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Water footprint and virtual water trade of China

Past and future

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WATER FOOTPRINT AND VIRTUAL WATER TRADE OF CHINA: PAST AND FUTURE

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Contents

Summary

The long-term sustainability of human's water consumption is being challenged by climate change, population growth, socio-economic development and intensified competition for finite water resources among different sectors. Previous studies into the relation between human consumption and indirect water resources use have unveiled the remote connections in virtual water (VW) trade networks, which show how communities externalize their water footprint (WF) to places far beyond their own region, but little has been done to understand variability in time. With a focus on crop production, consumption and trade of China, this study quantifies the inter-annual variability and developments in consumptive (green and blue) WFs and VW trade in China over the period 1978-2008 (Part 1) and assesses consumptive WFs and VW trade of China under alternative scenarios for 2030 and 2050 (Part 2). We consider five driving factors of change: climate, harvested crop area, technology, diet, and population. Evapotranspiration, crop yields and WFs of crops are estimated at a 5×5 arc-minute resolution for 22 crops. Four future scenarios (S1–S4) are constructed by making use of three of IPCC's shared socio-economic pathways (SSP1–SSP3) and two of IPCC's representative concentration pathways (RCP 2.6 and RCP 8.5) and taking 2005 as the baseline year.

Results show that, over the period 1978-2008, crop yield improvements helped to reduce the national average WF of crop consumption per capita by 23%, with a decreasing contribution to the total from cereals and increasing contribution from oil crops. The total consumptive WFs of national crop consumption and crop production, however, grew by 6% and 7%, respectively. Historically, the net VW within China was from the water-rich South to the water-scarce North, but intensifying North-to-South crop trade reversed the net VW flow since 2000, which amounted 6% of North's WF of crop production in 2008. China's domestic inter-regional VW flows went dominantly from areas with a relatively large to areas with a relatively small blue WF per unit of crop, which in 2008 resulted in a trade-related blue water loss of 7% of the national total blue WF of crop production. By 2008, 28% of total water consumption in crop fields in China served the production of crops for export to other regions and, on average, 35% of the crop-related WF of a Chinese consumer was outside its own province. Across the four future scenarios and for most crops, the green and blue WFs per tonne will decrease compared to the baseline year, due to the projected crop yield increase, which is driven by the higher precipitation and CO_2 concentration under the two RCPs and the foreseen uptake of better technology. The WF per capita related to food consumption decreases in all scenarios. Changing to the less-meat diet can generate a reduction in the WF of food consumption of 44% by 2050. As a result of the projected increase in crop yields and thus overall growth in crop production, China will reverse its role from net VW importer to net VW exporter. However, China will remain a big net VW importer related to soybean, which accounts for 5% of the WF of Chinese food consumption (in S1) by 2050.

The past of China shows that domestic trade, as governed by economics and governmental policies rather than by regional differences in water endowments, determines inter-regional water dependencies and may worsen rather than relieve the water scarcity in a country. All future scenarios show that China could attain a high degree of food self-sufficiency while simultaneously reducing water consumption in agriculture. However, the premise of realizing the presented scenarios is smart water and cropland management, effective and coherent policies on water, agriculture and infrastructure, and, as in scenario S1, a shift to a diet containing less meat.

Part 1. Water footprints and inter-regional virtual water flows in China over 1978-2008*

1. Introduction

Since the beginning of this millennium the body of scientific literature on water footprint (WF) and virtual water (VW) trade assessment is expanding exponentially, as witnessed by the number of papers published on the topic in Web of Science. The WF, as a multi-dimensional measure of freshwater used both directly and indirectly by a producer or a consumer, enables to analyse the link between human consumption and the appropriation of water to produce the products consumed (Hoekstra, 2013). The consumptive WF of producing a crop includes a green and blue component, referring to consumption of rainfall and irrigation water respectively, thus enabling the broadening of perspective on water resources as proposed by Falkenmark and Rockström (2004). The consumptive WF is distinguished from the degradative WF, the so-called grey WF, which represents the volume of water required to assimilate pollutants entering freshwater bodies. The WF of human consumption within a certain geographic area consists of an internal WF, referring to the WF within the area itself for making products that are consumed within the area, and an external WF, referring to the WF in other areas for making products imported by and consumed within the geographic area considered (Hoekstra et al., 2011). Thus, trade in water-intensive commodities like crops results into so-called VW flows between exporting and importing regions (Hoekstra, 2003). Crop trade saves water resources for an administrative region if it imports water-intensive crops instead of producing them domestically (Chapagain et al., 2006).

WF and VW trade studies have been carried out for geographies at different scales, from the city (Zhang et al., 2011) to the globe (Hoekstra and Mekonnen, 2012). Despite the vast body of literature, little attention has been paid to the annual variability and long-term changes of WFs and VW flows as a result of climate variability and structural changes in the economy. Most work thus far focussed on employing different models and techniques to assess WFs and VW flows, considering a specific year or short period of years. The effects of long-term changes in spatial patterns of production, consumption, trade and climate on WFs and VW flows have hardly been studied. This is paramount, though, for understanding how human pressure on water resources develops over time and how changing trade patterns influence inter-regional water dependencies.

The objective of Part 1 of this report is to quantify the effect of inter-annual variability of consumption, production, trade and climate on crop-related green and blue WFs and inter-regional VW trade, using China over the period 1978-2008 as a case study. First, we assess the historical development of the green and blue WFs related to crop *consumption* in China, per province. Second, we estimate, accounting for the climate variability within the period considered, the green and blue WFs related to crop *production*, at a 5×5 arc-minute resolution, year by year, crop by crop. Third, we quantify the annual inter-regional VW flows based on provincial crop trade balances for each crop. Finally, we estimate national water savings as a result of international and inter-regional crop trade. We consider twenty-two primary crops (Table 3), which covered 83%

* This part of the report is based on: Zhuo, L., Mekonnen, M.M. and Hoekstra, A.Y. (2016) The effect of inter-annual variability of consumption, production, trade and climate on crop-related green and blue water footprints and inter-regional virtual water trade: A study for China (1978-2008), Water Research, 94: 73–85.

of national crop harvested area in 2009 (NBSC, 2013) and 97% and 78% of the total blue and green WF of Chinese crop production in the period 1996-2005, respectively (Mekonnen and Hoekstra, 2011). In this study we exclude the grey WF of crops because of our focus on inter-annual variability and the fact that variability in climate plays a role particularly in estimating green and blue WFs, not in estimating grey WFs. We focus on the direct green and blue WF of crop growing in the field, thus excluding the indirect WF of other inputs into crop production, like the WF of machineries and energy used. The study area is Mainland China, which consists of 31 provinces and can be grouped into eight regions (Fig. 1).

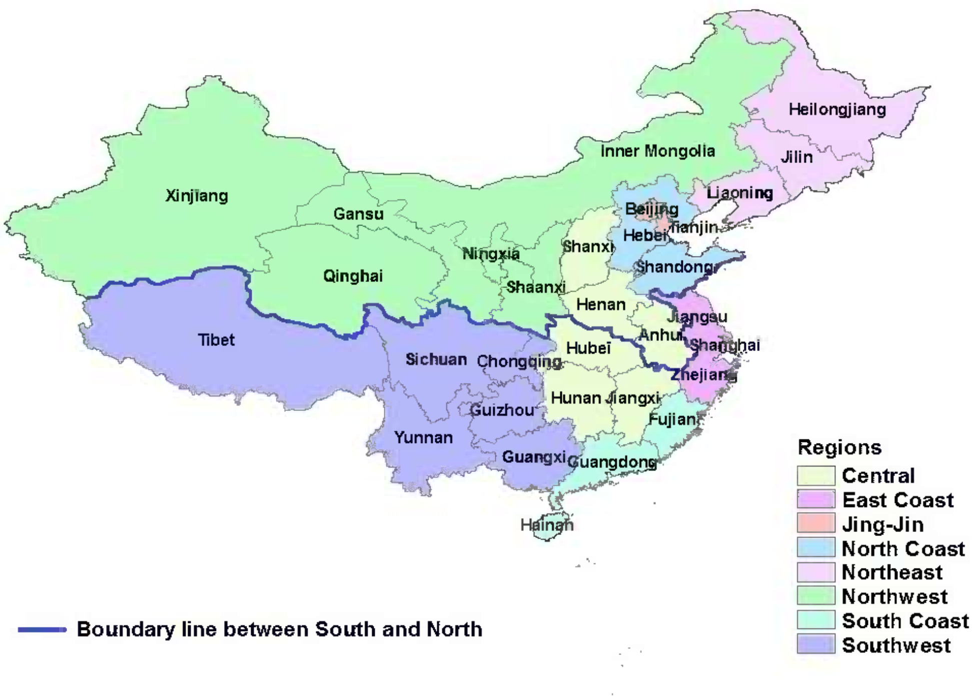


Figure 1. Provinces and regions of Mainland China.

China is facing severe water scarcity (Jiang, 2009; 2015). Since the economic reforms in 1978, the Chinese people consume increasing levels of oil crops, sugar crops, vegetables and fruits (Liu and Savenije, 2008). Chinese crop consumption per capita rose by a factor 2.1 over the period 1978-2008 (FAO, 2014), while China's population grew from 0.96 to 1.31 billion (NBSC, 2013). In order to meet the increasing food demand, China's crop production grew by a factor 2.8 from 1978 to 2008 (FAO, 2014), with an increase of only 4% in total harvested area, but a 31% growth in irrigated area. The expansion of the irrigated area occurred mainly (77%) in the water-scarce North, which now has 51% of the national arable land, but only 19% of the national blue water resources (Wu et al., 2010; Zhang et al., 2009). Agriculture is the biggest water user in China, responsible for 63% of national total blue water withdrawals (MWR, 2014) and 88% of the total WF within China (Hoekstra and Mekonnen, 2012). Currently, the Yellow River basin in the North suffers moderate to severe blue water scarcity during seven months of the year, mostly driven by agricultural water use (Zhuo et al., 2016a). The Yongding He Basin in northern China, a densely populated basin serving water to Beijing, faces severe water scarcity all year long (Hoekstra et al., 2012). It is estimated that about 64% of China's total population, mainly from the North, regularly faces severe blue water scarcity (Mekonnen and Hoekstra, 2016). The competition between different sectors over water resources has become severe (Zhu et al., 2013), which has led to the adoption of the No. 1 Document by the State Council of China (SCPRC, 2010), announcing a four trillion CNY (~US$600 billion) investment over ten years to guarantee water supplies through the improvement of water supply infrastructure. This includes the construction of new reservoirs, drilling of wells, and implementation of inter-basin water transfer projects (Gong et al., 2011; Yu, 2011), as well as targets to increase water productivity.

Today, China is the country with the largest WF related to crop consumption and the second largest WF related to crop production (Hoekstra and Mekonnen, 2012). Furthermore, China has substantive VW import through crop imports (Dalin et al., 2014). At present, net VW trade through crop trade is from the drier North to the wetter South (Ma et al., 2006; Cao et al., 2011). In 2005, China's domestic food trade resulted in national net water saving overall, but a net loss of blue water (Dalin et al., 2014), as a result of differences in WF of crops (m^3 t^{-1}) among trading provinces (Mekonnen and Hoekstra, 2011).

There have been quite a number of previous studies on the WF of Chinese crop consumption (Hoekstra and Chapagain, 2007, 2008; Liu and Savenije, 2008; Mekonnen and Hoekstra, 2011; Ge et al. 2011; Hoekstra and Mekonnen, 2012; Cao et al., 2015), the WF of Chinese crop production (Hoekstra and Chapagain, 2007, 2008; Siebert and Döll, 2010; Liu and Yang, 2010; Fader et al., 2010; Mekonnen and Hoekstra, 2011; Ge et al. 2011; Cao et al., 2014a,b), on China's international VW imports and exports associated with crop trade (Hoekstra and Hung, 2005; Hoekstra and Chapagain, 2007, 2008; Liu et al., 2007; Fader et al., 2011; Hoekstra and Mekonnen, 2012; Dalin et al., 2012; Chen and Chen, 2013; Shi et al., 2014) and on VW flows within China (Ma et al., 2006; Guan and Hubacek, 2007; Wu et al., 2010; Cao et al., 2011; Han and Sun, 2013; Sun et al., 2013; Dalin et al., 2014; Feng et al., 2014; Wang et al., 2014; Zhang and Anadon, 2014; Zhao and Chen, 2014; Fang and Chen, 2015; Jiang et al., 2015; Zhao et al., 2015). Despite all those studies, analyses of *inter-annual variability* and *long-term changes* in spatial WF and VW trade patterns are rare, not only in studies for China but in general. While in another paper (Zhuo et al., 2016a) we show the inter-annual variations in WFs of *crop production* as well as inter-annual variation of blue water scarcity (with a focus on the Yellow River basin), in the current study we also consider inter-annual variability in WFs of *crop consumption* and in inter-regional and international VW trade (for China as a whole).

2. Method and data

2.1. Estimating water footprint related to crop consumption

The annual green and blue WFs of crop *consumption* (in $m^3 y^{-1}$) were estimated per crop per year at provincial level based on the bottom-up approach (Hoekstra et al., 2011). The WF related to consumption of a crop ($m^3 y^{-1}$) was calculated per year by multiplying the provincial crop consumption volume ($t\ y^{-1}$) with the WF of the crop for the province ($m^3 t^{-1}$). Crop consumption volumes per capita were obtained from the Supply and Utilization Accounts expressed in crops primary equivalent of FAO (2014). We assumed consumption per capita data the same for all provinces. For edible crops, we took the sum of the "food" and "food manufactured" columns and added an amount representing seed and waste. Regarding the latter amount, we took a part of the utilization for seed and waste based on the utilization of crops for food and food manufactured relative to the utilization of crops for feed. For cotton and tobacco, we took the "other use" column as consumed quantities. The WF of crops per province were calculated as:

$$WF_{prov}[p] = \frac{P_{prov}[p] \times WF_{prod,prov}[p] + \sum_{e}(I_e[p] \times WF_{prod,e}[p])}{P_{prov}[p] + \sum_{e} I_e[p]} \qquad (1)$$

in which $P_{prov}[p]$ ($t\ y^{-1}$) represents the production quantity of crop p, $I_e[p]$ ($t\ y^{-1}$) the imported quantity of crop p from exporting place e (other regions in China or other countries), $WF_{prod,prov}[p]$ ($m^3 t^{-1}$) the specific WF of crop production in the province, and $WF_{prod,e}[p]$ ($m^3 t^{-1}$) the WF of the crop as produced in exporting place e. An example of WF estimation related to crop consumption is provided for wheat in the year 2006 in Appendix I.

2.2. Estimating water footprint of crop production

The green and blue WFs of crop *production* were estimated year by year at 5×5 arc minute resolution. The green and blue WF (in $m^3 t^{-1}$) of a crop within a grid cell is calculated as the actual green and blue evapotranspiration (ET, $m^3 ha^{-1}$) over the growing period divided by the crop yield (Y, $t\ ha^{-1}$). ET and Y were simulated per crop per grid per year at daily basis using the plug-in version of FAO's crop water productivity model AquaCrop version 4.0 (Steduto et al, 2009; Reas et al., 2009; Hsiao et al., 2009). The separation of green and blue ET was carried out by tracking the daily green and blue soil water balances based on the contribution of rainfall and irrigation, respectively, following Chukalla et al. (2015) and Zhuo et al. (2016a).

2.3. Estimating inter-regional virtual water flows

Inter-regional VW flows ($m^3 y^{-1}$) related to crop trade were calculated per year by multiplying the inter-regional crop trade flows ($t\ y^{-1}$) with the WF of the crop ($m^3 t^{-1}$) in the exporting region. Since inter-regional crop trade statistics are not available, we took the following steps:

1) The provincial crop trade balance or net import of a crop ($t\ y^{-1}$) was estimated as the total provincial crop utilization minus the provincial crop production. The national use of a crop for direct and manufactured food as given by FAO (2014) was distributed over the provinces based on provincial populations. The national use of a crop for feed was

distributed over provinces proportional to the national livestock units (LU) per province. LU is a reference unit which facilitates the aggregation of different livestock types to a common unit, via the use of a ‘livestock unit coefficient’ obtained by converting the livestock body weight into the metabolic weight by an exchange ratio (FAO, 2005). We used the livestock unit coefficients for East Asia from Chilonda and Otte (2006): 0.65 for cattle, 0.1 for sheep and goats, 0.25 for pigs, 0.5 for asses, 0.65 for horses, 0.6 for mules, 0.8 for camels, and 0.01 for chickens. Finally, we downscale national variations in crop stock to provincial level by assuming provincial stock variations proportional to the provincial share in national production.

2) We assume that international crop imports and exports relate to the provinces with deficit and surplus of the crop, respectively (following Ma et al., 2006). Further we assume that crop-deficit provinces primarily receive from crop-surplus provinces within the same region and subsequently – if insufficient surplus within the region itself – from other crop-surplus regions.
3) A crop-deficit region is assumed to import the crop preferentially from the crop-surplus region which has the highest agricultural export values to the crop-deficit region, according to the multi-regional input-output tables of the agricultural sector for the years 1997 (SIC, 2005), 2002 and 2007 (Zhang and Qi, 2011). How source regions supply deficit regions is determined in a few subsequent rounds. The source regions per region per allocation round are listed in Table 1. We assume that in each round the crop source regions supply crops to the deficit regions proportionally to their deficit.

Table 1. Crop source regions per region for Mainland China.

	Region*	Provinces	Crop source regions per allocation round						
			1	2	3	4	5	6	7
R1	Northeast (N)	Heilongjiang, Jilin, Liaoning	R3	R7	R6	R8	R5	R4	R2
R2	Jing-Jin (N)	Beijing, Tianjin	R3	R7	R1	R6	R8	R5	R4
R3	North Coast (N)	Hebei, Shandong	R7	R1	R6	R8	R2	R5	R4
R4	East Coast (S)	Jiangsu, Shanghai, Zhejiang	R6	R7	R3	R1	R8	R5	R2
R5	South Coast (S)	Fujian, Guangdong, Hainan	R6	R8	R7	R3	R1	R4	R2
R6	Central	Shanxi (N), Henan (N), Anhui (N), Hubei (S), Hunan (S), Jiangxi (S)	R3	R7	R1	R8	R5	R4	R2
R7	Northwest (N)	Inner Mongolia, Shaanxi, Ningxia, Gansu, Qinghai, Xinjiang	R6	R3	R8	R1	R5	R4	R2
R8	Southwest (S)	Sichuan, Chongqing, Guangxi, Yunnan, Guizhou, Tibet	R7	R1	R6	R3	R5	R4	R2

* N = North China; S = South China.

