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A.E. Ercin
A.Y. Hoekstra

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Water footprint scenarios for 2050

A global analysis and case study for Europe

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WATER FOOTPRINT SCENARIOS FOR 2050

A GLOBAL ANALYSIS AND CASE STUDY FOR EUROPE

A.E. ERCIN[1]

A.Y. HOEKSTRA[1]

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[1] Twente Water Centre, University of Twente, Enschede, the Netherlands;
corresponding author: Arjen Hoekstra, e-mail a.y.hoekstra@utwente.nl

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Summary

This study develops water footprint scenarios for 2050 based on a number of drivers of change: population growth, economic growth, production/trade pattern, consumption pattern (dietary change, bioenergy use) and technological development. Our study comprises two assessments: one for the globe as a whole, distinguishing between 16 world regions, and another one for Europe, whereby we zoom in to the country level. The objective of the global study is to understand the changes in the water footprint (WF) of production and consumption for possible futures by region and to elaborate the main drivers of this change. In addition, we assess virtual water flows between the regions of the world to show dependencies of regions on water resources in other regions under different possible futures. In the European case study, our objective is to assess the water footprint of production and consumption at country level and Europe's dependence on water resources elsewhere in the world.

We constructed four scenarios, along two axes, representing two key dimensions of uncertainty: globalisation versus regional self-sufficiency, and economy-driven development versus development driven by social and environmental objectives. The two axes create four quadrants, each of which represents a scenario: global markets (S1), regional markets (S2), global sustainability (S3) and regional sustainability (S4).

The WF of production in the world in 2050 has increased by 130% in S1 relative to the year 2000. In S2, the WF of production shows and increase of 175%, in S3 30% and in S4 46%. Among the scenarios, S1 and S2 have a larger WF of production as the world consumes more animal-based products. Scenario S2 yields the largest WF of production due to a larger population size and a higher demand for biofuels than S1. When the world food consumption depends less on animal products (S3 and S4), the increase in the WF of production becomes less. When we compare the trade liberalization scenarios (S1 and S3) to the self-sufficiency scenarios (S3 and S4), it is observed that trade liberalization decreases the WF globally. The world average WF of consumption per capita increases by +73% in S1, +58% in S2, -2% in S3 and 10% in S4 compared to 2000 volumes.

The total WF of production in Western Europe (WEU) increases by +12% in S1 and +42% in S2 relative to 2000 values. It decreases 36% in S3 and 29% in S4. Eastern Europe (EEU) increases its WF of production by +150% and +107% in S1 and S2 compared to 2000, respectively. The increase is lower in S3 and S4 than in the other scenarios, but volumes are 36% and 31% higher than in 2000, respectively. The total WF of consumption in WEU increases by 28% and 52% in S1 and S2 compared to 2000. The WF of consumption in WEU decreases by -19% in S3 and -20% in S4. EEU increases its WF of consumption in all scenarios compared to 2000, by +143% in S1, +75% in S2, +17% in S3 and +20% in S4. The WF of consumption per capita in WEU increases by +30% in S1 and +22% in S2 and decreases by -18% in S3 and -28% in S4. EEU has a higher WF of consumption per capita in 2050 than 2000 with an increase of 186% in S1, 57% in S2, 38% in S3 and 23% in S4.

Our analysis shows that water footprints can radically change from one scenario to another and are very sensitive to the drivers of change:

- Population growth: The size of the population is the major driver of change of the WF of production and consumption.
- Economic growth: Increased income levels result in a shift toward high consumption of water intensive commodities. GDP growth significantly increases industrial water consumption and pollution.
- Consumer preferences:. Diets with increased meat and dairy products result in very large water footprints in 2050 (S1 and S2 scenarios). In S3 and S4, the scenarios with low meat content, the total water footprint of consumption and production in the world drastically decrease.
- Biofuel use: Existing plans related to biofuel use in the future will increase the pressure on water resources. The study shows that a high demand for biofuel increases the water footprint of production and consumption in the world.
- Importance of international trade: A reduction in water footprints is possible in 2050 by liberalization of trade (S1 versus S2 and S3 versus S4). Trade liberalization, on the other hand, will imply more dependency of importing nations on the freshwater resources in the exporting nations and probably energy use will increase because of long-distance transport.
- Technology: Increased water productivity as a result of technological development will result in a reduction of the water footprint of consumption and production.

The study shows how different drivers will change the level of water consumption and pollution globally in 2050. The presented scenarios can form a basis for a further assessment of how humanity can mitigate future freshwater scarcity. We showed with this study that reducing humanity's water footprint to sustainable levels is possible even with increasing populations, provided that consumption patterns change. This study can help to guide corrective policies at both national and international levels, and to set priorities for the years ahead in order to achieve sustainable and equitable use of the world's fresh water resources.

1. Introduction

Availability of freshwater in sufficient quantities and adequate quality is a prerequisite for human societies and natural ecosystems. In many parts of the world, excessive freshwater consumption and pollution by human activities put enormous pressure on this availability as well as on food security, environmental quality, economic development and social well-being. Competition over freshwater resources has been increasing during decades due to a growing population, economic growth, increased demand for agricultural products for both food and non-food use, and a shift in consumption patterns towards more meat and sugar based products (Shen et al., 2008; Falkenmark et al., 2009; De Fraiture and Wichelns, 2010; Strzepek and Boehlert, 2010). It looks like today's problems related to freshwater scarcity and pollution will be aggravated in the future due to a significant increase in demand for water and a decrease in availability and quality. Many authors have estimated that our dependency on water resources will increase significantly in the future and this brings problems for future food security and environmental sustainability (Rosegrant et al., 2002; Alcamo et al., 2003a; Bruinsma, 2003; 2009; Rosegrant et al., 2009). A recent report estimates that global water withdrawal will grow from 4,500 billion m^3/year today to 6,900 billion m^3/year by 2030 (McKinsey, 2009).

Scenario analysis is a tool to explore the long-term future of complex socio-ecological systems under uncertain conditions. This method can and indeed has been used to assess possible changes to global water supply and demand. Such studies have been an interest not only of scientists but also of governmental agencies, businesses, investors and the public at large. Many reports have been published to assess the future status of water resources since the 1970s (Falkenmark and Lindh, 1976; Kalinin and Bykov, 1969; Korzun et al., 1978; L'vovich, 1979; Madsen et al., 1973; Schneider, 1976). Water scenario studies address changes in future water availability and/or changes in future water demand. Some of the recent scenario studies focused on potential impacts of climate change and socio-economic changes on water availability (e.g. Arnell, 1996, 2004; Milly et al. ,2005; Fung et al., 2011). Other scenario studies also included the changes in water demand (Alcamo et al., 1996; Seckler, 1998; Alcamo et al., 2000; Shiklomanov, 2000; Vörösmarty et al., 2000; Rosegrant et al. 2002, 2003; Alcamo et al., 2003a, b, 2007).

The major factors that will affect the future of global water resources are: population growth, economic growth, changes in production and trade patterns, increasing competition over water because of increased demands for domestic, industrial and agricultural purposes and the way in which different sectors of society will respond to increasing water scarcity and pollution. These factors are also mentioned in *Global Water Futures 2050*, a preparatory study on how to construct the upcoming generation of water scenarios by UNESCO and the United Nations World Water Assessment Programme (Cosgrove and Cosgrove, 2012; Gallopín, 2012). In this study, ten different drivers of change are identified as critical to assess water resources in the long-term future: demography, economy, technology, water stocks, water infrastructure, climate, social behaviour, policy, environment and governance.

In this study, we focus on water demand scenarios. In Table 1, we compare the scope of the current study with other recent water demand scenario studies. Vörösmarty et al. (2000) estimated agricultural, industrial and domestic water withdrawal for 2025, distinguishing single trajectories for population growth, economic development and change in water use-efficiency. The analysis was carried out at a 30′ grid resolution. Shiklomanov (2000) assessed water withdrawals and water consumption for 26 regions of the world for the year 2025. He projected agricultural, industrial and municipal water use considering population, economic growth and technology change (water efficiency). Another global water scenario study was undertaken by Rosegrant et al. (2002; 2003), who addressed global water and food security for the year 2025. They studied irrigation, livestock, domestic and industrial water withdrawal and consumption in 69 river basins under three main scenarios. Compared to other recent studies, their study includes the most extensive list of drivers of change: population growth, urbanization, economic growth, technology change, policies and water availability constraints. Technology change was addressed in terms of irrigation efficiency, domestic water use efficiency and growth in crop and animal yields. Policy drivers included water prices, water allocation priorities among sectors, commodity price policy as defined by taxes and subsidies on commodities. Climate change effects on water demand were not included in the study, but three alternative water availability constraints were included. Changes in food demand, production and trade were estimated for each scenario based on the drivers distinguished. The effect of increased biofuel consumption was not included. Different trajectories were considered for each driver, except for the economic and demographic drivers. Population growth, the speed of urbanization and economic growth were held constant across all scenarios. Alcamo et al. (2003a) analysed the change in water withdrawals for future business-as-usual conditions in 2025 under the assumption that current trends in population, economy and technology continue. They studied changes in water withdrawal at a 0.5° spatial resolution. A more recent assessment by Alcamo et al. (2007) improved their previous study by distinguishing two alternative trajectories for population and economic growth, based on the A2 and B2 scenarios of the IPCC for the years 2025, 2055 and 2075. Shen et al. (2008) studied changes in water withdrawals in the agricultural, industrial and domestic sectors for the years 2020, 2050 and 2070. They addressed socio-economic changes (population, GDP, water use efficiency) as described in four IPCC scenarios (A1, A2, B1 and B2), disaggregating the world into 9 regions. One of the most extensive water demand scenario studies was done by De Fraiture et al. (2007) and De Fraiture and Wichelns (2010). These studies focused on alternative strategies for meeting increased demands for water and food in 2050. They elaborated possible alternatives under four scenarios for 115 socio-economic units (countries and country groups). Their analysis distinguished water demand by green and blue water consumption. The agriculture sector was analysed considering 6 crop categories and livestock separately. The industrial sector was schematized into the manufacturing industry and the thermo-cooling sector. Many drivers were addressed explicitly, like food demand, trade structure, water productivity, change in water policies and investments, in addition to the conventional drivers of population and economic growth. Despite covering most of the critical drivers, they excluded effects of climate change and biofuel demand from their study. Most of these studies have paid little attention to the fact that, in the end, total water consumption and pollution relate to the amount and type of commodities we consume and to the structure of the global economy and trade, that supplies the various consumer goods and services to us. None of the global scenario studies addressed the question of how alternative consumer choices influence the future status of the water resources except Rosegrant et al. (2002; 2003). In addition, the links between trends in consumption, trade, social and economic development have not yet been fully integrated.

Table 1. Comparison of existing global water demand scenarios with the current study.

Study	Study characteristics	Sectoral disaggregation	Drivers used to estimate future water demand (no. of trajectories distinguished)
Vörösmarty et al. (2000)	Time horizon: 2025 Spatial scale: 30′ grid resolution Scenarios: 1 Scope: Blue water withdrawal	Agriculture Industry Domestic	Population growth (1) Economic growth (1) Technology change (1)
Shiklomanov (2000)	Time horizon: 2025 Spatial scale: 26 regions Scenarios: 1 Scope: Blue water withdrawal and consumption	Agriculture Industry Domestic	Population growth (1) Economic growth (1) Technology change (1)
Rosegrant et al. (2002; 2003)	Time horizon: 2025 Spatial scale: 69 river basins Scenarios: 3 Scope: Blue water withdrawal and consumption	Agriculture: 16 sub-sectors Industry Domestic	Population growth (1) Urbanization (1) Economic growth (1) Technology change (3) Policies (3) Water availability constraints (3)
Alcamo et al. (2003a)	Time horizon: 2025 Spatial scale: 0.5° spatial resolution Scenarios: 1 Scope: Blue water withdrawal	Agriculture Industry Domestic	Population growth (1) Economic growth (1) Technology change (1)
Alcamo et al. (2007)	Time horizon: 2025/2055/2075 Spatial scale: 0.5° spatial resolution Scenarios: 2 Scope: Blue water withdrawal	Agriculture Industry Domestic	Population growth (2) Economic growth (2) Technology change (1)
Shen et al. (2008)	Time horizon: 2020/2050/2070 Spatial scale: 9 regions Scenarios: 4 Scope: Blue water withdrawal	Agriculture Industry Domestic	Population growth (4) Economic growth (4) Technology change (4)
De Fraiture and Wichelns (2010)	Time horizon: 2050 Spatial scale: 115 socio-economic units Scenarios: 4 Scope: Green and blue water consumption	Agriculture: 7 sub-sectors Industry: 2 sub-sectors Domestic	Population growth (1) Economic growth (1) Production and trade patterns change (4) Technology change (4) Consumption patterns - diet (1)
Current study	Time horizon: 2050 Spatial scale: 227 countries, 16 regions Scenarios: 4 Scope: Green and blue water consumption, pollution as grey water footprint	Agriculture: 20 sub-sectors Industry Domestic	Population growth (3) Economic growth (4) Production and trade patterns change (4) Technology change (2) Consumption patterns - diets (2) Consumption patterns – biofuel (3)

The current study develops water footprint scenarios for 2050 based on a number of drivers of change: population growth, economic growth, production/trade pattern, consumption pattern (dietary change, bioenergy use) and technological development. It goes beyond the previous global water demand scenario studies by a combination of factors: (i) it addresses blue and green water consumption instead of blue water withdrawal volumes; (ii) it considers water pollution in terms of the grey water footprint; (iii) it analyses agricultural, domestic as well as industrial water consumption; (iv) it disaggregates consumption along major commodity groups; (v) it integrates all major critical drivers of change under a single, consistent framework. In particular, integrating all critical drivers is crucial to define policies for wise water governance and to help policy makers to understand the long-term consequences of their decisions across political and administrative boundaries.

We have chosen in this study to look at water footprint scenarios, not at water withdrawal scenarios as done in most of the previous studies. We explicitly distinguish between the green, blue and grey water footprint. The green water footprint refers to the consumptive use of rainwater stored in the soil. The blue water footprint refers to the consumptive use of ground or surface water. The grey water footprint refers to the amount of water contamination and is measured as the volume of water required to assimilate pollutants from human activities (Hoekstra et al., 2011).

Our study comprises two assessments: one for the globe as a whole, distinguishing between 16 world regions, and another one for Europe, whereby we zoom in to the country level. The objective of the global study is to understand the changes in the water footprint of production and consumption for possible futures by region and to elaborate the main drivers of this change. In addition, we assess virtual water flows between the regions of the world to show dependencies of regions on water resources in other regions under different possible futures. In the European case study, our objective is to assess the water footprint of production and consumption at country level and Europe’s dependence on water resources elsewhere in the world.

2. Method

2.1 Scenario description

For constructing water footprint scenarios, we make use of global scenario exercises of the recent past as much as possible. This brings two main advantages: building our scenarios on well-documented possible futures and providing readers quick orientation of the storylines. As a starting point, we used the 2×2 matrix system of scenarios developed by the IPCC (Nakicenovic et al., 2000). These scenarios are structured along two axes, representing two key dimensions of uncertainty: globalisation versus regional self-sufficiency, and economy-driven development versus development driven by social and environmental objectives. The two axes create four quadrants, each of which represents a scenario: global markets (S1), regional markets (S2), global sustainability (S3) and regional sustainability (S4) (Figure 1). Our storylines resemble the IPCC scenarios regarding population growth, economic growth, technological development and governance. For the purpose of our analysis, we had to develop most of the detailed assumptions of the scenarios ourselves, but the assumptions were inspired from the storylines of the existing IPCC scenarios. The scenarios are consistent and tell reliable stories about what may happen in future. It is important to understand that our scenarios are not predictions of the future; they rather show alternative perspectives on how water footprints may develop towards 2050.

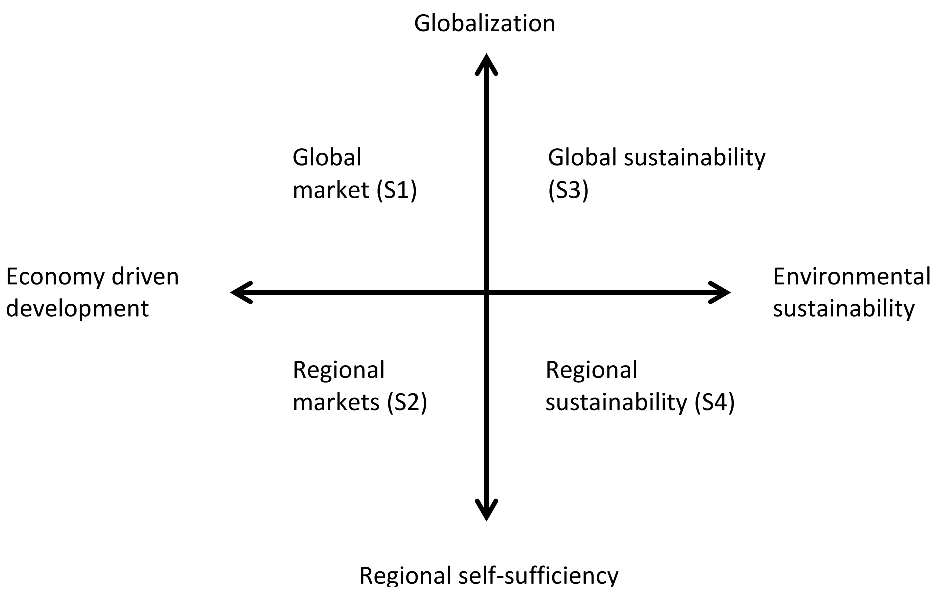

Figure 1. The four scenarios distinguished in this study.

First, we constructed a baseline for 2050, which assumes a continuation of the current situation into the future. The four scenarios were constructed based on the baseline by using different alternatives for the drivers of change. The baseline constructed for 2050 assumes the per capita food consumption and non-food crop demand as in the year 2000. It also considers technology, production and trade as in the year 2000. The increase in population size is taken from the medium-fertility population projection of the United Nations (UN, 2011). Economic growth is projected as described in IPCC scenario B2. Climate change is not taken into account. Therefore, changes in food and non-food consumption and in the water footprint of agriculture and domestic water supply are only subject to population growth. The industrial water footprint in the baseline depends on economic growth.

Scenario S1, *global market*, is inspired by IPCC's A1 storyline. The scenario is characterized by high economic growth and liberalized international trade. The global economy is driven by individual consumption and material well-being. Environmental policies around the world heavily rely on economic instruments and long-term sustainability is not in the policy agenda. Trade barriers are gradually removed. Meat and dairy products are important elements of the diet of people. A rapid development of new and efficient technologies is expected. Energy is mainly sourced from fossil fuels. Low fertility and mortality are expected.

