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Balancing water resources conservation and food security in China

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Abstract

China's economic growth is expected to continue into the next decades, accompanied by a sustained urbanization and industrialization. The associated increase in demand for land, water resources, and rich foods will deepen the challenge to sustainably feed the population and to balance agricultural and environmental policies. We combine a hydrological model with an economic model to project China's future food trade patterns and embedded water resources by 2030, and to analyze the effects of targeted irrigation reductions on this system, notably on national agricultural water consumption and food self-sufficiency. We simulate inter-provincial and international food trade with a general equilibrium welfare model and a linear programming optimization, and obtain province-level estimates of commodities' virtual water content with the hydrological model. We find that reducing irrigated land in regions highly dependent on scarce river flow and non-renewable groundwater resources - Inner Mongolia and the greater Beijing area - can improve the efficiency of agriculture and trade regarding water resources. It can also avoid significant consumption of irrigation water across China (up to 14.8 km^3/y, reduction by 14%), while incurring relatively small decreases in national food self-sufficiency (e.g. by 3% for wheat). Other researchers found that a national - rather than local - water policy would have similar effects on food production but only reduce irrigation water consumption by 5%.

Introduction

China's geographical mismatch between arable land and water availability has led to unsustainable agricultural expansion in dry areas, further supported by food self-sufficiency objectives. In particular, Inner Mongolia (in the Yellow River basin) and the greater Beijing area (Beijing, Tianjin and Hebei provinces, in the Hai River basin) suffer increasingly severe water scarcity. Major associated environmental issues include soil degradation, water resources over-exploitation and pollution, and land subsidence from groundwater overdraft; threatening both ecosystems and human activity (*1*). Current solutions to water scarcity are focused on sustaining existing activities, for example, the South to North Water Transfer (SNWT) project will increase water supply in the North through physical transfers. However, China's agricultural and water resources strategies could change. The country recently increased its trade openness significantly (e.g. soy imports, (*2*)) and major policy plans, in addition to supporting sustainable agriculture (*3*), newly emphasize land conservation and reduction of groundwater use as water saving strategies (*4*). Quantifying the effects of targeted agricultural water conservation measures will both allow for comparison with current water saving solutions and inform policy-makers of the trade-offs between environmental conservation and food self-sufficiency. Here, we estimate multiple effects of targeted water conservation efforts, notably on food self-sufficiency, by integrating agricultural production, water resources use, and domestic & international food trade.

We project China's future food trade and embedded water resources transfers (i.e. virtual water trade, VWT), and analyze the effects of reducing irrigated areas, concentrating on the dry regions of Inner Mongolia and the greater Beijing area. Elliot et al. project that freshwater limitations in regions of China could require conversion of cropland from irrigated to rainfed by end-of-century (*5*). We explore here the impacts of reducing irrigated cropland in areas with particularly scarce water resources. We previously identified Inner Mongolia as a target for water-use efficiency improvements in China, due to its large crop production with particularly low water productivity (*6*). The region's surface and groundwater resources are further threatened by projected droughts (*7*) and by the development of water-intensive coal industry (*8, 9*), which also affects river flow into more water-productive (*6*), important food producing provinces downstream (*10*). Besides, growing industrial and domestic demand will very likely worsen water scarcity in the greater Beijing area, which represents the largest urban region of arid Northern China (*11, 12*), and where 70% of water withdrawal (i.e. 20 km^3/y) is from North China Plain aquifers, one of the most quickly depleting groundwater system in the world (*13, 14*). We previously found that China's domestic food trade induced irrigation water losses (*6*), reflecting that provinces with relatively lower irrigation water productivity - such as Inner Mongolia - export to areas with higher productivity. This (in)efficiency of trade regarding water resources consumption at a global level are referred to as trade-induced water savings (losses).

We address the following questions: (i) How will future socio-economic changes affect China's food trade and associated water transfers? (ii) To what extent can localized reductions in irrigated area decrease agricultural water use while maintaining national food security? (iii) How would these strategies affect China's domestic and international VWT flows and trade-induced water savings (losses)?