The total crop-related net VW import ($m^3 y^{-1}$) of a province is equal to the international net VW import plus the inter-regional net VW import of the province. The WFs ($m^3 t^{-1}$) of crops imported from abroad were obtained from Mekonnen and Hoekstra (2011), assuming constant green and blue WFs of imported crops per source country. The provincial net VW export related to a certain crop export is calculated by multiplying the net crop export volume ($t\ y^{-1}$) with the WF ($m^3 t^{-1}$) of the crop in the province.

2.4. Quantifying water savings through crop trade

Water savings through crop trade were estimated using the method of Chapagain et al. (2006). The international crop trade-related water saving of a province ($m^3\ y^{-1}$) was calculated by multiplying the net international import volume of the province ($t\ y^{-1}$) by the WF per tonne of the crop in the province ($m^3\ t^{-1}$). The inter-regional crop trade-related water saving was estimated similarly, by multiplying the net inter-regional import volume of the province ($t\ y^{-1}$) with the WF per tonne of the crop in the province ($m^3\ t^{-1}$). If a specific crop is imported and not grown in the province itself at all, the national average WF per tonne of the crop was used. Overall trade-related water savings follow from the difference in the WF of a crop in the importing and exporting province (Hoekstra et al., 2011). When calculated trade-related water savings are negative, we talk about trade-related 'water losses', which refer to cases whereby crops are traded from a region with relatively low water productivity to a region with relatively high water productivity.

2.5. Data

The GIS polygon for Chinese provinces was obtained from NASMG (2010). Provincial population statistics over the study period and numbers of the different livestock types were obtained from NBSC (2013), and data on China's international trade per crop (in $t\ y^{-1}$) from FAO (2014). Data on monthly precipitation, reference evapotranspiration and temperature at 30×30 arc minute resolution were taken from Harris et al. (2014). Figure 2 shows the inter-annual variation of national average precipitation and reference evapotranspiration (ET_0) across China over the period 1978-2008. Data on irrigated and rain-fed areas for each crop at 5×5 arc-minute resolution were taken from Portmann et al. (2010). For crops not available in this source, we used Monfreda et al. (2008). Harvested areas and yields for each crop were scaled per year to fit the annual agriculture statistics at province level obtained from NBSC (2013). For crops not reported in NBSC (2013), we used FAO (2014). Soil texture data were obtained from Dijkshoorn et al. (2008). For hydraulic characteristics for each type of soil, the indicative values provided by AquaCrop were used. Data on total soil water capacity were obtained from Batjes (2012). Details on datasets used can be found in Table 2.

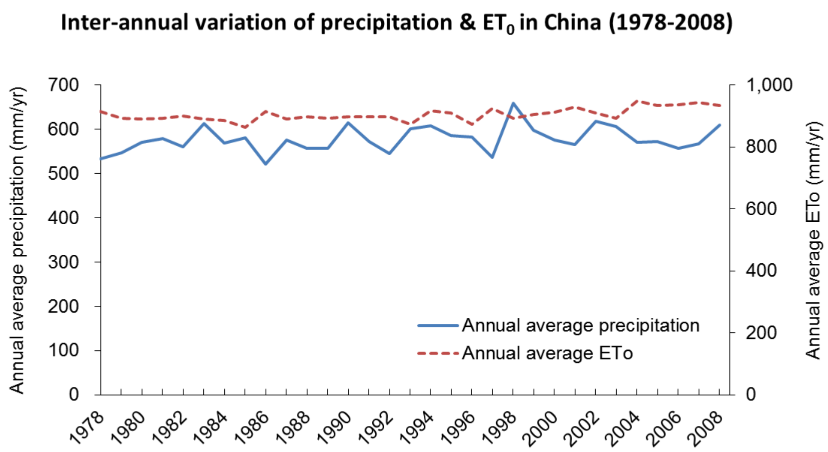


Figure 2. Inter-annual variation of national average precipitation and reference evapotranspiration (ET_0) across China over the period 1978-2008. Data source: Harris et al. (2014).

Table 2. Overview of data sources.

Data type	Spatial resolution	Source(s)
GIS database of administrations	Provincial	NASMG (2010)
Annual population statistics	Provincial	NBSC (2013)
Statistics on annual total production and total harvested area of each crop	Provincial/national	NBSC (2013) / FAO (2014)
Statistics on crop trade	International	FAO (2014)
Monthly climate data on precipitation and ET_0	30×30 arc minute	Harris et al., 2014
Irrigated and rain-fed area of each crop	5×5 arc minute	Portmann et al., 2010) / Monfreda et al. (2008)
Soil texture	1 : 1,000,000	Dijkshoorn et al. (2008)
Total soil water capacity	5×5 arc minute	Batjes (2012)

3. Results

3.1. Water footprint of crop consumption

Over the study period 1978-2008, Chinese annual per capita consumption of the 22 considered crops has grown by a factor 1.4, from 391 to 559 kg cap^{-1}. The national average WF per capita related to crop consumption reduced by 23%, from 625 m^3 cap^{-1} (149 m^3 cap^{-1} blue WF) in 1978 to 481 m^3 cap^{-1} (94 m^3 cap^{-1} blue WF) in 2008 (Fig. 3), which was mainly due to the decline in the WF per tonne of crops (Table 3). The decline in the WF per tonne of crop resulted from improved crop yields within China as well as the expanded international import of crops from other countries with relatively small WF. The share of the WF related to the consumption of oil crops (soybean, groundnuts, sunflower and rapeseed) in the total consumptive WF per capita grew from 8% in 1978 to 21% in 2008 (Fig. 3), as a result of the increased proportion of oil crops in Chinese consumption.

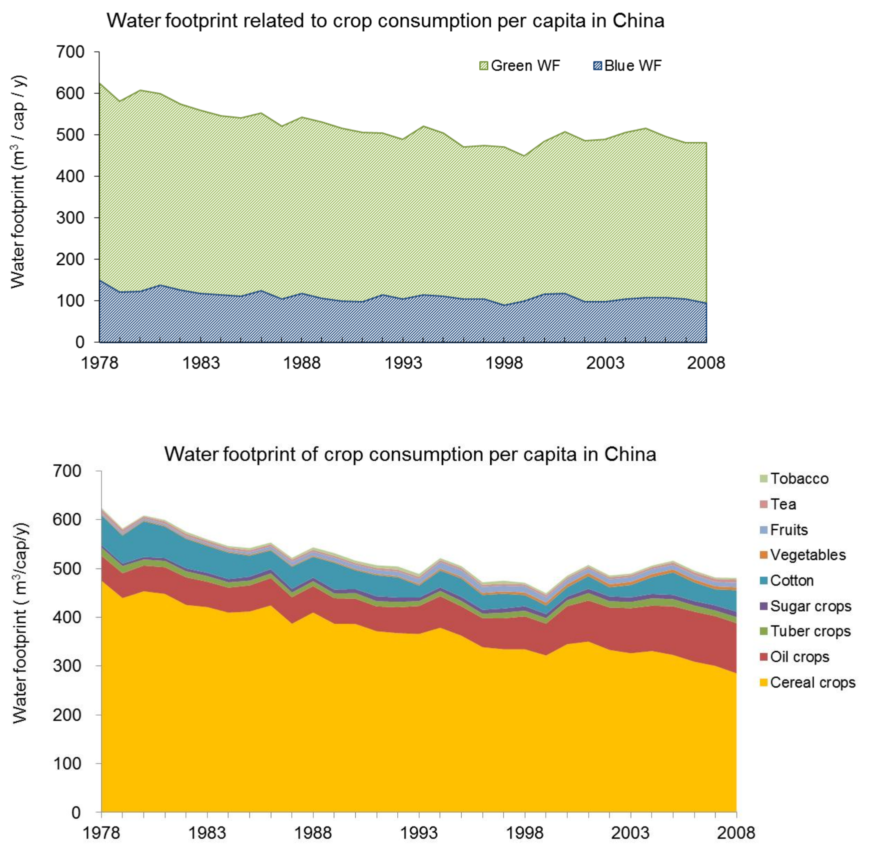


Figure 3. National average water footprint per capita (m^3 cap^{-1} y^{-1}) related to crop consumption in China, specified by water footprint colour (upper graph) and by crop group (lower graph). Period: 1978-2008. The figures represent crop consumption for food, thus excluding crop consumption for feed.

Due to differences in the WF (in m^3 t^{-1}) of the consumed crops in the different provinces, there were differences among provinces in terms of WFs per capita, ranging from 367 to 604 m^3 cap^{-1} y^{-1} for the total consumptive WF and from 29 to 228 m^3 cap^{-1} y^{-1} for the blue WF in the year 2008. Fourteen provinces, mostly located in Southwest, Northeast, North Coast and East Coast, have a WF per capita below the national average (Fig. 4). The three provinces with the largest WF per capita related to crop consumption in 2008 were Ningxia (604 m^3 cap^{-1} y^{-1}), Guangxi (587 m^3 cap^{-1} y^{-1}) and Guangdong (586 m^3 cap^{-1} y^{-1}). Chongqing had the smallest WF per capita (367 m^3 cap^{-1} y^{-1}). Provinces with a blue WF per capita smaller than the national average are mostly located in Southwest, Northeast and East Coast. The three provinces with the largest blue WF per capita in 2008 are all located in the semi-arid Northwest: Inner Mongolia (228 m^3 cap^{-1} y^{-1}), Xinjiang (214 m^3 cap^{-1} y^{-1}) and Ningxia (213 m^3 cap^{-1} y^{-1}). Anhui had the smallest blue WF per capita (29 m^3 cap^{-1} y^{-1}).

Although the total consumption of the 22 considered crops doubled between 1978 and 2008, with 37% of population growth in China, the national WF related to crop consumption increased only by 6%, from 599 to 632 billion m^3 y^{-1} (Fig. 5), thanks to the decline in the WF of crops (m^3 t^{-1}). The share of North China in the total national consumptive WF of crop consumption decreased from 48 to 44% over the study period, amongst other driven by the slightly faster population growth in the South. At provincial level, Shanghai had the largest increase in the WF of crop consumption, a 2.3 times increase over the study period (from 4.6 to 10.5 billion m^3 y^{-1}), followed by Beijing with a 2.0 times increase (from 4.4 to 8.6 billion m^3 y^{-1}). This was mainly driven by the doubling of the population in these two megacities (from 11.0 to 21.4 million in Shanghai and from 8.7 to 17.7 million in Beijing).

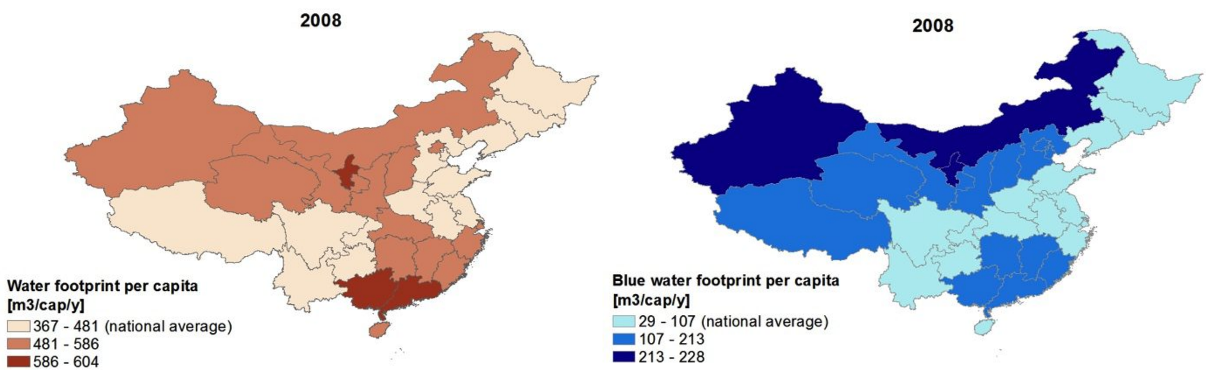


Figure 4. China's provincial average total and blue water footprints per capita (m^3 cap^{-1} y^{-1}) related to crop consumption in 2008. The figures refer to crop consumption for food, thus excluding crop consumption for feed.

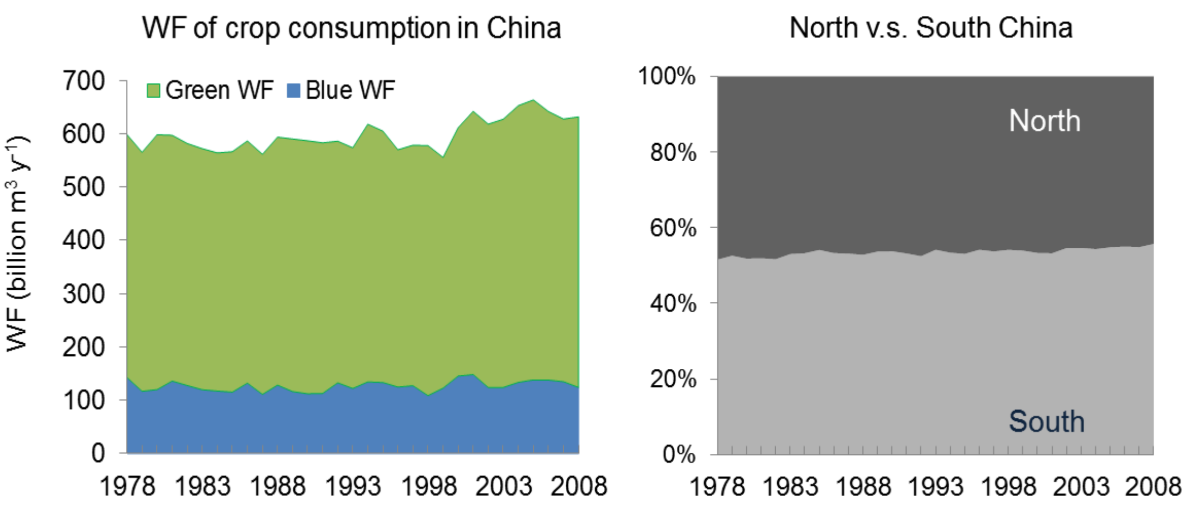


Figure 5. Consumptive water footprints (WFs) of crop consumption in China (left), and the relative contributions of North and South China to the total (right). The figures refer to crop consumption for food, thus excluding crop consumption for feed.

Table 3. National average water footprint of crops consumed in China for the years 1978 and 2008.

	1978			2008		
	Green WF	Blue WF	Total WF	Green WF	Blue WF	Total WF
	$m^3 t^{-1}$	$m^3 t^{-1}$	$m^3 t^{-1}$	$m^3 t^{-1}$	$m^3 t^{-1}$	$m^3 t^{-1}$
Wheat	2080	817	2897	839	312	1151
Maize	1412	121	1534	754	66	819
Rice	1486	615	2101	961	384	1345
Sorghum	1080	88	1168	714	45	759
Barley	839	558	1397	832	198	1030
Millet	2042	184	2225	1811	133	1945
Potatoes	264	7	271	189	7	196
Sweet potatoes	74	40	114	67	21	88
Soybean	3718	677	4395	2024	110	2134
Groundnuts	3165	395	3560	1345	191	1536
Sunflower seed	2177	289	2466	1087	184	1270
Rapeseed	4292	0	4292	1736	0	1736
Seed cotton	5093	539	5632	1278	503	1781
Sugar cane	208	3	211	120	1	121
Sugar beet	372	0	372	66	0	66
Spinach	100	8	107	79	4	83
Tomatoes	126	3	129	68	2	70
Cabbages	181	15	196	130	7	137
Apples	1367	157	1524	314	39	353
Grapes	1011	304	1314	316	104	421
Tea	33518	226	33744	8517	144	8662
Tobacco	2381	84	2465	1633	13	1646

National averages are calculated weighing the water footprints of domestically produced and imported crops.

3.2. Water footprint of crop production

The total green plus blue WF in China of producing the 22 crops considered increased over the period 1978-2008 by 7%, from 682 billion $m^3 y^{-1}$ (23% of blue) to 730 billion $m^3 y^{-1}$ (19% of blue) (Fig. 6), while total production of those crops grew by a factor 2.2. The relatively modest growth of the WF can be attributed to a significant decrease in the WFs per tonne of crop, which in turn result from an increase in crops yield. The national average WF of cereals (wheat, rice, maize, sorghum, millet, and barley), for example, decreased by 46%, from 2136 $m^3 t^{-1}$ (540 $m^3 t^{-1}$ blue WF) to 1146 $m^3 t^{-1}$ (249 $m^3 t^{-1}$ blue WF), due to an almost two-fold increase in cereal yield (from 2.9 to 5.6 t ha^{-1}) (Fig. 7). These findings correspond to long-term decreases in WFs per tonne found in a case study for the Yellow River basin by Zhuo et al. (2016a). Inter-annual climatic variability contributed to the fluctuations in consumptive WFs (m^3 t^{-1}) over the years. When comparing the fluctuations in the average green and blue WFs of a cereal crop in China over the period 1978-2008 (as shown in Fig. 7) to the variations in annual precipitation and ET_0 over the same period (Fig. 2), we find that the blue WF inversely relates to precipitation, and that the green and total consumptive WFs show a weak positive relation to ET_0.

In years with relatively large precipitation, the ratio of blue to total consumptive WF is generally smaller, a finding that could be expected because irrigation requirements will generally be less.

The total harvested area of the considered crops increased by 16% in the North and decreased by 13% in the South. The harvested area and the total consumptive WF of crop production decreased in the provinces that have relatively high urbanization levels (Beijing, Tianjin, Shanghai, Chongqing, Zhejiang, Fujian, Hubei, and Guangdong) and are mostly located in the water-rich South. The most significant drop in the total consumptive WF of crop production (a 65% decrease) was in Shanghai and Zhejiang, with halved harvested areas. At the same time, the other provinces mostly located in the water-scarce North, experienced increases in the total consumptive WF of crop production. The most significant increase (fivefold) in the total consumptive WF was observed in Inner Mongolia, which is located in the semi-arid Northwest, where the harvested area expanded by a factor 3.5 and the irrigated area by a factor 2. The contribution of the water-scarce North to the WF of national crop production increased from 43% in 1978 to 51% in 2008 as a result of increasing cropping area in the North compared to the South and increased irrigation in the North (Fig. 6).