Scenario S2, *regional markets,* follows IPCC's A2 storyline. It is also driven by economic growth, but the focus is more on regional and national boundaries. Regional self-sufficiency increases. Similar to S1, environmental issues are not important factors in decision-making, new and efficient technologies are rapidly developed and adopted, and meat and dairy are important components in the diets of people. Fossil fuels are dominant, but a slight increase in the use of biofuels is expected. Population growth is highest in this scenario.

Scenario S3, *global sustainability*, resembles IPCC's B1 storyline. The scenario is characterized by increased social and environmental values, which are integrated in global trade rules. Economic growth is slower than in S1 and S2 and social equity is taken into consideration. Resource efficient and clean technologies are developed. As the focus is on environmental issues, meat and dairy product consumption is decreased. Trade becomes more global and liberalized. Reduced agro-chemical use and cleaner industrial activity is expected. Population growth is the same as for S1.

Scenario S4, *local sustainability*, is built on IPCC's B2 storyline and dominated by strong national or regional values. Self-sufficiency, equity and environmental sustainability are at the top of the policy agenda. Slow long-term economic growth is expected. Personal consumption choices are determined by social and environmental values. As a result, meat consumption is significantly reduced. Pollution in the agricultural and industrial sectors is lowered. Biofuel use as an energy source is drastically expanded.

These scenarios are developed for 16 different regions of the world for the year 2050. We used the country classification and grouping as defined in Calzadilla (2011a). The regions covered in this study are: the USA; Canada; Japan and South Korea (JPK); Western Europe (WEU); Australia and New Zealand (ANZ); Eastern Europe (EEU); Former Soviet Union (FSU); Middle East (MDE); Central America (CAM); South America (SAM); South Asia (SAS); South-east Asia (SEA); China (CHI); North Africa (NAF); Sub-Saharan Africa (SSA) and the rest of the world (RoW). The composition of the regions is given in Appendix I.

2.2 Drivers of change

We identified five main drivers of change: population growth, economic growth, consumption patterns, global production and trade pattern and technology development. Table 2 shows the drivers and associated assumptions used in this study.

Table 2. Drivers and assumptions per scenario.

Driver		Scenario S1: Global market	Scenario S2: Regional markets	Scenario S3: Global sustainability	Scenario S4: Regional sustainability
Population growth		Low-fertility	High-fertility	Low-fertility	Medium fertility
Economic growth*		A1	A2	B1	B2
Consumption patterns	Diet	Western high meat	Western high meat	Less meat	Less meat
	Bio-energy demand	Fossil-fuel domination	Biofuel expansion	Drastic biofuel expansion	Drastic biofuel expansion
Global production and trade pattern		Trade liberalization (A1B+ TL2)	Self-sufficiency (A2+SS1)	Trade liberalization (A1B+TL1)	Self-sufficiency (A2+SS2)
Technology development		Decrease in blue water footprints in agriculture	Decrease in blue water footprints in agriculture	Decrease in green and grey water footprints in agriculture Decrease in blue and grey water footprints in industries and domestic water supply	Decrease in green and grey water footprints in agriculture Decrease in blue and grey water footprints in industries and domestic water supply

* The scenario codes refer to the scenarios as used by the IPCC (Nakicenovic et al., 2000).

Population growth

Changes in population size are a key factor determining the future demand for goods and services, particularly for food items (Schmidhuber and Tubiello, 2007; Godfray et al., 2010; Kearney, 2010; Lutz and KC, 2010). The IPCC scenarios (A1, A2, B1, and B2) used population projections from both the United Nations (UN) and the International Institute for Applied Systems Analysis (IIASA). The lowest population trajectory is assumed for the A1 and B1 scenario families and is based on the low population projection of IIASA. The population in the A2 scenario is based on the high population projection of IIASA. IPCC uses UN's medium-fertility scenario for B2. We used UN-population scenarios (UN, 2011) for all our scenarios: the UN high-fertility population scenario for S2, the UN medium-fertility population scenario for S4 and the UN low-fertility population scenario for S1and S3. Population forecasts per region are given in Appendix II.

Economic growth

We assumed that the water footprint of industrial consumption is directly proportional to the Gross Domestic Product (GDP). We used GDP changes as described in IPCC scenarios A1, A2, B1, and B2 for S1, S2, S3 and S4, respectively. The changes in GDP per nation are taken from the database of the Center for International Earth Science Information Network of Columbia University (CIESIN, 2002).

Consumption patterns

We distinguished two alternative food consumption patterns based on Erb et al. (2009):

- ‘Western high meat’: economic growth and consumption patterns accelerate in the coming decades, leading to a spreading of western diet patterns. This scenario brings all regions to the industrialised diet pattern.
- ‘Less meat’: each regional diet will develop towards the diet of the country in the region that has the highest calorie intake in 2000, but only 30% of the protein comes from animal sources.

We used the ‘western high meat’ alternative for S1 and S2 and the ‘less meat’ for S3 and S4. Erb et al. (2009) provide food demand per region in terms of kilocalories per capita for 10 different food categories: cereals; roots and tubers; pulses; fruits and vegetables; sugar crops; oil crops; meat; pigs, poultry and eggs; milk, butter and other dairy products; and other crops. We converted kilocalorie intake per capita to kg/cap by using conversion factors taken from FAO for the year 2000 (FAO, 2012). We also took seed and waste ratios per food category into account while calculating the total food demand in 2050. Appendices III and IV show the per capita food demand per region per scenario.

Per capita consumption patterns for fibre crops and non-food crop products were kept constant as it was in 2000. It is assumed that the change in demand for these items is only driven by population size. Per capita consumption values are taken from FAOSTAT for the year 2000 (FAO, 2012).

We integrated three different biofuel consumption alternatives into our scenarios. We used biofuel consumption projections as described by Msangi et al. (2010). They used the International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT) to estimate biofuel demand for 2050 for three different alternatives:

- Baseline: Biofuel demand remains constant at 2010 levels for most of the countries. This scenario is a conservative plan for biofuel development. This is used in S1.
- Biofuel expansion: In this scenario, it is assumed that there will be an expansion in biofuel demand towards 2050. It is based on current national biofuel plans. This is applied in S2.
- Drastic biofuel expansion: Rapid growth of biofuel demand is foreseen for this scenario. The authors developed this scenario in order to show the consequences of going aggressively for biofuels. This option is used for the S3 and S4 scenarios.

Msangi et al. (2010) provide biofuel demand in 2050 in terms of crop demands for the USA, Brazil and the EU (Table 3). We translated their scenarios to the regions as defined in our study by using the biofuel demand shares of nations for the year 2000. The demand shares are taken from the US Energy Information Administration (EIA, 2012).

Table 3. Biofuel demand in 2050 for different scenarios (in tons.)

Crop	Region	Baseline	Biofuel expansion	Drastic biofuel expansion
Cassava	World	660,000	10,640,000	21,281,000
Maize	EU	97,000	1,653,000	3,306,000
	USA	35,000,000	130,000,000	260,000,000
	RoW	2,021,000	30,137,000	60,274,000
Oil seeds	Brazil	16,000	197,000	394,000
	EU	1,563,000	18,561,000	37,122,000
	USA	354,000	3,723,000	7,447,000
	RoW	530,000	5,172,000	10,344,000
Sugar	Brazil	834,000	14,148,000	28,297,000
	USA	265,000	5,840,000	11,680,000
	RoW	163,000	2,785,000	5,571,000
Wheat	EU	1,242,000	15,034,000	30,067,000
	RoW	205,000	3,593,000	7,185,000

Source: Msangi et al. (2010).

Global production and trade pattern

The regional distribution of crop production is estimated based on Calzadilla et al. (2011a), who estimated agricultural production changes in world regions by taking climate change and trade liberalization into account (Appendix V). They used a global computable general equilibrium model called GTAP-W for their estimations. The detailed description of the GTAP-W and underpinning data can be found in Berrittella et al. (2007) and Calzadilla et al. (2010; 2011b). In their study, trade liberalization is implemented by considering two different options:

- Trade liberalization 1 (TL1): This scenario assumes a 25% tariff reduction for all agricultural sectors. In addition, they assumed zero export subsidies and a 50% reduction in domestic farm support.
- Trade liberalization 2 (TL2): It is a variation of the TL1 case with 50% tariff reduction for all agricultural sectors.

In addition, Calzadilla et al. (2011a) elaborated potential impacts of climate change on production and trade patterns considering IPCC A1B and A2 emission scenarios. In total, they constructed 8 scenarios for 2050 considering two climate scenarios (A1B and A2), two trade liberalization scenarios (TL1 and TL2) and their combinations (A1B+TL1, A1B+TL2, A2+TL1, A2+TL2). For the S1 and S3 scenarios, we considered production changes as estimated in A1B+TL2 and A1B+TL1 respectively. We used the A2 for the S2 and S4 scenarios but we also introduced self-sufficiency options to S2 and S4 as described below:

- Self-sufficiency (SS1): This alternative assumes 20% of reduction in import of agricultural products (in tons) by importing regions compared to the baseline in 2050. Therefore, exporting regions are reducing their exports by 20%. This is applied in S2.
- Self-sufficiency (SS2): In this alternative, we assumed 30% reduction in imports by importing nations relative to the baseline in 2050. This option is used for S4.

Technology development

The effect of technology development is considered in terms of changes in water productivity in agriculture, wastewater treatment levels and water use efficiencies in industry. For scenarios S3 and S4, we assumed that the green water footprints of crops get reduced due to yield improvements and for scenarios S1 and S2 we assumed that the blue water footprints of crops diminish as a result of improvements in irrigation technology. We assigned a percentage decrease to green and blue water footprints for each scenario based on the scope for improvements in productivity as given in De Fraiture et al. (2007), who give levels of potential improvement per region in a qualitative sense. For scenarios S1 and S2 we assume reductions in blue water footprints in line with the scope of improved productivity in irrigated agriculture per region as given by De Fraiture et al. (2007). For scenarios S3 and S4 we assume reductions in green water footprints in line with the scope for improved productivity in rainfed agriculture per region, again taking the assessment by De Fraiture et al. (2007) as a guideline. For scenarios S3 and S4 we took reductions in grey water footprints similar to the reductions in green water footprints. To quantify the qualitative indications of reduction potentials in De Fraiture et al. (2007), we assigned a reduction percentage of 20% to ‘some’ productivity improvement potential, 30% to ‘good’ productivity improvement potential and 40% for ‘high’ productivity improvement potential.

To reflect improvements in wastewater treatment levels and blue water use efficiencies, we applied a 20% reduction in the blue and grey water footprints of industrial products and domestic water supply in S3 and S4.

2.3 Estimation of water footprints

This study follows the terminology of water footprint assessment as described in the *Water Footprint Assessment Manual* (Hoekstra et al., 2011). The water footprint is an indicator of water use that looks at both direct and indirect water use of a consumer or producer. Water use is measured in terms of water volumes consumed (evaporated or incorporated into the product) and polluted per unit of time. The water footprint of an individual or community is defined as the total volume of freshwater that is used to produce the goods and services consumed by the individual or community. The ‘water footprint of national (regional) production’ refers to the total freshwater volume consumed or polluted within the territory of the nation (region). This includes water use for making products consumed domestically but also water use for making export products. It is different from the ‘water footprint of national (regional) consumption’, which refers to the total amount of water that is used to produce the goods and services consumed by the inhabitants of the nation (region). This refers to both water use within the nation (region) and water use outside the territory of the nation (region), but is restricted to the water use behind the products consumed within the nation (region). The water footprint of national (regional) consumption thus includes an internal and external component. The internal water footprint of consumption is defined as the use of domestic water resources to produce goods and services consumed by the national (regional) population. It is the sum of the water footprint of the production minus the volume of virtual-water export to other nations (regions) insofar as related to the export of products produced with domestic water resources. The external water footprint of consumption is defined as the volume of water resources used in other nations (regions) to produce goods and services consumed by the population in the nation (region) considered. It is equal to the virtual-water import minus the volume of virtual-water export to other nations (regions) because of re-export of imported products.

2.3.1 Water footprint of agricultural consumption and production

Regional consumption of food items

The food consumption $c_f(c,r)$ in ton/year related to commodity group *c* in region *r* in the year 2050 is defined as:

$$c_f(c,r) = pop(r) \times \; kcal(c,r) \times \; f_{ton/kcal} \tag{1}$$

where $pop(r)$ is the population in region *r* in 2050 and $kcal(c,r)$ the daily kilocalorie intake per capita related to commodity group *c* in region *r* in this year. The coefficient $f_{ton/kcal}$ is the conversion factor from kcal/cap/day to ton/cap/year, which is obtained from FAO (2012). Population and kcal values per region for the year 2050 are obtained from UN (2011) and Erb et al. (2009), respectively. Twenty commodity groups are distinguished as shown in Appendices III and IV.

Regional consumption of fibres and other non-food items

The fibre and other non-food consumption $c_{nf}(c,r)$, ton/year, related to commodity group *c* in region *r* in 2050 is defined as:

$$c_{nf}(c,r) = \sum_n (pop(n) \times \; f_c(c,n)|_{t=2000}) \tag{2}$$

where $f_c(c,n)|_{t=2000}$ is the per capita demand for commodity group *c* in nation *n* that is located in region *r*, in 2000, which is obtained from FAO (2012).

Regional consumption of biofuel

Crop use for biofuels $c_b(c,r)$, in ton/year, related to commodity group *c* in region *r* in 2050 is defined as:

$$c_b(c,r) = \sum_n (C_b(c) \times \; f_b(n)|_{t=2000}) \tag{3}$$

where $C_b(c)$ is the crop use for biofuels in 2050 regarding commodity group *c*, taken according to one of the scenarios as defined in Msangi et al. (2010), and $\mathrm{f_b(n)}|_{t=2000}$ the energy crop share in 2000 of nation *n* that is located in region *r* is taken from EIA (2012).

Global consumption

Total consumption for each commodity group in the world, in ton/year, is calculated as:

$$C_f(c) = \sum_r c_f(c,r) \tag{4}$$

$$C_{nf}(c) = \sum_r c_{nf}(c,r) \tag{5}$$

$$C_b(c) = \sum_r c_b(c,r) \tag{6}$$

Global production

We assume that, per commodity group, total production meets total consumption:

$$P_f(c) = C_f(c) \tag{7}$$

$$P_{nf}(c) = C_{nf}(c) \tag{8}$$

$$P_b(c) = C_b(c) \tag{9}$$

Production shares of the regions

The expected production $p(c,r)$ (ton/year) related to commodity group *c* in region *r* is defined as the multiplication of the production share $f_p(c,r)$ of region *r* and the total production of commodity group *c* in the world.

$$p(c,r) = P(c) \times \ f_p(c,r) \tag{10}$$

Production shares of the regions per scenario are taken from Calzadilla et al. (2011a).

Trade

The surplus $s(c,r)$ (ton/year) related to commodity group *c* in region *r* is defined as the difference between in production *p* and consumption *c*:

$$s(c,r) = p(c,r) - c(c,r) \tag{11}$$

Net import i (ton/year) per commodity group and per region is equal to the absolute value of the surplus if s is negative. Similarly, net export e is equal to the surplus if s is positive:

$$i\ (c,r) = \begin{cases} |s|, & s < 0 \\ 0, & s \geq 0 \end{cases} \tag{12}$$

$$e\ (c,r) = \begin{cases} 0, & s \leq 0 \\ s, & s > 0 \end{cases} \tag{13}$$

Trade, T (tons/year) of commodity group c, from exporting region r_e to importing region r_i is estimated as:

$$T\ (c, r_{e,} r_i) = i\ (c, r_i)\ \times\ f_e\ (c, r_e) \tag{14}$$

where $i(c, r_i)$ refers to the amount of import of commodity group c by importing region r_i and f_e to the export fraction of exporting region r_e, which is calculated as the share of export of region r_e in the global export of commodity group c.

Unit water footprint per agricultural commodity group per region

The unit water footprint, $WF(c,r)$ (m^3/ton), of commodity group c produced in region r is calculated by multiplying the unit WF of the commodity group in 2000 with a factor, α, to account for productivity increase:

$$WF(c,r) = WF\ (c,r)|_{t=2000}\ \times \propto (r) \tag{15}$$

The factor α is determined per scenario as described in Section 2.2. The values taken for α are presented in Appendix VI. The unit water footprints of commodities per region in 2000 are obtained from Mekonnen and Hoekstra (2010a; b).

Water footprint of agricultural production

The water footprint of production related to commodity group c in region r is calculated as:

$$WF_{p,a}\ (c,r) = p\ (c,r)\ \times\ WF\ (c,r) \tag{16}$$

Virtual water flows

The net virtual water flow VW (m^3/year) from exporting region r_e to importing region r_i as a result of trade in commodity group c is calculated by multiplying the commodity trade $T\ (c, r_{e,} r_i)$ between the regions and the unit water footprint $WF(c,r)$of the commodity group in the exporting region:

$$VW\ (c, r_e, r_i) = T\ (c, r_e, r_i) \times WF\ (c, r_e) \qquad (17)$$

<u>*Water footprint of consumption of agricultural commodities*</u>

The water footprint of consumption ($WF_{c,a}(c, r)$, Mm^3/year) related to the consumption of commodity group c in region *r* is calculated as the water footprint of production of that commodity, $WF_p(c, r)$, in region *r* plus the net virtual-water import to the region related to that commodity.

$$WF_{c,a}(c, r) = WF_p(c, r) + \sum_{r_e} VW\ (c, r_e, r_i) \qquad (18)$$

2.3.2 Water footprint of industrial consumption and production

<u>*Water footprint of consumption of industrial commodities*</u>

The water footprint related to the consumption of industrial commodities ($WF_{c,i}\ (r)$, Mm^3/year) in region *r* in 2050 is calculated by multiplying the water footprint of industrial consumption in 2000 by the growth in GDP and a factor *β* representing productivity increase (see Section 2.2).

$$WF_{c,i}\ (r) = \sum_n (WF_{c,i}\ (n)\big|_{t=2000} \times \frac{GDP_{2050}(n)}{GDP_{2000}(n)} \times \beta) \qquad (19)$$

The water footprint related to consumption of industrial commodities in nation *n* in 2000 is taken from Mekonnen and Hoekstra (2011). GDP changes are taken from CIESIN (2002).

<u>*Water footprint of industrial production*</u>

The water footprint of industrial production ($WF_{p,i}\ (r)$, Mm^3/year) in region *r* in 2050 is calculated by multiplying the global water footprint of industrial consumption in 2050 by the share of the water footprint of industrial production of region *r* in the global water footprint of industrial production in 2000.

$$WF_{p,i}\ (r) = \sum_r WF_{c,i}\ (r) \times \frac{WF_{p,i}\ (r)}{\sum_r WF_{p,i}\ (r)}\bigg|_{t=2000} \qquad (20)$$

The water footprint of industrial production per region *r* in 2000 is taken from Mekonnen and Hoekstra (2011).