We use socio-economic projections and an economic model to assess the future state of China's agricultural supply and demand, including domestic and international food trade. A detailed description of the baseline (BL) scenario used for these projections - which includes increasing urbanization, population and economic growth - is provided in the SI Appendix. We then apply a hydrological model to estimate water resources embedded in the produced and traded food. Next, we quantify the effects of two agricultural scenarios on China's VWT network and on the efficiency of food trade in terms of water resources. The first scenario (IM) reduces irrigated land area in Inner Mongolia by 50% in 2020 and 2030, relative to BL. The second (IM+B) simultaneously reduces irrigated land in Inner Mongolia and in the greater Beijing area by 50% in 2020 and 2030. We adapt inputs of both the economic model and the hydrological model accordingly, in order to estimate the impacts of these two scenarios on China's agricultural trade and embedded water resources.

Analysis of scenarios' impact requires economic and hydrological modeling tools that adequately account for input changes (e.g. shift in irrigated land area affects food price, production in other locations, and international imports). Most existing studies of China virtual water trade have used input-output methods to estimate current trade patterns (*8, 15*). In contrast, computable general equilibrium (CGE) models offer a larger flexibility - in particular in the face of changes in the supply side (*16*) - making this type of model more suitable for an accurate study of scenarios' impacts. Here, we combine the CHINAGRO applied general equilibrium (AGE) model (*17*) and the H08 hydrological model (*18*) to build the Chinese domestic and foreign VWT network in each scenario (BL, IM and IM+B). We combine provincial crop and livestock's virtual water content (VWC, water resources consumed for agricultural production) estimates from the H08 global hydrological model ((*19*), see *Material and Methods*) with detailed inter-regional food trade simulations from the CHINAGRO general equilibrium welfare model (8 regions, (*17*)), downscaled to the inter-provincial level (31 provinces, see *Material and Methods*). We take into account "green" (i.e. rainfall) and "blue" (i.e. from rivers, reservoirs and groundwater) sources of water, and 7 major crops and livestock products (i.e. corn, rice, soy, wheat, ruminant meat, pork and poultry). These products accounted for about 93% of China's domestic food supply in 2005 [in calories (FAO, http://faostat3.fao.org)].

Agriculture is a key sector in which to utilize water saving strategies, as it drives most water withdrawals across the globe (59% on global national average, 65% in China (*28*)). Previous work has focused on the impact of water shortages on future food production (*20*). In contrast, we analyze the effects of adjustments in agricultural production on water resources use and food trade. H. Yang and colleagues first proposed international grain imports as a solution to China's water scarcity (*21*), and further analysis of the role of virtual water trade would help inform the trade-offs between food security and environmental integrity (*22, 23*). While large infrastructure investments are devoted to improve irrigation water use efficiency in China (*25*), potential improvements are unlikely to compensate for food production loss in a low groundwater use scenario (*23*), showing the importance of trade-offs between food self-sufficiency and water conservation.

In this analysis, we focus on particularly water-scarce areas of China which have high potential water savings relative to associated decreases in food production when removed from cultivation. We integrate here, for the first time, provincial production with detailed inter-provincial and foreign trade to analyze the effects of a local agricultural production change on the entire water consumption and food supply system, focusing on the three main questions identified above.

Results

Future food and virtual water trade We find that virtual water transfers through China's agricultural trade will significantly intensify by 2030 (Fig. 1), the volumes involved will almost double, from 239 km^3 in 2005 to 445 km^3 in 2030 (86% increase). This growth is mostly driven by a rise in international food imports, corresponding to foreign virtual water imports (VWI) increasing from about $49km^3$ in 2005 to $137km^3$ in 2030. Domestic food trade and associated virtual water transfers are expected to increase less significantly, from $183km^3$ to $201km^3$, including exports from dry provinces such as Inner Mongolia and Xinjiang ($13.4km^3$ to $16.7km^3$ and $8.3km^3$ to $11.6km^3$, respectively). Thus, international VWI are projected to account for a larger share of China's total VWT (about 30% in 2030, vs. 20% in 2005).

As food trade intensifies over time, we find that associated trade-induced water savings (WS) rise from 47 km^3 to more than 70 km^3, mainly due to increased imports of foreign commodities, produced relatively more water-efficiently than in China. However, some inefficiencies, due to exports from provinces with low agricultural water productivity relative to their trade partners, will worsen with time. For example, exports from Inner Mongolia, the most inefficient trade flows, are projected to induce 6.4 km^3 of blue water losses (i.e. negative WS, accounting for blue water sources alone) in 2030, vs. 5.4 km^3 in 2005 (Fig1).

