THE ECONOMIC IMPACT OF MORE SUSTAINABLE WATER USE IN AGRICULTURE: A COMPUTABLE GENERAL EQUILIBRIUM ANALYSIS

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Abstract

Water problems are typically studied at the farm-level, the river–catchment-level or the country-level. About 70% of irrigation water is used for agriculture, and agricultural products are traded internationally. A full understanding of water use is impossible without understanding the international market for food and related products, such as textiles. Based on the global general equilibrium model GTAP-W, we offer a method for investigating the role of green (rain) and blue (irrigation) water resources in agriculture and within the context of international trade. Since problems related to groundwater availability are getting more severe in the future, we analyze the impact of different water use options for 2025 where data is readily available. We run two alternative scenarios. The first, called water crisis scenario, explores a deterioration of current trends and policies in the water sector. The second scenario, called sustainable water use scenario, assumes an improvement in policies and trends in the water sector and eliminates groundwater overdraft worldwide, increasing water allocation for the environment. In both scenarios, welfare gains or losses are not only associated with changes in agricultural water consumption. Under the water crisis scenario, welfare not only rises for regions where water consumption increases (China, South East Asia and the USA). Welfare gains are considerable for Japan and South Korea, Southeast Asia and Western Europe as well. These regions benefit from higher irrigated production and lower food prices. Alternatively, under the sustainable water use scenario, welfare losses not only affect regions where overdrafting is occurring. Welfare decreases in other regions as well. These results indicate that, for water use, there is a clear trade-off between economic welfare and environmental sustainability.

Keywords: Agricultural Water Use, Computable General Equilibrium, Groundwater Use, Irrigation, Sustainable Water Use, Water Scarcity

JEL Classification: Q17, D58, Q15, Q25, Q28

1 Introduction

Water is one of our basic resources, but it is often short. While in some countries groundwater resources still are abundant and readily available for development, in others depletion due to overdrafting, water-logging, salination as well as pollution cause severe problems. However, the increase in global water use in recent years has been based on groundwater (Villholth and Giordano 2007). In addition, the uneven distribution of water (and population) among regions has made the adequate supply critical for a growing number of countries. A rapid population growth and an increasing consumption of water per capita have aggravated the problem. This tendency is likely to continue as water consumption for most uses is projected to increase by at least 50% by 2025 compared to 1995 level (Rosegrant et al. 2002). One additional reason for concern is (anthropogenic) climate change, which may lead to increased drought in many places (IPCC 2001).

The agricultural sector is the main user of water including groundwater. In many arid and semi-arid regions such as India, Northern China as well as Pakistan groundwater is critical for development and food security. Also in developed arid regions of the world including the USA, Australia, Mexico as well as some Mediterranean countries like Spain, groundwater is the main source for agricultural use. In other regions of the world the situation is different. Countries in Sub-Saharan Africa, for example, could benefit from more intensive groundwater use for agricultural as well as other uses but are limited in their development due to among others a lack of infrastructure, poor energy access and money to invest (Villholth and Giordano 2007). However, taken together, the more serious problem today is not the development of groundwater but the sustainable management (Shah et al. 2000).

To ensure a more sustainable management of water resources and groundwater resources in particular, water-use policies need to be established or improved. These could include, for example, incentives to use more water-saving irrigation techniques. Water problems related to water-use management are typically studied at the farm-level, the river-catchment-level or the country-level. About 70 percent of all water is used for agriculture, and agricultural products are traded internationally. A full understanding of water use and the effect of more sustainable management of groundwater resources is impossible without understanding the international market for food and related products, such as textiles.

We use the new version of the GTAP-W model, based on GTAP 6, to analyze the economy-wide impacts of more sustainable water use in the agricultural sector. The GTAP-W model (Calzadilla et al. 2008) is a global computable general equilibrium (CGE) model that allows for a rich set of economic feedbacks and for a complete assessment of the welfare implications. Unlike the predecessor GTAP-W (Berrittella et al. 2007), the new production structure of the model, which introduces a differentiation between rainfed and irrigated crops, allows a better understanding of the use of water resources in agricultural sectors. In fact, the distinction between rainfed and irrigated agriculture in GTAP-W, allows us to model green (rain) and blue (irrigation) water used in crop production.

Efforts towards improving groundwater development as well as management, e.g. through more efficient irrigation methods, benefit societies by saving large amounts of water. These would be available for other uses. The aim of our paper is to analyze if improvements in groundwater management would be economically beneficial for the world as a whole as well as for individual countries and whether and to what extent water savings could be achieved. Problems related to groundwater use, as discussed above, are present today. Since problems related to groundwater availability are getting more severe in the future, it is important to analyze the impact of different water use options for the future. We use scenario data for 2025 where readily available.

Economic models of water use have generally been applied to look at the direct effects of water policies, such as water pricing or quantity regulations, on the allocation of water resources. In order to obtain insights from alternative water policy scenarios on the allocation of water resources, partial and general equilibrium models have been used. While partial equilibrium analysis focuses on the sector affected by a policy measure assuming that the rest of the economy is not affected, general equilibrium models consider other sectors or regions as well to determine the economy-wide effect; partial equilibrium models tend to have more detail. Most of the studies using either of the two approaches analyze pricing of irrigation water only (for an overview of this literature see Johannson et al. 2002). Rosegrant, et al. (2002) use the IMPACT model to estimate demand and supply of food and water to 2025. de Fraiture et al. (2004) extend this to include virtual water trade, using cereals as an indicator. Their results suggest that the role of virtual water trade is modest. While the IMPACT model covers a wide range of agricultural products and regions, other sectors are excluded; it is a partial equilibrium model. Studies using general equilibrium approaches are generally based on data for a single country or region assuming no interlinkages with the rest of the world regarding policy changes and shocks (e.g. Diao and Roe 2003; Gómez et al. 2004; Letsoalo et al. 2007).

The remainder of the paper is organized as follows: the next section describes the new GTAP-W model. Section 3 presents the data on agricultural production as well as green and blue water use, with a particular focus on the projections out to 2025. While changes in groundwater use in agriculture modify the use of blue water or irrigation endowment in GTAP-W, changes in green water use driven by changes in rainfed and irrigated crop production is modelled exogenously in the GTAP-W model using information from IMPACT. Section 4 lays down two simulation scenarios for future agricultural water use in 2025. Section 5 presents the results and section 6 discusses the findings and concludes.

2 The GTAP-W model

In order to assess the systemic general equilibrium effects of more sustainable water use in agriculture, we use a multi-region world CGE model, called GTAP-W. The model is a further refinement of the GTAP model[1] (Hertel 1997), and is based on the version modified by Burniaux and Truong[2] (2002) as well as on the previous GTAP-W model introduced by Berrittella et al. (2007).

The new GTAP-W model is based on the GTAP version 6 database, which represents the global economy in 2001. The model has 16 regions and 22 sectors, 7 of which are in agriculture.[3] However, the most significant change and principal characteristic of version 2 of the GTAP-W model is the new production structure, in which the original land endowment in the value-added nest has been split into pasture land (grazing land used by livestock) and land for rainfed and for irrigated agriculture. The last two types of land differ as rainfall is free but irrigation development is costly. As a result, land equipped for irrigation is generally more

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[1] The GTAP model is a standard CGE static model distributed with the GTAP database of the world economy (www.gtap.org). For detailed information see Hertel (1997) and the technical references and papers available on the GTAP website.

[2] Burniaux and Truong (2002) developed a special variant of the model, called GTAP-E. The model is best suited for the analysis of energy markets and environmental policies. There are two main changes in the basic structure. First, energy factors are separated from the set of intermediate inputs and inserted in a nested level of substitution with capital. This allows for more substitution possibilities. Second, database and model are extended to account for CO_2 emissions related to energy consumption.

[3] See table A1 in Annex I for the regional, sectoral and factoral aggregation used in GTAP-W.

valuable as yields per hectare are higher. To account for this difference, we split irrigated agriculture further into the value for land and the value for irrigation. The value of irrigation includes the equipment but also the water necessary for agricultural production. In the short-run irrigation equipment is fixed, and yields in irrigated agriculture depend mainly on water availability. The tree diagram in figure A1 in Annex I represents the new production structure.

Land as a factor of production in national accounts represents "the ground, including the soil covering and any associated surface waters, over which ownership rights are enforced" (United Nations 1993). To accomplish this, we split for each region and each crop the value of land included in the GTAP social accounting matrix into the value of rainfed land and the value of irrigated land using its proportionate contribution to total production. The value of pasture land is derived from the value of land in the livestock breeding sector.