2.3.3 Water footprint of domestic water supply

The water footprint of domestic water supply per region in 2050, $WF_{dom}(r)$(Mm^3/year), is calculated by multiplying the population in 2050 with the water footprint of domestic water supply per capita in 2000 and factor *β* representing productivity increase:

$$WF_{dom}(r) = \sum_{n}(pop(n) \times WF_{dom,cap}(n)\big|_{t=2000} \times \beta) \tag{21}$$

The data for the water footprint of domestic water supply in 2000 are taken from Mekonnen and Hoekstra (2011).

2.4 European case study

In the global study, Europe is described by two regions: Western and Eastern Europe. To enable us to make a more detailed analysis for Europe, we use country specific data on population change and per capita food consumption for Western and Eastern Europe. We down-scaled the results obtained for Western and Eastern Europe to the nations within Europe. To estimate production, trade, virtual water flows, and water footprint of production and consumption per country within Europe, we followed the same methodology as described in the Section 2.3. The regions in the equations are replaced by the nations of Europe. The production distribution among the European countries in 2050 is done by taking the production patterns in 2000 (FAO, 2012).

3. Global water footprint in 2050

3.1 Water footprint of production

The WF of production in the world in 2050 has increased by 130% in S1 relative to the year 2000 (Table 4). In S2, the WF of production shows an increase of 175%, in S3 30% and in S4 46%. The increase in the total WF of production is highest for industrial products in S1 (600%). This increase is less for the other scenarios as they have a lower increase in GDP than S1. The WF of agricultural production is higher in S1 and S2 (112 and 180% more than 2000 values) than in S3 and S4 (18 and 38% more than 2000), which is due to dietary differences between S1/S2 and S3/S4. Among the scenarios, S2 has the largest WF of production as it has the highest population and high meat consumption. The WF of production related to domestic water supply increases by 18% in S1, 55% in S2, -6% in S3 and 9% in S4.

In 2000, approximately 91% of the total WF of production is related to agricultural production, 5% to industrial production and 4% to domestic water supply. The WF of industrial production increases its share in the total for the S1, S2 and S4 scenarios.

In all scenarios, the WF of production is dominated by the green component. However, the share of the green component decreases from 76% in 2000 to 74% in 2050 in S1 (Figure 2). The share of the blue component decreases from 10% in 2000 to 7% in 2050 in S1. The grey WF increases its share from 14% in 2000 to 19% in S1. The shares of the green, blue and grey WF of production in S2 are 82, 7, and 11% respectively. The share of the green component falls down to 68 and 69% in S3 and S4, while an increase is observed in the share of blue WF.

Among the scenarios, S1 and S2 have a larger WF of production as the world consumes more animal-based products. Scenario S2 yields the largest WF of production due to a larger population size and a higher demand in biofuels than S1. When the world food consumption depends less on animal products (S3 and S4), the increase in the WF of production becomes less.

Among the regions, SAM and ANZ show the highest increase in the total WF of production in S1. The increase in ANZ is 217% for S1, 251% for S2, 54% for S3 and 33% for S4. The increase is quite significant for SAM as well (361, 422, 168, and 144% for S1, S2, S3 and S4, respectively). SSA increases its water footprint of production 181% in S1, 364% in S2, 81% in S3 and 184% in S4. The USA, CAM, Canada, SEA, EEU, FSU, MDE, NAF and SAS are the other regions, which have a larger WF of production in 2050 compared to 2000 in all scenarios.

The WF of JPK's production decreases for all scenarios. The change is -46% for S1, -21% for S2, -68% for S3 and -55% for S4. This relates to the fact that JPK increasingly externalizes its WF of consumption towards 2050. The WF of production in WEU increases in S1 and S2 by 12 and 42%, respectively, but decreases for S3 and S4, by 36 and 29% relative to 2000 values. The main reason for the decrease in S3 and S4 is due to dietary preferences, shifting from high to low meat content. Despite the increase in the WF of production in China in S1 and S2 (by 137 and 129%), a decrease is observed in S3 (6%).

Table 4. Percentage change in the water footprint of production compared to 2000. 'A' refers to WF of agricultural production, 'D' refers to WF of domestic water supply, 'I' refers to WF of industrial production and 'T' refers to total WF.

Region	S1				S2				S3				S4			
	A	D	I	T	A	D	I	T	A	D	I	T	A	D	I	T
USA	105	24	16	87	154	57	20	128	49	-1	-9	38	59	12	-13	46
Canada	139	26	57	118	193	58	44	161	84	1	37	70	80	13	18	66
WEU	19	-3	-45	12	51	22	-28	42	-34	-23	-57	-36	-28	-13	-46	-29
JPK	-52	-20	-16	-46	-24	1	-15	-21	-75	-36	-31	-68	-60	-28	-34	-55
ANZ	221	40	-75	217	255	77	-50	251	55	12	-77	54	34	26	-57	33
EEU	50	-24	833	150	85	0	274	107	-17	-39	393	36	-17	-30	355	31
FSU	46	-18	1,649	135	83	10	531	105	-12	-34	735	30	-11	-24	529	19
MDE	40	44	208	46	157	88	80	151	1	15	122	5	78	32	41	74
CAM	143	21	341	142	204	63	127	196	37	-3	198	39	44	13	142	45
SAM	372	24	474	361	441	66	158	422	172	-1	262	168	149	15	160	144
SAS	67	38	1,160	84	149	85	353	150	-10	11	1,495	16	25	28	653	36
SEA	127	32	953	151	191	76	257	188	32	6	458	45	37	22	400	49
CHI	89	-12	1,885	137	127	16	338	129	-22	-29	555	-6	-22	-19	967	6
NAF	32	43	533	44	81	90	236	85	2	14	651	17	27	32	112	29
SSA	179	122	863	181	367	183	243	364	78	78	649	81	184	101	335	184
RoW	114	-9	71	106	195	11	12	177	12	-27	-11	9	34	-20	110	36
World	112	18	601	130	180	55	158	175	18	-6	311	30	38	9	261	46

The WF of industrial production shows a drastic increase relative to 2000 for CHI, FSU and SAS in S1. Industrial WFs in these regions increase by a factor of more than 10 times, up to 18 times for CHI. Other regions with high industrial WF increase in S1 are SSA, NAF, SEA, SAM and CAM. These regions have a larger WF of industrial production in S2 as well. WEU, ANZ and JPK have a smaller WF of industrial production in 2050 compared to 2000, in all scenarios.

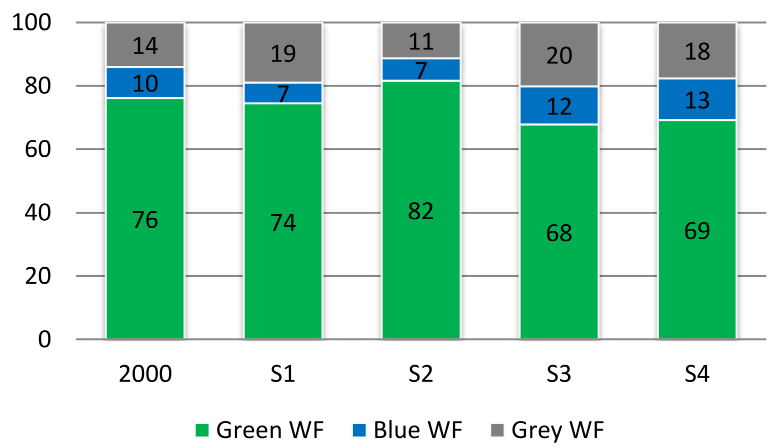

Figure 2. Green, blue and grey WF of production as a percentage of total WF in 2000 and 2050 according to the four scenarios.

The effect of trade liberalization versus increased self-sufficiency on the WF of production can be seen by observing the differences between S1 and S2 and between S3 and S4. Importing regions like MDE and SSA have a larger WF of production in S2 (regional markets) compared to S1 (global market) and a larger WF in S4 (regional sustainability) compared to S3 (global sustainability).

We separately analysed the effect of trade liberalization and climate change on the WF of production in the world. For this purpose, we first run a scenario with a changed global production pattern under trade liberalization (TL1) as the only driver of change to the baseline in 2050. Next, we run a scenario with a changed global production pattern under climate change (A1B) as the only driver of change to the baseline in 2050. The results show that trade liberalization has a limited effect on the global WF of production (Figure 3). On regional basis, it increases the WF of production in Canada, CHI, JPK, ANZ, MDE, SAM and SEA and decreases the WF in the USA, WEU, EEU, FSU, CAM, NAF, SSA and SAS. However, in all cases the change is not more than 2%.

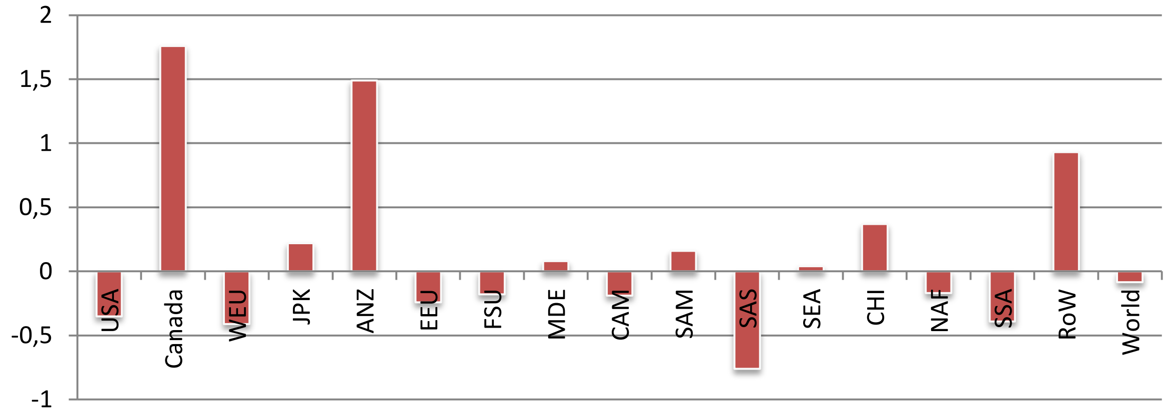

Figure 3. Percentage change of the WF of production by trade liberalization compared (TL1) to the baseline in 2050.

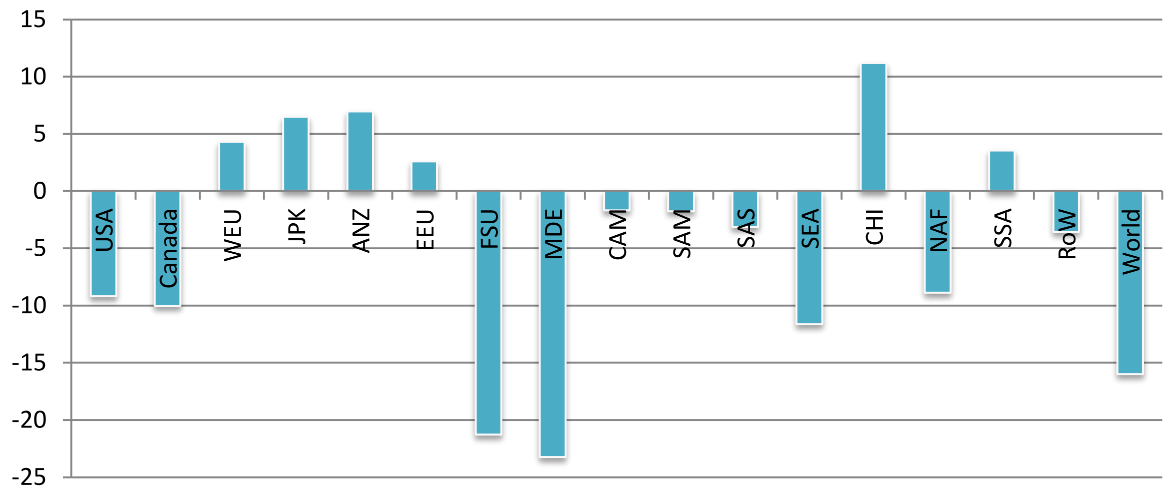

Figure 4. Percentage change of the WF of production by climate change (A1B) compared to the baseline in 2050.

On the contrary, the effect of climate change on the total WF of production is significant and results in a decrease of around 15% for the world (Figure 4). The effect of climate change is most visible in the USA, Canada, MDE, FSU, NAF and SEA, where a clear decrease is observed. Climate change affects the WF of production in the opposite direction in other regions, including CHI, ANZ, JPK, WEU, SSA and EEU.

3.2 Virtual water flows between regions

Net virtual water import per region for each scenario is given in Table 5. The regions WEU, JPK, SAS, MDE, NAF and SSA are net virtual water importers for all scenarios in 2050. The USA, Canada, ANZ, EEU, FSU, CAM, SAM, SEA and CHI are net virtual water exporters in 2050.

All net virtual water-exporting regions in 2000 stay net virtual water exporters in all 2050 scenarios. Net virtual water export from these regions increases in S1 and S2 compared to 2000, except for Canada and SEA. SAM, FSU and the USA substantially increase their net virtual water export in S1 and S2. SAM becomes the biggest virtual water exporter in the world in 2050 for all scenarios and increases its net virtual water export around 10 times in S1 and S2. The change is also large in S3 and S4, with an increase by a factor 6 and 5, respectively. Another region that will experience a significant increase in net virtual water export is the FSU. Compared to 2000, the net virtual water flow leaving this region becomes 9 times larger in S1, 6 times in S2 and S3, and 4 times in S4. The net virtual water export from the USA increases by a factor 3 in both S1 and S2 relative to 2000. The net virtual export from the USA decreases in S3 and S4 compared to 2000. Although Canada continues to be a net virtual water exporter in 2050, its virtual water export decreases below the levels of 2000 for S1, S3 and S4. Despite still being a net virtual water exporter in 2050, SEA experiences a decrease in the net virtual water export volumes compared to 2000 in all scenarios.

All net virtual water-importing regions in 2000 stay net virtual water importers in 2050 for all scenarios, except CAM and CHI, which become net virtual water exporters in 2050. The net virtual water import by WEU stays below the 2000 volume for S2 and S4. Although JPK has a slightly higher net virtual water import in S1 and S2 than 2000, it decreases its net virtual water import for the other scenarios. SSA is the region where the highest increase in virtual water import is observed in 2050. Its net virtual water import rises drastically in S1 and S2 compared to 2000. Other regions with a significant increase in net virtual water import are MDE and SAS. The net virtual water import is the highest in S1 for all importing regions except SAS and NAF. WEU shows a different pattern, where the net virtual water import is the highest in S3. The reason behind this is the significant increase in biofuel demand in WEU in S3.

The regions show similar patterns for the virtual water flows related to trade crop products. For the virtual water flows related to trade in animal products, this is slightly different. The USA, Canada, WEU, ANZ, EEU, FSU, CAM, SAM and CHI are net virtual water exporters and JPK, MDE, SAS, SEA, NAF and SSA are net virtual water importers regarding trade in animal products.

Table 5. Net virtual water import per region (Gm^3/year). 'A' refers to the net virtual water import related to agricultural products, 'I' to the net virtual water import related to industrial products and 'T' to the total net virtual water import.

	2000			S1			S2			S3			S4		
	A	I	T	A	I	T	A	I	T	A	I	T	A	I	T
USA	-117	27	-91	-377	92	-284	-350	48	-303	-101	57	-44	-101	39	-62
Canada	-42	-1	-43	-43	4	-39	-48	1	-47	-37	2	-35	-31	2	-29
WEU	59	43	102	3	101	104	6	60	66	42	70	112	24	38	61
JPK	90	9	99	89	22	111	89	11	100	55	15	71	43	9	52
ANZ	-72	3	-70	-140	5	-134	-154	3	-151	-102	4	-97	-82	2	-80
EEU	-8	-2	-10	-59	46	-13	-63	3	-60	-46	11	-35	-36	15	-21
FSU	-9	-34	-43	-183	-198	-381	-200	-77	-277	-150	-109	-259	-119	-56	-174
MDE	20	5	25	416	50	465	402	14	416	261	30	291	198	11	209
CAM	14	3	18	-127	41	-86	-117	11	-106	-83	23	-60	-59	12	-48
SAM	-174	1	-173	-1,695	34	-1,661	-1,736	6	-1,730	-1,007	15	-992	-801	10	-792
SAS	232	-8	224	1,056	14	1,070	1,117	-12	1,105	625	-29	596	509	7	515
SEA	-191	-12	-203	-146	-33	-179	-149	-16	-165	-140	-25	-166	-102	-11	-113
CHI	116	-38	78	-171	-244	-415	-152	-66	-218	-101	-103	-204	-63	-97	-159
NAF	60	0	60	66	14	80	84	3	87	47	11	59	46	3	49
SSA	3	1	4	1,249	20	1,269	1,223	3	1,226	720	12	732	564	6	569
RoW	21	3	24	60	31	92	49	8	56	15	14	29	10	11	21

The net virtual water flows related to industrial products in 2050 have a completely different structure. The USA, Canada, WEU, JPK, ANZ, EEU, MDE, CAM, SAM, NAF and SSA are the virtual water importers and FSU, SEA and CHI are net virtual water exporters related to trade in industrial products in all scenarios. SAS is a net virtual water importer in S1 and S4 and a net virtual water exporter in S2 and S3 regarding trade in industrial products. Most of the virtual water export related to industrial products comes from considering industrial products. In all regions, both net virtual water imports and exports are the highest in the S1 scenario regarding trade in industrial products, as this scenario foresees the highest GDP increase and trade liberalization. Interregional virtual water trade related to industrial products decreases from S2 to S4. The decrease in S2 is due to increased self-sufficiency among the regions and the decrease in S3 and S4 is mainly due to improvements in water use efficiency and wastewater treatment in the industry sector.

Regarding interregional blue virtual water flows, the USA, ANZ, FSU, CAM, SAM and CHI are the net exporters and Canada, JPK, SAS and SSA are the net importers in all scenarios and in 2000. Despite being a net blue virtual importer in 2000, WEU becomes a net blue virtual water exporter in S2 and S4. NAF, a net blue virtual water importer in 2000, becomes a net blue virtual water exporter in S1 and S2. In all scenarios, the biggest net blue virtual water importers are SSA and SAS, whereas the biggest net blue virtual water exporters are SAM and CHI.

CHI and FSU are the biggest net virtual water exporting regions in terms of the grey component. Other net exporting regions are Canada, SEA, SAM and ANZ, for all scenarios. The USA, WEU, JPK, MDE, CAM, SAS, NAF and SSA are the net grey virtual water importing regions in all scenarios. EEU is a net importer of grey virtual water in S1, S3 and S4 but a net exporter in S2.