Effects of targeted irrigation reductions on water resources and food self-sufficiency When irrigated land in both Inner Mongolia and the greater Beijing area is reduced by half (IM+B scenario), national corn and wheat production decreases by only 4.3% and 4.5%, respectively (SI Appendix, Table S2), whereas production reduction in the four provinces alone corresponds to a 4.6% and a 5.5% drop in national production, respectively. Indeed, higher crop prices (due to the reduced supply) increase production in other provinces, which compensates for part of the local decline. These local decreases mainly concern corn (in Inner Mongolia and Hebei) and wheat (mostly in Hebei) production. However, the national decrease in soy production (0.4% in IM scenario) is even greater than the reduction imposed in Inner Mongolia (0.3% of national soy production). Because Chinese soy is poorly competitive on world market, the rise in price only increases international imports, and not production in other Chinese provinces, as observed for other crops.

Even as crop production increases in provinces other than Inner Mongolia and the greater Beijing area, the net effect of the reductions in irrigated land is a decrease in China's water consumption. Remarkably, 14.8 km^3 of blue water consumption is avoided in scenario IM+B relative to BL (14% decrease in China's agricultural blue water consumption), including 6.2 km^3 in the greater Beijing area (47% decrease in agricultural blue water consumption) and 5.2 km^3 in Inner Mongolia (43% decrease in agricultural blue water consumption, Tables 1, SI Appendix, S4 and S5). This saved water resources represent about a third of the total annual water transfer projected for 2050 via the SNWT scheme. These direct water savings come at the cost of a relatively small drop in China's food self-sufficiency (Table 1, SI Appendix, S2 and S3). We define the self-sufficiency ratio of a commodity as production divided by the sum of production and net international imports (*26*). The largest change in self-sufficiency affects corn, with a 1.8 and 3.6 percentage points decrease in IM and IM+B scenarios, respectively. The corn self-sufficiency ratio thus decreases only from 86.1% in the baseline to 84.3% and 82.4% in IM and IM+B scenarios, respectively (Table 1).

Effects of targeted irrigation reductions on virtual water trade and its water-efficiency

As food production and trade patterns shift due to decreased irrigated land areas (in IM and IM+B scenarios), we observe three major effects on virtual water trade flows (Fig. 2). First, a 30% decrease in virtual water exports from the net exporter Inner Mongolia in IM scenario. Second, a 5% increase in virtual water imports by the greater Beijing area (a net importer) in IM+B scenario. Third, an increase in China's foreign virtual water imports, of 2% and 6% from BL to IM and IM+B, respectively.

In both IM and IM+B scenarios, irrigation-intensive commodity exports from Inner Mongolia decline, and corresponding virtual water exports are reduced by $5km^3$, accounting for approximately 3% of all VWT flows in the BL scenario and year 2030 (Fig 2A). In 2030, Inner Mongolia is displaced from 3^{rd} (in BL) to 8^{th} (in IM) and 9^{th} (in IM+B) top agricultural exporter (SI Appendix, Tables S8, S9 and S10). As this province uses significantly more irrigation per unit crop than others (i.e. high blue VWC, SI Appendix, Table S8), this export decline improves the efficiency of food trade in terms of water resources. We observe that these local changes also have significant indirect effects on China's domestic and international VWT, such as an increase in foreign virtual water imports by Liaoning and Shanghai, redistributed to Shaanxi and then to Hunan/Hubei (previously supplied by Inner Mongolia) and Zheijang (previously supplied by Jilin, Fig 2A,B).

In the IM+B scenario, in which irrigated land of the greater Beijing area is also reduced by half, we observe an increase of $3.1km^3$ in virtual water imports by this area, relative to BL in 2030 (Fig 1 and 2C,D). This corresponds to the volume of water embedded in additional domestic and international food imports, required to fill the gap left by a decrease in agricultural production in that location. Importantly, this volume is smaller than the direct blue water savings (avoided irrigation water consumption) gained from reducing irrigated land (Table 1), leading to a net reduction of water consumption at the national level. Production is thus displaced from the greater Beijing area to more water-productive regions in China and the rest of the world (ROW), resulting in enhanced water efficiency of food trade. Importantly, corresponding reductions in water withdrawals for agriculture are even larger than the reductions in irrigation water consumption presented here, as they include avoided water losses through distribution systems (average loss rate is 55% in China (*27*)).