In the next step, we split the value of irrigated land into the value of land and the value of irrigation using the ratio of irrigated yield to rainfed yield. These ratios are based on IMPACT data. The numbers indicate how relatively more valuable irrigated agriculture is compared to rainfed agriculture. The magnitude of additional yield differs not only with respect to the region but also to the crop. On average, producing rice using irrigation is relatively more productive than using irrigation for growing oil seeds, for example. Regions like South America seems to grow on average relatively more using irrigation instead of rainfed agriculture compared to countries in North Africa or Sub-Saharan Africa.

The procedure we described above to introduce the four new endowments (pasture land, rainfed land, irrigated land and irrigation) allows us to avoid problems related to model calibration. In fact, since the original database is only split and not altered, the original regions' social accounting matrices are balanced and can be used by the GTAP-W model to assign values to the share parameters of the mathematical equations. For detailed information about the social accounting matrix representation of the GTAP database see McDonald, et al. (2005).

As in all CGE models, the GTAP-W model makes use of the Walrasian perfect competition paradigm to simulate adjustment processes. Industries are modelled through a representative firm, which maximizes profits in perfectly competitive markets. The production functions are specified via a series of nested constant elasticity of substitution functions (CES) (figure A1). Domestic and foreign inputs are not perfect substitutes, according to the so-called ''Armington assumption'', which accounts for product heterogeneity.

A representative consumer in each region receives income, defined as the service value of national primary factors (natural resources, pasture land, rainfed land, irrigated land, irrigation, labour and capital). Capital and labour are perfectly mobile domestically, but immobile internationally. Pasture land, rainfed land, irrigated land, irrigation and natural resources are imperfectly mobile. While perfectly mobile factors earn the same market return regardless of where they are employed, market returns for imperfectly mobile factors may differ across sectors. The national income is allocated between aggregate household consumption, public consumption and savings. The expenditure shares are generally fixed, which amounts to saying that the top level utility function has a Cobb–Douglas specification. Private consumption is split in a series of alternative composite Armington aggregates. The functional specification used at this level is the constant difference in elasticities (CDE) form: a non-homothetic function, which is used to account for possible differences in income elasticities for the various consumption goods. A money metric measure of economic welfare, the equivalent variation, can be computed from the model output.

In the original GTAP-E model, land is combined with natural resources, labour and the capital-energy composite in a value-added nest. In our modelling framework, we incorporate the possibility of substitution between land and irrigation in irrigated agricultural production by using a nested constant elasticity of substitution function (figure A1). The procedure how the elasticity of factor substitution between land and irrigation (σ_{LW}) was obtained is explained in more detail in Calzadilla et al. (2008). Next, the irrigated land-water composite is combined with pasture land, rainfed land, natural resources, labour and the capital-energy composite in a value-added nest through a CES structure.

The IMPACT model provides detailed information on green water use in rainfed production (defined as effective rainfall); and both green and blue water use in irrigated production (blue water or irrigation is defined as the water diverted from water systems).[4] In the GTAP-W benchmark equilibrium, water used for irrigation is supposed to be identical to the volume of blue water used for irrigated agriculture in the IMPACT model. An initial

[4] Green water used in crop production or effective rainfall is part of the rainfall that is stored in the root zone and can be used by the plants. The effective rainfall depends on the climate, the soil texture, the soil structure and the depth of the root zone. The blue water used in crop production or irrigation is the applied irrigation water diverted from water systems. The blue water used in irrigated areas contributes additionally to the freshwater provided by rainfall (Rosegrant et al. 2002).

sector and region specific shadow price for irrigation water can be obtained by combining the social accounting matrix information about payments to factors and the volume of water used in irrigation from IMPACT. Contrary to blue water, green water used in rainfed and irrigated crop production has no price. It is modelled exogenously in the GTAP-W model using information from IMPACT.

The distinction between rainfed and irrigated agriculture within the production structure of the GTAP-W model allows us to study expected physical constraints on water supply due to, for example, climate change. In fact, changes in rainfall patterns can be exogenously modelled in GTAP-W by changes in the productivity of rainfed and irrigated land. In the same way, water excess or shortages in irrigated agriculture can be modelled by exogenous changes to the initial irrigation water endowment.

3 Future baseline simulation

To obtain a 2025 benchmark equilibrium dataset for the GTAP-W model we use the methodology described by Dixon and Rimmer (2002). This methodology allows us to find a hypothetical general equilibrium state in the future imposing forecasted values for some key economic variables in the initial calibration dataset. In this way, we impose forecasted changes in regional endowments (labour, capital, natural resources, rainfed land, irrigated land and irrigation), in regional factor-specific and multi-factor productivity and in regional population. We use estimates of the regional labour productivity, labour stock and capital stock from the G-Cubed model (McKibbin and Wilcoxen 1998). Changes in the allocation of rainfed and irrigated land within a region as well as irrigation and agricultural land productivity are implemented according to the values obtained by the IMPACT model. The information supplied by the IMPACT model (demand and supply of water, demand and supply of food, rainfed and irrigated production and rainfed and irrigated area) provides the GTAP-W model with detailed information for a robust calibration of a new dataset. Finally, we use the medium variant population estimates for 2025 from the Population Division of the United Nations (United Nations 2004).

Compared to the 2000 baseline data (table 1), the IMPACT model projects a growth in both harvested crop area as well as crop productivity for 2025 under normal climate conditions (table 2). The world’s crop harvested area is expected to increases by about 1.4 percent between 2000 and 2025. This is equivalent to a total area of 1.3 billion hectares in 2025, 34.4 percent of which is under irrigation. For the same period, green water used (effective rainfall) in rainfed areas is expected to increase by 27.2 percent; and both green and blue water used (water diverted from water systems) in irrigated areas are expected to increase by 33.7 and 32.1 percent, respectively. As a result, total water used in agriculture is expected to rise by 30.4 percent, to 6,466 cubic kilometres in 2025.

Tables 1 and 2 about here

Farmers in Sub-Saharan Africa and South Asia use around 37 percent of the world's rainfed area in 2025, which accounts for about 24 percent of the world's crop area (table 2). Similarly, 62 percent of the world's irrigated area in 2025 is in Asia, which accounts for about 21 percent of the world's crop area. Sub-Saharan Africa, South Asia and China use more than half of total green water used worldwide. Principal users of blue water are South Asia, China and the United States, using almost 70 percent of the total. On the crop level, rainfed production of "cereal grains" and "other agricultural product" consumes about half of the total green water used in dry farms. Similarly, irrigated production of "rice" and "other agricultural products" uses around half of the total green and blue water used in irrigated agriculture.

4 Simulation scenarios

To model water supply and demand at the basin scale, Rosegrant et al. (2002) introduced the concept of maximum allowable water withdrawal (MAWW), which is the water withdrawal capacity available for agricultural, municipal and industrial water uses. The MAWW constrains the actual water withdrawals and depends on the availability of surface and groundwater; the physical capacity of water withdrawal; instream flow requirements for navigation; hydropower generation; environmental constrains; recreation purposes; and water demand.

Future projections of allowable water withdrawals are presented by Rosegrant et al. (2002) under three alternative scenarios: business as usual, water crisis and sustainable water use. In the business as usual scenario (BAU), MAWW projections are according to current conditions of water withdrawal capacity and physical constrains on pumping; and consider projected growth in water demand and investments in infrastructure. In the water crisis scenario (CRI), MAWW projections reflect a deterioration (from an environmental perspective) of current trends and policies in the water sector. In contrast to the previous scenario, the sustainable water use scenario (SUS) projects improvements in policies and trends in the water sector, with greater environmental water reservation.

Table 3 shows the annual MAWW for surface and groundwater for BAU, CRI and SUS for 1995 and 2025. Compared to 1995 levels, the business as usual projection for 2025 considers a small decline in extraction rates for those countries or regions pumping in excess. Overexploitation of groundwater aquifers is observable particularly in northern India, northern China, West Asia and North Africa, and in the western United States, where extraction rates substantially exceed recharge rates (total MAWW for China; India; and West Asia and North Africa increases by 29.5, 22.2 and 18.2 percent, respectively). Alternatively, for those countries or regions underutilizing groundwater relative to the water withdrawal capacity, they assume a gradual increase in the extraction rates. MAWW for surface and groundwater increases considerably in Sub-Saharan Africa (93.2 and 38.1 percent, respectively). Southeast Asia is in a similar situation, MAWW for both surface and groundwater increases more than 45.5 percent.