3.3 Water footprint of consumption

The WF of consumption in the world increases by +130% relative to 2000 for the S1 scenario. It increases by +175% in S2, +30% in S3 and +46% in S4. The high increase in the WF of consumption for S1 and S2 can, for a significant part, be explained by increased meat consumption. When we compare trade liberalization (S1 and S3) to self-sufficiency scenarios (S3 and S4), it is observed that trade liberalization decreases the WF of consumption globally.

The WF of consumption increases significantly for the regions SSA and MDE in all scenarios. The biggest change is observed in SSA with an increase by +355% in S1, +531% in S2, +181% in S3 and +262% in S4. MDE is the region with the second highest increase: +207% for S1, +294% for S2, +106% for S3 and +146% for S4.

The USA, Canada, ANZ, CAM, SAM, EEU, SAS, SEA and NAF are the other regions with a larger WF of consumption in 2050 relative to 2000. WEU, JPK, FSU and CHI have a larger WF of consumption in S1/S2 and a smaller in S3/S4 relative to 2000. Population growth and dietary preferences are the two main drivers of change determining the future WF of consumption. In many regions of the world, S2 shows the largest WF of consumption as it has the largest population size with high-meat content diets. S4 shows larger WF values than S3 due to a larger population size in S4 compared to S3.

The largest component of the total WF of consumption is green (67-81% per scenario), followed by grey (10-20%) and blue (7-13%). Consumption of agricultural products has the largest share in the WF of consumption, namely 85-93% for all scenarios. The share of domestic water supply is 2-3% and of industrial products 4-13%.

The WF of consumption of agricultural products is 112%, 180%, 18% and 38% higher in 2050 than 2000 in S1, S2, S3 and S4, respectively. SSA and MDE show the highest increase in all scenarios. WEU, JPK, EEU, CHI and FSU demonstrate increases in WF of consumption in S1/S2 and decreases in S3/S4 compared to 2000. S2 is the scenario with the largest WF related to consumption of agricultural products in all regions and S3 shows the smallest values among all scenarios.

The main driver of the WF of domestic water supply is population size. The scenario with the highest population projection, S2, has therefore the largest WF related to domestic water supply. S3 has the lowest values as it has a relatively low population size and a reduced WF per household. The regions that show reduction in WF of domestic water supply in S1, have population sizes lower than 2000. The reductions in S3 are due a combination of lower estimates of population and reduced per capita domestic water use. Regarding the WF of consumption of industrial products, all regions show a significant increase compared to 2000, in all scenarios.

Table 6. Percentage change of the WF of consumption relative to 2000. 'A' refers to the WF of agricultural products, 'D' refers to the WF domestic water supply, 'I' refers to the WF of industrial products and 'T' refers to the total WF.

Region	S1				S2				S3				S4			
	A	D	I	T	A	D	I	T	A	D	I	T	A	D	I	T
USA	29	24	112	41	83	57	69	80	29	-1	50	30	39	12	28	36
Canada	48	26	95	54	91	58	52	83	5	1	55	13	14	13	38	18
WEU	19	-3	112	28	52	22	65	52	-27	-23	52	-19	-24	-13	12	-20
JPK	11	-20	113	19	39	1	50	38	-36	-36	58	-26	-29	-28	15	-25
ANZ	172	40	107	171	201	77	62	199	20	12	73	20	5	26	13	5
EEU	12	-24	1024	143	45	0	285	75	-47	-39	438	17	-41	-30	419	20
FSU	6	-18	975	61	39	10	268	51	-44	-34	366	-20	-37	-24	340	-15
MDE	198	44	720	207	309	88	229	294	99	15	436	106	153	32	152	146
CAM	100	21	865	115	165	63	264	163	9	-3	490	20	24	13	292	30
SAM	117	24	722	126	181	66	204	177	21	-1	370	27	29	15	231	32
SAS	128	38	1206	143	214	85	313	212	27	11	1399	49	55	28	676	64
SEA	96	32	769	117	160	76	169	156	2	6	317	13	16	22	338	27
CHI	79	-12	1391	113	117	16	205	116	-29	-29	346	-18	-25	-19	771	-3
NAF	65	43	811	81	122	90	298	125	25	14	881	45	50	32	171	52
SSA	353	122	1415	355	538	183	334	531	179	78	969	181	263	101	486	262
RoW	212	-9	893	240	274	11	211	259	37	-27	366	52	51	-20	400	67
World	112	18	596	130	180	55	157	175	18	-6	308	30	38	8	259	46

Figure 5 shows the contribution of different consumption categories to the total WF of consumption for 2000 and for different scenarios. Consumption of cereals has the largest share (26%) in the total WF in 2000. Other products with a large share are meat (13%), oil crops (12%), poultry (10%), vegetables and fruits (8%) and dairy products (8%). Meat consumption becomes the major contributor to the WF of consumption in S1 and S2 (19-20%). Oil crops, vegetables, and fruits are the other consumption categories that have a large contribution to the total WF of consumption in S1 and S2. The share of cereals decreases to 19% in S2 and to 17% in S1. Cereal consumption has the largest share (30%) in S3 and S4, which are characterized by low meat content diets. Oil crops follow cereals with 16%. The share of meat consumption decreases in these scenarios to 13%. Consumption of industrial products becomes another significant contributor in S3 and S4 (7%).

Cereals are the largest contributor to the blue WF of consumption in all scenarios. Its share is 25% in S1 and S2, and 39% in S3 and S4. Cereals are followed by vegetables and fruits in S1 and S2 (17%) and by oil crops for S3 and S4 (14%). Other product groups with a large share in the blue WF of consumption are meat, poultry, dairy products and sugar crops. The grey WF of consumption is dominated by industrial products and domestic water supply in all scenarios. The share of industrial products in the grey WF of consumption increases to 36% in S1 and S2 and 43% in S3 and S4, while it is 28% in 2000. The WF related to domestic water supply is the second largest contributor to the grey WF of consumption, with 18% for all scenarios.

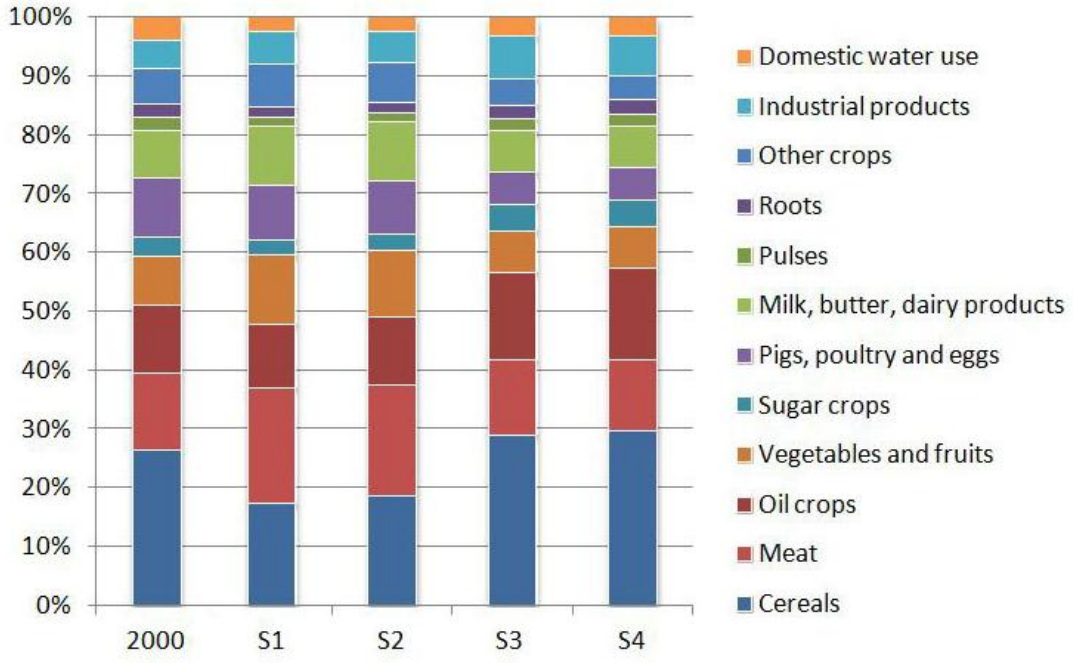

Figure 5. The contribution of different consumption categories to the total WF of consumption in the world.

The share of the external WF of consumption in the total is given in Figure 6. Regions with large external WFs apparently depend upon freshwater resources in other regions. The regions with a large share of external footprint in 2000, like JPK and MDE, increase their dependency on external water resources in 2050 significantly. For example, the share of the external WF in JPK will go up to 55% in S1 and to 56% in S3, in which trade is relatively liberalized compared to 2000. Our scenarios show that WEU, JPK, MDE, SAS, SEA and SSA increase their share of external WF while the other regions decrease their dependencies. The regions with increased production, like the USA, Canada and ANZ, decrease their external WF of consumption. In the scenarios with increased self-sufficiency, S2 and S4, the share of the external WF of consumption in the total WF of consumption is lower than other two scenarios, S1 and S3, which are characterized by trade liberalization.

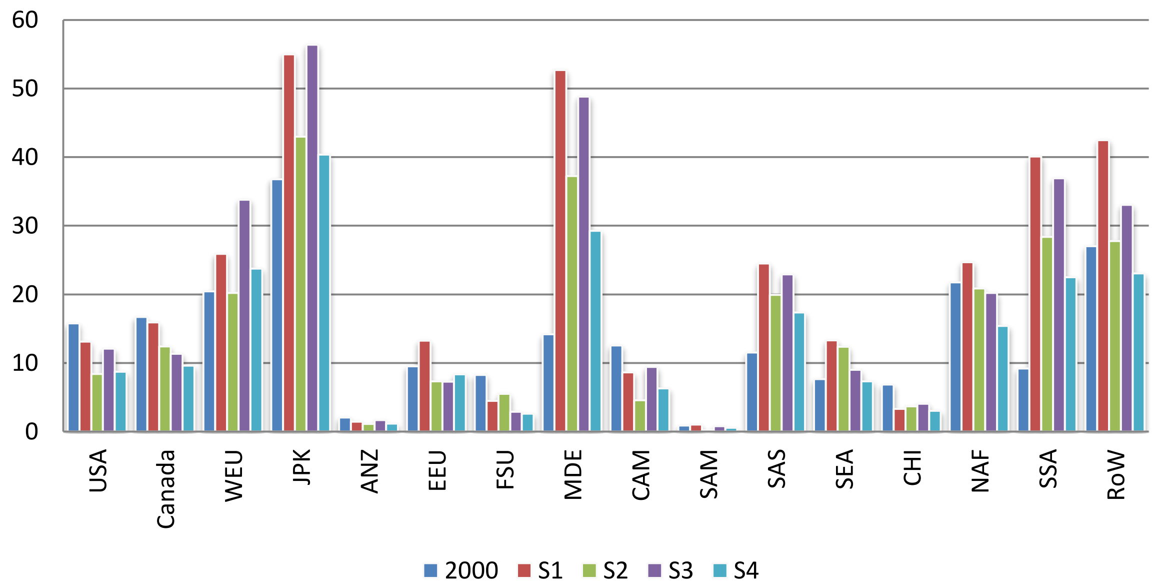

Figure 6. The share of the external water footprint of consumption in the total WF of consumption (%).

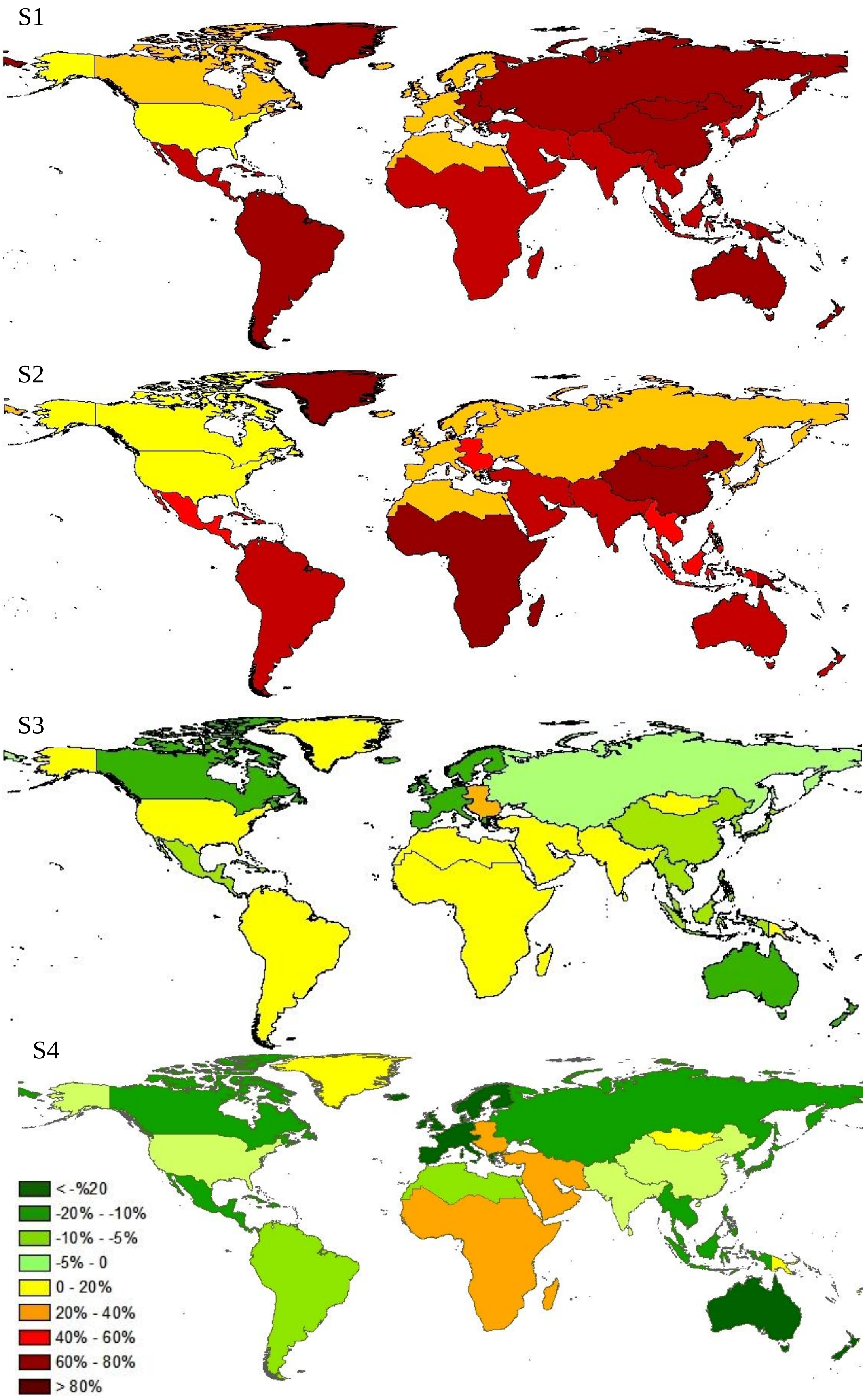

Figure 7. Percentage change of the WF of consumption per capita relative to 2000.

Figure 7 shows the change in the WF of consumption per capita per region for different scenarios relative to 2000 volumes. The world average WF of consumption per capita increases by +73% in S1, +58% in S2, -2% in S3 and 10% in S4 compared to 2000 volumes. All the regions increase their WF of consumption per capita in S1 and S2 compared to 2000. Canada, WEU, JPK, FSU, CAM, SEA, ANZ, CHI decrease their WF of consumption per capita in S3 compared to 2000 The other regions have a larger WF of consumption per capita in S3 than 2000. Most of the regions have smaller WFs of consumption per capita in S4 than 2000 except EEU, MDE and SSA. The regions with relatively low meat consumption in 2000 experience the biggest change in S1 and S2, which assume western meat diet patterns in 2050. SSA is a good example for this, where per capita WF of consumption increases by +92% in S2. The change in the regions with high meat diet in 2000 already (the USA, Canada and WEU) is lower than in other regions in S1 and S2. A decrease is observed in S3 and S4 in these regions due to reduction in consumption of animal products except USA in S3. The reason for the increase in per capita WF of consumption in the USA in S3 is increased biofuel consumption. In the year 2000, the USA has the largest WF per capita in the world. Other regions with a large per capita WF of consumption are Canada, ANZ, FSU and WEU. In 2050, for the S1 and S2 scenarios, EEU has the largest WF per capita and is followed by the USA, FSU and Canada. WEU goes down in the ranking and has a smaller WF of consumption per capita than the average of the world in 2050. The regions with larger WF of consumption per capita than the world average in 2000 also have higher values in S3 and S4, except WEU. The regions with relatively small WFs will continue to have lower values per capita in all scenarios (SEA, CHI, and SAS). Among the scenarios, S1 demonstrates the largest WF of consumption per capita and S4 shows the smallest.

4. The water footprint of Europe in 2050

In this section, we examine the WF scenarios for the two European regions (WEU and EEU) in more detail and zoom in to the country level. We estimate the WF of production and consumption per nation and per scenario inside Europe. In addition, we address the virtual water flows between Europe and the other regions of the world and the international virtual water flows within Europe.

4.1 Water footprint of production

The total WF of production in WEU increases by +12% in S1 and +42% in S2 relative to 2000 values. It decreases 36% in S3 and 29% in S4. The green WF of production becomes 17% and 48% larger in S1 and S2 and 38% and 32% smaller in S3 and S4 compared to 2000. The blue component changes in a similar way: increases by 9 and 35% in S1 and S2 and decreases by 11% in S3 and 1% in S4 (Figure 8). The grey component decreases in S1, S3 and S4 by 6, 40, 30% respectively, and increases by 22% in S2.

The WF of agricultural production in WEU increases by 19% in S1 and 51% in S2 and falls by 34 and 28% in S3 and S4 compared to 2000. The industrial WF of production in WEU decreases in all scenarios. The WF of domestic water supply reduces in S1, S3 and S4 but increases in S2 compared to 2000.

EEU increases its WF of production by +150% and +107% in S1 and S2 compared to 2000, respectively. The increase is lower in S3 and S4 than in the other scenarios, but volumes are 36% and 31% higher than in 2000, respectively. The grey WF of production in EEU shows the biggest growth: 448% in S1, 174% in S2, 197% in S3 and 179% in S4. The blue WF of production increases significantly as well: 231% in S1, 94% in S2, 93% in S3 and 81% in S4. Increases can also be seen in the green WF of production, which is 51% and 86% larger than 2000 in S1 and S2, respectively. In S3 and S4, the green WF of production decreases (18-19% lower than 2000).

The WF of industrial production in EEU in S1 becomes 8 times higher than in 2000. The less drastic but still large increase is also detected in the other scenarios. The WF related to agricultural production becomes larger in S1 and S2, by 50% and 85%, respectively. It stays below the 2000 volumes in S3 and S4. The WF of domestic water supply remains on the value of 2000 in S2 and decreases by around 24-39% for S1, S3 and S4.