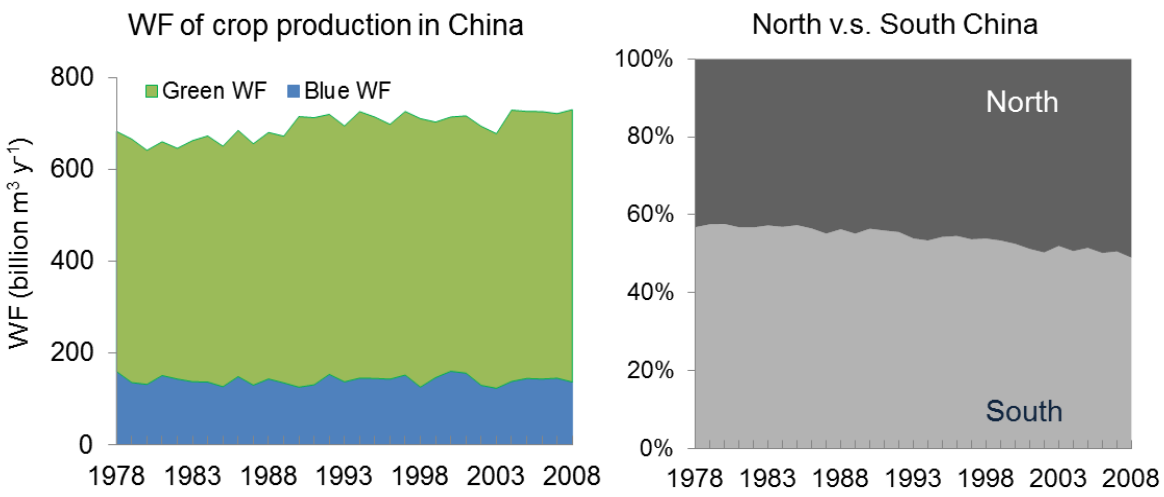


Figure 6. Consumptive water footprints (WFs) of crop production in China, and the relative contributions of North and South China.

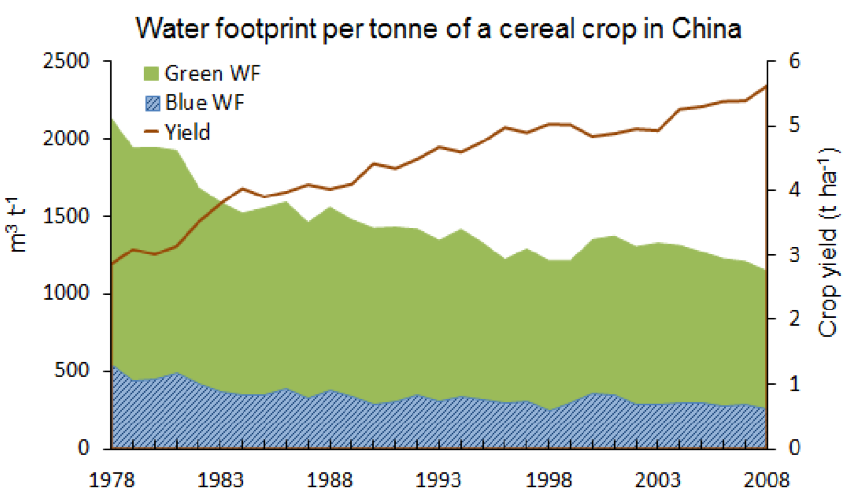


Figure 7. Green and blue WF of cereals (m3 t-1) and cereal yield (t ha-1) in China.

Figure 8 shows the spatial distribution of the total consumptive WF (in mm y^{-1}) of crop production, as well as the share of blue in the total, averaged over the period 1999-2008. Large total consumptive WFs correlate with large overall harvested areas and/or the production of relatively water-intensive crops, while a large share of blue WF in the total reflects the presence of intensive irrigated agriculture. In the semi-arid Northwest and North Coast, blue WF shares exceed 40%, with Xinjiang having the highest share (54%), followed by Hebei (43%) and Ningxia (35%).

Cereals (wheat, maize, rice, sorghum, millet and barley) accounted for 74% of the overall consumptive WF of the 22 crops considered, 87% of the blue WF, and 71% of the green WF. More than half of the total blue WF within China was from rice fields (51%), followed by wheat (28%). Rice (32%) and wheat (20%) together also shared half of the total green WF.

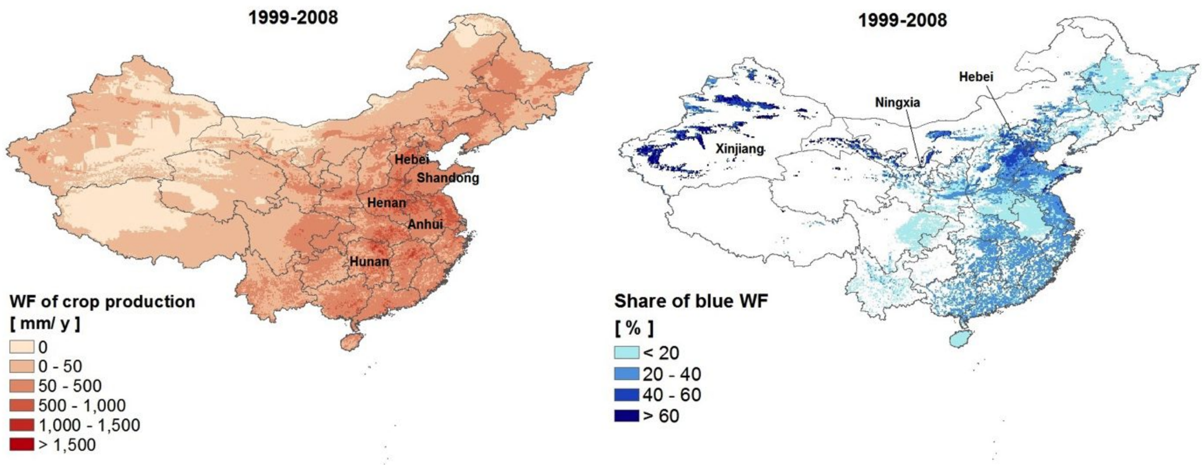


Figure 8. Spatial distribution of consumptive water footprints (WFs) (mm y^{-1}) of crop production (left) and the share of the blue WF in the total (right) in China.

3.3. Crop-related inter-regional virtual water flows in China

China's annual net VW import from abroad nearly tripled over the period 1978-2008 (from 34 to 95 billion $m^3 y^{-1}$). The external WF related to crop consumption in China as a whole was 6% of the total in 1978 and 13% in 2008. The inter-regional VW flows within China were larger than the country's international VW flow. The sum of China's inter-regional VW flows was relatively constant over the period 1978-2000 (with an average of 187 billion $m^3 y^{-1}$), and rose to a bit higher level during the period 2001-2008 (average 207 billion $m^3 y^{-1}$) (Fig. 9). With a total consumptive WF of Chinese crop production in 2008 of 730 billion $m^3 y^{-1}$ and a total gross inter-regional VW trade of 207 billion $m^3 y^{-1}$, we find that 28% of total water consumption in crop fields in China serves the production of crops for export to other regions. When we consider blue water consumption specifically, we find the same value of 28%. Further we find that, on average, in 2008, 35% of the crop-related WF of a Chinese consumer is outside its own province. For some provinces we find much larger external WFs in 2008: 92% for Tibet (83% in other provinces, 10% abroad), 88% for Beijing (68% in other provinces, 20% abroad) and 86% for Shanghai (66% in other provinces, 20% abroad).

The estimated inter-regional trade of the crops considered increased by a factor 2.3 over the study period, but the sum of inter-regional VW trade flows increased only modestly due to the general decline in WFs per tonne of crops traded. Trade in rice is responsible for the largest component in the inter-regional VW trade flows, although its importance is declining: rice-trade related inter-regional VW flows contributed 48% to the total inter-regional VW flows in China in

1978, but 30% in 2008. More and more rice was transferred from the Central region, which has a relatively large WF per tonne of rice, to deficit regions. Rice production in Central accounted for 38% of total national rice production in 1978 and 44% in 2008. The South Coast became a net rice importer since 2005 due to its increased rice consumption (11% of national rice consumption in 2008) and reduced rice production (from 15% of national rice production in 1978 to 9% in 2008). Wheat- and maize-related inter-regional VW flows increased over the period 1978-2008 by 62% and 60%, respectively, due to the estimated increased inter-regional trade volumes of the two staple crops (from 9 to 36 million t y^{-1} for wheat, and from 17 to 51 million t y^{-1} for maize), driven by North China's increased share in national crop production but decreased share in national crop consumption.

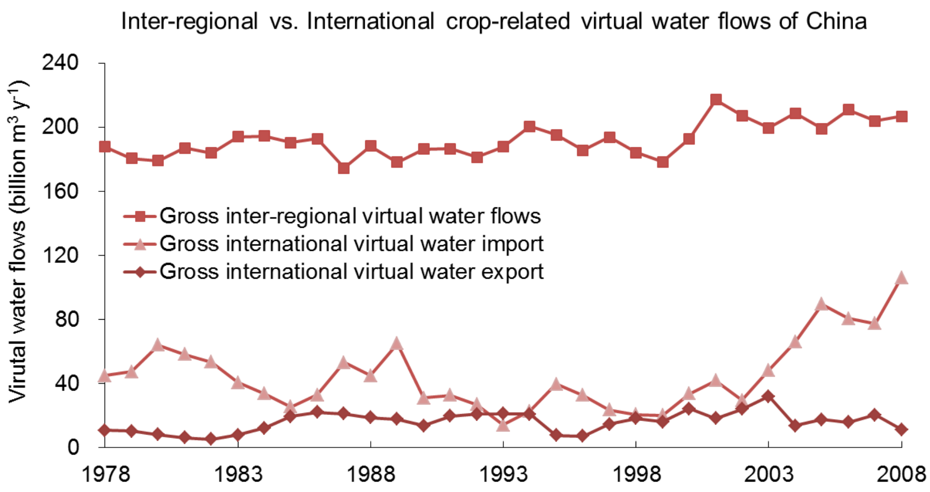


Figure 9. China's inter-regional and international virtual water flows.

Historically, VW flows within China went from South to North, but over time the size of this flow declined and since the year 2000 the VW flow – related to the 22 crops studied here – goes from North to South (Fig. 10). In 2008, the North-to-South VW flow is related to twelve of the twenty-two considered crops (wheat, maize, sorghum, millet, barley, soybean, cotton, sugar beet, groundnuts, sunflower seed, apples and grapes). Still, other crops, most prominently rice, go from South to North. The main driving factor of the reversed VW flow is the faster increase of production in the North and the faster increase of consumption in the South. By 2008, the crop-related net VW flow from North to South has reached 27 billion $m^3 y^{-1}$, equal to 7% of the total consumptive WF of crop production in the North.

Fig. 11 presents the net VW trade balances of all provinces for the years 1978 and 2008, for total VW trade as well as for blue and green VW trade separately, with positive balances reflecting net VW import and negative balances indicating net VW export. The figure also shows total, blue and green net VW flows between North and South and the international net VW flows towards the North and South. International net VW imports to both North and South increased. With regard to blue water, China was a net VW exporter to other countries in the 1978, which was mainly from the South and mostly related to rice exports. With the increased crop consumption of the Chinese population, China as a whole became a net blue VW importer in 1990 and remained since.

Over the whole study period, we find a blue VW flow from South to North. It is the green VW flow, and with that the total VW flow, that reversed direction in the study period. This is the first study that shows this, because previous studies didn't distinguish between the green and blue components in the VW flow between North and South. The reason for the continued blue VW flow from South to North is the continued trade of rice in this direction.

The provinces Zhejiang, Guangdong and Fujian, all located in the South, have changed from net VW exporters to net VW importers, in the years 1999, 1987 and 1981, respectively. By 2008, Guangdong was the largest net VW importing province (36 billion $m^3 y^{-1}$), followed by Sichuan (18 billion $m^3 y^{-1}$) and Zhejiang (15 billion $m^3 y^{-1}$). In the meantime, the provinces Henan and Shandong in the North became net VW exporters, in 1993 and 1983, respectively. In 2008, the three largest crop-related net VW exporters were Heilongjiang (21 billion $m^3 y^{-1}$), Jiangxi (12 billion $m^3 y^{-1}$) and Anhui (10 billion $m^3 y^{-1}$).

The inter-regional VW network related to crop trade has changed significantly over the study period (Fig. 12). The Jing-Jin, Northwest, and Southwest regions were all-time net VW importers. The net VW import of Jing-Jin, where Beijing is located, from other regions has more than doubled, from 4.5 to 9.7 billion $m^3 y^{-1}$, which can be explained by the 84% growth of its population. Central was net VW exporter over the whole study period, with a net VW export increasing from 28 to 52 billion $m^3 y^{-1}$. East Coast and South Coast have changed from net VW exporter in 1978 to net VW importer in 2008, while North Coast reversed in the other direction. The direction of the net VW flow from South Coast to Northeast has been reversed during the study period due to a reversed direction of rice trade between the two regions. While Northeast shifted from a net importer of rice to a net exporter, the reverse happened in South Coast.

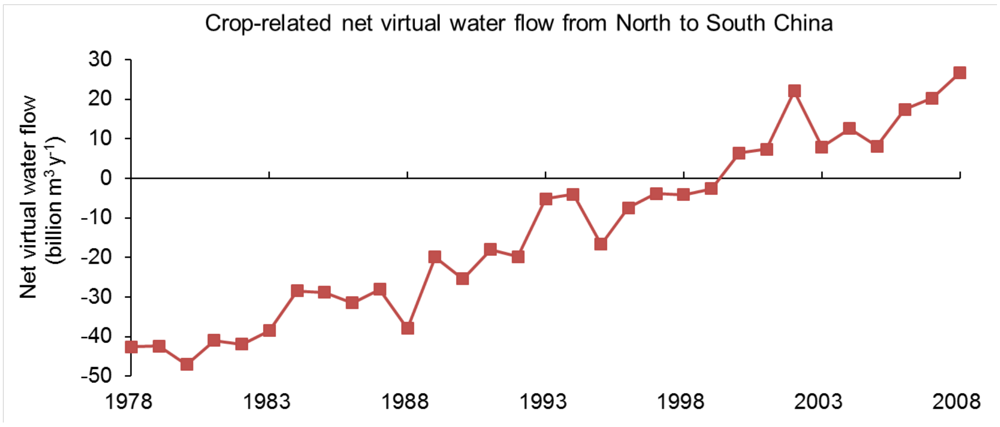


Figure 10. Net virtual water transfer from North to South China resulting from inter-regional crop trade.

3.4. National water saving related to international and inter-regional crop trade

As shown in Fig. 13, China's total national water saving as a result of international crop trade highly fluctuated, amounting to 41 billion $m^3 y^{-1}$ (6% of total national WF of crop production) in 1978 and 108 billion $m^3 y^{-1}$ (15% of total national WF of crop production) in 2008. From 1981 onwards, inter-regional crop trade in China started to save increasing amounts of water for the country in total, reaching to 121 billion $m^3 y^{-1}$ (17% of the total national WF of crop production) by 2008. Inter-regional crop trade in China did not lead to an overall saving of blue water; instead, the trade pattern increased the blue WF in China as a whole, due to the fact that blue WFs per tonne of crop in the exporting regions were often larger than in the importing regions. The blue water loss resulting from inter-regional trade was 20 billion $m^3 y^{-1}$ (13% of national blue WF of crop production) in 1978 and 9 billion $m^3 y^{-1}$ (6% of national blue WF of crop production) in 2008. The decrease was the result of the increased blue water productivity over the years.

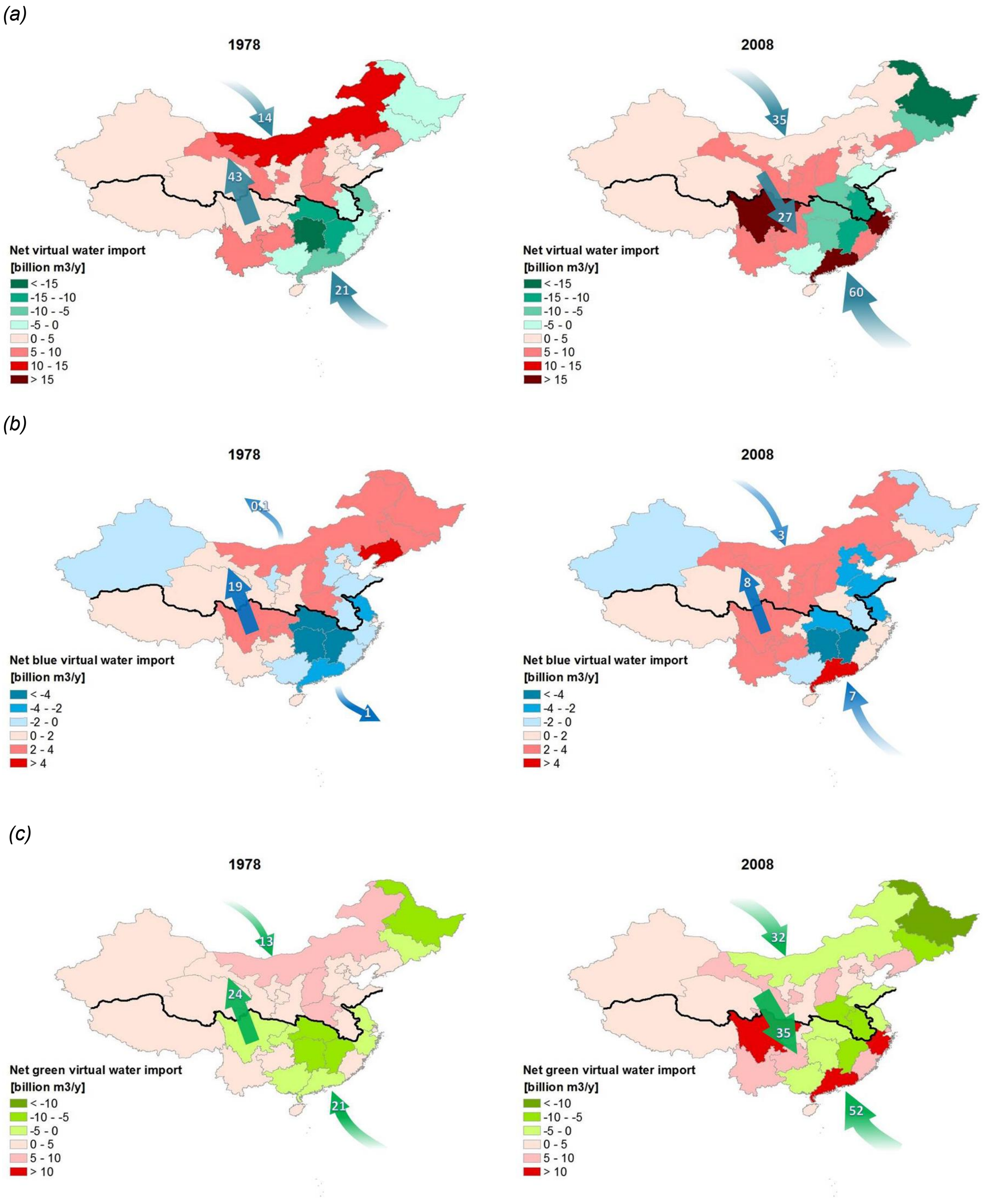


Figure 11. China's provincial crop-related total (a), green (b) and blue (c) net virtual water imports for 1978 (left) and 2008 (right). The net virtual water flows between North and South and the international net virtual water flows of North and South are shown by arrows, with the numbers indicating the size of net virtual water flows in billion m^3 y^{-1}.