Table 3 about here

The water crisis scenario assumes, for countries pumping in excess, the same growth in extraction rates as the business as usual scenario until 2010, followed by a rapid decline in MAWW for groundwater until 2025. The decline in groundwater is more than compensated by additional use of surface water. For South Asia including India and West Asia as well as North Africa the MAWW for groundwater declines by 29.3 and 18.9 percent respectively, while the MAWW for surface increases in both regions by 13.8 and 15.2 percent respectively (table 3). For regions where overdrafting is not a problem, extraction rates and MAWW for surface and groundwater are higher compared to the business as usual scenario. The MAWW for surface and groundwater for Sub-Saharan Africa increases by 57.4 and 25.3 percent, respectively. In Southeast Asia, MAWW for surface and groundwater increases by 31.1 and 28.1 percent, respectively. Under the water crisis scenario, the world's annual MAWW for surface water increases by 794 cubic kilometres compared to the business as usual scenario. MAWW for groundwater increases only slightly (11 cubic kilometres). In the water crisis scenario, there is more water available for agriculture than in the business as usual scenario. The crisis is therefore not a crises for agriculture, but rather a crises for the natural environment which would have to make do with less water.

In the sustainable water use scenario, groundwater overdrafting is eliminated gradually until 2025 through a reduction in the extraction rates. Compared to the business as usual scenario, the MAWW for groundwater decreases substantially in all regions except for Sub-Saharan Africa and South Asia where overdrafting is not occurring. The MAWW for surface remains unchanged. Under this scenario the world's annual MAWW for groundwater decreases by 190 cubic kilometres compared to the business as usual scenario. This constrains agriculture, but leaves more water for the natural environment.

Based on the three scenario projections of maximum allowable water withdrawals for surface and groundwater presented by Rosegrant et al. (2002), we evaluate the effects of the water crisis and sustainable water use scenarios on production and income. Both scenarios are compared with the business as usual scenario; assuming that the BAU scenario generates a future baseline with current policies and trends in the water sector (i.e. 2025 baseline).

Table 4 shows for 2025 the percentage change in the total (surface plus groundwater) maximum allowable water withdrawal used in the agricultural sector for the water crisis and sustainable water use scenarios.[5] Under the water crisis scenario, all regions increase the maximum water withdrawal capacity for agriculture compared to the business as usual scenario. In developing regions increases are higher than in developed regions. In Sub-Saharan Africa and Southeast Asia, total MAWW for agriculture increases by 29.9 and 22.1 percent, respectively. The numbers for South and Central America are much lower (17.9 and 14.5 percent, respectively). Under the sustainable water use scenario, water constraints occur in all regions except in those regions where groundwater is underutilized (Central and South America, Southeast Asia and Sub-Saharan Africa). Only in Sub-Saharan Africa, total MAWW for agriculture increases slightly by 0.9 percent. Reductions in total MAWW for agriculture are significant for North Africa, the Middle East and South Asia (6.2, 5.6 and 5.5 percent, respectively).

Table 4 about here

Projections of future surface and groundwater use in agriculture, according to the water crisis and sustainable water use scenarios, are introduced in the 2025 GTAP-W baseline simulation based on information in table 4. Under the water crisis scenario, higher levels of surface and groundwater withdrawal are assumed to expand irrigated agriculture. Irrigated crop area and irrigation are increased in GTAP-W according to table 4. Under the sustainable water use scenario, constraints in surface and groundwater capacity are assumed to reduce irrigated agriculture (first stage). As a consequence of the decline in agricultural production and income, farmers react and expand rainfed crop areas to offset the initial losses (second stage). In the first stage, irrigated crop area and irrigation are reduced in GTAP-W according to table 4. In the second stage, rainfed crop area is increased according to the initial

[5] The maximum allowable water withdrawal for surface and groundwater from Rosegrant et al. (2002) presented in table 1 was updated with information regarding groundwater used by the agricultural sector (AQUASTAT database).

reduction in irrigated crop area. That is, total harvested area stays the same, but crop production falls as rainfed agriculture is less productive than irrigated agriculture.

5 Results

Water crisis scenario: Deterioration of current trends and policies in the water sector

Higher surface and groundwater withdrawal capacity increases irrigation water supply, which promotes irrigated crop production and relegates rainfed production. Table 5 shows the percentage changes, with respect to the baseline simulation, in crop production and green and blue water use by region and crop type in 2025. At the global level, global irrigated production increases by 9.9 percent while global rainfed production decreases by 6.7 percent; as a result, total production increases slightly by 0.4 percent.

Table 5 about here

At the regional level, the tendency is similar. Irrigated crop production increases in all regions, particularly in developing regions where overdrafting in not occurring. In Sub-Saharan Africa, Southeast Asia and South America irrigated agriculture expands by 30, 22 and 18 percent, respectively. Contrary to irrigated production, rainfed crop production declines in all regions. Rainfed production declines between 8 to 13 percent in most of the developing regions. In developed regions, rainfed production declines between 1 to 6 percent. Exceptions are Japan and South Korea, where rainfed production declines by around 13 percent.

The combined effect of changes in irrigated and rainfed agriculture on total crop production is mixed; but total crop production increases mostly in developing regions. In China, Southeast Asia and Central America total crop production increases by 2.0, 1.3 and 1.2 percent, respectively. Reductions in total crop production are considerable in Canada (2.8 percent), followed by Australia and New Zealand; the Middle East; and Western Europe (0.8, 0.7 and 0.7 percent, respectively).

Green and blue water use changes accordingly. At the global level, total agricultural water consumption increases by 1.6 percent (105 cubic kilometres). While blue water use increases by 8.9 percent (155 cubic kilometres), green water use decreases by 1.1 percent (50 cubic kilometres). At the regional level, total agricultural water consumption decreases only in four regions: Canada; Western Europe; Japan and South Korea; and Southeast Asia (2.9, 0.8, 0.7 and 0.2 percent, respectively). Regional blue water use increases more in developing regions where groundwater is underutilized: Sub-Saharan Africa, Southeast Asia, and South and Central America (30.0, 21.9, 18.0 and 13.6 percent, respectively). In developing regions, pumping groundwater in excess, including China, South Asia, North Africa and the Middle East, blue water use increases between 5.4 to 8.9 percent. Regional green water use in rainfed and irrigated production changes according to the additional crop production.

Changes in green and blue water use in agricultural production by crop type are shown in the bottom of table 5. For all crops, total agricultural water use increases as a consequence of higher crop production. Total green water use decreases while blue water use increases for all crops. An exception is “other agricultural products”, the crop with the highest increase in production (1.3 percent), for which both green and blue water consumption increase by 0.3 and 9.4 percent, respectively.

An increase in withdrawal capacity raises agricultural use of blue water turning rainfed crop production to irrigated crop production. Global irrigated production increases for all crops between 7 to 13 percent, which implies an increase in green water use in irrigated agriculture by 10 percent (167 cubic kilometres) and an increase in the additional blue water required for crop production by 9 percent (155 cubic kilometres) (table 5). Global rainfed production decreases for all crops between 4 to 9 percent; only rainfed rice production decreases more (22 percent). Green water use changes according to rainfed crop production; total green water use in rainfed agriculture declines by 7 percent (217 cubic kilometres).

Higher surface and groundwater extraction promotes irrigation and improves agricultural yields, which in turn leads to a decrease in the production costs of agricultural products. The last column in table 5 reports the percentage change in world market prices. For all agricultural products, world market prices decrease as a consequence of lower production costs. Reductions in world market prices are considerable for rice, sugar cane and sugar beet (5.1 and 2.4 percent, respectively). Lower market prices stimulate consumption and total production of all agricultural products increases. Total production increases particularly for “other agricultural products” (1.3 percent). The increase is lower for rice and oil seeds production (0.6 and 0.4, respectively). Lower prices and higher supply of crops promotes non-agricultural activities as well. Market prices for food related products, animal production and meat declines by 0.4, 0.2 and 0.1 percent, respectively.

Changes in water withdrawal capacity alter competitiveness and induce changes in welfare. At the global level, welfare increase when more water is used in agriculture. However, at the regional level, the results are more mixed. Welfare decreases mainly in food-exporting regions (356 million USD in South America; 326 million USD in Australia and New Zealand; and 234 in Sub-Saharan Africa) (table 1). The competitive advantage of those regions decreases as other regions increase irrigated agriculture. Welfare changes are positive in all other regions, with the exception of Canada (welfare decreases by 85 million USD). Welfare gains are considerable for China and South Asia, developing regions where overdrafting of groundwater is high (welfare increases by 2,241 and 2,044 million USD, respectively). In Japan and South Korea, Southeast Asia and Western Europe welfare gains are lower (1,397; 1.104 and 1101 million USD, respectively).

Figure 1 about here

Sustainable water use scenario: Improvements in policies and trends in the water sector

Unlike the water crisis scenario, the sustainable water use scenario focuses on the sustainable exploitation of groundwater resources. Under this scenario, no restriction is imposed upon surface water withdrawal; however, groundwater overdrafting is eliminated gradually until 2025. The scenario is divided into two stages, in the first stage restrictions in irrigation water withdrawal constraint irrigated agriculture, which in turn reduce total production and income. In the second stage, farmers react and increase rainfed harvested areas in order to compensate the initial losses in income. Table 6 shows the percentage changes in crop production as well as green and blue water use by region in 2025, compared to the baseline simulation. Displayed are the results for both stages as well as the final result. At the global level, total production decreases by 0.13 percent in the first stage and increases by 0.06 percent in the second stage. The final result is a small decrease in total production by 0.07 percent.