Among the agricultural products, the WF related to meat production has the largest share (28%) in the total for S1 and S2 in WEU. The share of meat production decreases to 19-22% in S3 and S4. Oil crops and cereals increase their share in the total WF of production in S3 and S4 partly due to the high demand for biofuel by WEU. The WF of meat production shows the biggest increase in S1 and S2 but it decreases 20% in S3 and S4 compared to 2000. The WF of vegetable and fruit production increases largely in S1 and S2 and decreases by 20%and 30% in S3 and S4 compared to 2000. For most of product groups, the WF of production increases in S1/S2 and decreases in S3/S4. The total WF of oil crop and sugar crop production increases in S2 and S4 and decreases in S1 and S3, compared to 2000.

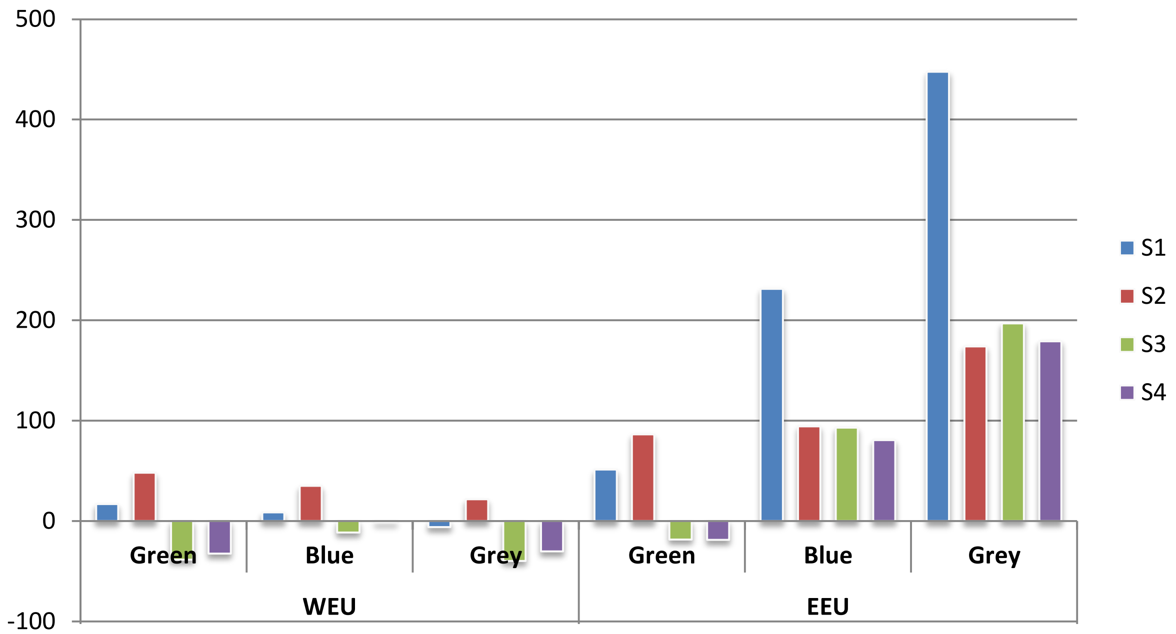

Figure 8. Percentage change in the WF of total production in WEU and EEU relative to 2000.

The WF of agricultural production increases notably in EEU in S1 and S2 for all product groups. The WFs related to the production of meat, dairy products, vegetables and fruits multiply more than two times in S1 and S2. However, the total WF of production for these product groups reduces by 30% in S3 and S4. The total WF of sugar crop and oil crop production increases in S1, S2 and S4 compared to 2000. The increase in the overall WF of agricultural production is the highest in S2 because of the large population size and high meat content diet in this scenario.

On national level, Eastern European countries like Poland, Hungary, Bulgaria and Romania become important producers and significantly increase their WF of consumption in S1 and S2 compared to 2000 (Figure 9). The countries with the largest WF of production in 2000, like France and Spain, continue to have the largest WF of production in 2050. A shift from Southern Europe to Northern Europe is observed in the WF of cereal production. Norway, Luxembourg, Iceland, Cyprus and Malta have the highest increase in the WF of production in S1 and S2 compared to 2000.

All Eastern European countries have a larger WF of production in S3 and S4 relative to 2000, although the increase (around 30%) is smaller than the increases in the WF of production observed in S1 and S2. All of the WEU countries decrease their WF of production in S3 compared to 2000, except Cyprus, Malta, Iceland and Norway. A reduction in WF of production is seen in the Netherlands, Belgium, Sweden, Germany, the UK, Ireland, Austria, Switzerland and Denmark in S4 compared to 2000. Spain and Italy, two counties with a large WF of production in 2000 in Europe, decrease their WF of production relative to 2000 only in S3 among all scenarios. Low-meat content diets and a shift of production to Central and Eastern Europe are the main reasons for this. Among the WEU countries, the Netherlands and Denmark have the highest reduction in the total WF of production compared to 2000, in S3 and S4. France reduces its WF of production in S3 but increases in S4 compared to 2000. Germany has a smaller WF of production in S3 and S4 compared to 2000.

The small island countries in Europe, Cyprus and Malta, increase their blue WF of production in S1 and S2 significantly (two and six times larger than in 2000). These countries already experience high blue water scarcity, so scenarios S1 and S2 will be very problematic for these countries. The blue WF of production in Malta increases significantly in S3 and S4 as well. Spain, another country with large water scarcity, decreases its blue WF of production by 3% in S1, 27% in S3 and 5% in S4, but increases it by 32% in S2. Italy, Portugal, Denmark, France, Ireland, the Netherlands and the UK have larger blue WFs of production in S1 and S2 than in 2000 and smaller blue WFs of production in S3 and S4 than in 2000. Austria, Finland, Norway, Iceland, Sweden, Belgium, Switzerland and Luxembourg increase their blue WF of production in all scenarios (Figure 10).

Most of the EEU countries double their blue WF of production in S1 and S2. They also have a larger blue WF of production in S3 and S4, except Croatia and Bosnia and Herzegovina. Serbia, the Czech Republic, Slovenia and Macedonia have the highest increase in blue WF of production in EEU.

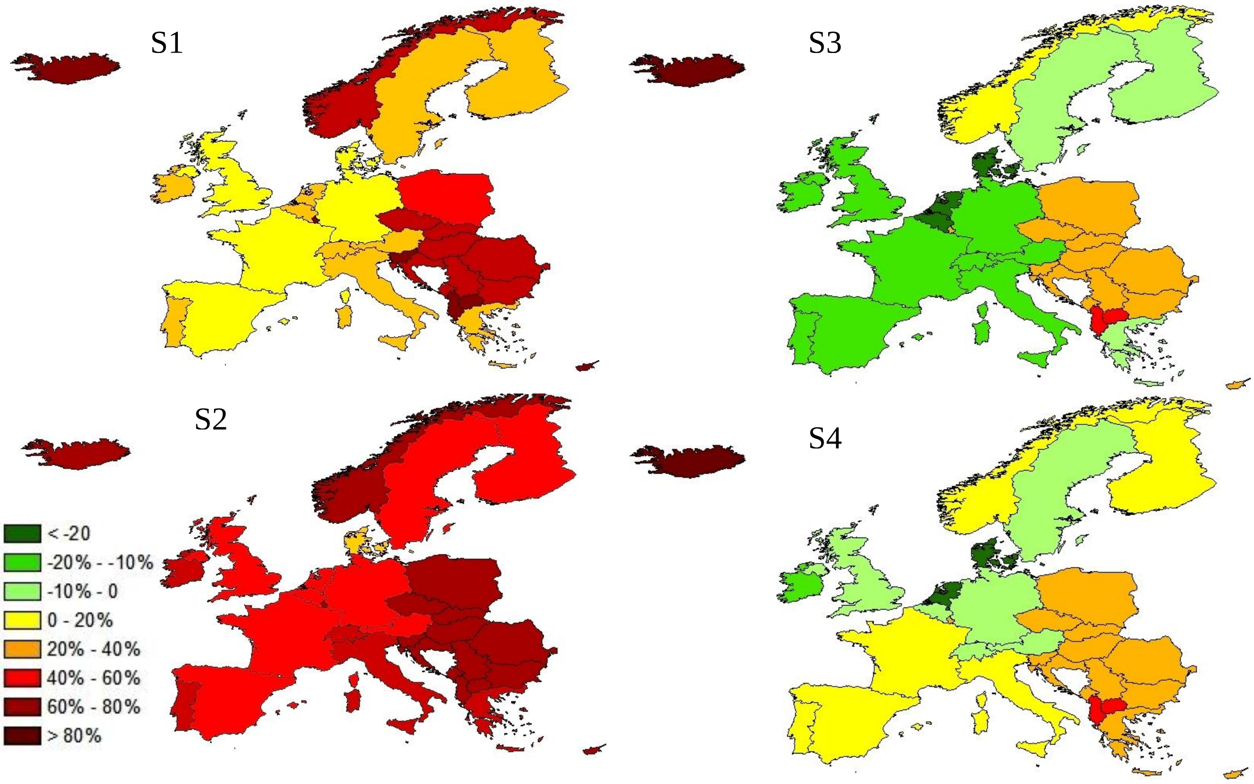

Figure 9. Percentage change of the WF of total production relative to 2000.

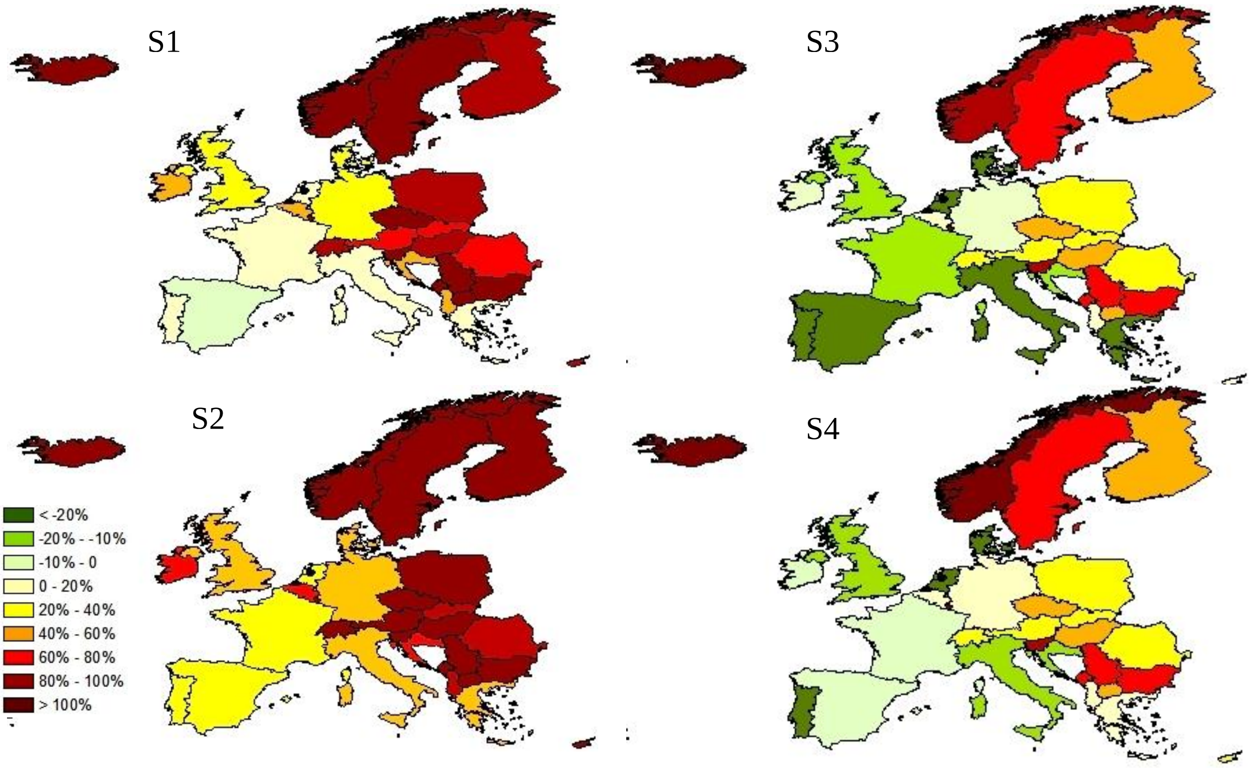

Figure 10. Percentage change of the blue WF of production relative to 2000.

4.2 Virtual water flows between countries

WEU is a net virtual water importer in 2000 (Figure 11). It will remain a net virtual water importer; however, it decreases its net virtual water import in S2 and S4 compared to 2000. It increases its net virtual water import by +2% in S1 and +10% in S3. The reduction in net virtual water import by WEU is -35% in S2 and -40% in S4. The net virtual water imports to WEU were mainly from SEA, SAM, FSU, CHI and SSA in 2000. The virtual water import from SAM increases by around +200% in S1, S2 and S3 and +120% in S4, which makes SAM the biggest virtual water exporter to WEU in 2050. Although SEA has a large net virtual water export to WEU in 2050, its net virtual water export to WEU decreases by -35% for S1, S2 and S3 and -55% for S4. The net virtual water imports from Canada, EEU and ANZ decrease as well, more than -50% in all scenarios. The net virtual water import from the USA increases more than 10 times in 2050 for all scenarios but remain relatively small compared to the net virtual water exports from other regions. The virtual water import volume from FSU increases by 210% in S1, 100% in S2 and S3 but decreases by 4% in S4. WEU increases its net virtual water import from China by +410% in S1 and more than +100% in S2, S3 and S4. Being net virtual water exporters to WEU in 2000, SSA and MDE become net virtual water importers from WEU in 2050 for all scenarios. WEU is a net virtual water exporter to SAS, MDE, NAF, SSA and JPK in 2050. The largest net virtual water export is to SSA in all scenarios, followed by SAS and MDE. The net virtual water exports by WEU to SSA increases significantly in 2050 due to increased trade in animal products.

EEU, a net virtual water exporter in 2000, remains a net virtual water exporter in 2050. It considerably increases its net virtual water export, by +100% S4 up to +500% in S2 compared to 2000 (Figure 12). Its virtual water exports are higher than its imports from all the regions except the USA, Canada, CHI, SAM, FSU, CAM and

ANZ in 2050. The largest net virtual water flow from EEU is to SSA, MDE and SAS in 2050. Being a net virtual water exporter to CHI and FSU in 2000, EEU becomes a net virtual water importer from these regions in 2050. Among the scenarios, net virtual water import by EEU is the highest in S1 and lowest in S3.

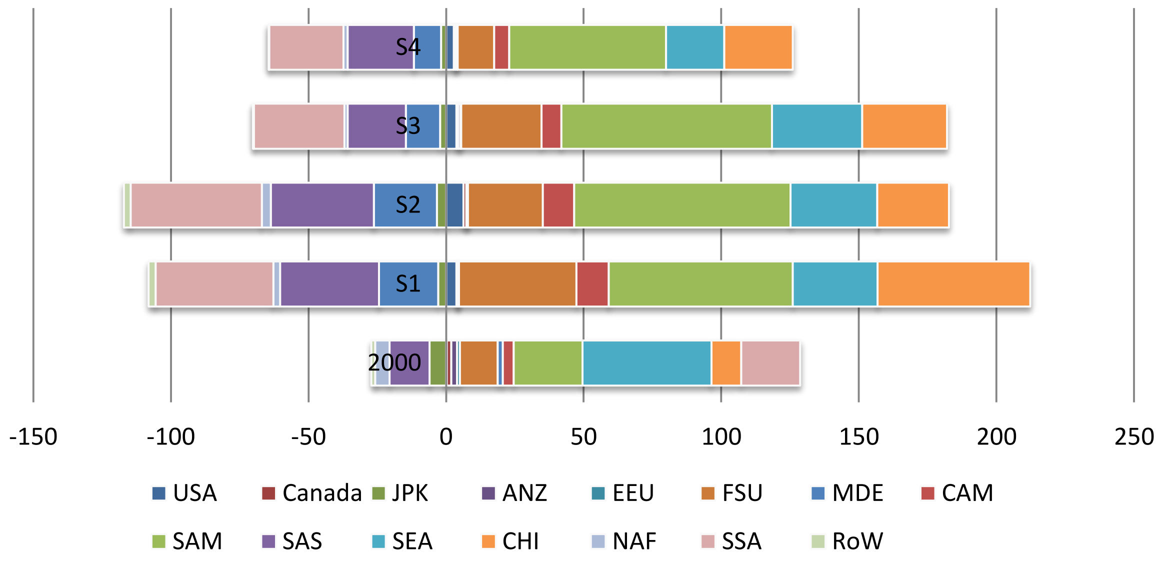

Figure 11. Net virtual water import by WEU specified by region (Gm^3/year).

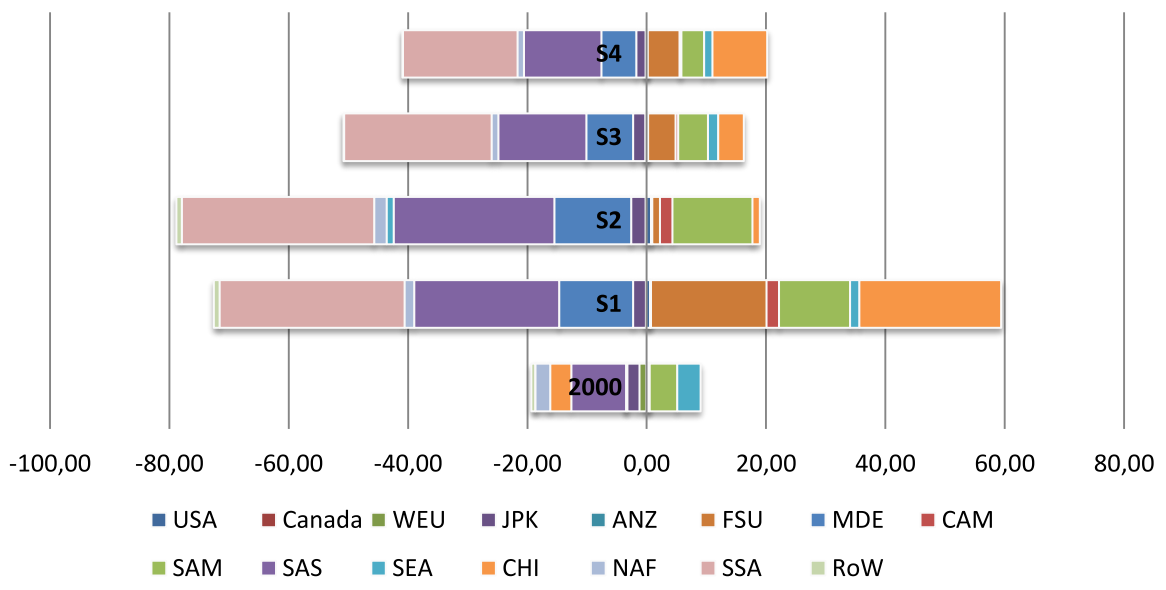

Figure 12. Net virtual water import by EEU specified by region (Gm^3/year).