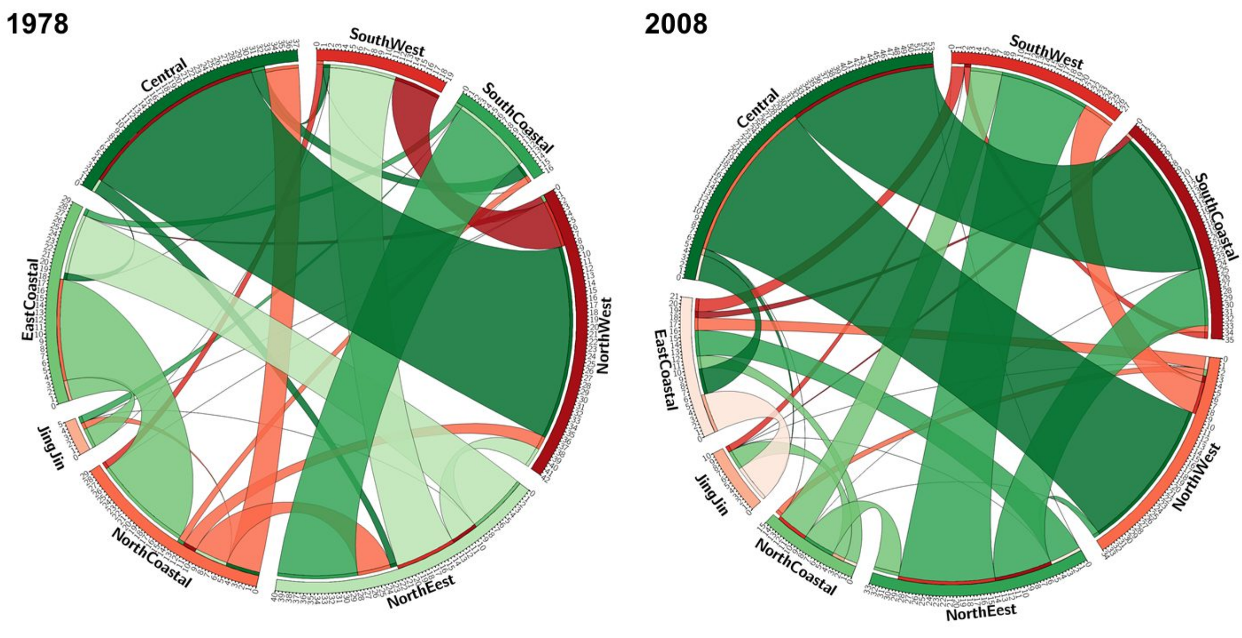


Figure 12. Inter-regional VW flows in China as a result of the trade in 22 crops for 1978 and 2008. The widths of the ribbons are scaled by the volume of the VW flow. The colour of each ribbon corresponds to the export region. The net VW exporters are shown in green segments, the net VW importers are shown in red segments.

Table 4 lists the national water saving related to international and inter-regional trade of China, per crop, for both 1978 and 2008. In recent years, soybean plays the biggest role in the national water saving of China through international crop trade, which confirms earlier findings (Liu et al., 2007; Shi et al., 2014; Chapagain et al., 2006; Dalin et al., 2014). We found that before 1997 the largest national water saving related to international trade was for wheat trade. In 2008, international trade of only four of the 22 crops considered (soybean, rapeseed, cotton and barley) resulted in national water saving for China. The international export of tea led to the greatest national water loss in 2008.

Most of the national water saving related to inter-regional crop trade in 2008 was due to trade in rapeseed, wheat and groundnuts. Due to the increasing inter-regional trade of rapeseed (from 0.8 million t y^{-1} in 1978 to 5 million t y^{-1} in 2008), the generated water saving increased by a factor 4.5 over the study period. The biggest contributor to the national water loss through inter-regional crop trade was rice, with a national water loss of 29 billion m^3 y^{-1} (11% of total consumptive WF of rice production) in 2008. Particularly inter-regional trade in rice and wheat led to blue water losses.

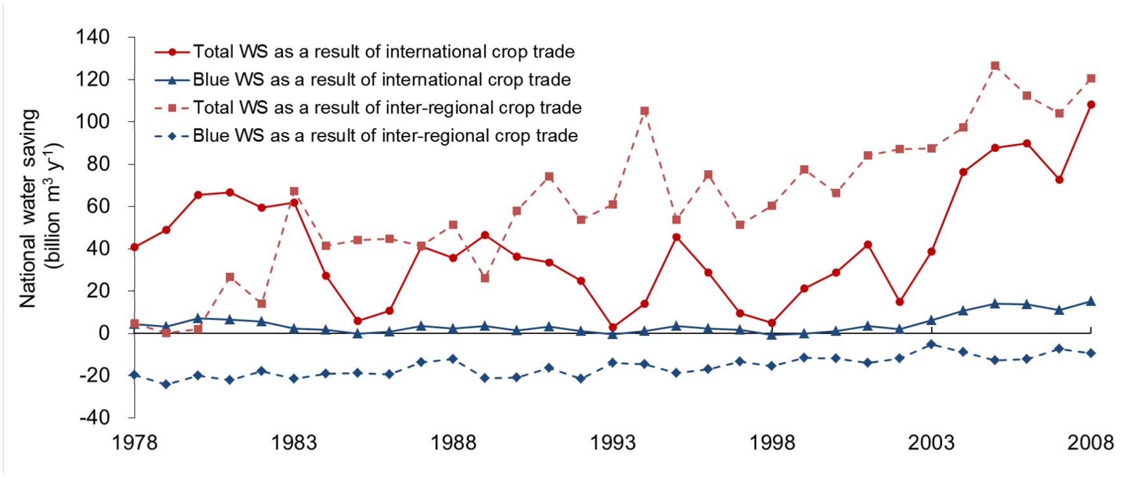


Figure 13. National water saving (WS) as a result of China's international and inter-regional crop trade.

Table 4. National water saving (WS) through international and inter-regional crop trade of China.

	National WS through international crop trade (billion $m^3 y^{-1}$)		National WS through inter-regional crop trade (billion $m^3 y^{-1}$)		Blue WS through inter-regional crop trade (billion $m^3 y^{-1}$)	
	1978	2008	1978	2008	1978	2008
Wheat	33.8	-0.6	23.9	59.6	-10.4	-3.2
Maize	1.6	-0.9	13.2	3.5	3.6	-0.6
Rice	-4.9	-1.6	-55.7	-28.9	-17.2	-10.7
Sorghum	0.0	-0.1	-1.1	0.0	0.2	0.1
Barley	-0.0	0.3	0.0	-0.0	-0.0	-0.0
Millets	-0.1	-0.0	3.7	0.7	1.2	0.3
Potatoes	-0.0	-0.1	0.7	0.2	0.2	0.1
Sweet potatoes	-0.0	-0.0	0.3	0.2	-0.5	0.1
Soybean	0.4	86.1	1.7	-1.3	1.0	0.7
Groundnuts	-0.1	-0.9	3.5	10.2	1.8	4.3
Sunflower	-0.0	-0.2	0.1	0.1	0.1	0.1
Rapeseed	-0.0	20.4	13.7	64.9	0.0	0.0
Sugar beet	0.0	-0.0	-0.1	0.2	-0.0	-0.0
Sugar cane	0.0	0.0	-0.0	3.0	0.1	0.3
Cotton	12.9	9.4	0.1	0.0	0.2	-0.3
Spinach	-0.0	-0.0	0.0	0.1	0.0	0.0
Tomatoes	-0.0	-0.0	0.8	7.3	0.0	0.1
Cabbages	-0.0	-0.1	-0.0	-0.0	-0.0	-0.0
Apples	-0.1	-0.9	-0.4	0.6	-0.0	-0.1
Grapes	-0.0	-0.0	-0.0	-0.2	-0.0	-0.5
Tea	-2.7	-2.5	-0.0	0.3	0.0	0.0
Tobacco	-0.0	-0.2	0.4	0.2	0.1	0.1
Total	40.7	108.1	4.6	120.6	-19.6	-9.3

3.5. Discussion

We compared the national average WF of each crop (in $m^3 t^{-1}$) as estimated in the current study with three previous studies that gave average values for different periods: Mekonnen and Hoekstra (2011) for 1996-2005, Liu et al. (2007) for 1999-2007 and Shi et al. (2014) for 1986-2008 (Fig. 14). Our estimates match well with previous reported values, with R-square values of 0.96, 0.89 and 0.98 for the three studies, respectively.

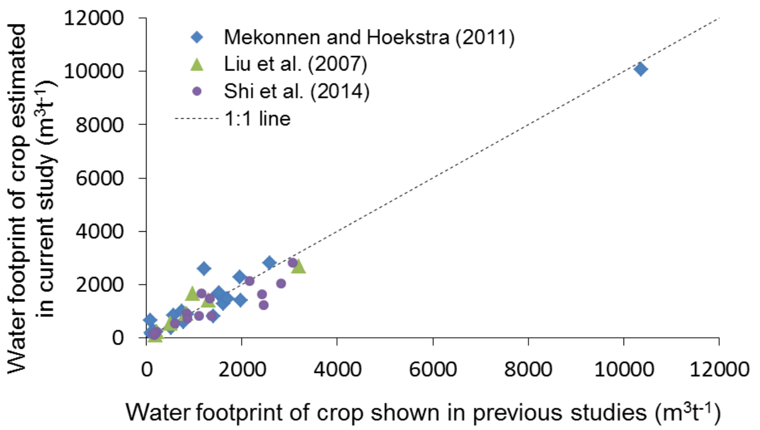


Figure 14. Comparison of current estimates of national average consumptive water footprint of each crop (in $m^3 t^{-1}$) with results from Mekonnen and Hoekstra (2011), Liu et al. (2007) and Shi et al. (2014).

A number of limitations should be taken into account when interpreting the results of this study. First, in simulating WFs of crops, a number of crop parameters, such as harvest index, cropping calendar and the maximum root depth for each type of crop, were taken constant over the whole period of analysis. Second, the annual variation of the initial soil water content for each crop (at the beginning of the growing season) in each grid cell was not taken into consideration. Third, we assumed, per crop, that the changes in cropping area over the study period only happened in grid cells where a harvested area for that crop existed around the year 2000 according to the database used (Monfreda et al., 2008; Portmann et al., 2010). Fourth, in estimating WFs of crop consumption, the spatial variation of per capita crop consumption levels (e.g. urban vs. rural) was ignored due to lack of data. Finally, the specific trade flows between crop surplus and crop deficit regions were estimated assuming static multi-regional input-output tables as explained in the method section.

The various assumptions that have been taken by lack of more accurate data translate to uncertainties in the results. The assumptions on harvest indexes and maximum root depths mainly affect the magnitude of modelled crop yield levels; the effect of uncertainties in these model parameters has been minimized by the fact that we calibrated the simulated yields in order to match provincial yield statistics. Regarding assumed cropping calendars and initial soil water content values, a detailed sensitivity analysis to these two variables has been carried out by Zhuo et al. (2014) for the Yellow River basin, the core of Chinese crop production, and by Tuninetti et al. (2015) at global level. By varying the crop planting date by ±30 days, Zhuo et al. (2014) found that the consumptive WF of crops generally decreased by less than 10% with late planting date due to decreased crop ET and that crop yields hardly changed. By changing the initial soil water content by ±1 mm m^{-1}, Tuninetti et al. (2015) showed that an increment in the initial soil water content resulted in decreases in consumptive WF due to higher yield. Again, the effects on yield simulations were diminished by calibration to fit yield statistics. Since none of the factors mentioned can influence the order of magnitude of the outcomes, the broad conclusions with respect to declining WFs of crops (m^3 t^{-1}), declining WFs per capita (m^3 y^{-1} cap^{-1}), increasing total WFs of consumption and production (m^3 y^{-1}) and the reversing of the VW flow between South and North China, are solid.

4. Conclusions

For China as a whole, even though the per capita consumption of considered crops grew by a factor of 1.4 over the study period, China's average WF per capita ($m^3 cap^{-1} y^{-1}$) related to crop consumption decreased by 23%, owing to improved yields. Due to the population growth (37%), the total consumptive WF ($m^3 y^{-1}$) of Chinese crop consumption increased by 6%, with a tripled net VW import as a result of importing crops from other countries. The production of the 22 crops considered doubled, while the harvested area increased only marginally (4%). The increased crop yields in China have led to significant reductions in the WF of crops (e.g. halving the WF per tonne of cereals), resulting in a slight increase (7%) in the total consumptive WF of crop production. About 28% of total consumptive water use in crop fields in China serves the production of crops for export to other regions. About 35% of the crop-related WF of a Chinese consumer is outside its own province. By 2000, the North has become net VW exporter through crops to the South. This is in line with the findings in earlier studies (e.g. Ma et al., 2006; Cao et al., 2011; Dalin et al., 2014), but we add the nuance that the North-South VW flow concerns green water. There is still a blue VW flow from the South to the North, although this flow more than halved over the study period.

If these trends continue, this will put an increasing pressure on the North's already limited water resources. The on-going South-North Water Transfer Project (SNWTP) may alleviate this pressure to a certain extent, but might be insufficient (Barnett et al., 2015). The Middle Route of the South-North Water Transfer project, which is operational since late 2014, is transferring 3 billion m3 of blue water per year to support agriculture, with the aim to increase irrigated land by 0.6 million ha in the drier North (SCPRC, 2014). The Government's plan to expand irrigated agriculture by using the transferred water for irrigation will stimulate crop export from the North and thus further increase the blue VW transfer from North to South. The blue water supply through the SNWTP will thus not significantly reduce the pressure on water resources in the North, but rather support agricultural expansion. Efforts to reduce water demand will be needed to address the growing water problems in China.

Crop yield improvements have led to a drop in the WF of crops ($m^3 t^{-1}$), but further reduction in the WF is possible. Setting WF benchmark values for the different crops, taking into account the agro-ecological conditions of the different regions, formulating targets to reduce the WFs of crops to benchmark levels and making proper investments to reach these targets will be important steps toward further reduction of the WF (Hoekstra, 2013). As the economy grows, the per capita consumption of water-intensive goods such as animal products and oil crops will increase, putting further pressure on China's already scarce water resources (Liu and Savenije, 2008). Thus, efforts are necessary to influence the food preferences of the population in order to curb the increasing consumption of meat, dairy and water-intensive crops, which is useful from a health perspective as well (Du et al., 2004).

The case of China shows that domestic trade, as governed by economics and governmental policies rather than by regional differences in water endowments, determines inter-regional water dependencies and may worsen rather than relieve the water scarcity in a country.

Part 2. Water footprint and virtual water trade scenarios for 2030 and 2050*

1. Introduction

Intensified competition for finite water resources among different sectors is challenging the sustainability of human society. Agriculture is the biggest water consumer, accounting for 92% of global water consumption (Hoekstra and Mekonnen, 2012). In China, the world's most populous country, agriculture was responsible for 64% of the total blue water withdrawal in 2014 (MWR, 2015). About 81% of the nation's water resources are located in the south, but 56% of the total harvested crop area is located in the north (Piao et al., 2010; NBSC, 2013; Jiang, 2015). China is a net virtual water importer related to agricultural products (Hoekstra and Mekonnen, 2012). Local overuse of water threatens the sustainability of water resources in China (Hoekstra et al., 2012). China's agricultural water management will be increasingly challenged by climate change, population growth, and socio-economic development (NDRC, 2007; Piao et al., 2010; Jiang, 2015).

The Chinese government pursues self-sufficiency in major staple foods (wheat, rice and maize) (NDRC, 2008; SCPRC, 2014) and has set the 'three red lines' policy on sustainable agricultural blue water use, which sets targets regarding total maximum national blue water consumption (670 billion $m^3 y^{-1}$), improving irrigation efficiency (aiming at 55% at least) and improving water quality (SCPRC, 2010). However, risks to water security arise not only from blue water scarcity, but also from scarcity of green water (rainwater stored in soil), which limits the national food production potential (Falkenmark, 2013). An important question is whether China can pull off the political plan to attain water, food as well as energy security (Vanham, 2016) under climate change combined with population growth and socio-economic development. A question relevant for the world as a whole is how the development of Chinese food consumption and production, given future socio-economic changes and climate change, will impact on the country's net crop trade and related net virtual water trade.

In Part 2 of this report we assess green and blue WFs and VW trade in China under alternative scenarios for 2030 and 2050, with a focus on crop production, consumption and trade. We consider five driving factors of change: climate, harvested crop area, technology, diet, and population. We consider the same 22 primary crops (Table 3) as in Part 1 of this report. We take the year 2005 as the baseline. The spatial resolution of estimating the WF of crop production is 5 by 5 arc min.