Table 6 about here

At regional level, results vary widely. For developing regions where overdrafting is a problem, the results of the first stage show a decrease in irrigated and total crop production. Total production decreases in South Asia, China, North Africa and the Middle East by 0.7, 0.5, 0.3 and 0.1 percent, respectively. In the second stage, rainfed and total crop production increases. However, this increase is insufficient to offset the initial reduction in total production. As a final result, total production declines in these regions. Total production declines by 0.4 percent in China and 0.2 percent in South Asia and North Africa. The only exception is the Middle East, where total production increases by 0.14 percent. For the USA, a developed country pumping in excess, total production in both stages increases slightly; as a final result total crop production increases by 0.1 percent.

For regions where overdrafting is not occurring, irrigated production decreases and total production increases in the first stage. Exceptions are Sub-Saharan Africa, where groundwater is underutilized and irrigated production increases by 0.78 percent; and the Rest of the World, where total production decreases slightly. In the second stage, rainfed and total production decreases. The only exception is the Rest of the World, where rainfed and total production increases a little. As a final result, total production increases in all these regions, particularly in Canada and Australia and New Zealand by 0.4 and 0.3 percent, respectively.

Changes in rainfed and irrigated production have an effect on the demand for green and blue water resources. At the global level, water savings are expected since groundwater is constrained. Total water use decreases by 0.65 percent (42 cubic kilometres) in the first stage and increases slightly by 0.04 percent (3 cubic kilometres) in the second stage. The final result is a decrease in total water use by 0.61 percent (40 cubic kilometres). While blue water use decreases, total green water use increases in both stages. As a final result, blue water use decreases by 2.76 percent (48 cubic kilometres) and total green water use increases by 0.17 percent (8 cubic kilometres).

At the regional level, green and blue water use varies widely. For regions where overdrafting is a problem, blue and total water use decrease in the first stage, particularly in North Africa (6.6 and 2.7 percent, respectively), the Middle East (5.5 and 2.4 percent, respectively) and South Asia (5.5 and 2.1 percent, respectively). In the second stage blue as well as total water use increases (exceptions are the USA and South Asia). However, the final result, taken the results of stages 1 and 2 together, blue and total water use decrease. Together total water savings in all these regions reach 42 cubic kilometres (blue water use declines by 48 cubic kilometres and total green water use raises by 6 cubic kilometres). South Asia accounts for more than two-thirds of the total water savings in these regions.

For regions where overdrafting is not occurring, results are less pronounced. Total water use increases in the first stage and decreases in the second stage (except for the Rest of the World). The final result is mixed. Total water use decreases slightly in Eastern Europe, the former Soviet Union and in the Rest of the World. In all other regions, total water use increases slightly. Total water use in all these regions increases by 2.17 cubic kilometres.

Changes in green and blue water use by crop type are reported in table 7. In the first stage, when groundwater withdrawal is limited, there is a shift in production from irrigated to rainfed agriculture. Global irrigated production decreases by 2.2 percent, which implies a reduction in green and blue water use by 2.5 percent (41 cubic kilometres) and 2.8 percent (48 cubic kilometres), respectively. Irrigated production declines between 1.0 to 3.2 percent for all crop types. By contrast, global rainfed production and green water use increases by 1.4 percent and 1.5 percent (46 cubic kilometres), respectively. Rainfed production increases considerably for rice and wheat (5.1 and 3.2 percent, respectively). As a result, global production decreases by 0.1 percent and water savings reach 42 cubic kilometres. Water savings are marked for the crops “other agricultural products”, wheat and rice (13, 11 and 9 cubic kilometres, respectively).

Table 7 about here

In the second stage, when rainfed areas expand to neutralize production and income losses, global rainfed and total production increases slightly. In this stage, green and blue water use together increase by 2.5 cubic kilometres. Taking the results of both stages together, the final results show, at the bottom of table 7, a decrease in total production for all crops. The sectors “Other agricultural products” and rice have the largest decrease in total production (0.28 and 0.13 percent, respectively). While blue water use declines for all crops, total green water use increases for all crops except for “other agricultural products”. The final water savings reach 40 cubic kilometres. As in the first stage, “other agricultural products”, wheat and rice are the crops with the highest water savings (12, 11 and 8 cubic kilometres, respectively).

The last column in table 7 shows the changes in world market prices for all crop types. When groundwater use is constrained (first stage), world market prices increase for all crops and for agricultural related products (food products, animal production and meat production). World market prices increase mainly for rice; sugar cane and sugar beet; and wheat (1.50, 0.98 and 0.84 percent, respectively). In the second stage, world market prices decrease for all crops when rainfed areas are increased. World market prices decline mainly for oil seeds and vegetables, fruits and nuts (0.86 and 0.76 percent, respectively). The combined effect of both stages shows a decrease in price for oil seeds and vegetables, fruits and nuts (0.22 and 0.26 percent, respectively). For all other crops including agricultural related activities, world market prices increase. Final world market prices for rice; sugar cane and sugar beet; and wheat increase by 1.25, 0.52 and 0.6 percent, respectively.

Reducing groundwater overdraft worldwide alters the competitiveness of regions and induces changes in welfare. At the global level, welfare declines in the first stage by 2,993 million USD and increases by 2,490 million USD in the second stage. Taken both results together, welfare declines by 503 million USD (figure 1). At the regional level, welfare effects are diverse depending on the region. In the first stage, welfare decreases for most of the regions, but mainly for developing regions where overdrafting is excessive. In South Asia, China and the Middle East welfare decreases by 1,721; 643 and 274 million USD, respectively. In this stage, welfare gains are observable mainly in developing regions where groundwater use is underutilized. Welfare increases in South America, Sub-Saharan Africa and Central America by 167, 77 and 20 million USD, respectively. In the second stage, welfare changes for all regions have an opposite sign than in the first stage. In South Asia, China and the Middle East welfare increases by 1,537; 546 and 221 million USD, respectively. In South America, Sub-Saharan Africa and Central America welfare declines by 115, 61 and 12 million USD, respectively.

Regional welfare gains in the second stage are considerably lower or more than offset welfare losses in the first stage. Taken the results of stages 1 and 2 together, final welfare changes are negative for regions with excessive overdraft. Welfare losses are highest for South Asia and China (183 and 96 million USD, respectively). For regions where groundwater use is underutilized, welfare changes are mostly positive. Welfare increases in South America, Sub-Saharan Africa and Central America by 52, 16 and 8 million USD, respectively. The only exception is Southeast Asia, where welfare decreases by 23 million USD. For the rest of the regions where groundwater overdraft is not problematic, welfare changes are mostly negative. The highest decreases in welfare are present in Japan and South Korea; and Western Europe (97 and 59 million USD, respectively). Exceptions are Australia and New Zealand; and Canada, where welfare increases by 40 and 25 million USD, respectively.

6 Discussion and conclusions

In our analysis, the water crisis and sustainable water use scenarios lead to different patterns in agricultural water consumption. While the water crisis scenario explores a deterioration in current conditions and policies in the water sector, the sustainable water use scenario assumes an improvement and eliminates groundwater overdraft worldwide.

Irrigation water use is promoted under the water crisis scenario. At the global level, total production increases by 1.6 percent. Irrigated production expands suppressing rainfed production. As a result, total agricultural water consumption increases by 105 cubic kilometres. Blue water consumption increases by 155 cubic kilometres and total green water consumption decreases by 50 cubic kilometres. Higher levels of irrigation increase agricultural yields, which in turn reduces production costs and crop prices. World market prices decrease for all crops and for agricultural related products (food products, animal production and meat production). Reductions in world market prices are considerable for rice, sugar cane and sugar beet (5.1 and 2.4 percent, respectively). This scenario leads to an increase in global welfare by 9,104 million USD relative to the business as usual scenario.

An opposite picture is obtained under the sustainable use scenario. At the global level, total elimination of groundwater overdraft decreases total production moderately by 0.07

percent. As groundwater use is limited, irrigated production decreases and rainfed production increases. Global water saving are achieved. Total water consumption decreases by 40 cubic kilometres. Blue water consumption decreases by 48 cubic kilometres and total green water decreases by 8 cubic kilometres. World market prices increase, but not for all crops. World market prices increase mainly for rice, wheat, sugar cane and sugar beet (1.2, 0.6 and 0.5 percent, respectively) and decrease for vegetables, nuts and fruits as well as for oil seeds (0.3 and 0.2 percent, respectively). Global welfare declines by 563 million USD relative to the business as usual scenario.