Figure 13 shows the net virtual water flows from/to WEU and EEU by their green, blue and grey components. WEU is a net blue virtual water importer in 2000. In 2050, WEU becomes a net blue virtual water exporter in S2 and S4. By 2050, most of the net blue virtual water flows from WEU are to SSA, SAS and MDE and net blue virtual water imports to WEU are from SAM, the USA and ANZ. From the green water perspective, WEU is a net virtual water importer in all scenarios. As for grey component, WEU continues to be a net importer in 2050 and increases its net virtual water import by +143% in S1, +29% in S2, +74% in S3. EEU is a net virtual water exporter in terms of green and blue components in 2050. It is a net grey virtual water importer in S1, S3 and S4 and exporter in S2. The green component has the biggest share in net virtual water exports from EEU.

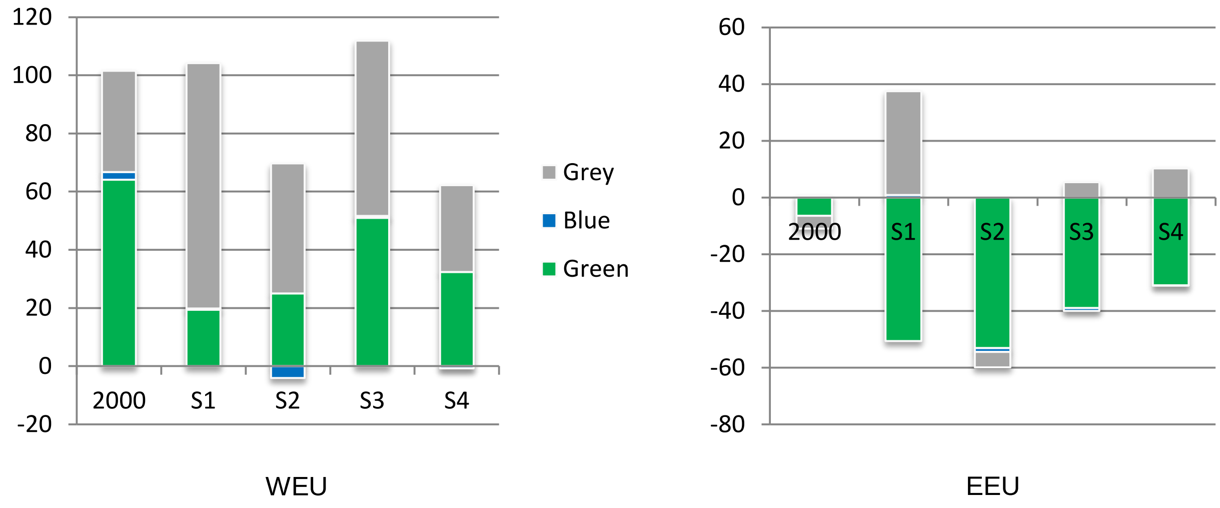

Figure 13. Net virtual water import by WEU and EEU specified by green, blue and grey components (Gm^3/year).

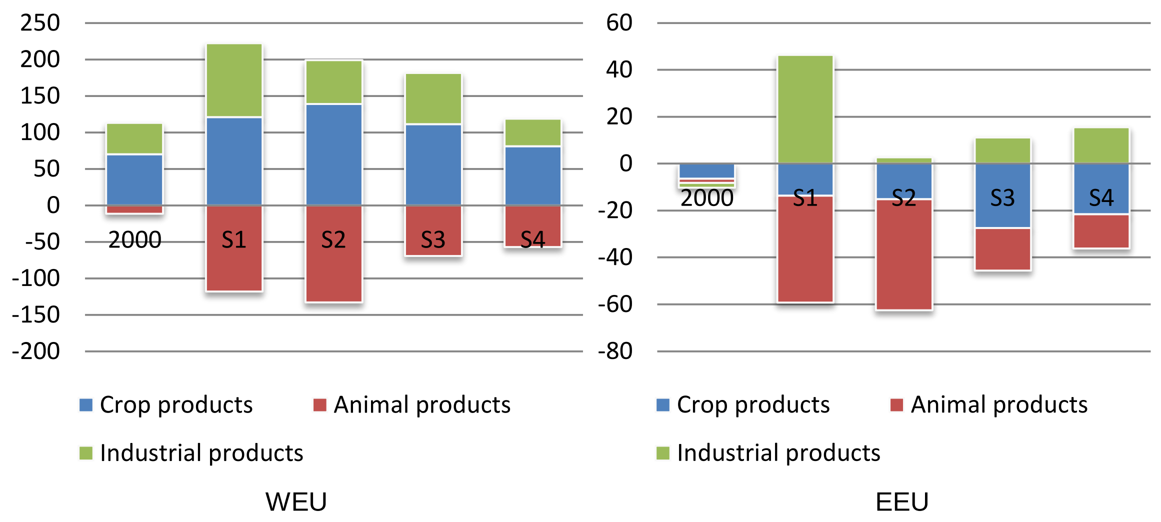

Figure 14. Net virtual water import by WEU and EEU specified by commodity group (Gm^{3}year).

The net virtual water import to WEU is mainly related to crop products and industrial products. The region is a net virtual water exporter considering animal products in 2050 (Figure 14). The net virtual water export related to animal products increases very substantially in EEU as well. Although EEU is a net virtual water exporter in 2000 regarding all product groups, it becomes a net virtual water importer related to industrial products in 2050.

The virtual water export from EEU to WEU is larger than imports, therefore a net virtual water flow from EEU to WEU is observed in 2000. This continues towards 2050 but the net virtual water import by WEU from EEU is reduced largely in S1, by -90%.

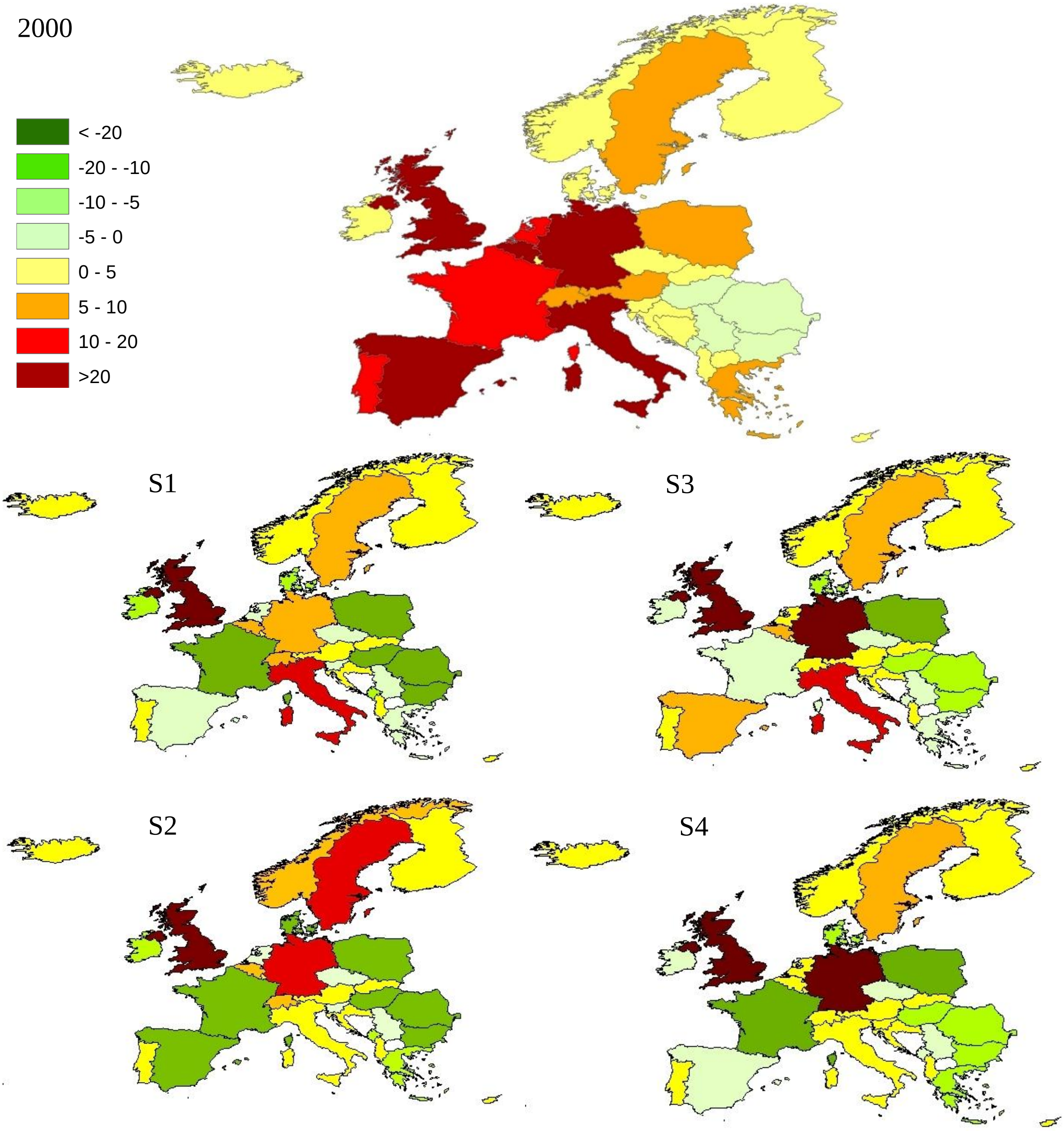

Figure 15. Net virtual water import per European country (Gm^{3}year).

Figure 15 shows net virtual water imports per nation in Europe for 2000 and four scenarios. All WEU countries are net virtual water importers in 2000. Countries like France, Spain, Ireland, Denmark, Greece and the Netherlands become net virtual water exporters for scenarios S1 and S2. In particular, the change in France is quite big. The UK, Italy, Portugal, Sweden, Norway, Finland, Germany, Austria, Belgium, Switzerland, Malta, Cyprus and Iceland remain net virtual water importers in S1 and S2. The net virtual water flow changes direction for some countries in S3. Spain and the Netherlands are net importers in S3. France, Denmark, Greece, and Ireland are net virtual water exporters in S3 and S4.

Romania, Bulgaria, Serbia and Montenegro are net virtual water exporters in 2000 and stay so in 2050. Poland, the Czech Republic and Hungary are net virtual water importers in 2000 and become net virtual water exporters in 2050. Slovakia, Macedonia, Bosnia and Herzegovina, Croatia and Albania are net virtual water importers in 2000 and 2050. Slovenia is a net virtual water exporter in S1 and S2 and a net virtual water importer in S3 and S4.

4.3 Water footprint of consumption

The total WF of consumption in WEU increases by 28% and 52% in S1 and S2 compared to 2000. The WF of consumption in WEU decreases by -19% in S3 and -20% in S4. EEU increases its WF of consumption in all scenarios compared to 2000, by +143% in S1, +75% in S2, +17% in S3 and +20% in S4. The WF of consumption per capita in WEU increases by +30% in S1 and +22% in S2 and decreases by -18% in S3 and -28% in S4. EEU has a larger WF of consumption per capita in 2050 than in 2000, with an increase of 186% in S1, 57% in S2, 38% in S3 and 23% in S4. Approximately 70% of the total WF of consumption in WEU is green, in both 2000 and 2050. It is followed by the grey and blue components with shares of 20% and 10%, respectively. The share of green WF of consumption in the total in EEU decreases from 73% in 2000 to 34% in S1, S3 and S4. The share of grey WF of consumption in EEU increases from 23% in 2000 to 60% in S1, S3 and S4. The shares of the green, blue and grey components in the total WF of consumption in EEU in S2 are the same as the shares in 2000.

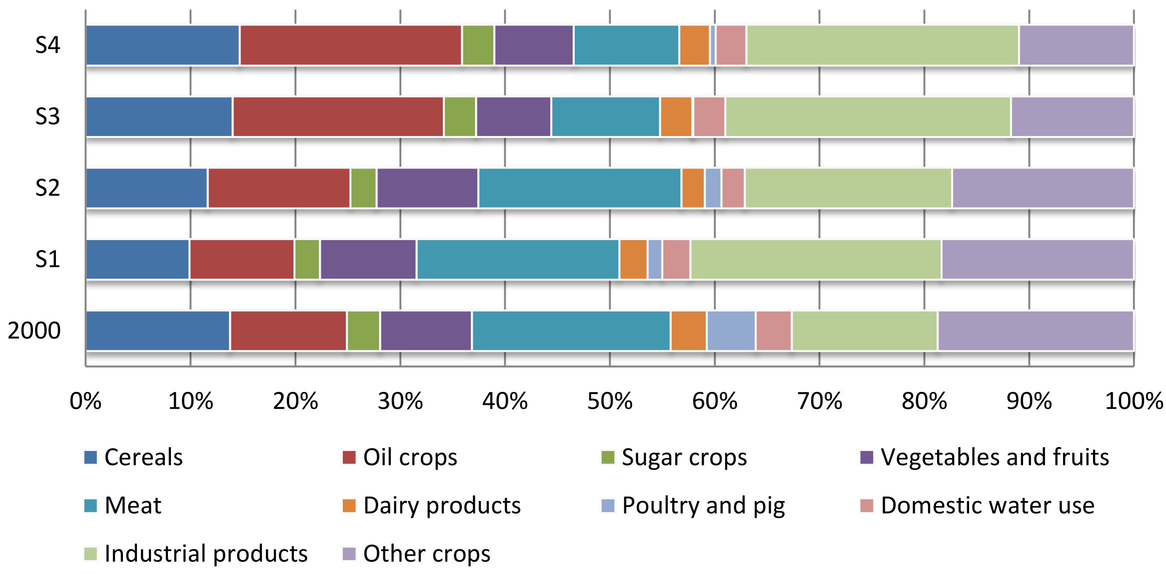

Figure 16. The composition of the total WF of European consumption by commodity.

The WF of consumption per commodity group in Europe is given in Figure 16. Meat and cereals are the product groups with the biggest share in the WF of consumption in 2000. The share of meat consumption decreases in S1 and S2. It falls down considerably in S3 and S4 scenarios. The WF related to the consumption of industrial products doubles its share in 2050 compared to 2000. Other commodities with a large share in the total WF of consumption in 2050 are cereals and oil crops. Especially the share of oil crops significantly increases in S3 and S4, due to drastic biofuel expansion.

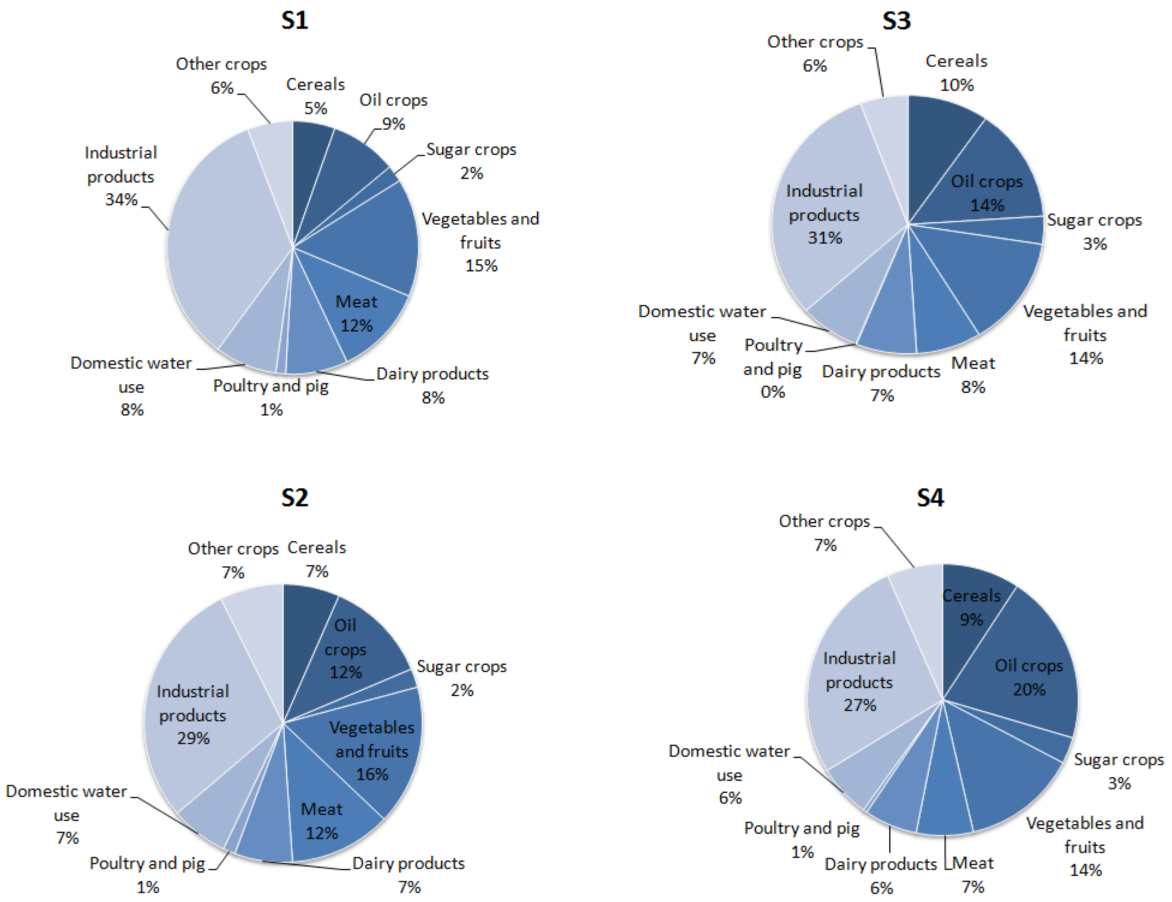

Figure 17. The composition of the blue WF of European consumption by commodity.

The blue WF of consumption in Europe is mainly due to industrial products in 2050 (Figure 17). Vegetables and fruits are the second biggest contributor to the total blue WF of consumption in 2050 (14-16%). The share of oil crops in total blue WF of consumption increases with 9% in S1, 12% in S2, 14% in S3 and 20% S4. The share of the blue WF of meat consumption in the total blue WF of consumption is 12% in S1 and S2, 8% in S3 and 7% in S4. Other product groups with a large share in the total blue WF of consumption are dairy products, domestic water supply and cereals, in all scenarios.

The grey WF of consumption is mainly from industrial products, with a share of 66% in S1 and S2 and 69% in S3 and S4. Domestic water supply is another big contributor to the total grey WF of consumption, 7% of the total grey WF of consumption in all scenarios. Other product groups with a large share in the total grey WF of consumption are dairy products (6-7%), cereals (5-6%), meat (4-7%) and vegetables and fruits (2-3%). The composition of the grey WF of consumption does not differ much from scenario to scenario (Figure 18).