A number of WF and VW trade scenario studies are available, some at global level (Fader et al., 2010; Pfister et al., 2011; Hanasaki et al., 2013a,b; Konar et al., 2013; Liu et al., 2013; Ercin and Hoekstra, 2014; Haddeland et al., 2014; Wada and Bierkens, 2014), others focussing on China (Thomas, 2008; Mu and Khan, 2009; Xiong et al., 2010; Dalin et al., 2015; Zhu et al., 2015). Several studies suggest that blue water scarcity in China will increase as a result of a growing blue WF of crop production and a decreasing blue water availability in the course of the 21st century (Mu and Khan, 2009; Xiong et al., 2010; Pfister et al., 2011; Hanasaki et al., 2013a; Hanasaki et al., 2013b; Haddeland et al., 2014; Wada and Bierkens, 2014). However, the scenario analyses generally exclude the potential decrease of consumptive WFs

* This part of the report is based on: Zhuo, L., Mekonnen, M.M. and Hoekstra, A.Y. (2016) Consumptive water footprint and virtual water trade scenarios for China - with a focus on crop production, consumption and trade, Environment International, 94: 211–223.

per unit of crop under the combined effect of climate and technological progress. Besides, regarding the consumptive WF of crop production in climate change scenarios, the findings of several studies contradict each other. Zhu et al. (2015) find a significant increased total blue WF for croplands in northwest, southeast and southwest China as a result of climate change under IPCC SRES B1, A1B and A2 scenarios by 2046-2065. On the contrary, Liu et al. (2013) find that both blue and total consumptive WFs will decrease in the North China Plain and southern parts of China and increase in the other parts of the country under the IPCC SRES A1FI and B2 scenarios. Thomas (2008) finds a decreased blue WF in north and northwest China by 2030, based on a climate change scenario extrapolated from a regression trend derived from the time series for 1951-1990. Fader et al. (2010) and Zhao et al. (2014) project a decline in consumptive WF per tonne of crops in China as a result of climate change under the IPCC SRES A2 scenario, owing to increased crop yields because of increased CO_2 fertilization. By considering five socio-economic driving factors for 2050, Ercin and Hoekstra (2014) developed four global WF scenarios from both production and consumption perspectives. Under two of the global WF scenarios, China's WF of agricultural production will increase, while it will decrease in the other two WF scenarios. Dalin et al. (2015) assess future VW trade of China related to four major crops and three livestock products by 2030 under socio-economic development scenarios. They find that the VW import of China related to major agricultural products tends to increase given socio-economic growth by 2030. Konar et al. (2013) assess future global VW trade driven by both climate change and socio-economic developments for 2030, and find that China will remain the dominant importer of soybean. But they consider only three crops (rice, wheat and soybean) and neglected changes in crop yield to climate changes. By taking a more comprehensive approach – studying 22 crops (Table 3), looking at production, consumption as well as trade, and considering climate change as well as socio-economic driving factors – the current study aims to achieve a broader understanding of how the different driving forces of change may play out.

2. Method and data

2.1 Scenario set-up

Scenarios are sets of plausible stories, supported with data and simulations, about how the future might unfold from current conditions under alternative human choices (Polasky et al., 2011). In the current study we build on the 5th IPCC Assessment Report (IPCC, 2014), which employs a new generation of scenarios (Moss et al., 2010), including socio-economic narratives named shared socio-economic pathways (SSPs) (O'Neill et al., 2012) and emission scenarios named representative concentration pathways (RCPs) (van Vuuren et al., 2011).

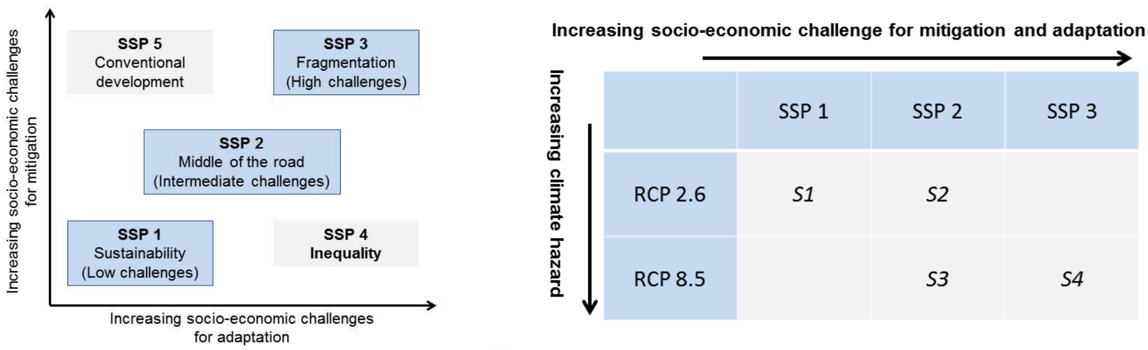
Five SSPs (SSP1-SSP5) were developed within a two-dimensional space of socio-economic challenges to mitigation and adaptation outcomes (O'Neill et al., 2012) (Fig. 15a). In sustainability scenario SSP1, the world makes relatively good progress towards sustainability: developing countries have relatively low population growth as well as rapid economic growth; increasingly developed technology is put towards environmentally friendly processes including yield-enhancing technologies for land; the consumption level of animal products is low. In middle-of-the-road scenario SSP2, the typical trends of recent decades continue, with a relatively moderate growth in population; most economics are stable with partially functioning and globally connected markets. In fragmentation scenario SSP3, the world is separated into regions characterized by extreme poverty, pockets of moderate wealth and a bulk of countries that struggle to maintain living standards for a strongly growing population, and slow technology development. In inequality scenario SSP4, mitigation challenges are low due to some combination of low reference emissions and/or high latent capacity to mitigate. While challenges to adaptation are high due to relatively low income and low human capital among the poorer population and ineffective institutions. In conventional development scenario SSP5, the world suffers high greenhouse gas emissions and challenges to mitigation from fossil dominated rapid conventional development. While lower socio-environmental challenges to adaptation are due to robust economic growth, highly engineered infrastructure and highly managed ecosystems. From SSP1 to SSP3, socio-economic conditions increasingly pose challenges and difficulties to mitigate and adapt to climate change. In order to cover the full range from the best to the worst possible future conditions of China, we choose to consider the two extreme scenarios SSP1 and SSP3. SSP1 represents a world with relatively low challenges to both climate change mitigation and adaptation, and SSP3 represents a world with relatively large challenges in both respects. In addition, we consider the middle of the road scenario SSP2 with an intermediate level of challenges.

The IPCC distinguishes four RCPs (RCP 2.6, 4.5, 6 and 8.5) based on different radiative forcing levels by 2100 (from 2.6 to 8.5 W/m^2) (van Vuuren et al., 2011). In this study, we consider the two climate change scenarios RCP2.6 (also called RCP 3PD) (van Vuuren et al., 2007) and RCP8.5 (Riahi et al., 2007). RCP2.6 represents pathways below the 10th percentile and RCP8.5 pathways below the 90th percentile of the reference emissions range (Moss et al., 2010). By combining the RCPs and SSPs, a matrix framework was proposed showing that an increased level of mitigation efforts corresponds to a decreased level of climate hazard (Kriegler et al., 2010). For the purpose of our study we constructed two scenarios S1 and S2 by combining climate scenarios forced by RCP2.6 with socio-economic scenarios SSP1 and SSP2, respectively. In addition, we constructed two scenarios S3 and S4 that combine climate outcomes forced by RCP8.5 with SSP2 and SSP3, respectively (Fig. 15b).

The assumptions for the four scenarios S1-S4 are summarised in Table 5. The five driving factors of change considered in this study have been quantified per scenario as will be discussed below.

Population. The SSPs of the IPCC consist of quantitative projections of population growth as given by IIASA (2013) (Table 6).

Climate. Climate change projections by four Global Climate Models (GCMs) within the Coupled Model Intercomparison Project (CMIP5) (Taylor et al., 2012) were used: CanESM2 (Canadian Centre for Climate Modelling and Analysis), GFDL-CM3 (NOAA Geophysical Fluid Dynamics Laboratory), GISS-E2-R (NASA Goddard Institute for Space Studies), and MPI-ESM-MR (Max Planck Institute for Meteorology). The models were selected from nineteen GCMs in such a way that the outcomes of the selected GCMs span the full range of projections for China on precipitation (mm) for spring and summer (March to July), when most crops grow. The projections by CanESM2 and GFDL-CM3 represent relatively wet conditions and the projections by GISS-E2-R and MPI-ESM-MR relatively dry conditions (Table 7).



(a) *(b)*

Figure 15. (a) SSPs in the conceptual space of socio-economic challenges for mitigation and adaptation. Source: O'Neill et al. (2012). (b) Definition of scenarios S1-S4 used in the current study in the matrix of SSPs and RCPs.

Table 5. Summary of the four scenarios S1-S4 in the current study.

	S1	*S2*	*S3*	*S4*
Shared socio-economic pathway (SSP)	*SSP1*	*SSP2*	*SSP2*	*SSP3*
Population growth	Relatively low	Medium	Medium	Relatively high
Diet	Less meat	Current trend	Current trend	Current trend
Yield increase through technology development	High	Medium	Medium	Low
Representative concentration pathway (RCP)	*RCP 2.6*	*RCP 2.6*	*RCP 8.5*	*RCP 8.5*
climate outcomes (GCMs)	CanESM2, GFDL-CM3, GISS-E2-R and MPI-ESM-MR			
Harvested crop area (IAM)	IMAGE	IMAGE	MESSAGE	MESSAGE

Table 6. Population projections for China under SSP1 to SSP3.

	2005	2030			2050		
		SSP 1	*SSP 2*	*SSP 3*	*SSP 1*	*SSP 2*	*SSP 3*
Population (million)	1307.59	1359.51	1380.65	1398.88	1224.52	1263.14	1307.47

Source: IIASA (2013).

Table 7. Projected changes in national average precipitation (PR), maximum temperature (T_{max}), minimum temperature (T_{min}), reference evapotranspiration (ET_0) and CO_2 concentration in China for the four selected GCMs for RCP2.6 and RCP8.5 by the years 2030 and 2050 compared to 2005.

Changes in climate variables	*RCP2.6*				*RCP8.5*			
	CanESM2	GFDL-CM3	GISS-E2-R	MPI-ESM-MR	CanESM2	GFDL-CM3	GISS-E2-R	MPI-ESM-MR
Year: 2030								
Relative changes in annual PR	15%	12%	1%	4%	16%	8%	2%	7%
Increase in T_{max} (^oC)	1.9	2.4	0.9	1.2	2.2	2.6	1.4	1.6
Increase in T_{min} (^oC)	1.7	2.0	0.5	0.9	2.1	2.2	1.1	1.4
Relative changes in annual ET_0	3%	5%	2%	2%	3%	5%	3%	2%
Relative changes in CO_2 concentration	13%				18%			
Year: 2050								
Relative changes in annual PR	19%	20%	3%	5%	24%	20%	6%	7%
Increase in T_{max} (^oC)	2.2	3.1	0.9	1.3	3.5	4.3	2.2	2.7
Increase in T_{min} (^oC)	2.1	2.5	0.5	1.0	3.5	3.7	1.8	2.6
Relative changes in annual ET_0	3%	8%	2%	2%	6%	11%	5%	5%
Relative changes in CO_2 concentration	17%				42%			

Harvested crop area. We use the harmonized land use (HLU) scenarios provided at a resolution of 30 by 30 arc min from Hurtt et al. (2011). We downscale the original data to a 5 by 5 arc min resolution. The changes in cropland area, provided as a fraction of each grid cell, were obtained from the IMAGE model (van Vuuren et al., 2007) for the RCP2.6 pathway and the MESSAGE model (Rao and Riahi, 2006; Riahi et al., 2007) for the RCP8.5 pathway. We apply the projected relative changes in the cropland area per crop and grid cell to the current cropland area per crop and grid cell as provided by Portmann et al. (2010) and Monfreda et al. (2008). The total harvested crop area for the selected crops in China was 124.9 million ha in the baseline year 2005, and is projected to increase by 19% from 2005 to 2050 in RCP2.6 and by 4% in RCP8.5, on the expense of forest and pasture land uses (Hurtt et al., 2011).

Crop yield increase through technology development. According to a recent global yield gaps analysis for major crops (Mueller et al., 2012), it is possible to increase yields by 45%-70% for most crops. For China's case, studies are available only for wheat, maize and rice. Meng et al. (2013) reported that experimental attainable maize yield was 56% higher than the average farmers' yield (7.9 t ha^{-1}) in China for 2007-2008. Lu and Fan (2013) found that the yield gap for winter wheat is 47% of the actual yield in the North China Plain. Zhang et al. (2014) estimated that the national average yield gap for rice is 26% of the actual yield. With limited land and water resources available to expand the acreage of croplands, the only way to enlarge production is by yield increase (Huang et al., 2002). In a scenario analysis on potential global yield increases, De Fraiture et al. (2007) conclude that yield growth can reach 20-72% for rain-fed cereals and 30-77% for irrigated cereals as compared to the year 2000. Due to a lack of quantitative data on crop yield growth under each SSP, we took the values from De Fraiture et al. (2007) as a starting point by assuming a yield increase of 72% from 2000 to 2050 in SSP1, 46% in SSP2, and 20% in SSP3. Assuming a linear increase in the crop yield over time, corresponding yield increases over the period 2005-2030 are 34% in SSP1, 22% in SSP2, and 10% in SSP3, and corresponding yield increases over the period 2005-2050 are 60% in SSP1, 40% in SSP2, and 18% in SSP3.

Diet. We make use of the two diet scenarios for East Asia for 2050 by Erb et al. (2009). We assume the less-meat scenario for SSP1 and the current-trend scenario for SSP2 and SSP3. We assume that the conversion factor from the kilocalorie intake to kilogram consumption of each type of crop per capita remains constant over the years. As shown in Table 8, the share of animal products in the Chinese diet will decrease by 37% in the less-meat scenario and increase by 4.4% in the current-trend scenario, compared to baseline year 2005.

Table 8. Two diet scenarios for China.

Consumption per capita in kcal/day per category	2005[a]	2050	
		Current-trend scenario[b]	Less-meat scenario
Cereal	1458	1552 (6.4%)	1709 (17.2%)
Roots	187	149 (-20.6%)	201 (7.6%)
Sugar crops	60	85 (41.7%)	124 (106.7%)
Oil crops	246	288 (17.1%)	265 (7.8%)
Vegetables and fruits	247	205 (-16.9%)	219 (-11.2%)
Other crops	95	66 (-30.4%)	82 (-13.5%)
Animal products	586	612 (4.4%)	372 (-36.5%)
Total	2879	2956 (2.8%)	2973 (3.3%)

a. Source: FAO (2014);

b. Values were generated according to the scenarios for East Asia by Erb et al. (2009), with relative changes from 2005 level in brackets.

2.2. Estimating water footprints and virtual water trade

Following Hoekstra et al. (2011), green and blue WFs of producing a crop (m^3 t^{-1}) are calculated by dividing the total green and blue evapotranspiration (ET, m^3 ha^{-1}) over the crop growing period, respectively, by the crop yield (Y, t ha^{-1}). Daily ET and Y were simulated, at a resolution level of 5 by 5 arc min, with the FAO crop water productivity model AquaCrop (Hsiao et al., 2009; Raes et al., 2009; Steduto et al., 2009). Following Zhuo et al. (2016a), the daily green and blue ET were derived based on the relative contribution of precipitation and irrigation to the daily green and blue soil water balance of the root zone, respectively. In AquaCrop, the daily crop transpiration (Tr, mm) is used to derive the daily gain in above-ground biomass (B) via the normalized biomass water productivity of the crop, which is normalized for the CO_2 concentration of the bulk atmosphere, the evaporative demand of the atmosphere (ET_0) and crop classes. The harvestable portion (the crop yield) of B at the end of the growing period is determined as product of B and the harvest index. Harvest index is adjusted to water stress depending on the timing and extent of the stress (Hsiao et al., 2009; Raes et al., 2009; Steduto et al., 2009). Therefore, changes of crop yield to climate changes were simulated through AquaCrop modelling by taking consideration of effects of changes in precipitation, ET_0 and CO_2 concentration. We considered multi-cropping of rice (i.e. twice a year in southern China) and assumed single cropping for other crops. The simulated Y of each crop for the baseline year was scaled to match provincial statistics (NBSC, 2013). The projected Y under climate scenarios was obtained by multiplying the scaled baseline Y by the ratio of the simulated future Y to the simulated baseline Y, corrected for the assumed Y increases per scenario.

The water footprint of food consumption ($WF_{cons,\ food}$, $m^3\ y^{-1}$) includes the WF related to the consumption of crops and crop products as well as the WF related to the consumption of animal products. The WF related to crop consumption ($m^3\ y^{-1}$) under each scenario was obtained, per crop, by multiplying the crop consumption volume ($C_{crop,\ food}$, $t\ y^{-1}$) by the WF per tonne of the crop ($WF_{cons,\ unit\ crop}$, $m^3\ t^{-1}$). The WF related to the consumption of animal products ($m^3\ y^{-1}$) was estimated by multiplying total animal products consumption ($C_{animal,\ food}$, $kcal\ y^{-1}$) by the WF per kilocalorie of animal products ($WF_{cons,\ unit\ animal}$, $m^3\ kcal^{-1}$).

$C_{crop,\ food}$ was calculated, per crop, as the crop consumption per capita (in $kg\ cap^{-1}\ y^{-1}$) times the projected population (Table 2). We consider the seed and waste as part of the food consumption. The fraction of seed and waste in the crop consumption is assumed to be constant in the coming decades and calculated as the ratio of total waste and seed to the total crop use in the baseline year (FAO, 2014). $WF_{cons,\ unit\ crop}$ was calculated, per crop, as Eq. (1). The WF of the imported crop, taken as the global average WF of the crop as reported by Mekonnen and Hoekstra (2011). Here the possible changes in global average WF of crops to global changes under each scenario were not considered. Under each scenario, the trade volume of a crop (I_{crop}, $t\ y^{-1}$) equals to the sum of the crop consumption for food ($C_{crop,\ food}$) and the crop consumption for feed ($C_{crop,\ feed}$, $t\ y^{-1}$) minus the national production of the crop (P_{crop}). A negative value for I_{crop} means export. The crop import I_{crop} multiplied with WFi_{prod} refers to the net VW import related to trade in the crop ($m^3\ y^{-1}$).