At the regional level, results vary widely. Under the water crisis scenario, total production increases mainly in China, Southeast Asia and Central America and decreases principally in Canada and Australia and New Zealand. Under the sustainable water use scenario, total production decreases only in China, South Asia and North Africa and increases in all other regions mainly in Canada and Australia and New Zealand.

Under the water crisis scenario, irrigated production increases in all regions but more in developing regions where overdraft is not a problem. In Sub-Saharan Africa, Southeast Asia and South America irrigated agriculture expands by 30, 22 and 18 percent, respectively. Irrigated production increases less in regions where overdrafting is occurring. Under the sustainable water use scenario, irrigated production decreases in all regions, but mainly in developing regions where overdrafting is occurring, between 2.5 to 6.3 percent. Irrigated production increases only in Sub-Saharan Africa (region where groundwater is underutilized).

For all crop types, under the water crisis scenario, irrigated and total production increases, while rainfed production decreases. The opposite occurs under the sustainable water use scenario, irrigated and total production decreases, while rainfed production increases. Major changes in production are observable for “other agricultural products” and rice production.

Regional use of green and blue water resources changes according to the additional regional and sectoral crop production. In absolute terms, under the water crisis scenario, most of the total water consumption occurs in regions where overdrafting is a problem, mainly in China, South East Asia and the USA (43, 40 and 8 cubic kilometres, respectively). For all regions, total green water use decrease and blue water use increase. The only exceptions are Japan and South Korea and China. In Japan and South Korea, both green and blue water consumption decreases slightly. In China, both green and blue water consumption increases by 14 and 28 cubic kilometres, respectively. Under the sustainable water use scenario, water restrictions affect predominantly regions where groundwater resources are on pressure. Total water consumption decrease mainly in South Asia, China and the Middle East (27, 9 and 3 cubic kilometres, respectively).

In both scenarios, welfare gains or losses are not only associated with changes in agricultural water consumption. Under the water crisis scenario, welfare not only increases for regions where water consumption increases (China, South East Asia and the USA). Welfare gains are considerable for Japan and South Korea, Southeast Asia and Western Europe as well. These regions benefit from higher irrigated production and lower food prices. Alternatively, under the sustainable water use scenario, welfare losses not only affect regions where overdrafting is occurring. Welfare decreases in other regions as well. Under the sustainable water use scenario, global and regional welfare losses could be significant if farmers do not increase rainfed areas to offset initial losses in production and income due to irrigation constraints.

The results reveal a clear trade-off between agricultural production, and hence human welfare as measurable by consumption of market goods on the one hand and nature conservation on the other hand. There is more water available for agriculture in the water crisis scenario than in business as usual scenario, and welfare is higher. The sustainable water use scenario has less water for agriculture, and lower welfare. However, the amount of water available to the natural environment moves in the opposite direction: More water for agriculture means less water for nature. This paper does not quantify the benefits of water to nature. It does, however, quantify the welfare implications of restricting or increasing the human take of total water. In the water crisis scenario, for instance, the human benefits of taking 105 cubic kilometres of water out of nature are some 9 billion USD – less than $1.3 per person. The welfare costs of the policies presumed in the sustainable water use scenario are also very small.

Several limitations apply to the above results. First, our analysis is based on regional averages. We do not differentiate between different regions within a country. China is an example of such a country. Although on average water is not short, water supply is a problem in Northern China, where groundwater overexploitation occurs. In our sustainable water use scenario we try to account for this effect. Second, under the water crisis scenario, we do not consider any cost or investment associated with irrigation expansion. Therefore, our results might overestimate the benefits of this scenario. Third, we implicitly assume, for the sustainable water crisis scenario, availability and accessibility of green water resources when rainfed agriculture expands. Forth, the GTAP-W model considers water quantity and prices but ignores non-market benefits or costs of water use. For instance, the model is unable to predict the direct ecological impact of limiting groundwater use. Fifth, our analysis does not account for groundwater use apart from agriculture, since the necessary data are missing. These issues should be addressed in future research.

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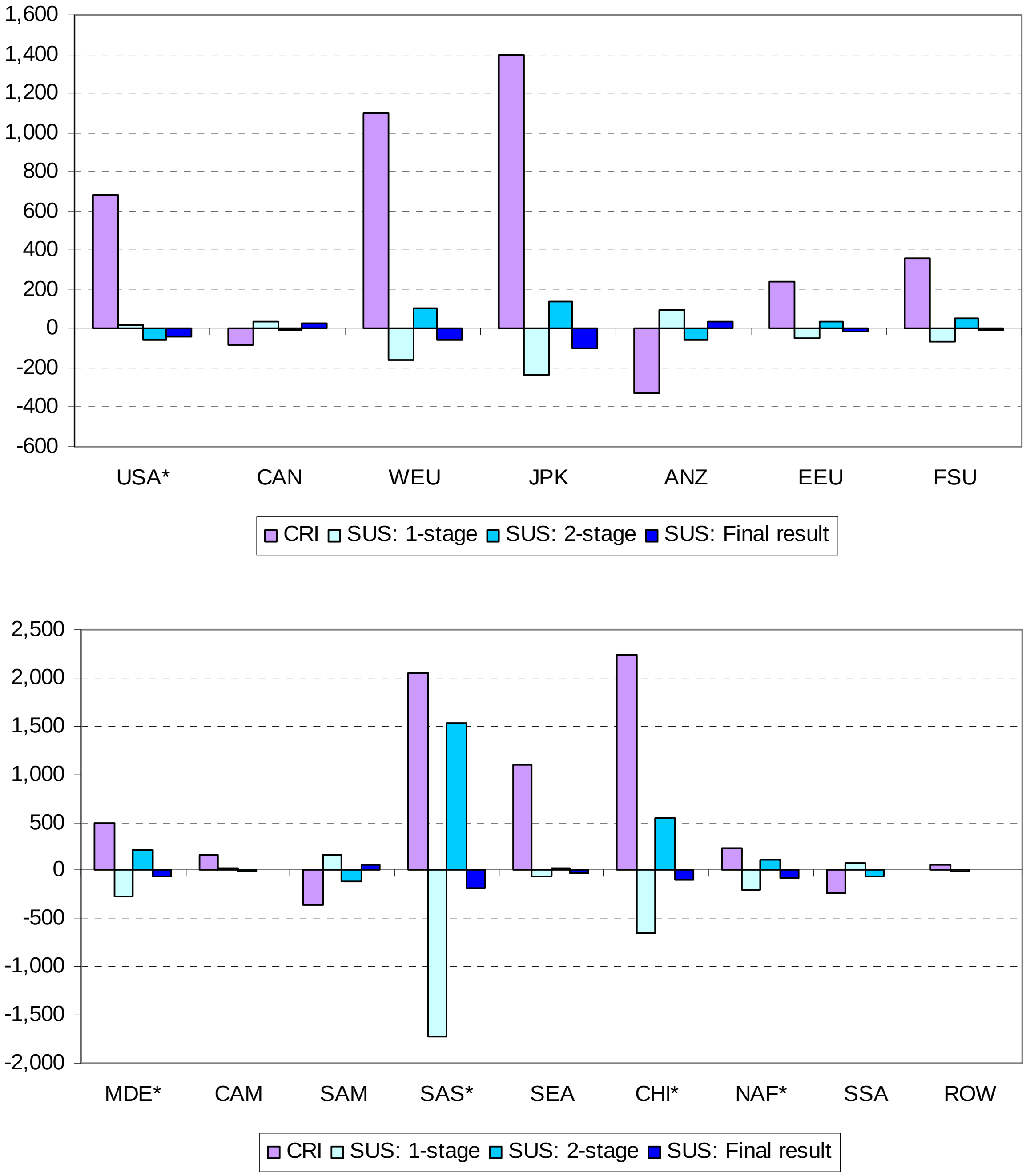

Figure 1. Changes in regional welfare, water crisis and sustainable water use scenarios (million USD)

Note: Developed regions (top panel) and developing regions (bottom panel). Regions where overdrafting of groundwater aquifers occurs are denoted by an asterisk (*).