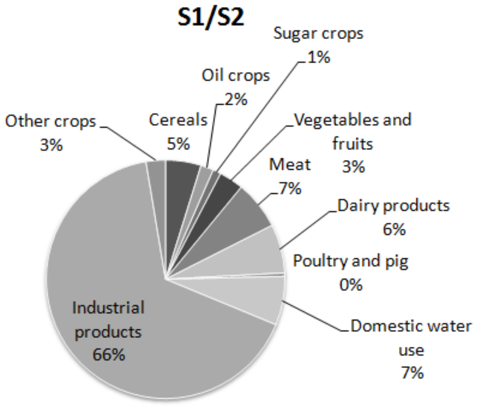

Figure 18. The composition of the grey WF of European consumption by commodity.

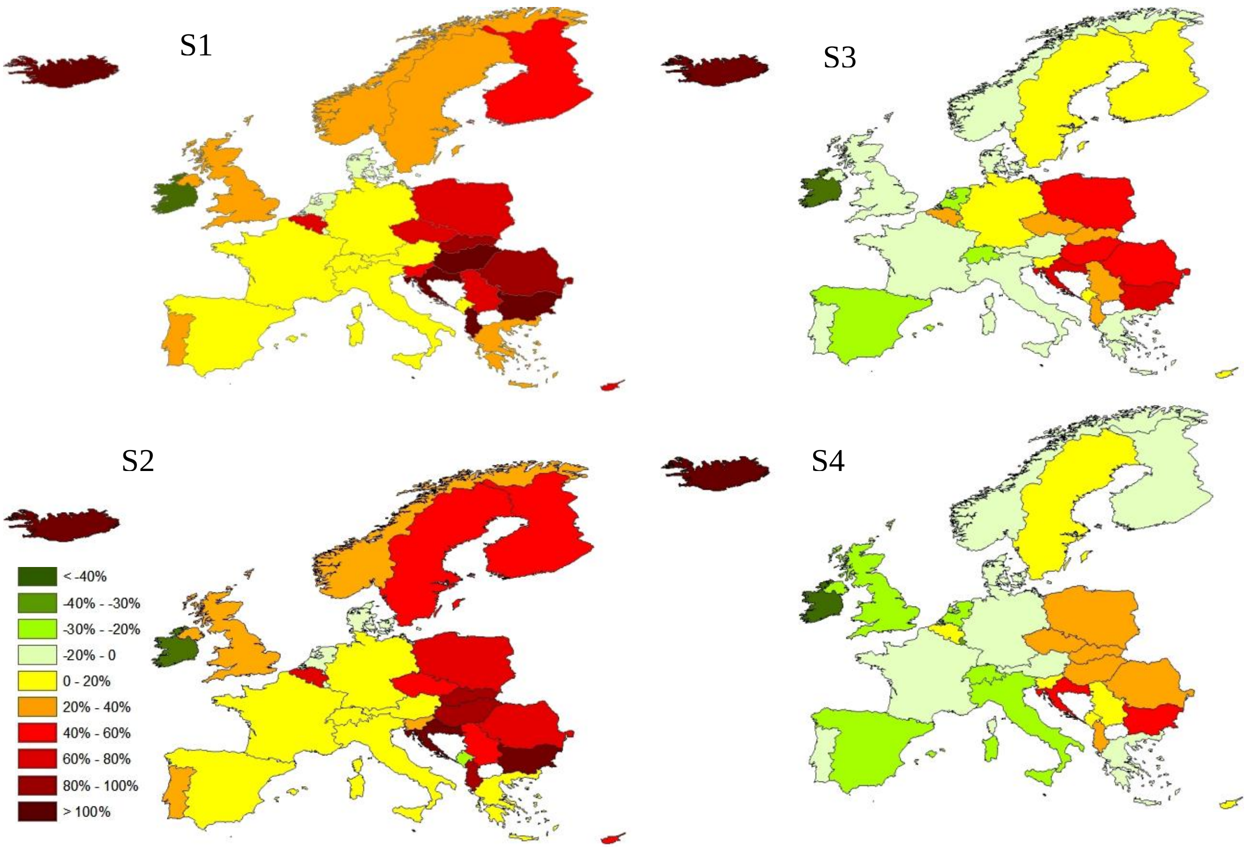

Figure 19. Percentage change of the WF of consumption per capita relative to 2000.

The change in WF of consumption per capita relative to 2000 for the nations of Europe is shown in Figure 19. All WEU countries have a larger WF of consumption per capita in S1 and S2 than 2000, except Denmark, Ireland, Luxembourg and the Netherlands. Belgium, Sweden, Cyprus, Iceland and Malta have a larger WF of consumption per capita in 2050 than in 2000. Austria, France, Greece, Italy, Norway, Portugal, Spain, Switzerland and the UK decrease their WF of consumption in S3 and S4 compared to 2000. Italy, the Netherlands, Spain, Switzerland, Luxembourg and the UK reduce their WF of consumption per capita values by more than -20% in S4. Within WEU, Cyprus, Malta and Iceland significantly increase their WF of consumption per capita in S1 and S2. Spain has the largest WF of consumption per capita in 2000. In 2050, Malta has the largest WF of consumption per capita.

In 2050, EEU countries have a larger WF of consumption per capita than in 2000. Bulgaria, Hungary, Croatia, Macedonia and Bosnia and Herzegovina increase their WF of consumption per capita by more than +100% in S1 and S2. Montenegro is the only country in EEU with a reduction in the WF of consumption per capita in S2.

The share of the external WF of consumption in the total WF of consumption increases in WEU in 2050. However, the countries with a relatively large external WF in 2000, like the Netherlands (94% of the total WF), Malta (90%) and Belgium (90%), significantly reduce this ratio, to below 50% in all scenarios. The UK, Switzerland and Luxembourg have an external WF of more than 60% of the total WF of consumption in all scenarios. Spain significantly reduces its share of external WF of consumption in 2050. All of the EEU counties reduce the share of external WF of consumption in S2,S3 and S4.

5. Discussion and conclusion

This study is the first global water footprint scenario study. It explores how the water footprint of humanity will change towards 2050 under four alternative scenarios, which differ from each other in terms of specific trajectories for the main drivers of change. Although we included the major drivers of change in our analysis, some of them were kept outside the scope of this study. First, we excluded the impact of resource availability. The constraints related to water and land availability are only addressed implicitly in the production and trade scenarios. A future step would be to integrate such limitations explicitly. Climate change effects are partially addressed in our study. We implicitly included the impact of climate change on production and trade patterns, but we excluded CO_2 fertilization effects in yields and climate change effects on crop water use. Another limitation is that we assumed a homogeneous and single industrial sector in estimating the water footprint of industrial production and consumption.

Our analysis shows that water footprints can radically change from one scenario to another and are very sensitive to the drivers of change:

- Population growth: The size of the population is the major driver of change of the WF of production and consumption. The WF of production and consumption is largest in the scenario in which the population projection is the highest (S2).
- Economic growth: The effect of economic growth is observed in terms of income levels and GDP changes. Increased income levels result in a shift toward high consumption of water-intensive commodities. GDP growth significantly increases industrial water consumption and pollution. S1 has the largest WF of industrial production and consumption among all scenarios because it foresees the highest GDP.
- Consumer preferences: The diet of people strongly influences the WFs of consumption and production. Diets with increased meat and dairy products result in very large WFs in 2050 (S1 and S2). In S3 and S4, the scenarios with low meat content, the total WF of consumption and production in the world drastically decrease. This shows us that a reduction in humanity's WF is possible in 2050 despite population increase.
- Biofuel use: Existing plans related to biofuel use in the future will increase the pressure on water resources. The study shows that a high demand for biofuel increases the WF of production and consumption in the world and especially in Western Europe, the USA and Brazil.
- Importance of international trade: A reduction in WFs is possible in 2050 by liberalization of trade (S1 versus S2 and S3 versus S4). Trade liberalization, on the other hand, will imply more dependency of importing nations on the freshwater resources in the exporting nations and probably energy use will increase because of long-distance transport.
- Climate change: The global agricultural production and trade structure will be affected by climate change. The production volumes will decrease in some parts of the world and will increase in others. The production changes across the world will affect the WF of production. In overall, our results show that the total WF of production of humanity will decrease because of climate change effects on the global

agricultural production pattern. However, it does not result in a similar change in all parts of the world. It will increase the WF of production in Europe, Australia and East Asia and decrease the WF of production in the USA, Middle East and Russia. Evidently, climate change will also affect water availability and scarcity around the world differently and this should be combined with this information carefully.

- Technology: Technologic development directly affects water productivity, water use efficiency and wastewater treatment levels. Increased water productivity as a result of technological development result in reduction of the WF of consumption and production.

From the European point of view, this study shows that the most critical driver of change that affects the future WF of production and consumption for Europe is consumption pattern. The WF of production and consumption in WEU increase in the 'high-meat' scenarios (S1 and S2) and decrease in the 'low-meat' scenarios (S2 and S3). In addition, extra demand created by biofuel needs put additional pressure on European water resources (S3 and S4). The European countries with a large external WF of consumption ratio in 2000 decrease their dependencies on foreign water resources (e.g. the Netherlands, Belgium and Luxembourg).

The study shows how different drivers will change the level of water consumption and pollution globally in 2050. These estimates can form a basis for a further assessment of how humanity can mitigate future freshwater scarcity. We showed that reducing humanity's water footprint to sustainable levels is possible even with increasing populations, provided that consumption patterns change. This study can help to guide corrective policies at both national and international levels, and to set priorities for the years ahead in order to achieve sustainable and equitable use of the world's fresh water resources.

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Appendix I: Countries and regional classification

Region code	Region	Countries
1	USA	United States of America
2	Canada	Canada
3	WEU	Andorra, Austria, Cyprus, Denmark, Finland, France, Germany Greece, Iceland, Ireland, Italy, Malta, Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, United Kingdom, Belgium, Luxembourg
4	JPK	Japan, Dem. People's Republic of Korea
5	ANZ	Australia, New Zealand
6	EEU	Albania, Bulgaria, Bosnia and Herzegovina, Hungary, Croatia, TFYR Macedonia, Czech Republic, Poland, Romania, Slovenia, Slovakia, Serbia Montenegro
7	FSU	Armenia, Azerbaijan, Belarus, Estonia, Georgia, Kazakhstan, Kyrgyzstan, Latvia, Lithuania, Republic of Moldova, Russian Federation, Tajikistan, Turkmenistan, Ukraine, Uzbekistan
8	MDE	Bahrain, Iran, Iraq, Israel, Jordan, Kuwait, Lebanon, Qatar, Saudi Arabia, Syrian Arab Republic, Oman, Turkey, United Arab Emirates, Yemen, Occupied Palestinian Territory
9	CAM	Caribbean, El Salvador, Grenada, ,Mexico, , Nicaragua, Panama
10	SAM	Argentina, Bolivia , Brazil, Chile, Colombia, Ecuador, ,French Guiana, Guyana, Paraguay, Peru, Suriname, Uruguay, Venezuela
11	SAS	Afghanistan, Bangladesh, Bhutan, Sri Lanka, India, Maldives, Nepal, Pakistan
12	SEA	Brunei, Darussalam, Myanmar, Indonesia, Cambodia, Laos, Malaysia, Philippines, Timor-Leste, Singapore, Thailand, Viet Nam
13	CHI	China
14	NAF	Algeria, Egypt, Libyan Arab Jamahiriya, Morocco, Western Sahara, Tunisia
15	SSA	Angola, Botswana, Burundi, Cameroon, Cape Verde, Central African Republic, Chad, Comoros, Congo, Benin, Equatorial Guinea, Djibouti, Gabon, Gambia, Ghana, Guinea, Côte d'Ivoire, Kenya, Lesotho, Liberia, Madagascar, Malawi, Mali, Mauritania, Mauritius, Mozambique, Niger, Nigeria, Guinea-Bissau, Eritrea, Zimbabwe, Réunion, Rwanda, Senegal, Seychelles, Sierra Leone, Somalia, South Africa, Sudan, Swaziland, Tanzania Togo, Uganda, Burkina Faso, Ethiopia, Congo, Zambia, Mayotte
16	RoW	Other non-specified areas (Rest of the World)

Appendix II: Population and GDP forecasts

Population

Region code	Region	S1-2050	S2-2050	S3-2050	S4-2050
1	USA	357,007,000	452,394,000	357,007,000	403,100,000
2	CAN	38,845,000	48,791,000	38,845,000	43,641,000
3	WEU	385,569,000	487,475,000	385,569,000	434,634,000
4	JPK	119,338,000	151,811,000	119,338,000	134,930,000
5	ANZ	32,903,000	41,515,000	32,903,000	37,063,000
6	EEU	93,422,000	122,034,000	93,422,000	107,097,000
7	FSU	239,902,000	320,767,000	239,902,000	278,366,000
8	MDE	403,048,000	525,568,000	403,048,000	461,667,000
9	CAM	225,896,000	304,142,000	225,896,000	262,882,000
10	SAM	419,973,000	564,683,000	419,973,000	488,073,000
11	SAS	1,990,834,000	2,660,586,000	1,990,834,000	2,308,540,000
12	SEA	655,577,000	872,810,000	655,577,000	759,206,000
13	CHI	1,130,211,000	1,479,309,000	1,130,211,000	1,295,603,000
14	NAF	200,112,000	265,577,000	200,112,000	231,496,000
15	SSA	1,731,742,000	2,204,177,000	1,731,742,000	1,960,102,000
16	RoW	81,243,000	98,602,000	81,243,000	89,589,000
17	World	8,105,622,000	10,600,241,000	8,105,622,000	9,295,989,000

GDP (1990 US$ MEX)

Region code	Region	S1-2050	S2-2050	S3-2050	S4-2050
1	USA	21758785042065	17355484996242	19249661687548	16414353161340
2	CAN	1853763940822	1446163121773	1836185439521	1634556518207
3	WEU	23553103572664	18374308098248	21125539816549	15553707375045
4	JPK	9082835848045	6430169278057	8424823206354	6141977795023
5	ANZ	948923321297	740344752629	988793402357	643490166991
6	EEU	3366254712014	1153188770022	2015141767763	1941334293422
7	FSU	10005897982675	3427752851389	5416984803691	5115675629960
8	MDE	12575743797432	5038190390666	10267041500486	4821689528756
9	CAM	7091959678872	2674606474631	5426717678644	3598373232136
10	SAM	15866432073256	5873001540866	11334363400416	7985386183870
11	SAS	12836624204768	4063470017500	18425511851559	9533839146457
12	SEA	10838071266980	3354806708623	6509907246729	6832038421202
13	CHI	25718590039554	5262355190158	9620976808823	18778528893685
14	NAF	4954364041239	2164826449829	6669075096881	1844179845178
15	SSA	13162859514781	3768938467049	11610784630915	6362618805968
16	RoW	8253990018825	2585651189853	4844943399150	5195770140139

Appendix III: Consumption of crops per region per scenario - 2050 (tons)

Scenario S1

Region	Cereals	Oil crops	Other crops	Pulses	Roots	Sugar crops	Vegetables and fruits	Fibres	Others-non food
USA	112,400,594	66,198,783	6,953,961	2,401,202	32,555,019	156,913,087	175,844,852	77,887	231,883
Canada	9,381,159	4,398,355	890,458	259,365	3,527,101	17,056,954	18,694,815	3,974	25,231
WEU	76,575,723	35,902,064	7,885,212	2,105,744	41,119,221	135,435,247	163,395,639	278,448	2,018,421
JPK	27,485,718	11,002,379	628,063	200,114	8,392,979	16,314,038	62,261,492	44,555	79,480
ANZ	7,115,629	3,025,111	577,778	426,884	3,225,819	13,003,698	13,735,690	12,979	97,961
EEU	20,049,753	6,625,409	1,674,391	379,088	13,962,643	46,058,066	45,268,059	58,337	274,122
FSU	54,745,306	18,404,623	2,713,010	281,229	36,089,942	94,100,730	104,166,323	175,224	580,185
MDE	96,658,421	51,224,841	3,906,740	2,867,140	13,858,198	126,783,903	167,419,006	27,768	1,251,874
CAM	41,259,785	15,875,125	1,813,382	3,040,371	17,265,115	110,647,591	104,447,916	150,462	1,156,465
SAM	92,618,301	37,021,447	5,720,773	5,682,804	32,300,730	210,634,082	172,272,123	471,361	458,363
SAS	399,960,440	154,307,465	23,596,328	19,664,231	57,073,145	770,204,216	632,162,921	4,785,298	7,264,544
SEA	156,028,801	54,843,553	5,331,034	1,961,389	27,857,462	183,641,033	207,092,122	916,961	667,036
CHI	216,080,744	128,081,902	4,418,399	1,743,218	69,646,653	151,513,281	661,305,952	962,256	752,719
NAF	41,242,501	16,537,310	2,391,416	1,371,619	6,737,780	60,586,984	78,699,748	50,939	239,915
SSA	263,659,905	138,064,531	12,527,512	18,953,059	321,468,418	320,988,944	509,672,142	356,036	2,625,891
RoW	14,248,857	11,272,788	1,231,233	159,735	5,871,974	31,214,583	39,401,802	12,100	53,062

Scenario S2

Region	Cereals	Oil crops	Other crops	Pulses	Roots	Sugar crops	Vegetables and fruits	Fibres	Others-non food
USA	229,942,438	86,077,598	8,811,957	3,042,767	45,863,571	204,342,140	222,827,997	92,101	293,839
Canada	13,062,518	6,537,045	1,118,436	325,768	4,590,666	21,607,295	23,481,127	4,913	31,691
WEU	110,547,541	60,502,427	9,968,086	2,662,915	53,383,890	172,781,030	206,513,038	345,837	2,551,691
JPK	35,166,156	13,890,123	798,781	254,404	10,701,973	20,777,215	79,240,876	46,150	101,106
ANZ	8,982,012	3,815,034	729,067	538,597	4,094,421	16,434,135	17,330,355	15,932	123,600
EEU	27,404,424	9,743,867	2,184,372	494,809	18,368,588	60,368,813	59,172,968	61,681	358,629
FSU	73,293,883	23,806,583	3,627,369	375,973	48,258,798	125,830,586	139,266,874	183,493	775,500
MDE	125,761,154	61,761,180	5,090,073	3,736,799	18,076,994	165,771,228	218,269,854	27,556	1,634,720
CAM	55,672,470	20,958,572	2,440,733	4,093,308	23,247,417	148,991,188	140,605,833	179,439	1,557,076
SAM	148,424,384	48,816,169	7,698,966	7,640,730	46,421,128	296,343,473	231,727,524	525,947	616,302
SAS	534,968,095	203,559,539	31,468,875	26,345,022	76,302,696	1,029,459,950	844,778,603	5,925,054	9,708,467
SEA	208,429,912	72,426,276	7,093,971	2,611,438	37,164,284	244,593,317	275,754,051	1,074,948	888,066
CHI	285,035,670	165,627,488	5,783,149	2,281,661	91,436,663	198,629,684	865,569,354	1,116,253	985,218
NAF	54,708,656	21,492,096	3,173,255	1,820,316	8,941,494	80,407,341	104,443,260	57,069	318,402
SSA	335,508,972	176,806,265	15,962,941	24,100,735	408,326,608	409,315,680	648,166,343	520,391	3,311,861
RoW	17,351,118	13,166,292	1,482,228	205,092	7,176,049	37,821,663	48,465,570	13,153	62,822