$C_{crop,\ feed}$ changes with animal products consumption, which is driven by population growth, personal income growth and diet changes (Rosegrant et al., 1999; Du et al., 2004; Bouwman et al., 2005; Keyzer et al., 2005; Liu and Savenije, 2008; Trostle, 2008; Nonhebel and Kastner, 2011; Shiferaw et al., 2011; Hoekstra and Mekonnen, 2012; Hoekstra and Wiedmann, 2014). Here we assume that the relative change in $C_{crop,\ feed}$ under each scenario is the same as the relative changes in the total consumption of animal products, which is driven by corresponding diet changes (Table 4) and population growth. $C_{crop,\ feed}$ in China for the baseline year 2005 was obtained from FAO (2014).

Values for $WF_{cons,\ unit\ animal}$ in China in the baseline year were obtained from Hoekstra and Mekonnen (2012). The WF of animal feed contributes 98% to the WF of animal products (Mekonnen and Hoekstra, 2012). Animal productivity (i.e. animal production output per unit mass of feed) ($\triangle_{productivity}$, %) was assumed to grow in the future as a result of higher offtake rates and higher carcass weights or milk or egg yields (Bruinsma, 2003). We use the projections on $\triangle_{productivity}$ for the various types of animal products by Bouwman et al. (2005) for East Asia from 1995 to 2030, assuming a linear increase. We took a weighted average based on production of each type of animal product in the baseline year (NBSC, 2013), which implies an animal productivity increase of 4% by 2030 and 8% by 2050 compared to the baseline year

2005. Therefore, in each scenario, $WF_{cons, unit animal}$ was estimated by considering relative changes in the WF of animal feed ($\triangle WF_{feed}$, %) and $\triangle_{productivity}$:

$$WF_{cons,unit\ animal} = \frac{WF_{cons,unit\ animal[2005]} \times (1 + \Delta WF_{feed})}{(1 + \Delta_{productivity})} \quad (2)$$

$\triangle WF_{feed}$ was calculated as a weighted average of changes in the WF of feed crops ($\triangle WF_{feed\ crops}$, %) and changes in the WF of other feed ingredients (i.e. pasture, crop residues and other roughages) ($\triangle WF_{feed\ other}$, %), given their corresponding shares in the total WF of animal feed in China ($pct_{feed\ crops}$ and $pct_{feed\ other}$, %):

$$\Delta WF_{feed} = \Delta WF_{feed\ crops} \times pct_{feed\ crops} + \Delta WF_{feed\ other} \times pct_{feed\ other} \quad (3)$$

We assume that the composition of the animal feed in China stays constant. Currently, the 13 selected crops from 22 considered crops (wheat, maize, rice, barley, millet, sorghum, potato, sweet potato, sugar cane, sugar beet, soybean, sunflower seed and rape seed) account for 75% of the total feed crop consumption in quantity (FAO, 2014) and contribute 70% and 86% to the green and blue WFs of feed crops consumed in China, respectively (Hoekstra and Mekonnen, 2012). For the selected crops we account changes in WF by yield increase for each crop under each scenario. For the feed crops that are not included in the current study, the $\triangle WF_{feed\ other}$ was assumed in line with the average level of assessed crop yield increase under each scenario. The values of $pct_{feed\ crops}$ and $pct_{feed\ others}$ for green and blue WFs were obtained from Mekonnen and Hoekstra (2012).

China's international virtual water trade was estimated per crop by considering the difference between the WF of crop production and the WF of crop consumption (in the form of food, feed, seed or waste) within China.

2.3. Data

The downscaled GCM outputs at 5 by 5 arc min grid level for China on monthly PR, Tmax and Tmin were obtained from Ramirez-Villegas and Jarvis (2010). Since this dataset does not include data on ET_0, we calculated monthly ET0 with inputs on temperature through the Penman-Monteith method introduced in Allen et al. (1998) for the baseline year 2005 and each climate scenario. Then the monthly ET0 under each climate scenario was corrected by adding the absolute changes in the calculated ET0 from 2005 to the values of 2005 in CRU-TS database. The projected CO_2 concentrations (in ppm) under the two RCPs were obtained from IIASA (2009).

3. Results

3.1. Water footprint of crop production

For most of the crops studied, consumptive WFs per tonne of crop were projected to decrease across all scenarios, as shown in Table 5. Taking cereal crops (wheat, rice, maize, sorghum, millet and barley) as an example, compared to the baseline year 2005, the consumptive WF per tonne of cereal crops reduced by 41%, 35%, 36% and 24% till 2050 under S1, S2, S3 and S4, respectively, averaged across the four GCMs. From Figure 2 we can see that the reductions in the WFs of cereal crops were mainly driven by significant increases in crop yields, which have larger impact than the relatively small changes in ET under each scenario. The effects of climate change on WF of crops can be observed by comparing scenarios S2 and S3 under the same SSP and different RCPs. Positive effects on crop yields by increased CO_2 fertilization have been widely reported (Yao et al., 2007; Tao and Zhang, 2011; Wada et al., 2013; Zhao et al., 2014), which is also shown in the current result. With relatively small differences in ET_0 and precipitation for RCP 2.6 and RCP8.5 (see Table 7), scenario S3 for RCP8.5 with significant higher CO_2 concentration had higher cereal yields than scenario S2 for RCP 2.6 (Fig. 16). The effect of the application of better technology on the WF can be observed by comparing S1 versus S2 (both RCP2.6) and S3 versus S4 (both RCP8.5). The scenarios with a higher level of technology development (S1 and S3) have a higher yield increase and a lower WF per tonne of crop. The increase in irrigated cereal yields is around 20% higher than the increase in rain-fed cereal yields under each scenario, which reflects the limits on yield increases by water stress on rain-fed fields. The reduction of the blue WF per tonne of cereal crop is higher than for the green WF under each scenario. This is because of the decrease in irrigation requirements and thus in blue ET as a result of projected increases in precipitation across the GCM scenarios for both RCP2.6 and RCP 8.5. The relative changes in the national average yield for the selected crops under the four scenarios from 2005 to 2050 are listed in Appendix IV.

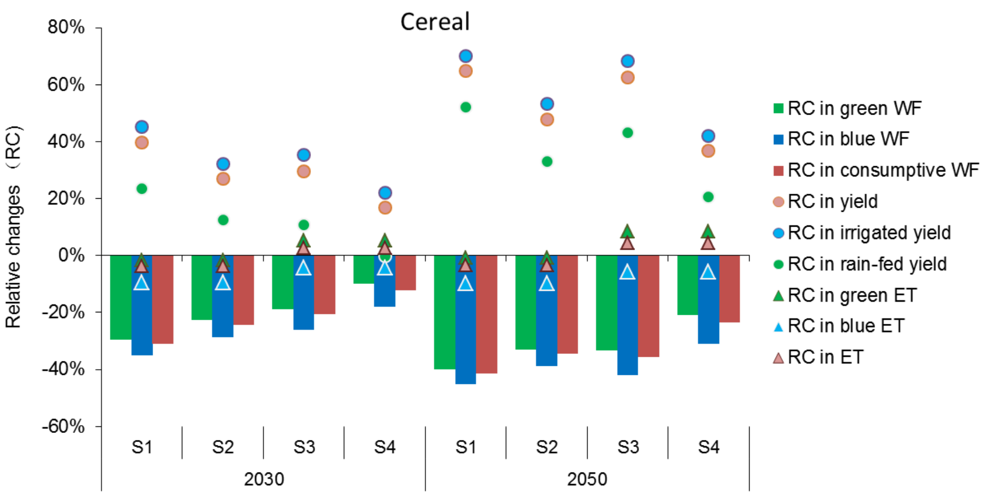


Figure 16. Relative changes (RC) in water footprint (WF) per tonne of a cereal crop, cereal yield and average ET at cereal croplands in China across scenarios as compared to the baseline year 2005.

Table 9. Relative changes in the green, blue and total consumptive water footprint ($m^3\ t^{-1}$) of the 22 considered crops in China across scenarios, compared to the baseline year 2005

Crop		Baseline 2005		Relative changes in consumptive WF per tonne of crops compared to baseline level (%)							
				2030				2050			
		Consumptive WF ($m^3\ t^{-1}$)	Yield ($t\ ha^{-1}$)	S1	S2	S3	S4	S1	S2	S3	S4
Wheat	Green	990	4.28	-20	-12	-18	-9	-31	-21	-35	-23
	Blue	713		-31	-24	-23	-15	-43	-34	-44	-33
	Total	1703		-25	-17	-20	-11	-36	-27	-38	-27
Rice	Green	948	6.26	-33	-26	-28	-20	-44	-36	-42	-31
	Blue	280		-38	-32	-30	-22	-48	-40	-44	-33
	Total	1229		-34	-27	-28	-20	-45	-37	-42	-31
Maize	Green	736	5.29	-37	-30	-4	6	-49	-42	-17	-2
	Blue	161		-45	-40	-35	-28	-57	-51	-46	-36
	Total	898		-38	-32	-10	0	-51	-43	-22	-8
Sorghum	Green	914	4.47	-34	-28	-22	-14	-44	-36	-32	-19
	Blue	58		-18	-10	-12	-2	-33	-24	-25	-11
	Total	972		-33	-27	-22	-13	-43	-35	-32	-19
Millet	Green	1374	2.10	-43	-37	-41	-34	-52	-46	-50	-41
	Blue	47		-37	-30	-37	-30	-50	-43	-50	-41
	Total	1422		-42	-37	-41	-34	-52	-45	-50	-41
Barley	Green	727	4.14	-9	0	-21	-13	-25	-15	-39	-27
	Blue	60		-34	-28	-35	-28	-46	-39	-52	-43
	Total	787		-11	-2	-22	-14	-27	-16	-40	-28
Soybean	Green	2517	1.71	-33	-26	-28	-21	-45	-37	-42	-32
	Blue	142		-47	-41	-35	-28	-60	-54	-50	-40
	Total	2659		-33	-27	-29	-21	-46	-38	-43	-32
Sweet potato	Green	236	22.18	7	17	-26	-18	-9	3	-41	-30
	Blue	11		-31	-24	-34	-26	-42	-34	-52	-43
	Total	247		5	15	-27	-19	-11	2	-42	-31
Potato	Green	192	14.52	29	42	-19	-10	-13	-1	-36	-24
	Blue	7		-27	-20	-27	-19	-44	-35	-46	-35
	Total	199		27	40	-19	-11	-14	-2	-36	-24
Cotton	Green	1404	3.92	-26	-18	-28	-20	-38	-29	-43	-32
	Blue	244		-20	-12	-28	-20	-36	-27	-46	-36
	Total	1648		-25	-17	-28	-20	-37	-28	-43	-33
Sugar cane	Green	120	63.97	47	62	-15	-6	-6	7	-27	-13
	Blue	1		12	23	-45	-39	-9	4	-57	-49
	Total	121		47	61	-15	-6	-6	7	-27	-14
Sugar beet	Green	100	37.51	-66	-62	-67	-63	-72	-68	-73	-68
	Blue	0		13	24	-69	-66	-10	3	-75	-70
	Total	100		-66	-62	-67	-63	-72	-68	-73	-68

Groundnut	Green	1616	3.08	-16	-8	-25	-17	-33	-23	-41	-30
	Blue	133		-25	-17	-26	-18	-41	-32	-46	-36
	Total	1749		-17	-9	-25	-17	-34	-24	-41	-31
Sunflower	Green	896	1.89	-46	-41	-39	-32	-55	-49	-52	-43
	Blue	79		-38	-32	-38	-31	-51	-43	-53	-44
	Total	976		-46	-40	-39	-32	-55	-49	-52	-43
Rape seed	Green	1416	1.79	3	13	-13	-4	-9	4	-31	-19
	Total	1416		3	13	-13	-4	-9	4	-31	-19
Tomato	Green	66	35.00	40	54	-3	8	49	71	-19	-4
	Blue	1		-21	-14	-42	-36	-26	-16	-62	-55
	Total	67		39	53	-4	7	48	69	-20	-5
Cabbage	Green	129	33.68	-20	-13	-26	-18	-30	-20	-41	-29
	Blue	7		-38	-32	-32	-25	-75	-71	-44	-33
	Total	135		-21	-14	-26	-18	-32	-23	-41	-30
Spinach	Green	96	19.35	-36	-29	-39	-33	-43	-35	-41	-30
	Blue	24		-47	-42	-43	-37	-56	-50	-58	-51
	Total	120		-38	-32	-40	-33	-46	-38	-44	-34
Grape	Green	346	14.19	-31	-24	-29	-21	-42	-33	-43	-33
	Blue	134		-29	-22	-24	-16	-42	-33	-41	-30
	Total	479		-30	-23	-28	-20	-42	-33	-43	-32
Apple	Green	374	12.70	-31	-24	-33	-26	-41	-32	-48	-38
	Blue	27		-46	-40	-43	-37	-55	-49	-59	-52
	Total	401		-32	-25	-34	-27	-42	-34	-49	-39
Tea	Green	9178	0.89	-27	-20	-24	-16	-42	-34	-34	-21
	Blue	142		-51	-46	-52	-46	-65	-60	-57	-49
	Total	9320		-27	-20	-25	-17	-42	-34	-34	-22
Tobacco	Green	1831	1.97	-34	-27	-28	-20	-45	-37	-42	-31
	Blue	53		-39	-32	-31	-23	-53	-47	-48	-38
	Total	1884		-34	-27	-28	-20	-45	-37	-42	-31

Figure 17 shows maps of multi-GCM averaged projected changes in green, blue and total consumptive WF per tonne of cereal crop over the period 2005-2050 under RCP8.5. Under this RCP, the national average green, blue and total consumptive WFs of cereal crops are projected to decrease by 7%, 19% and 10%, respectively. Reductions in both green and blue WFs of cereal crops larger than 40% were mostly located in Northwest China, which includes the upper and middle reaches of the severely water stressed Yellow River Basin, due to the projected increases in annual precipitation by more than 60% across GCM scenarios (see Appendix II). The projected wetter climate in the Northwest helps to reduce the water stress on rain-fed fields and the resulted yield loss. In most areas in the Northeast, the green and blue WF per tonne of crops was projected to increase by more than 40% as a result of the projected increase in ET_0 and decrease in precipitation in the Northeast across the GCM scenarios (Appendix II, III).

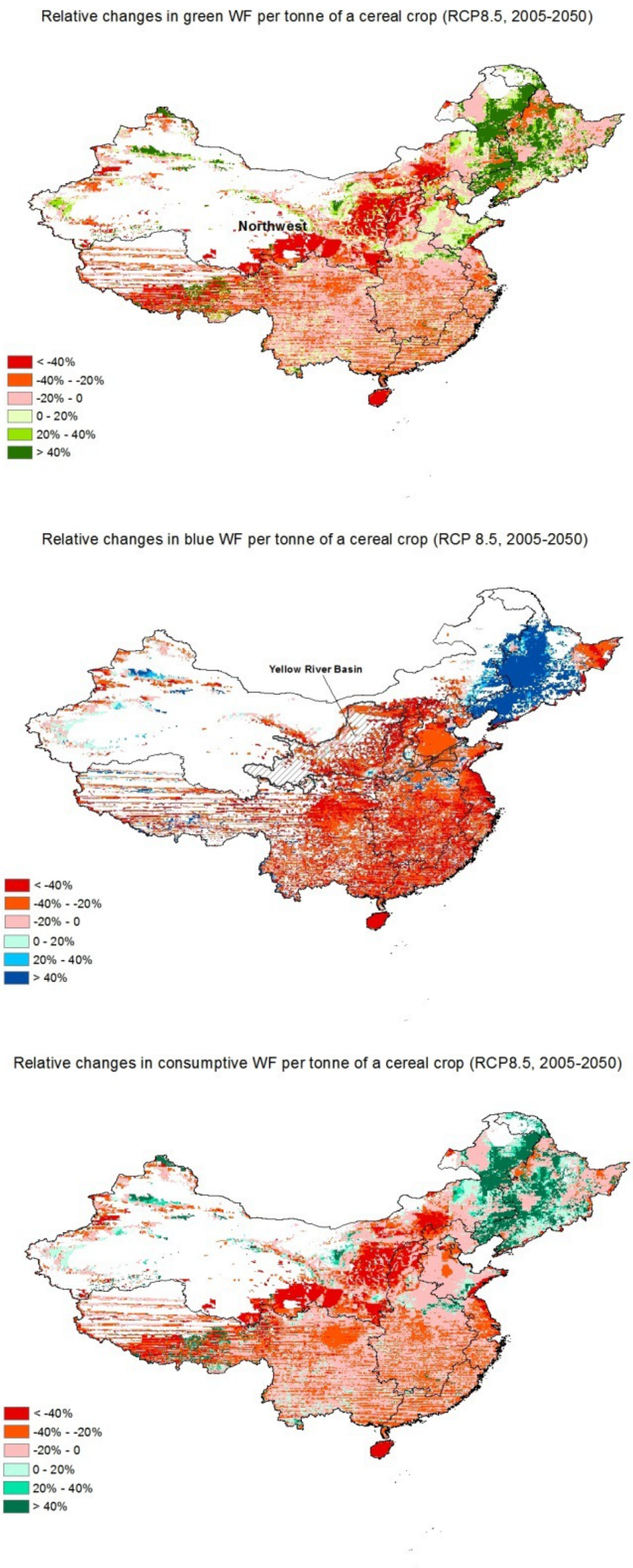


Figure 17. Changes in green, blue and overall consumptive water footprint (WF) per tonne of cereal crop in China over the period 2005-2050 under RCP8.5.

In Fig.18 we plotted the relative changes in WF per tonne of the crops studied against the corresponding relative changes in crop yield under each scenario. The referential line indicates the relative changes in WFs when only yields change (thus without the effect of changing ET on WFs). The vertical deviation of the dots from the line shows the impact of changing ET on WFs. The dots below the line, which is the majority, show the positive impact of reduced ET on reducing the WF per unit mass of crops.