Table 1. 2000 Baseline data: Crop harvested area and production by region and crop

Regions	Rainfed Agriculture			Irrigated Agriculture				Total			
	Area (thousand ha)	Production (thousand mt)	Green water (km3)	Area (thousand ha)	Production (thousand mt)	Green water (km3)	Blue water (km3)	Area (thousand ha)	Production (thousand mt)	Green water (km3)	Blue water (km3)
United States	35,391	209,833	89	67,112	440,470	159	190	102,503	650,303	248	190
Canada	27,267	65,253	61	717	6,065	2	1	27,984	71,318	62	1
Western Europe	59,494	462,341	100	10,130	146,768	19	10	69,624	609,108	118	10
Japan and South Korea	1,553	23,080	6	4,909	71,056	21	3	6,462	94,136	27	3
Australia and New Zealand	21,196	67,204	45	2,237	27,353	5	15	23,433	94,557	50	15
Eastern Europe	37,977	187,468	95	5,958	40,470	16	14	43,935	227,939	111	14
Former Soviet Union	85,794	235,095	182	16,793	74,762	25	47	102,587	309,857	208	47
Middle East	29,839	135,151	40	21,450	118,989	25	62	51,289	254,140	65	62
Central America	12,970	111,615	47	8,745	89,637	28	46	21,715	201,252	76	46
South America	79,244	649,419	335	9,897	184,304	40	47	89,141	833,723	375	47
South Asia	137,533	491,527	313	114,425	560,349	321	458	251,958	1,051,877	634	458
Southeast Asia	69,135	331,698	300	27,336	191,846	134	56	96,471	523,543	434	56
China	64,236	615,196	185	123,018	907,302	419	278	187,254	1,522,498	604	278
North Africa	15,587	51,056	19	7,352	78,787	4	42	22,938	129,843	23	42
Sub-Saharan Africa	171,356	439,492	588	5,994	43,283	19	37	177,349	482,775	608	37
Rest of the World	3,810	47,466	12	1,093	23,931	5	5	4,903	71,397	16	5
World	**852,381**	**4,122,894**	**2,417**	**427,164**	**3,005,371**	**1,242**	**1,310**	**1,279,545**	**7,128,265**	**3,659**	**1,310**
Crops											
Rice	59,678	108,179	264	93,053	294,934	407.55	320.89	152,730	403,113	671	321
Wheat	124,147	303,638	240	90,492	285,080	133.49	296.42	214,639	588,718	374	296
Cereal grains	225,603	504,028	637	69,402	369,526	186.53	221.22	295,005	873,554	824	221
Vegetables, fruits, nuts	133,756	1,374,128	394	36,275	537,730	95.53	81.59	170,031	1,911,858	489	82
Oil seeds	68,847	125,480	210	29,578	73,898	72.54	78.75	98,425	199,379	282	79
Sugar cane, sugar beet	16,457	846,137	98	9,241	664,023	48.86	89.07	25,699	1,510,161	147	89
Other agricultural products	223,894	861,303	574	99,122	780,180	297.22	222.11	323,017	1,641,483	871	222
Total	**852,381**	**4,122,894**	**2,417**	**427,164**	**3,005,371**	**1,242**	**1,310**	**1,279,545**	**7,128,265**	**3,659**	**1,310**

Note: 2000 data are three-year averages for 1999-2001.
Source: IMPACT, 2000 baseline data.

Table 2. 2025 baseline simulation: Crop harvested area and production by region and crop

Regions	Rainfed Agriculture			Irrigated Agriculture				Total			
	Area (thousand ha)	Production (thousand mt)	Green water (km3)	Area (thousand ha)	Production (thousand mt)	Green water (km3)	Blue water (km3)	Area (thousand ha)	Production (thousand mt)	Green water (km3)	Blue water (km3)
United States	33,561	282,634	95	68,312	649,118	178	269	101,873	931,752	272	269
Canada	24,547	84,579	64	668	7,816	2	2	25,216	92,395	65	2
Western Europe	49,655	471,745	82	9,206	170,610	17	13	58,861	642,355	99	13
Japan and South Korea	1,330	25,507	7	4,339	72,386	25	2	5,669	97,893	32	2
Australia and New Zealand	20,574	87,458	45	2,211	37,586	5	21	22,785	125,044	50	21
Eastern Europe	33,620	214,995	91	5,411	56,306	15	26	39,031	271,301	106	26
Former Soviet Union	83,041	327,597	194	16,850	107,271	28	62	99,890	434,868	222	62
Middle East	30,330	171,058	41	22,838	192,787	28	84	53,169	363,844	69	84
Central America	13,197	177,760	63	9,543	149,400	40	63	22,740	327,161	103	63
South America	89,653	1,305,413	468	11,725	391,766	60	79	101,378	1,697,179	528	79
South Asia	117,502	567,087	384	129,479	893,522	511	594	246,981	1,460,609	895	594
Southeast Asia	73,223	457,800	409	27,488	307,826	178	76	100,711	765,626	587	76
China	61,143	710,893	227	120,294	1,041,731	526	316	181,436	1,752,624	753	316
North Africa	16,117	79,552	18	7,820	114,835	4	55	23,937	194,388	22	55
Sub-Saharan Africa	200,093	727,357	873	8,311	98,412	37	62	208,404	825,769	910	62
Rest of the World	4,122	78,566	16	1,260	47,376	7	8	5,382	125,941	23	8
Total	**851,709**	**5,770,002**	**3,075**	**445,754**	**4,338,747**	**1,660**	**1,730**	**1,297,463**	**10,108,749**	**4,736**	**1,730**
Crops											
Rice	52,329	107,187	318	91,357	335,710	542.15	364.85	143,686	442,897	860	365
Wheat	115,502	370,764	245	88,649	397,007	141.15	335.74	204,150	767,771	387	336
Cereal grains	221,740	682,485	787	74,630	566,363	244.02	321.84	296,370	1,248,848	1,031	322
Vegetables, fruits, nuts	142,260	1,838,783	523	41,014	806,515	134.72	146.85	183,274	2,645,298	658	147
Oil seeds	71,325	137,662	278	30,735	99,416	90.05	111.35	102,060	237,078	368	111
Sugar cane, sugar beet	21,827	1,662,782	173	11,997	1,202,418	83.59	144.46	33,823	2,865,200	257	144
Other agricultural products	226,726	970,340	751	107,373	931,317	424.58	305.38	334,099	1,901,657	1,175	305
Total	**851,709**	**5,770,002**	**3,075**	**445,754**	**4,338,747**	**1,660**	**1,730**	**1,297,463**	**10,108,749**	**4,736**	**1,730**

Note: Linear interpolation from IMPACT 2050 simulation with no climate change.
Source: IMPACT.

Table 3. Annual maximum allowable water withdrawal for surface and groundwater under business as usual, water crisis and sustainable water use scenario, 1995 and 2025 (km^3)

Country/Region	**Surface** (km^3)				**Groundwater** (km^3)				**Total** (km^3)			
	1995	**2025 projection**			**1995**	**2025 projection**			**1995**	**2025 projection**		
	Baseline	**BAU**	**CRI**	**SUS**	**Baseline**	**BAU**	**CRI**	**SUS**	**Baseline**	**BAU**	**CRI**	**SUS**
Asia	1,919	2,464	2,926	2,464	478	542	519	389	2,397	3,006	3,445	2,853
China	584	764	916	764	138	171	176	137	722	935	1,092	901
India	573	735	872	735	237	255	235	163	810	990	1,107	898
Southeast Asia	194	286	375	286	22	32	41	32	216	318	416	318
South Asia including India	318	390	444	390	57	58	41	32	375	448	485	422
Latin America	251	358	452	358	65	79	90	79	316	437	542	437
Sub-Saharan Africa	73	141	222	141	63	87	109	90	136	228	331	231
West Asia / North Africa	246	302	348	302	72	74	60	45	318	376	408	347
Developed countries	976	1,131	1,247	1,131	255	278	293	267	1,231	1,409	1,540	1,398
Developing countries	2,425	3,197	3,875	3,197	670	773	769	594	3,095	3,970	4,644	3,791
World	**3,401**	**4,328**	**5,122**	**4,328**	**925**	**1,051**	**1,062**	**861**	**4,326**	**5,379**	**6,184**	**5,189**

Note: Business as usual (BAU), water crisis (CRI) and sustainable water use (SUS).
Source: Rosegrant et al. (2002).

Table 4. Percentage change in total (surface plus groundwater) maximum allowable water withdrawal used in the agricultural sector, 2025 (percentage change with respect to the business as usual scenario)

Regions (according the GTAP-W)	CRI (%)	SUS (%)
United States	3.84	-0.32
Canada	1.09	-0.09
Western Europe	2.33	-0.20
Japan and South Korea	5.13	-0.43
Australia and New Zealand	5.46	-0.46
Eastern Europe	2.80	-0.23
Former Soviet Union	5.11	-0.43
Middle East	6.21	-5.63
Central America	14.46	0.00
South America	17.91	0.00
South Asia	7.82	-5.49
Southeast Asia	22.08	0.00
China	11.37	-2.46
North Africa	6.87	-6.22
Sub-Saharan Africa	29.85	0.87
Rest of the World	7.53	-2.00

Note: Water crisis (CRI) and sustainable water use (SUS).

