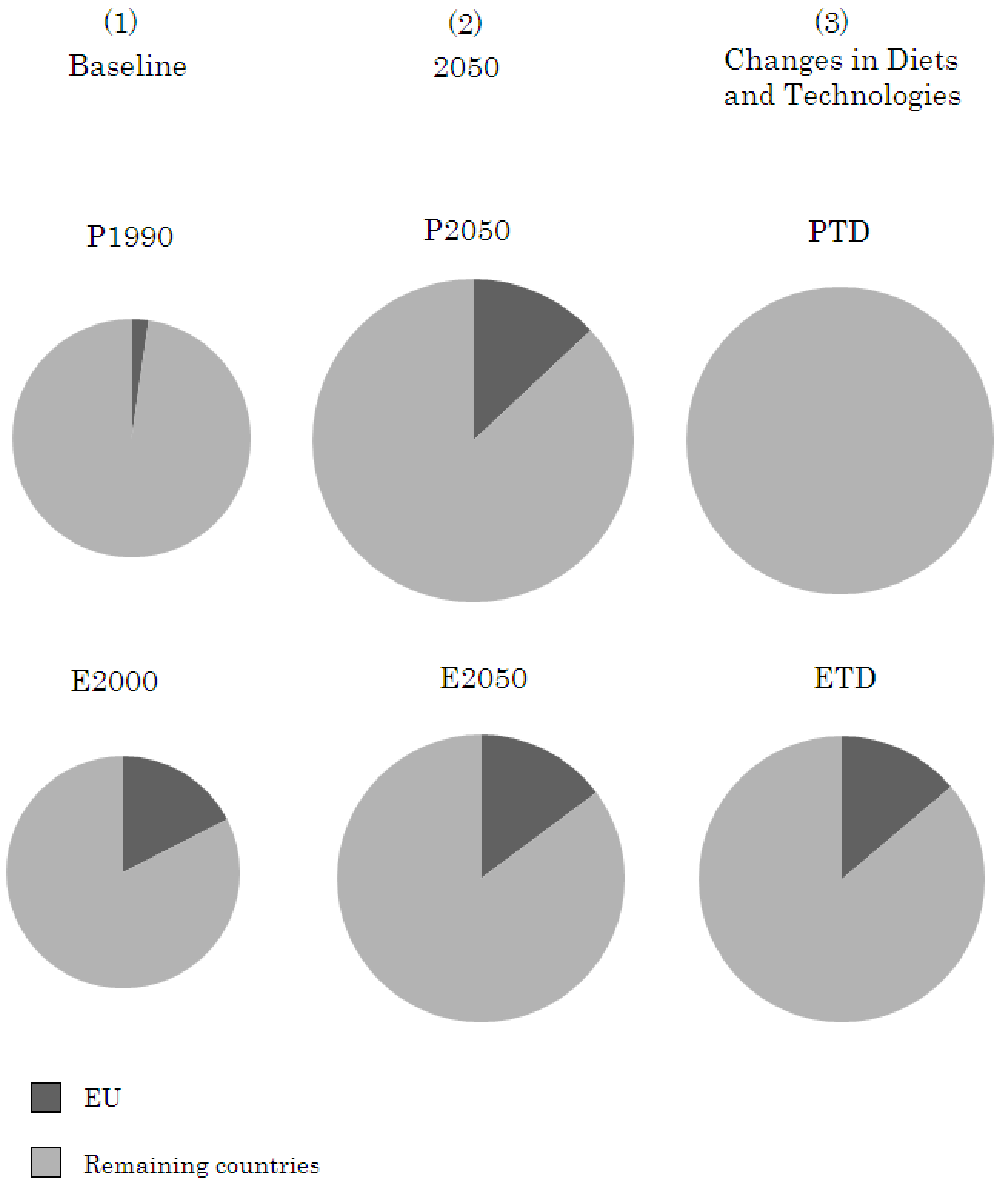


Source: Own computations.
Notes: Pie chart areas in columns (2) and (3) reflect changes in volumes relative to the baseline in column 1. See discussion in text.

Figure 8. Global Blue Water Withdrawals and Agricultural Green Water Consumption (m³)

Source: Own computations.
Notes: Pie chart areas in columns (2) and (3) reflect changes in volumes relative to the baseline in column 1. See discussion in text.

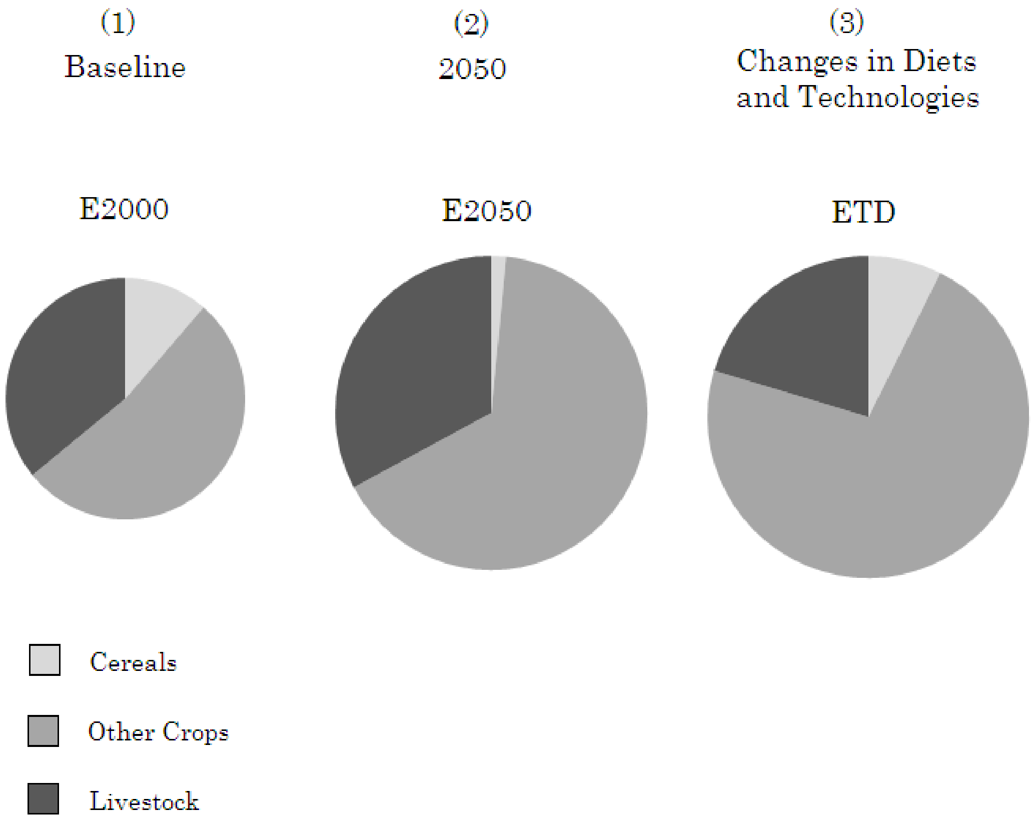
Figure 9. Agricultural Production in EU as a Share of Global Production (€)