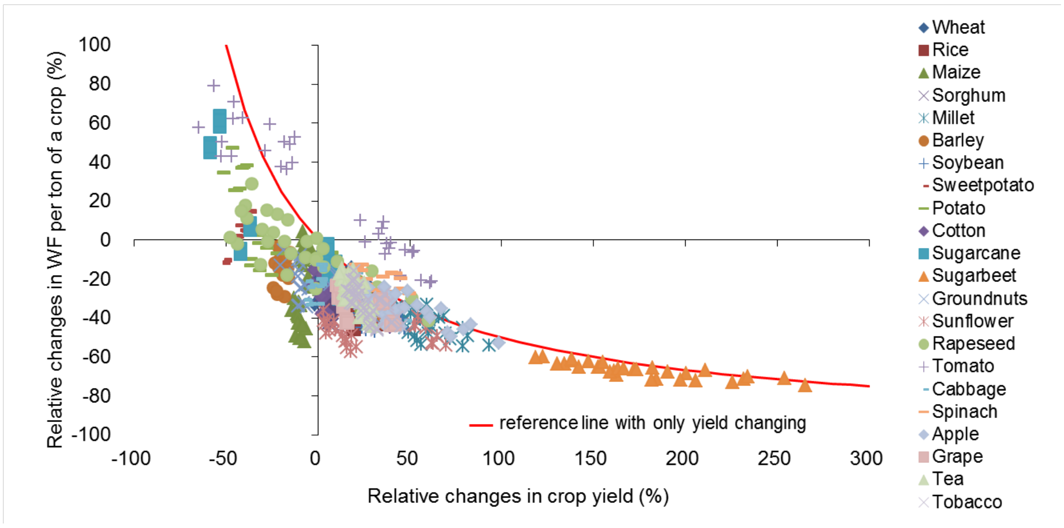


Figure 18. Relationship between relative changes in crop yields and relative changes in corresponding water footprint per tonne of crop. One dot refers to the projection for one crop under one GCM for one scenario for one year.

Over the period 2005-2050, the total national consumptive WF (in $m^3 y^{-1}$) of crop production increases by 18% under RCP2.6 (S1 and S2), and by 0.8% under RCP8.5 (S3 and S4), as a result of the combined effect of climate change and projected changes in harvested crop area. The impact of projected changes in harvested crop area under each RCP (19% increase from 2005 to 2050 under RCP2.6 and 4% decrease under RCP8.5) on the total WF was significant, because average ET per hectare over croplands increases by only 3.1% from 2005 to 2050 for RCP2.6 and by 5.6% for RCP8.5. The total green WF of crop production increases under both RCPs (by 21% from 2005 to 2050 under RCP2.6 and by 4% under RCP8.5). The total blue WF increases under RCP2.6 (by 4.3% to 2050) and decreases under RCP8.5 (by 10% to 2050).

3.2. Water footprint of food consumption

The water footprint of food consumption per capita in China decreases across all scenarios as compared to the baseline year (927 $m^3 cap^{-1} y^{-1}$), driven by the decreased WF per tonne of most crops. The largest decrease in the WF of food consumption per capita (by 44% to 2050) is observed under scenario S1 (Fig. 19). This large decrease is due to the less-meat diet combined with the largest decrease in consumptive WF per unit of crops and animal products. S4 shows the most modest decrease in the WF of food consumption per capita (20% to 2050), which is due to diet type (current-trend diet) and a relatively low reduction level in the WFs per unit of crop and animal product compared to the other scenarios. In "current trend" diet scenarios (S2-S4), animal product consumption was the largest contributor (~41-46%) to WF of food consumption followed by cereal consumption (~31-32%) and oil crop consumption (~14-18%). In the "less meat" scenario (S1), the WF of animal product consumption decreased significantly (by 65% from 2005 to 2050) and became the second largest contributor, after cereal consumption, to total WF of Chinese food consumption. This reduction was driven by decreases in both animal product consumption (by 37% to 2050) and WF per unit calorie of animal products (by 43% to 2050).

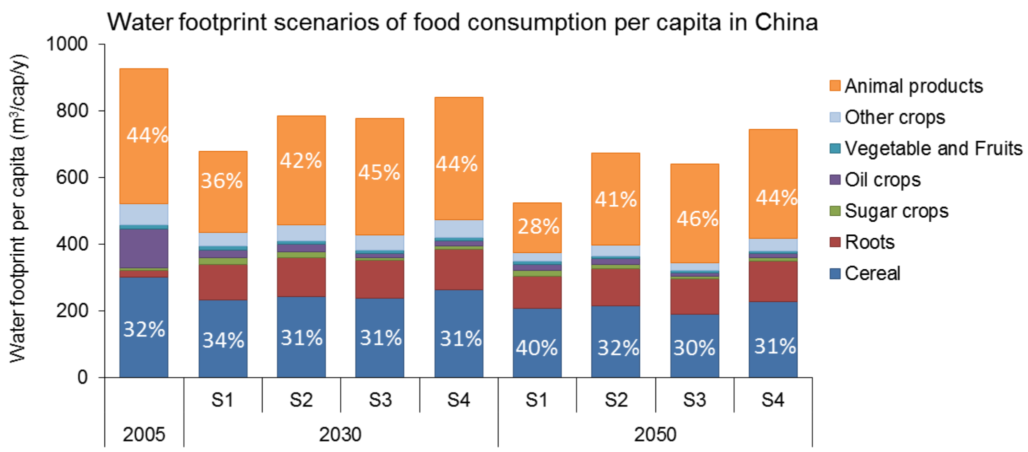


Figure 19. Water footprint of food consumption per capita under the four scenarios of China.

The total national consumptive WF of food consumption is projected to decrease across all scenarios, compared to the baseline level of 2005 (1212 billion $m^3 y^{-1}$) (Fig. 20). Even under an increased population by 2030, we observe a decrease in the total WF of consumption. The main reason for this decrease is the decrease in WF per unit of consumed crop and animal products, and the fact that the population increase to 2030 remains modest. The more significant decrease by 2050 is a combination of the projected declining population and the further decrease in WFs per unit of crops and animal products. In S1, with the smallest population size and the largest decrease in WF per capita, the total WF of food consumption drops most, decreasing on average by 24% and 47% by 2030 and 2050, respectively. With the current-trend diet, the smaller decrease in the WF of food consumption in S4 compared to S2 and S3 results from the relatively large size of the population and the relatively high WFs per unit of crops and animal products.

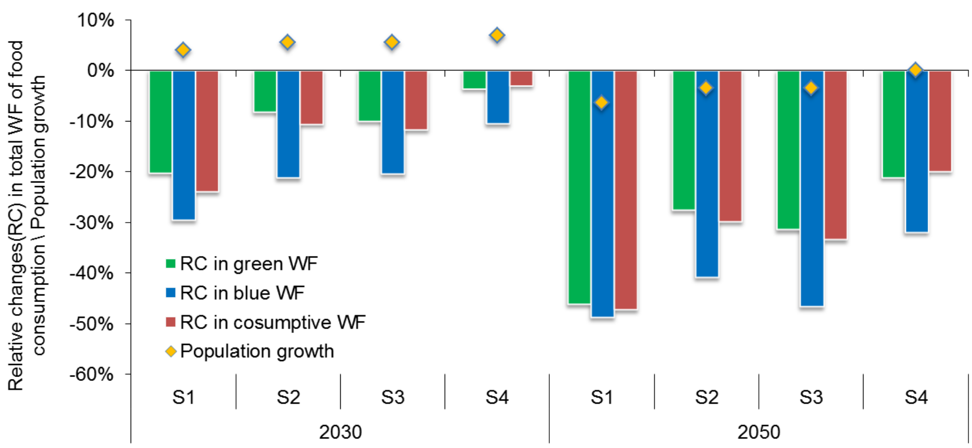


Figure 20. Changes in China's green, blue and total consumptive water footprint of food consumption across scenarios, as compared to the baseline year 2005. The green, blue and overall consumptive water footprints in 2005 are 1030, 183, and 1212 billion $m^3 y^{-1}$, respectively.

The reductions in blue WFs are higher than those in green WFs across all scenarios, in line with the higher reductions in the blue WFs per unit of production, which result from climate change and yield improvements through technology. The reduction in the green WF of food consumption in S1 is higher than in the other scenarios, as a result of larger share of roots and sugar crops in the diet and the low fraction of blue WF in the total consumptive WF per unit for roots and sugar crops (~2-3% for root crops and ~ 0-8% for sugar crops).

3.3. National virtual water trade related to crop products

While in the baseline year 2005 China was a net virtual water importer (with respect to trade in the crops considered in this study), the country will have become net virtual water exporter by 2050, in all scenarios. In scenarios S1-S3 this is already the case in 2030. The potential reversal of China's role in the global VW trade network was also reported by Ercin and Hoekstra (2014), but contradicts the projected increase in net VW import of major agricultural products by Dalin et al. (2015). However, the result of Dalin et al. (2015) was based on a totally different scenario, with decreasing irrigation area and reduced exports of crops. The current result shows an enhanced self-sufficiency in food supply and a potential contribution to the global VW trade network as an exporter. Table 10 presents the multi-GCM averaged net VW import related to crop trade across scenarios. The VW export of China under S1 is larger than in the other scenarios, with the net VW export as high as 38% of the total consumptive WF of crop production. This is the result of the relatively high increase in crop production, by the relatively high crop yield and expansion of harvested crop area, and smaller crop consumption due to the projected population decrease and less-meat diet. In S4, China is still a net VW importer by 2030, due to the VW import related to the large soybean import, which is larger than the total VW export through all exported crops.

Table 10. Net virtual water import of China related to trade in considered crops, for the baseline year 2005 and for 2030 and 2050 in the four scenarios.

Net virtual water import (10^9 m^3 y^{-1})	2005	2030				2050			
		S1	S2	S3	S4	S1	S2	S3	S4
Green water	82	-133	-70	-3	65	-267	-192	-139	-40
Blue water	14	-39	-26	-9	9	-71	-59	-48	-23
Total	97	-172	-96	-12	73	-338	-250	-187	-62

Figure 21 shows the multi-GCM averaged net VW import of China related to different crops under the four scenarios. China's shift from net VW importer to net VW exporter occurs most in particular through the projected export of rice and wheat. In the baseline year, export of maize contributes most to China's virtual water export, responsible for 86% of the crop-related VW exports of China. In the future, rice export is expected to become the biggest contributor to China's virtual water export, accounting for 38% of total VW export in 2050 in S1, 42% in S2, 33% in S3, and 32% in S4. In S1, the net VW export related to rice export even becomes 53% of the total WF of rice production in China by 2050. China will remain a big VW importer related to soybean in all scenarios. According to Konar et al. (2013), China could become world's largest VW importer through soybean trade in the future. In the baseline year, 61% of Chinese soybean consumption depends on import. By 2050, the projected dependency on soybean imports is 24%, 37%, 45% and 55% in S1, S2, S3 and S4, respectively. The fraction of the external WF in the total WF of crop consumption decreases in all scenarios, most in S1 and least in S4 (Table 11).

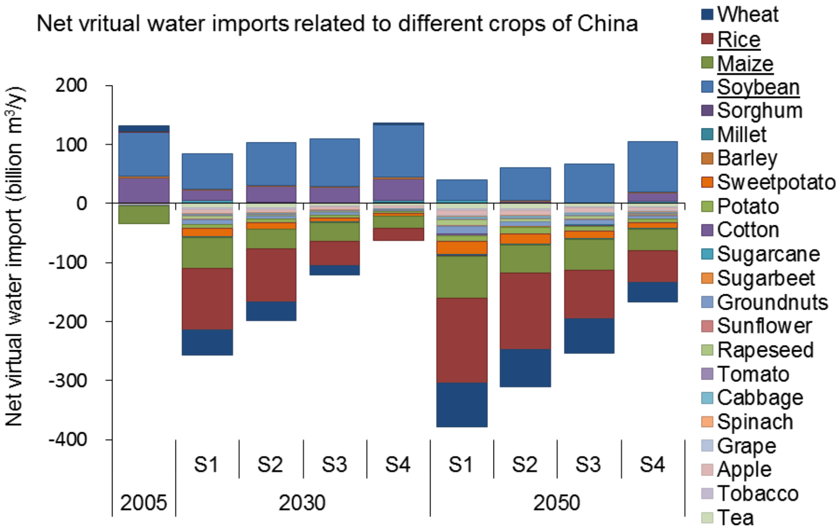


Figure 21. Net virtual water import of China related to its trade in different crops, for the baseline year 2005 and for 2030 and 2050 in the four scenarios.

Table 11. Fraction of the external water footprint (WF) in the total water footprint of Chinese crop consumption, in the baseline year and in 2030 and 2050 under the four scenarios.

Fraction of external WF in total WF of crop consumption	2005	2030				2050			
		S1	S2	S3	S4	S1	S2	S3	S4
Green WF	17%	10%	12%	15%	17%	5%	8%	10%	14%
Blue WF	11%	6%	7%	8%	11%	1%	2%	1%	6%
Consumptive WF	15%	9%	11%	13%	16%	5%	7%	9%	13%

3.4. Discussion

In Table 12 we compare the current results with the results from earlier studies where possible. The relative changes in WF per tonne of wheat and maize in China in the current study are in the same direction but much larger than the global average values as suggested by (Fader et al., 2010). The differences in magnitude originate from the different geographic scopes of the studies, but also from the fact that different climate scenarios and crop models are used. The relative changes in total blue WF at the current irrigated cropland in China from the current study, which considers the impacts of both changing precipitation and ET_0, are smaller than the estimates for Asia provided by Pfister et al. (2011), who considers the impact of changing precipitation only. The changes in WF of crop production in China found in the current study are much smaller than the figures presented by Ercin and Hoekstra (2014). The decrease in total WF of food consumption in scenario S1 in the current study is greater than the decrease in scenarios S3 and S4 in Ercin and Hoekstra (2014), which are based on the same less-meat diet scenario, but exclude the effect of reduced WFs per unit of food products by climate change that has been included in the current study. The relative changes in VW import related to soybean for S3 in the current study agree best with the result for the low-yield scenario in Konar et al. (2013).

Table 12. Comparison between the current results and previous studies.

Reference	**Year**	**Study case**	**Scenario**	**Changes in consumptive WF per tonne of consumed crops (%)**
Fader et al. (2010)	2041-70	global wheat global maize	SRES A2	-0.43/-0.45 -0.35/-0.44
Current study	2005-2050	China wheat	RCP 2.6	-27/-36
			RCP 8.5	-26/-39
		China maize	RCP 2.6	-44/-50
			RCP 8.5	-7/-23
	Year	**Study case**	**Scenario**	**Changes in total blue WF at current irrigated area (%)**
Pfister et al.(2011)	2000-2050	Asia	SRES A1B	-11
Current study	2005-2050	China	RCP 2.6	-8
			RCP 8.5	-2
	Year	**Study case**	**Scenario**	**Changes in total consumptive WF for crop production (%)**
Ercin and Hoekstra (2014）	2000-2050	China	"S1/S2/S3/S4" based on IPCC AR4	89/127/-22/-22
Current study	2005-2050		"S1/S2/S3/S4" based on IPCC AR5	17/17/0.8/0.8
	Year	**Study case**	**Scenario**	**Changes in total consumptive WF for crop consumption (%)**
Ercin and Hoekstra (2014）	2000-2050	China	"S1/S2/S3/S4" based on IPCC AR4	79/117/-29/-25
Current study	2005-2050		"S1/S2/S3/S4" based on IPCC AR5	-47/-30/-33/-20
	Year	**Study case**	**Scenario**	**Net virtual water import (10^9 m^3 y^{-1})**
Konar et al. (2013)	2030	Soybean	low yield' / 'high yield' (SRES A2)	25.44 / 32.44
Ercin and Hoekstra (2014）	2050	Agricultural products	"S1/S2/S3/S4" based on IPCC AR4	-171/-152/ -101/-63
Current study	2030	Soybean	"S1/S2/S3/S4" based on IPCC AR5	60(-19%)/71(-3%)/ 81(11%)/90(21%)
	2050	Crop products		-338/-250/-187/-62

Currently, four billion people live under severe blue water scarcity for at least for one month a year, and 0.9 billion of the four billion live in China (Mekonnen and Hoekstra, 2016). We added the current results on relative changes in national blue WF (m^3 y^{-1}) of crop production in China under each scenario to the context of current China's total water blue WF and compare to the current maximum sustainable blue WF (Mekonnen and Hoekstra, 2016). In scenarios S1and S2 under RCP2.6, the increase of 5% in total blue WF from 2005 to 2050 of crop production will slightly increase current blue water scarcity of China as a whole from 0.49 (low blue water scarcity) (Mekonnen and Hoekstra, 2016) to 0.51 (moderate blue water scarcity). The projected decrease of 9% in total blue WF of China's crop production in S3 and S4 under RCP8.5 will reduce the current blue water scarcity accordingly to 0.45. There have been studies on changes in blue water availability in China to future climate changes (Hanasaki et al., 2013b; Elliott et al., 2014; Santini and di Paola, 2015). The finding on significant decrease in blue water availability in the Yellow River Basin of more than 40% from 2005 to 2050 under RCP 8.5 was unified across these studies. According to the current study, even though the total blue WF of crop production in the Yellow River Basin will decrease by 11% under RCP 8.5 (S3 and S4), the basin could still suffer increasing blue water scarcity from the possible declining runoff. While for other parts of China, the current level of blue water scarcity (Mekonnen and Hoekstra, 2016) will not change significantly for considered scenarios from 2005 to 2050, given the projected slight increase (~10%) in blue water availability (Hanasaki et al., 2013b; Elliott et al., 2014; Santini and di Paola, 2015) and current projected slight increase (~4%) in total blue WF of crop production under RCP2.6 and decreases (~10%) under RCP8.5.

In addition, there are inherent uncertainties in scenario studies. All scenarios are based on assumptions regarding climate change and socio-economic developments like population growth, changes in diets, technological improvements and land use changes. Different GCMs result in different climate projections for a given emission scenario, which can be addressed by using the projections from multiple GCMs (Semenov and Stratonovitch, 2010), as we did in the current study, although we considered four GCMs only. Finally, the crop model used, the Aquacrop model in our study, and parameter values chosen, will inevitably result in different yield predictions when compared to studies based other models and parameter sets (Asseng et al., 2013).