Scenario S3

Region	Cereals	Oil crops	Other crops	Pulses	Roots	Sugar crops	Vegetables and fruits	Fibres	Others-non food
USA	331,536,347	102,336,392	3,686,437	1,920,961	37,571,711	258,220,572	94,249,350	72,681	231,883
Canada	10,907,540	8,820,412	472,050	207,492	3,354,105	27,222,743	10,020,050	3,912	25,231
WEU	97,161,227	70,680,865	4,285,442	1,821,184	37,419,158	160,875,923	111,971,631	273,540	2,018,421
JPK	34,197,641	9,264,215	251,225	266,819	8,378,270	16,028,023	30,567,657	36,278	79,480
ANZ	6,167,874	3,233,223	254,902	406,556	2,622,906	14,111,722	6,572,100	12,627	97,961
EEU	24,925,992	8,768,646	353,745	451,295	15,903,088	40,520,048	16,580,109	47,219	274,122
FSU	57,319,381	17,965,946	966,993	401,755	40,846,810	95,492,561	33,920,534	137,235	580,185
MDE	122,189,413	49,651,343	2,251,342	3,460,342	14,860,927	136,297,015	104,340,457	21,304	1,251,874
CAM	37,925,343	20,333,834	533,348	2,908,181	15,724,246	138,668,790	46,973,931	133,275	1,156,465
SAM	135,454,944	48,196,084	1,682,580	5,435,725	35,718,143	291,348,140	77,476,881	391,164	458,363
SAS	430,820,370	159,974,187	9,075,511	20,989,910	62,130,427	862,068,822	260,441,653	4,431,785	7,264,544
SEA	177,660,772	59,697,241	1,269,294	2,558,333	34,232,686	247,260,348	75,181,959	807,405	667,036
CHI	270,415,892	109,776,223	1,767,360	2,324,291	69,700,761	149,002,067	324,672,173	852,831	752,719
NAF	52,092,546	17,103,993	1,378,104	1,655,403	7,219,050	65,126,074	49,048,002	43,415	239,915
SSA	350,260,308	118,987,003	4,661,400	20,551,510	343,560,078	337,410,039	236,271,854	409,009	2,625,891
RoW	12,336,861	11,702,895	543,191	152,129	4,680,583	33,734,537	18,852,537	10,838	53,062

Scenario S4

Region	Cereals	Oil crops	Other crops	Pulses	Roots	Sugar crops	Vegetables and fruits	Fibres	Others-non food
USA	340,254,222	114,587,417	4,162,388	2,168,974	41,130,453	290,051,049	106,417,740	82,065	261,822
Canada	11,909,368	9,620,363	530,326	233,107	3,725,192	30,534,634	11,257,068	4,395	28,346
WEU	105,599,732	75,315,103	4,830,483	2,053,206	41,801,923	180,893,387	126,197,836	308,349	2,275,196
JPK	38,620,409	10,435,055	284,014	301,578	9,467,030	18,113,231	34,569,836	41,018	89,863
ANZ	6,946,885	3,641,290	287,138	457,942	2,947,750	15,887,527	7,402,791	14,223	110,344
EEU	28,171,368	9,615,472	405,344	517,187	18,180,668	46,414,799	19,013,606	54,131	314,458
FSU	66,477,308	20,832,962	1,122,003	466,112	47,387,495	110,798,355	39,358,560	159,238	673,077
MDE	139,749,992	56,823,767	2,577,807	3,962,629	17,020,173	156,320,116	119,504,897	24,306	1,434,928
CAM	44,100,067	23,636,160	620,711	3,384,275	18,289,421	161,368,224	54,658,701	155,096	1,345,841
SAM	148,926,234	55,793,868	1,956,093	6,317,053	40,446,962	333,979,779	90,051,976	454,592	532,688
SAS	499,490,332	185,396,624	10,512,748	24,370,506	72,022,258	999,672,682	301,987,055	5,139,988	8,423,853
SEA	205,503,511	68,936,775	1,469,565	2,962,820	39,608,041	286,312,921	87,075,647	935,034	772,476
CHI	309,278,689	125,246,156	2,025,991	2,664,422	79,812,165	170,706,134	372,183,933	977,633	862,870
NAF	60,252,356	19,776,011	1,594,133	1,915,035	8,351,200	75,339,640	56,740,351	49,974	277,543
SSA	396,376,486	134,700,319	5,279,124	23,250,114	388,440,704	382,264,236	267,309,440	462,848	2,958,110
RoW	13,628,155	12,778,818	596,435	172,893	5,180,365	37,167,586	20,937,277	11,951	57,752

Appendix IV: Consumption of animal products per region per scenario - 2050 (tons)

Scenario S1

Regions	Bovine meat	Mutton & goat meat	Meat, other	Offal, edible	Fats, animals, raw	Butter, ghee	Cream	Milk - excluding butter	Pig meat	Poultry meat	Eggs
USA	14,344,328	192,803	202,833	255,213	1,128,957	688,466	3,347	85,068,474	9,912,476	15,752,142	4,801,652
Canada	1,229,624	32,741	1,091	53,599	256,475	103,444	245,375	7,586,466	1,130,307	1,305,313	410,127
WEU	6,634,673	1,214,957	1,195,821	1,507,986	1,833,561	1,594,821	1,426,156	85,978,889	15,215,442	7,142,750	4,330,660
JPK	1,685,048	46,697	99,976	478,485	120,640	103,757	0	12,378,950	2,877,271	2,388,654	3,076,603
ANZ	1,468,078	674,019	41,237	358,270	145,245	147,929	1,472	7,657,169	693,716	1,165,923	248,103
EEU	1,047,777	162,421	96,269	412,688	731,598	263,503	291,635	21,805,123	4,460,226	1,868,941	1,307,001
FSU	4,441,653	532,968	237,488	1,270,556	545,985	584,843	433,447	45,433,520	3,535,852	2,241,336	2,942,517
MDE	5,429,152	6,433,272	415,932	2,185,180	303,350	1,786,982	48,552	91,596,551	119,249	16,414,237	7,825,621
CAM	4,187,892	264,917	321,527	1,169,354	666,912	140,826	23,205	29,407,062	2,909,727	5,956,787	3,422,919
SAM	16,920,040	484,723	568,473	1,866,448	1,157,613	298,618	18,100	66,293,173	5,854,251	13,753,032	3,844,874
SAS	13,131,927	5,453,388	710,944	3,508,024	945,922	10,570,754	501	361,865,312	2,016,687	3,946,740	8,746,952
SEA	5,919,142	639,786	197,518	2,953,323	1,621,671	272,401	54,707	28,377,057	15,470,014	14,098,339	8,792,243
CHI	6,977,331	3,619,562	1,126,845	4,865,920	3,585,415	171,355	17,135	16,986,954	54,983,083	17,381,675	27,012,833
NAF	3,605,369	1,847,839	713,414	835,623	197,639	774,084	16,535	32,350,954	13,483	4,803,327	1,997,137
SSA	35,539,018	15,812,188	11,531,608	10,538,807	2,543,523	1,038,725	90,906	198,978,329	8,835,256	20,448,189	11,883,182
RoW	4,384,738	932,379	412,214	1,301,631	566,236	256,379	21,030	6,972,542	2,418,610	1,212,116	1,051,357

Scenario S2

Regions	Bovine meat	Mutton & goat meat	Meat, other	Offal, edible	Fats, animals, raw	Butter, ghee	Cream	Milk - excluding butter	Pig meat	Poultry meat	Eggs
USA	18,176,920	244,317	257,027	323,403	1,430,597	872,414	4,242	107,797,512	12,560,943	19,960,881	6,084,582
Canada	1,544,437	41,124	1,371	67,322	322,139	129,928	308,197	9,528,780	1,419,693	1,639,503	515,129
WEU	8,388,219	1,536,071	1,511,876	1,906,547	2,318,172	2,016,332	1,803,090	108,703,141	19,236,889	9,030,581	5,475,255
JPK	2,143,559	59,403	127,180	608,684	153,467	131,990	0	15,747,334	3,660,193	3,038,620	3,913,765
ANZ	1,852,317	850,429	52,030	452,040	183,259	186,647	1,857	9,661,272	875,281	1,471,078	313,038
EEU	1,368,676	212,165	125,753	539,081	955,661	344,205	380,953	28,483,300	5,826,244	2,441,334	1,707,292
FSU	5,938,807	712,616	317,539	1,698,824	730,021	781,977	579,550	60,747,861	4,727,686	2,996,826	3,934,355
MDE	7,079,521	8,388,877	542,369	2,849,437	395,564	2,330,194	63,311	119,440,332	155,498	21,403,884	10,204,476
CAM	5,638,492	356,679	432,898	1,574,395	897,917	189,605	31,243	39,593,068	3,917,597	8,020,096	4,608,548
SAM	22,750,189	651,745	764,352	2,509,571	1,556,492	401,514	24,337	89,135,853	7,871,454	18,491,922	5,169,705
SAS	17,549,742	7,288,006	950,119	4,688,186	1,264,147	14,126,946	669	483,603,288	2,695,137	5,274,493	11,689,584
SEA	7,880,517	851,787	262,968	3,931,940	2,159,030	362,664	72,835	37,780,119	20,596,180	18,769,985	11,705,654
CHI	9,132,481	4,737,568	1,474,903	6,368,900	4,692,874	224,282	22,428	22,233,865	71,966,193	22,750,507	35,356,525
NAF	4,784,838	2,452,346	946,802	1,108,991	262,295	1,027,320	21,944	42,934,329	17,894	6,374,699	2,650,485
SSA	45,234,383	20,125,895	14,677,534	13,413,888	3,237,420	1,322,098	115,705	253,261,414	11,245,594	26,026,639	15,125,021
RoW	5,321,644	1,131,604	500,293	1,579,756	687,226	311,160	25,524	8,462,396	2,935,405	1,471,115	1,276,005

Scenario S3

Regions	Bovine meat	Mutton & goat meat	Meat, other	Offal, edible	Fats, animals, raw	Butter, ghee	Cream	Milk - excluding butter	Pig meat	Poultry meat	Eggs
USA	5,348,732	71,893	75,633	95,164	420,967	258,835	1,259	31,982,265	3,725,966	5,921,018	1,804,876
Canada	458,504	12,209	407	19,986	95,635	38,891	92,251	2,852,201	424,867	490,649	154,161
WEU	2,679,387	490,656	482,928	608,994	740,477	643,743	575,662	34,705,020	6,173,330	2,898,013	1,757,070
JPK	783,191	21,704	46,468	222,395	56,072	46,359	0	5,531,020	1,317,834	1,094,040	1,409,131
ANZ	581,359	266,911	16,330	141,875	57,517	58,606	583	3,033,578	273,951	460,428	97,977
EEU	500,075	77,519	45,947	196,965	349,172	126,823	140,363	10,494,735	2,149,749	900,796	629,951
FSU	2,065,227	247,813	110,424	590,768	253,866	272,502	201,960	21,169,297	1,656,267	1,049,889	1,378,337
MDE	2,603,453	3,084,961	199,453	1,047,864	145,466	850,944	23,120	43,617,405	57,032	7,850,287	3,742,689
CAM	1,944,378	122,997	149,281	542,915	309,638	65,219	10,747	13,618,844	1,349,306	2,762,295	1,587,284
SAM	7,855,733	225,050	263,934	866,565	537,463	138,295	8,382	30,701,347	2,714,747	6,377,589	1,782,954
SAS	9,056,501	3,760,957	490,306	2,419,327	652,360	7,152,231	339	244,840,062	1,356,680	2,655,079	5,884,313
SEA	3,110,058	336,159	103,781	1,551,746	852,064	144,212	28,963	15,023,148	8,125,664	7,405,188	4,618,148
CHI	3,242,985	1,682,332	523,745	2,261,625	1,666,461	76,563	7,656	7,589,916	25,183,092	7,961,073	12,372,290
NAF	1,728,890	886,098	342,105	400,708	94,774	368,612	7,874	15,405,216	6,448	2,297,243	955,152
SSA	19,065,202	8,482,580	6,186,227	5,653,631	1,364,494	555,937	48,654	106,495,444	4,752,759	10,999,715	6,392,332
RoW	1,516,029	334,165	152,736	445,221	197,777	96,425	13,844	3,509,708	879,834	543,585	421,397

Scenario S4

Regions	Bovine meat	Mutton & goat meat	Meat, other	Offal, edible	Fats, animals, raw	Butter, ghee	Cream	Milk - excluding butter	Pig meat	Poultry meat	Eggs
USA	6,039,299	81,175	85,398	107,451	475,317	292,253	1,421	36,111,446	4,207,020	6,685,471	2,037,901
Canada	515,108	13,716	457	22,453	107,441	43,692	103,640	3,204,317	477,319	551,222	173,193
WEU	3,020,349	553,093	544,382	686,491	834,705	725,661	648,917	39,121,358	6,958,908	3,266,796	1,980,663
JPK	885,513	24,540	52,539	251,450	63,398	52,416	0	6,253,635	1,490,006	1,236,974	1,593,231
ANZ	654,848	300,651	18,394	159,809	64,787	66,014	657	3,417,050	308,581	518,630	110,362
EEU	573,277	88,866	52,672	225,797	400,284	145,388	160,909	12,030,965	2,464,431	1,032,655	722,164
FSU	2,396,347	287,545	128,129	685,486	294,568	316,192	234,341	24,563,388	1,921,818	1,218,218	1,599,327
MDE	2,982,095	3,533,633	228,461	1,200,264	166,623	974,704	26,483	49,961,056	65,327	8,992,021	4,287,020
CAM	2,262,733	143,136	173,722	631,806	360,335	75,897	12,506	15,848,672	1,570,229	3,214,569	1,847,172
SAM	9,129,556	261,542	306,731	1,007,080	624,614	160,719	9,742	35,679,635	3,154,950	7,411,728	2,072,064
SAS	10,501,779	4,361,148	568,552	2,805,414	756,467	8,293,616	393	283,912,754	1,573,186	3,078,789	6,823,359
SEA	3,601,674	389,297	120,186	1,797,035	986,753	167,008	33,541	17,397,901	9,410,112	8,575,748	5,348,152
CHI	3,717,556	1,928,520	600,388	2,592,586	1,910,326	87,767	8,777	8,700,606	28,868,326	9,126,077	14,182,822
NAF	2,000,042	1,025,070	395,759	463,554	109,638	426,423	9,109	17,821,304	7,460	2,657,533	1,104,954
SSA	21,579,273	9,601,152	7,001,986	6,399,158	1,544,426	629,247	55,069	120,538,673	5,379,490	12,450,214	7,235,270
RoW	1,694,412	372,096	169,506	498,175	220,813	106,860	14,700	3,793,496	977,958	592,761	464,050

Appendix V: Agricultural production changes in 2050 relative to the baseline in 2050

Region	Baseline relative to 2000 (%)	Percentage change relative to baseline 2050							
		TL1	TL2	A1B	A2	A1B+T1	A1B+TL2	A2+TL1	A2+TL2
USA	89	-0.41	-0.35	-9.20	-10.12	-9.40	-9.36	-10.31	-10.28
CAN	50	0.66	1.76	-10.04	-8.53	-9.53	-8.78	-7.99	-7.21
WEU	5	0.21	-0.41	4.30	4.83	4.73	4.19	5.27	4.72
JPK	6	-0.26	0.22	6.47	6.86	6.61	7.52	7.01	7.85
ANZ	67	1.48	1.49	6.95	9.49	8.40	8.41	10.90	10.93
EEU	33	-0.14	-0.24	2.59	2.29	2.49	2.43	2.18	2.12
FSU	79	-0.15	-0.18	-21.28	-20.42	-21.30	-21.28	-20.41	-20.39
MDE	93	0.11	0.08	-23.24	-16.81	-23.23	-23.22	-16.76	-16.75
CAM	139	-0.12	-0.19	-1.70	-2.70	-1.81	-1.89	-2.80	-2.88
SAM	248	0.21	0.16	-1.77	-1.81	-1.65	-1.76	-1.70	-1.80
SAS	84	-0.73	-0.76	-3.16	-2.17	-3.89	-3.84	-2.97	-2.93
SEA	101	0.01	0.04	-11.63	-12.28	-11.74	-11.68	-12.40	-12.34
CHI	31	0.20	0.37	11.18	9.04	11.54	11.88	9.36	9.68
NAF	110	0.12	-0.17	-8.90	-13.73	-8.91	-9.00	-13.73	-13.81
SSA	158	-0.29	-0.39	3.54	3.69	3.24	3.13	3.39	3.28
RoW	173	0.91	0.93	-3.58	-3.64	-2.82	-2.79	-2.89	-2.86

Source: Calzadilla et al. (2011a)

Appendix VI: Coefficient for change in unit water footprint of agricultural commodities per region per scenario (α values)

Region	S1 & S2			S3 & S4		
	Blue WF	Green WF	Grey WF	Blue WF	Green WF	Grey WF
USA	0.80	1.00	1.00	1.00	0.80	0.80
Canada	0.80	1.00	1.00	1.00	0.80	0.80
WEU	0.80	1.00	1.00	1.00	0.80	0.80
JPK	0.80	1.00	1.00	1.00	0.80	0.80
ANZ	0.80	1.00	1.00	1.00	0.80	0.80
EEU	0.80	1.00	1.00	1.00	0.70	0.70
FSU	0.80	1.00	1.00	1.00	0.70	0.70
MDE	0.80	1.00	1.00	1.00	0.80	0.80
CAM	0.70	1.00	1.00	1.00	0.80	0.80
SAM	0.70	1.00	1.00	1.00	0.80	0.80
SAS	0.70	1.00	1.00	1.00	0.60	0.60
SEA	0.70	1.00	1.00	1.00	0.60	0.60
CHI	0.70	1.00	1.00	1.00	0.60	0.60
NAF	0.80	1.00	1.00	1.00	0.80	0.80
SSA	0.60	1.00	1.00	1.00	0.80	0.80
RoW	0.80	1.00	1.00	1.00	0.80	0.80

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UNESCO-IHE
P.O. Box 3015
2601 DA Delft
The Netherlands

Website www.unesco-ihe.org
Phone +31 15 2151715

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Institute for Water Education

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