Source: Own computations.

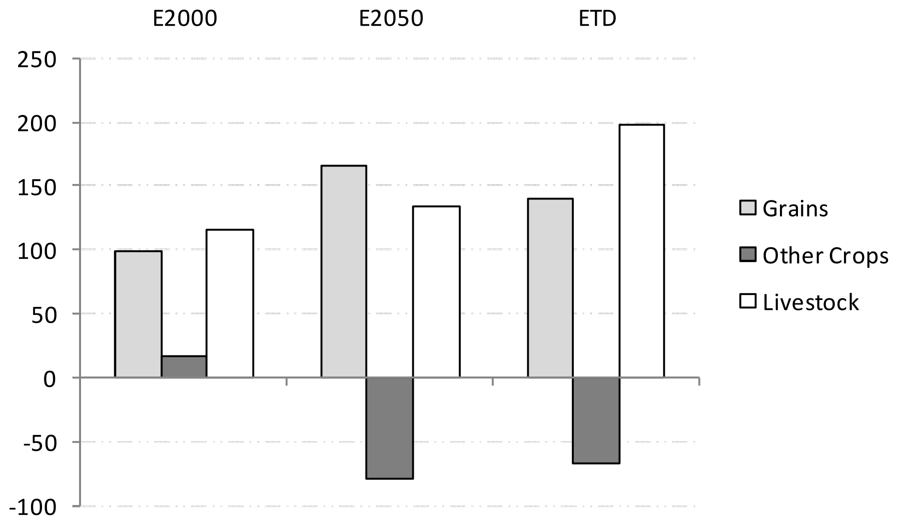
Notes: Pie chart areas in columns (2) and (3) reflect changes in volumes relative to the baseline in column 1. The two regions distinguished in pie charts are defined differently in two databases, with the prototype regions including countries beyond the EU. See discussion in text and Table 2 and Table 10 for classification differences.

Figure 10. EU Production of Cereals, Other Crops and, Livestock (€)



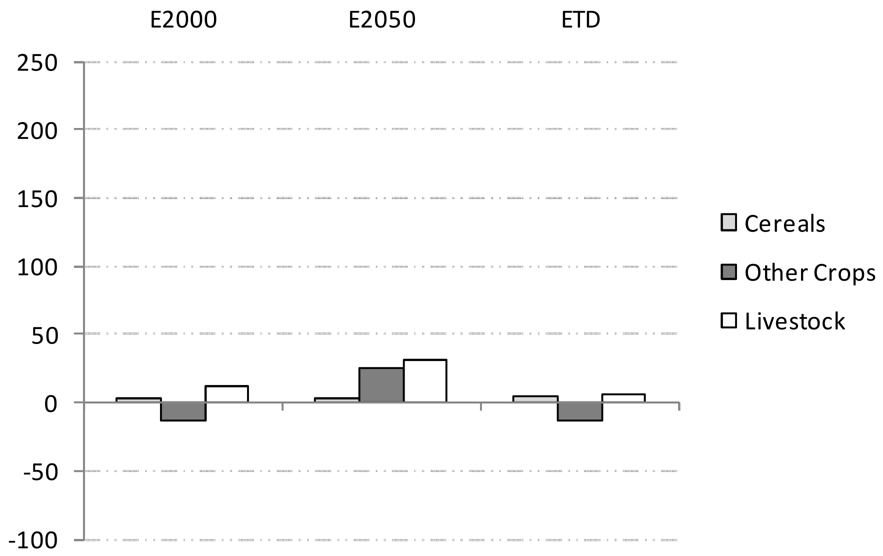
Source: Own computations.
Notes: Pie chart areas in columns (2) and (3) reflect changes in volumes relative to the baseline in column 1. The EU includes France, Germany, Italy, Spain, UK, Other Western EU, and Eastern EU. See discussion in text and Table 2 for classification.

Figure 11. Net Imports of Agricultural Crops in Western EU for WTM/EXIOPOL Scenarios (€)



Source: Own computations.
Notes: Western EU includes France, Germany, Italy, Spain, UK, and Other Western EU. See discussion in text and Table 2 for classification.

Figure 12. Net Imports of Agricultural Crops in Eastern EU for WTM/EXIOPOL Scenarios (€)



Source: Own computations.
Notes: See discussion in text and Table 2 for classification of Eastern EU.

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