4. Conclusion

The study provides a comprehensive analysis of the consumptive WF and VW trade of China by 2030 and 2050, focusing on the agricultural sector, developing four alternative scenarios forced by different levels of population growth and by changes in production, consumption and climate. The four scenarios differ in assumptions and outcomes, but the projected futures share a few commonalities:

(i) On average, the WF of producing a tonne of crop decreases due to the combined effect of climate change and technology improvements on yield increase. Wetter climate projections in Northwest China potentially reduce the local blue WF of crop production that can help to reduce the high blue water stress from the agriculture sector;

(ii) The WF of food consumption per capita decreases, up to 44% by 2050 if diets change to less meat (scenario S1). The total national WF of food consumption also decreases across all scenarios;

(iii) China will shift from net VW importer through crop trade to net VW exporter. However, China will remain depending on soybean imports.

The results suggest that the target of the Chinese government to achieve higher self-sufficiency in food supply while simultaneously reducing the WF of crop production (SCPRC, 2010; MOA et al., 2015) is feasible. However, the premise of realizing the presented scenarios is smart water and cropland management, effective and coherent policies on water, agriculture and infrastructure, and, in scenario S1, a successful shift to a diet containing less meat.

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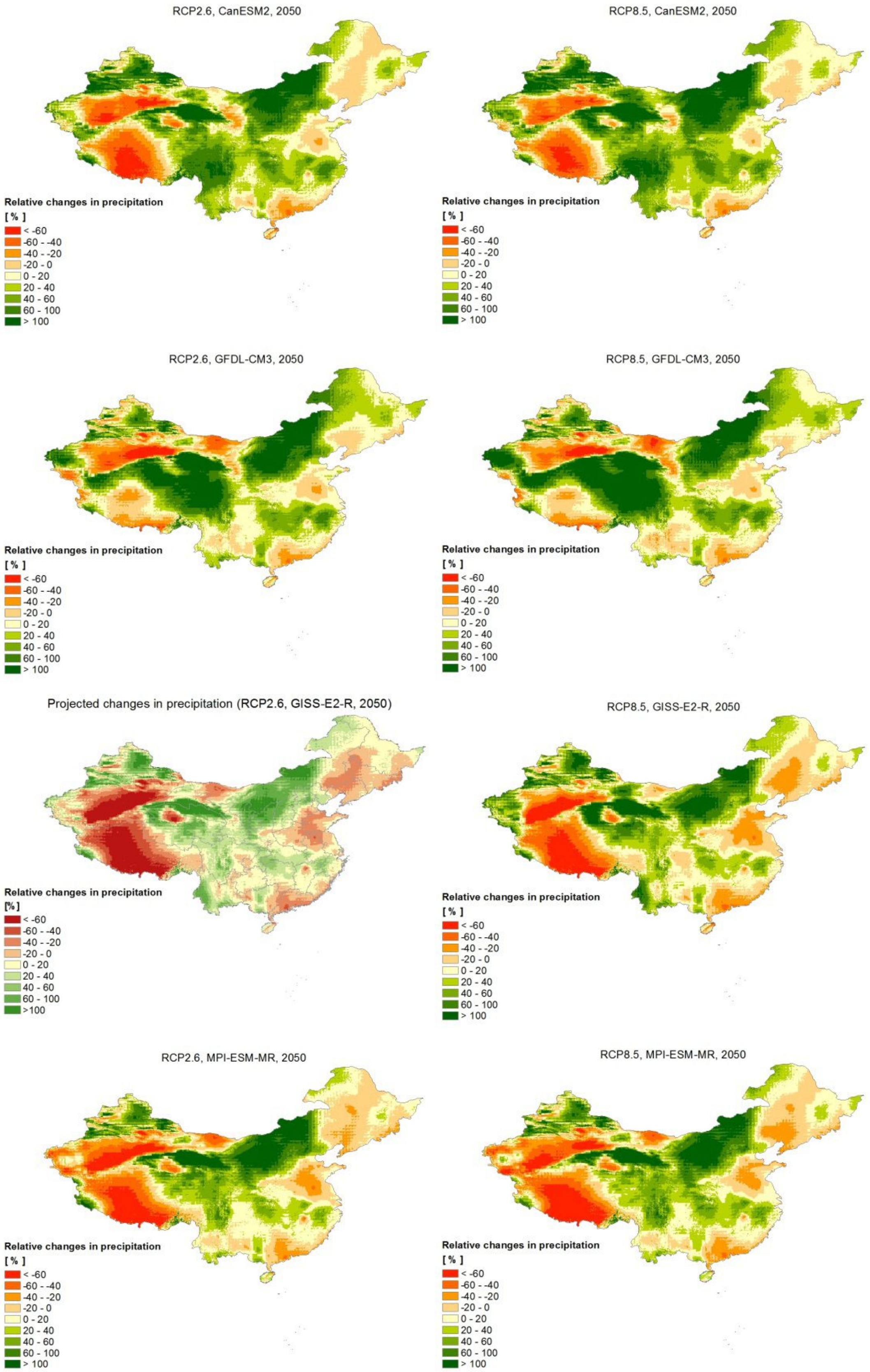
Appendix I. An example of assessing the water footprint related to crop consumption in China: wheat in the year 2006

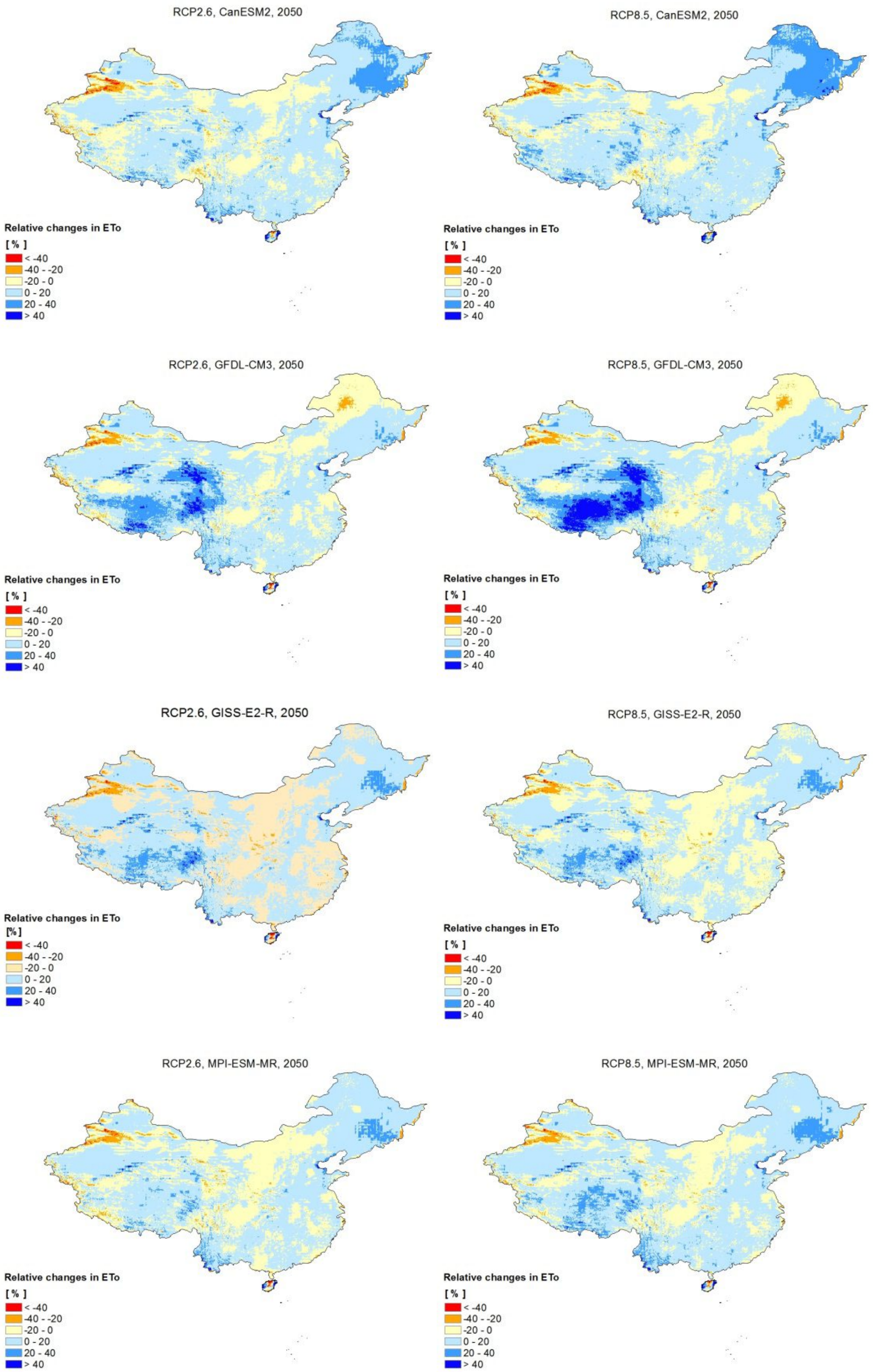
Province	Population[B] (10^4)	Livestock (10^4LU)	Utilization (10^3 t)					Supply (10^3 t)					WF of crop production ($10^6m^3/y$)			Net virtual water import as result of International crop trade ($10^6m^3/y$)			Net virtual water import as result of Inter-regional crop trade($10^6m^3/y$)			Virtual water trade balance ($10^6m^3/y$)			WF of consumed crop (m^3/t)			WF of food consumption ($10^6m^3/y$)		
			Food[E]	Feed	Seed	Waste	Otheruse	Production	Stock var.	International trade[C]	Inter-regional trade	Crop trade balance[D]	Blue	Green	Total	Blue	Green	Total	Blue	Green	Total	Blue	Green	Total	Blue	Green	Total	Blue	Green	Total
Beijing	1601	61	1109	15	49	31	28	300	-8	12	928	940	177	74	251	0.5	23	23	533	578	1111	534	601	1134	574	680	1254	681	646	1327
Tianjin	1075	62	745	15	33	21	19	499	-13	5	342	347	335	165	500	0.2	8	9	197	213	410	197	222	419	629	501	1130	502	365	866
Hebei	6898	1102	4778	274	219	141	120	11897	-307	-231	-5827	-6058	9030	5320	14350	-175.3	-103	-279	-4423	-2606	-7028	-4598	-2709	-7307	729	3726	4455	3885	2289	6174
Shanxi	3375	322	2338	80	105	68	59	2271	-59	6	431	437	1570	1540	3110	0.2	11	11	77	480	557	77	490	568	609	1522	2130	1524	1878	3402
Inner Mongolia	2415	1241	1673	308	86	55	42	1722	-44	6	481	487	1940	549	2489	0.2	12	12	303	349	652	303	361	664	1016	1817	2833	1820	738	2558
Liaoning	4271	712	2959	177	136	88	74	31	-1	44	3359	3403	17	16	33	1.7	82	84	1931	2092	4023	1933	2174	4107	568	1799	2367	1800	2022	3822
Jilin	2723	670	1886	166	89	57	47	3	0	29	2214	2243	3	2	5	1.1	54	55	1273	1379	2652	1274	1433	2708	569	1148	1717	1149	1292	2440
Heilongjiang	3823	783	2648	194	123	79	67	930	-24	29	2177	2206	483	504	987	1.1	53	54	1252	1356	2608	1253	1409	2662	554	1569	2123	1570	1731	3302
Shanghai	1964	35	1360	9	59	38	34	113	-3	18	1372	1390	65	138	203	0.7	34	34	213	1744	1957	214	1777	1991	186	270	456	270	1856	2126
Jiangsu	7656	533	5303	132	236	152	133	9016	-233	-108	-2719	-2827	1210	12700	13910	-14.5	-152	-166	-365	-3830	-4195	-379	-3982	-4361	132	748	880	762	8003	8765
Zhejiang	5072	287	3513	71	155	100	88	157	-4	49	3726	3775	13	281	294	1.9	91	93	578	4734	5312	580	4825	5405	151	569	720	568	4887	5455
Anhui	6110	487	4232	121	189	122	106	10390	-268	-204	-5148	-5352	978	18300	19278	-19.2	-359	-379	-485	-9067	-9551	-504	-9426	-9930	90	409	499	427	7986	8413
Fujian	3585	369	2483	92	112	72	62	16	0	37	2769	2805	0	35	35	1.4	68	69	496	3081	3577	497	3149	3646	177	470	647	469	3002	3471
Jiangxi	4339	503	3006	125	136	88	76	20	-1	44	3365	3409	0	95	95	1.7	82	84	603	3744	4347	604	3827	4431	177	568	745	568	3682	4249
Shandong	9309	1387	6448	345	294	190	162	20130	-520	-464	-11707	-12171	9730	14300	24030	-224.3	-330	-554	-5659	-8316	-13975	-5883	-8646	-14529	455	3140	3595	3339	4907	8247
Henan	9392	2191	6506	544	305	197	163	29365	-758	-797	-20094	-20891	5900	27800	33700	-160.1	-754	-914	-4037	-19023	-23061	-4197	-19778	-23975	182	1267	1449	1400	6598	7999
Hubei	5693	793	3944	197	179	116	99	3111	-80	20	1485	1504	134	8540	8674	0.8	36	37	266	1652	1918	267	1688	1955	87	367	454	367	9363	9730
Hunan	6342	1219	4393	303	203	131	110	29	-1	67	5046	5113	0	86	86	2.6	124	126	904	5616	6520	907	5739	6646	177	831	1008	830	5331	6161
Guangdong	9442	665	6541	165	291	187	164	3	0	96	7249	7345	0	8	8	3.7	177	181	1299	8067	9366	1302	8245	9547	178	1244	1422	1242	7869	9111
Guangxi	4719	903	3269	224	151	98	82	6	0	50	3769	3818	2	24	26	1.9	92	94	2009	2692	4701	2011	2784	4795	527	1843	2370	1844	2571	4415
Hainan	836	143	579	36	27	17	15	0	0	9	664	673	0	0	0	0.3	16	17	119	739	858	119	755	875	178	110	288	110	696	806
Chongqing	2808	447	1945	111	89	57	49	476	-12	23	1765	1788	4	1070	1074	0.9	43	44	941	1260	2201	942	1304	2245	418	870	1288	870	2185	3055
Sichuan	8169	2189	5659	544	269	173	142	4436	-114	32	2433	2465	250	7930	8180	1.2	60	61	1297	1738	3035	1299	1797	3096	225	1359	1584	1360	8545	9905
Guizhou	3690	838	2556	208	120	77	64	451	-12	34	2552	2586	28	1520	1548	1.3	62	64	1361	1823	3184	1362	1885	3247	458	1252	1710	1253	3070	4323
Yunnan	4483	1292	3105	321	148	96	78	930	-24	37	2806	2843	514	2730	3244	1.4	69	70	1496	2004	3500	1497	2073	3570	534	1772	2306	1774	4235	6008
Tibet	285	639	197	159	15	10	5	265	-7	2	126	128	72	134	206	0.1	3	3	67	90	158	67	93	161	355	75	430	75	122	197
Shaanxi	3699	430	2562	107	116	75	64	3901	-101	-33	-843	-877	1670	6050	7720	-14.3	-52	-66	-361	-1308	-1669	-375	-1359	-1735	423	1160	1584	1175	4257	5432
Gansu	2547	691	1764	172	84	54	44	2607	-67	-16	-405	-421	1590	3720	5310	-9.8	-23	-33	-247	-578	-826	-257	-601	-858	605	1143	1748	1153	2697	3850
Qinghai	548	543	380	135	22	14	10	594	-15	-1	-17	-18	131	617	748	-0.2	-1	-1	-4	-18	-22	-4	-19	-23	220	89	310	90	422	512
Ningxia	604	137	418	34	20	13	11	833	-22	-12	-304	-316	951	473	1424	-13.8	-7	-21	-347	-173	-520	-361	-180	-541	1115	499	1614	512	255	766
Xinjiang	2050	865	1420	215	71	46	36	3962	-102	-79	-1994	-2073	2560	1020	3580	-51.1	-20	-71	-1288	-513	-1801	-1339	-534	-1873	619	940	1559	983	392	1374
China[A]	129523	22539	89721	5600	4130	2665	2254	108466	-2800	-1296	0	-1296	39358	115740	155098	-657	-600	-1257	0	0	0	-657	-600	-1257	355	1081	1436	34371	103891	138263

A. National total crop utilization and supply accounts are obtained from FAO (2014).
B. Statistics on provincial population and livestock are obtained from NBSC (2013).
C. Positive value means import. Negative value means export.
D. Provincial “crop trade balance” refers to net crop import.
E. “Food” is equal to the sum of ”food directly” and ”food manufactured” obtained from FAO (2014).

Appendix II. Relative changes in annual precipitation in China from 2005 to 2050 across GCMs for RCP2.6 (left) and RCP8.5 (right)



Appendix III. Relative changes in annual reference evapotranspiration in China from 2005 to 2050 across GCMs for RCP2.6 (left) and RCP8.5 (right)



Appendix IV. Relative changes in national average crop yield in China from 2005-2050 under each scenario

	Baseline 2005	Relative changes from 2005-2050 (%)			
	t ha^{-1}	S1	S2	S3	S4
Wheat	4.28	7	6	34	29
Rice	6.26	20	17	35	29
Maize	5.29	-10	-8	-3	-3
Sorghum	4.47	9	8	6	5
Millet	2.1	61	53	77	65
Barley	4.14	-22	-19	31	26
Soybean	1.71	27	24	42	36
Sweet potato	22.18	-51	-45	34	29
Potato	14.52	-32	-28	27	23
Cotton	3.92	4	3	41	34
Sugar cane	63.97	-42	-37	11	10
Sugar beet	37.51	198	174	233	196
Groundnuts	3.08	-9	-8	33	28
Sunflower	1.89	17	15	65	55
Rapeseed	1.79	-35	-31	22	19
Tomato	35	-54	-47	56	47
Cabbage	33.68	-4	-4	40	34
Spinach	19.35	25	21	39	33
Grape	14.19	16	14	41	34
Apple	12.7	39	34	80	68
Tea	0.89	28	24	24	20
Tobacco	1.97	30	27	42	36

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