Source: Authors' estimates based on Rosegrant et al. (2002) and the AQUASTAT database.

Table 5. Water crisis scenario: Percentage change in crop production, green and blue water use and world market price by region and crop type, compared to the 2025 baseline simulation

Description	Rainfed Agriculture		Irrigated Agriculture			Total				World market price
	Production	Green water	Production	Green water	Blue water	Production	Green water	Blue water	Total water	
Regions										
United States	-5.33	-6.92	3.09	3.44	3.18	0.54	-0.15	3.18	1.50	
Canada	-3.21	-3.09	1.35	0.96	0.81	-2.83	-2.99	0.81	-2.88	
Western Europe	-1.81	-1.75	2.56	2.24	1.60	-0.65	-1.07	1.60	-0.77	
Japan and South Korea	-12.56	-10.73	4.60	2.04	-0.35	0.13	-0.67	-0.35	-0.65	
Australia and New Zealand	-3.74	-2.66	5.88	5.70	5.72	-0.85	-1.81	5.72	0.41	
Eastern Europe	-0.81	-0.79	2.79	2.76	2.77	-0.06	-0.28	2.77	0.32	
Former Soviet Union	-1.82	-1.59	5.12	5.08	5.09	-0.11	-0.76	5.09	0.52	
Middle East	-8.10	-8.71	5.91	5.28	5.43	-0.67	-3.07	5.43	1.61	
Central America	-9.07	-10.75	13.33	13.44	13.60	1.16	-1.41	13.60	4.29	
South America	-5.54	-4.56	18.21	17.98	17.98	-0.06	-1.98	17.98	0.63	
South Asia	-10.55	-11.70	7.65	7.55	7.74	0.58	-0.70	7.74	2.66	
Southeast Asia	-12.43	-13.79	21.74	21.90	21.88	1.31	-2.99	21.88	-0.16	
China	-11.29	-16.02	11.04	9.65	8.94	1.98	1.91	8.94	3.99	
North Africa	-10.57	-12.94	6.75	6.83	5.98	-0.34	-9.18	5.98	1.60	
Sub-Saharan Africa	-4.73	-3.30	30.00	30.00	30.03	-0.59	-1.95	30.03	0.10	
Rest of the World	-4.51	-3.69	7.43	7.35	7.39	-0.02	-0.37	7.39	1.63	
Total	**-6.69**	**-7.05**	**9.93**	**10.05**	**8.93**	**0.44**	**-1.05**	**8.93**	**1.62**	
Crops										
Rice	-21.63	-21.89	7.75	9.31	7.91	0.64	-2.22	7.91	0.80	-5.08
Wheat	-7.94	-7.30	7.49	7.31	8.05	0.04	-1.96	8.05	2.69	-1.99
Cereal grains	-5.36	-4.77	7.09	9.63	9.18	0.28	-1.36	9.18	1.15	-1.72
Vegetables, fruits, nuts	-4.06	-3.91	9.79	11.61	10.17	0.16	-0.73	10.17	1.26	-1.60
Oil seeds	-3.97	-3.72	6.39	8.91	6.61	0.37	-0.63	6.61	1.05	-1.83
Sugar cane, sugar beet	-8.70	-10.02	12.66	14.40	12.41	0.26	-2.07	12.41	3.14	-2.38
Other agricultural products	-7.44	-5.81	10.46	11.04	9.44	1.33	0.28	9.44	2.17	-1.90
Total	**-6.69**	**-7.05**	**9.93**	**10.05**	**8.93**	**0.44**	**-1.05**	**8.93**	**1.62**	

Table 6. Sustainable water use scenario: Percentage change in crop production and green and blue water use by region, compared to the 2025 baseline simulation

Regions	Rainfed		Irrigated Agriculture			Total			
	Produc.	Green water	Produc.	Green water	Blue water	Produc.	Green water	Blue water	Total water
First stage									
United States	0.77	1.08	-0.25	-0.25	-0.27	0.06	0.21	-0.27	-0.03
Canada	0.93	0.88	-0.14	0.01	0.07	0.84	0.86	0.07	0.84
Western Europe	0.33	0.37	-0.27	-0.14	0.37	0.17	0.28	0.37	0.29
Japan and South Korea	1.61	2.96	-0.44	-0.41	-0.40	0.09	0.31	-0.40	0.27
Australia and New Zealand	0.78	0.79	-0.62	-0.36	-0.43	0.36	0.67	-0.43	0.35
Eastern Europe	0.10	0.11	-0.23	-0.22	-0.22	0.03	0.06	-0.22	0.01
Former Soviet Union	0.24	0.25	-0.44	-0.41	-0.41	0.07	0.16	-0.41	0.04
Middle East	6.17	6.21	-5.58	-5.49	-5.50	-0.05	1.50	-5.50	-2.36
Central America	0.21	0.27	-0.10	-0.08	-0.07	0.07	0.13	-0.07	0.06
South America	0.14	0.26	-0.17	-0.08	-0.06	0.07	0.22	-0.06	0.18
South Asia	6.68	7.36	-5.33	-5.32	-5.47	-0.67	0.12	-5.47	-2.11
Southeast Asia	0.15	0.19	-0.03	0.00	0.00	0.08	0.13	0.00	0.12
China	2.20	3.10	-2.41	-2.12	-1.96	-0.54	-0.55	-1.96	-0.96
North Africa	8.17	9.93	-6.23	-6.27	-6.62	-0.34	6.86	-6.62	-2.73
Sub-Saharan Africa	0.09	0.17	0.78	0.81	0.82	0.17	0.19	0.82	0.23
Rest of the World	1.12	0.88	-1.92	-1.92	-1.93	-0.02	0.04	-1.93	-0.47
Total	**1.41**	**1.51**	**-2.19**	**-2.46**	**-2.76**	**-0.13**	**0.12**	**-2.76**	**-0.65**
Second stage									
United States	0.15	0.12	-0.01	0.00	-0.01	0.04	0.04	-0.01	0.02
Canada	-0.43	-0.35	0.09	0.18	0.13	-0.39	-0.34	0.13	-0.32
Western Europe	-0.18	-0.18	0.01	-0.02	-0.10	-0.13	-0.15	-0.10	-0.15
Japan and South Korea	-0.03	0.08	-0.03	0.01	0.02	-0.03	0.03	0.02	0.03
Australia and New Zealand	-0.22	-0.18	0.17	0.18	0.18	-0.10	-0.15	0.18	-0.05
Eastern Europe	-0.02	-0.03	0.00	0.00	0.00	-0.02	-0.02	0.00	-0.02
Former Soviet Union	-0.06	-0.07	0.01	0.00	0.00	-0.04	-0.06	0.00	-0.05
Middle East	0.34	0.55	0.04	0.19	0.17	0.19	0.39	0.17	0.26
Central America	-0.18	-0.22	0.07	0.06	0.06	-0.07	-0.11	0.06	-0.05
South America	-0.10	-0.21	0.10	0.07	0.05	-0.06	-0.18	0.05	-0.15
South Asia	1.16	1.28	-0.10	-0.03	-0.07	0.43	0.49	-0.07	0.26
Southeast Asia	-0.08	-0.07	0.01	0.03	0.02	-0.04	-0.04	0.02	-0.03
China	0.42	0.52	-0.04	0.01	0.02	0.15	0.16	0.02	0.11
North Africa	0.41	0.48	-0.04	0.02	0.07	0.16	0.38	0.07	0.16
Sub-Saharan Africa	-0.18	-0.17	0.02	0.00	0.01	-0.15	-0.17	0.01	-0.16
Rest of the World	0.07	0.09	-0.02	-0.01	-0.02	0.04	0.06	-0.02	0.04
Total	**0.11**	**0.08**	**-0.02**	**0.00**	**-0.01**	**0.06**	**0.06**	**-0.01**	**0.04**
Final result									
United States	0.93	1.20	-0.27	-0.25	-0.28	0.10	0.26	-0.28	-0.01
Canada	0.50	0.53	-0.05	0.19	0.20	0.45	0.52	0.20	0.51
Western Europe	0.15	0.19	-0.26	-0.16	0.27	0.04	0.13	0.27	0.14
Japan and South Korea	1.58	3.04	-0.47	-0.40	-0.38	0.06	0.33	-0.38	0.29
Australia and New Zealand	0.56	0.60	-0.45	-0.18	-0.25	0.25	0.52	-0.25	0.30
Eastern Europe	0.08	0.08	-0.23	-0.22	-0.22	0.01	0.04	-0.22	-0.01
Former Soviet Union	0.18	0.17	-0.43	-0.41	-0.42	0.03	0.10	-0.42	-0.01
Middle East	6.53	6.72	-5.54	-5.29	-5.32	0.14	1.88	-5.32	-2.09
Central America	0.03	0.05	-0.04	-0.02	-0.01	0.00	0.02	-0.01	0.01
South America	0.04	0.05	-0.07	-0.02	-0.01	0.01	0.05	-0.01	0.04
South Asia	7.92	8.55	-5.42	-5.36	-5.54	-0.24	0.60	-5.54	-1.85
Southeast Asia	0.06	0.12	-0.02	0.02	0.02	0.03	0.09	0.02	0.08
China	2.64	3.61	-2.46	-2.11	-1.94	-0.39	-0.39	-1.94	-0.85
North Africa	8.61	10.37	-6.26	-6.25	-6.54	-0.18	7.21	-6.54	-2.57
Sub-Saharan Africa	-0.09	-0.01	0.80	0.81	0.83	0.01	0.02	0.83	0.08
Rest of the World	1.19	0.97	-1.94	-1.93	-1.95	0.01	0.10	-1.95	-0.43
Total	**1.53**	**1.59**	**-2.21**	**-2.45**	**-2.76**	**-0.07**	**0.17**	**-2.76**	**-0.61**

Table 7. Sustainable water use scenario: Percentage change in crop production, green and blue water use and world market price by crop type, compared to the 2025 baseline simulation

Crops	Rainfed Agriculture		Irrigated Agriculture			Total				World market price
	Production	Green water	Production	Green water	Blue water	Production	Green water	Blue water	Total water	
First stage										
Rice	5.11	4.49	-1.95	-2.35	-2.85	-0.24	0.18	-2.85	-0.72	1.50
Wheat	3.19	2.91	-3.15	-2.56	-4.30	-0.09	0.91	-4.30	-1.51	0.84
Cereal grains	0.94	0.84	-1.22	-1.51	-1.38	-0.04	0.28	-1.38	-0.11	0.41
Vegetables, fruits, nuts	0.99	0.75	-2.47	-2.30	-2.91	-0.07	0.13	-2.91	-0.43	0.49
Oil seeds	0.69	0.71	-1.04	-1.63	-1.24	-0.04	0.13	-1.24	-0.18	0.64
Sugar cane, sugar beet	1.24	0.81	-1.93	-1.43	-2.52	-0.09	0.08	-2.52	-0.86	0.98
Other agricultural products	1.88	1.48	-2.67	-3.52	-3.00	-0.35	-0.33	-3.00	-0.88	0.65
Total	**1.41**	**1.51**	**-2.19**	**-2.46**	**-2.76**	**-0.13**	**0.12**	**-2.76**	**-0.65**	
Second stage										
Rice	0.43	0.27	0.02	0.00	0.00	0.13	0.10	0.00	0.07	-0.25
Wheat	0.05	0.01	0.04	0.06	0.05	0.04	0.02	0.05	0.03	-0.24
Cereal grains	0.05	0.05	0.00	-0.03	-0.02	0.02	0.03	-0.02	0.02	-0.28
Vegetables, fruits, nuts	0.14	0.10	-0.09	-0.13	-0.10	0.07	0.05	-0.10	0.02	-0.76
Oil seeds	-0.01	-0.03	0.05	0.05	-0.01	0.02	-0.01	-0.01	-0.01	-0.86
Sugar cane, sugar beet	0.09	0.04	-0.01	0.01	-0.05	0.05	0.03	-0.05	0.00	-0.46
Other agricultural products	0.15	0.10	-0.02	0.04	0.01	0.07	0.08	0.01	0.06	-0.49
Total	**0.11**	**0.08**	**-0.02**	**0.00**	**-0.01**	**0.06**	**0.06**	**-0.01**	**0.04**	
Final result										
Rice	5.56	4.78	-1.93	-2.36	-2.85	-0.12	0.28	-2.85	-0.65	1.25
Wheat	3.24	2.92	-3.11	-2.51	-4.25	-0.05	0.94	-4.25	-1.48	0.60
Cereal grains	0.99	0.89	-1.22	-1.54	-1.39	-0.02	0.31	-1.39	-0.09	0.12
Vegetables, fruits, nuts	1.12	0.85	-2.55	-2.43	-3.00	0.00	0.18	-3.00	-0.40	-0.27
Oil seeds	0.68	0.68	-0.99	-1.58	-1.25	-0.02	0.13	-1.25	-0.19	-0.22
Sugar cane, sugar beet	1.33	0.84	-1.93	-1.42	-2.56	-0.04	0.11	-2.56	-0.85	0.52
Other agricultural products	2.03	1.58	-2.70	-3.49	-2.99	-0.28	-0.25	-2.99	-0.82	0.15
Total	**1.53**	**1.59**	**-2.21**	**-2.45**	**-2.76**	**-0.07**	**0.17**	**-2.76**	**-0.61**	

Annex I:

Table A1. Aggregations in GTAP-W

A. Regional Aggregation

1. USA - United States
2. CAN - Canada
3. WEU - Western Europe
4. JPK - Japan and South Korea
5. ANZ - Australia and New Zealand
6. EEU - Eastern Europe
7. FSU - Former Soviet Union
8. MDE - Middle East
9. CAM - Central America
10. SAM - South America
11. SAS - South Asia
12. SEA - Southeast Asia
13. CHI - China
14. NAF - North Africa
15. SSA - Sub-Saharan Africa
16. ROW - Rest of the World

B. Sectoral Aggregation

1. Rice - Rice
2. Wheat - Wheat
3. CerCrops - Cereal grains
4. VegFruits - Vegetable, fruits, nuts
5. OilSeeds - Oil seeds
6. Sug_Can - Sugar cane, sugar beet
7. Oth_Agr - Other agricultural products
8. Animals - Animals
9. Meat - Meat
10. Food_Prod - Food products
11. Forestry - Forestry
12. Fishing - Fishing
13. Coal - Coal
14. Oil - Oil
15. Gas - Gas
16. Oil_Pcts - Oil products
17. Electricity - Electricity
18. Water - Water
19. En_Int_Ind - Energy intensive industries
20. Oth_Ind - Other industry and services
21. Mserv - Market services
22. NMServ - Non-market services

C. Endowments

Wtr - Irrigation
Lnd - Irrigated land
RfLand - Rainfed land
PsLand - Pasture land
Lab - Labour
Capital - Capital
NatlRes - Natural resources

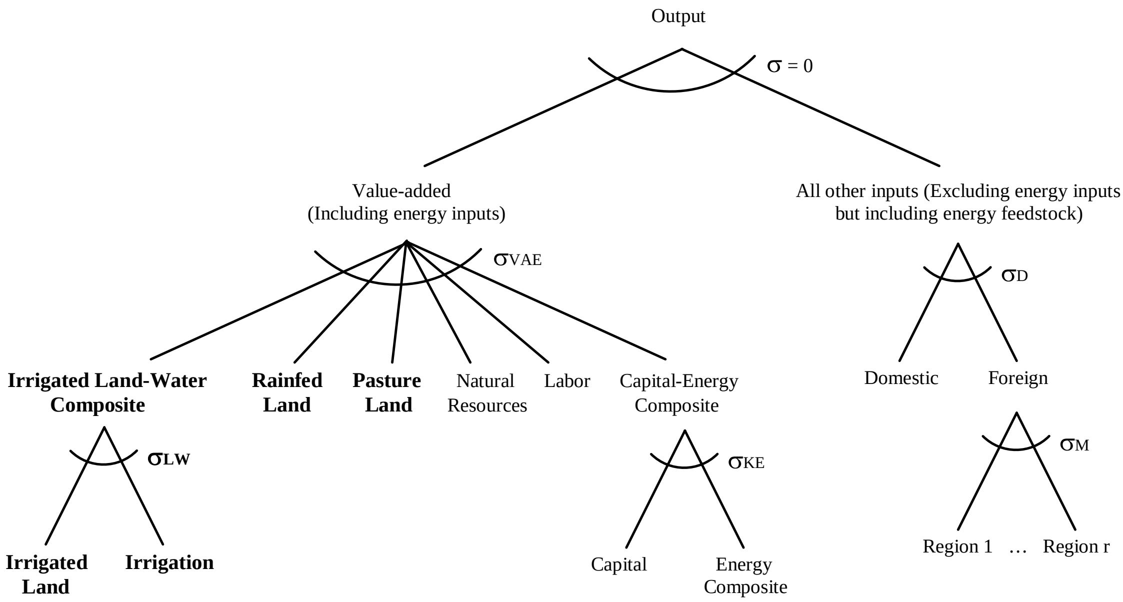

Figure A1. Nested tree structure for industrial production process in GTAP-W (truncated)

Note: The original land endowment has been split into pasture land, rainfed land, irrigated land and irrigation (bold letters).

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Research Unit Sustainability and Global Change

Hamburg University and Centre for Marine and Atmospheric Science

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