This enhanced water-efficiency of food trade is particularly observed for blue water resources (SI Appendix, Fig S1). Indeed, blue WS induced by domestic trade of local goods increase from $-2.4km^3$ ($5.4km^3$ for all water sources) in BL to $0.4km^3$ ($5.0km^3$ all sources) and $0.4km^3$ ($5.5km^3$ all sources) in IM and IM+B, respectively. Blue WS from both domestic and foreign food trade rise from $38km^3$ in BL ($71.6km^3$ all sources) to $41km^3$ (7% increase) in both IM and IM+B ($71.2km^3$ and $71.8km^3$ all sources, respectively) (SI Appendix, Fig S1).

We observe the impact of reduction in irrigated crop production in Inner Mongolia (IM scenario), through the reduced water losses induced by Inner Mongolian food exports: 3.0 km^3 of blue water losses vs. 6.4 km^3 in the baseline in 2030 (SI Appendix, Fig S2). These losses are lowered back below 2005 level (i.e. $5.4km^3$). Agricultural trade becomes more efficient regarding irrigation water resources, with $3km^3$ additional savings, mostly due to corn trade shifts (SI Appendix, Fig S1) and decreased exports from Inner Mongolia (Fig 2).

Discussion

While foreign imports are projected to account for a larger share of China's future VWT, water-inefficient trade flows, originating in low water productive and dry regions, are expected to increase (Fig 1). This further supports the need to explore additional domestic strategies to cope with water scarcity.

To increase production per unit water withdrawn, agricultural water supply-side options include improving water-use efficiency (consumption by plants over withdrawal) and crop water productivity (plant yield over water consumption, inverse of VWC) (*29*), while demand side strategies can range from incentives like water pricing to policies focused on limiting groundwater overdraft. Future scenarios of possible coping strategies for water scarcity have been analyzed, including water pricing and reduction of groundwater overdraft globally (*23*) and in China's 9 water basins (*24*). Water pricing affecting all sectors in China have been projected to reduce consumption of irrigation water by about 16% by 2025, to be associated with a 4% decrease in irrigated cereal production (*23*). These changes are comparable to the impacts on consumption of irrigation water and land use change estimated in this paper's IM+B scenario (SI Appendix, Tables S4 and S2). In addition, strong limitations on groundwater withdrawal were estimated to lead to a 3% decrease in China's cereal production and a 4% decrease in irrigated area (*23*). Our IM+B scenario, corresponding to a comparable land use change, similarly affects China's cereal production in 2030. However, we find a larger decrease in irrigation water consumption (by about 14% versus 5% in (*23*)). This suggests the geographical focus of our scenario (e.g. Inner Mongolia, with low VWC) leads to the expected effects: greater water savings per unit of avoided food production. This comparison shows our results are quite robust to varying socio-economic and agricultural projections. More studies would be needed to assess a comprehensive range of possible effects of future scenarios.

Direct measures, e.g. important water transfer projects, have been adopted to release pressure on scarce resources while maintaining current agricultural output in China. The total transfer projected through the SNWT scheme by 2050 ($45km^3/y$) is about three times the volume saved in IM+B scenario relative to BL. However, providing more water to these regions with both scarce resources and inefficient use may encourage the development of wasteful water-intensive activities in dry areas (*30*), thus failing at improving environmental sustainability. In addition, the SNWT canals will not provide resources to the driest agricultural lands in North West China, where the coal industry and agriculture compete for increasingly scarce water resources. Finally, long-distance water transfers have serious socioeconomic and environmental costs, like population displacement, in addition to important benefits (*31*).

We showed that reducing irrigated land in Inner Mongolia and the greater Beijing area would save water nationally. In addition to conserving surface and groundwater resources, reducing irrigation in these regions would also benefit the local environment. Indeed, irrigation in arid lands can reduce crop yields by increasing soil salinity (*32*), and continued groundwater overdraft hinders a sustained availability of fossil water, threatening both socio-economic activities and ecosystems. These issues are of particular concern in North China, where, even though mining of renewable and nonrenewable water resources supports economic activities in the short term (*34*), there is an urgent need to reduce groundwater use (*34, 35*).

Grain self-sufficiency is historically a central political issue in China (95% target set in 1996 (*33*)), but increasing food demand and limited available resources have induced a decreasing trend in self-sufficiency, and led to less constraining recent policies (”high rate” target in 2013 (*4*)). In the scenarios studied, China’s corn and wheat self-sufficiency would decrease from 86.1% and 98.2%, respectively, to 84.3% (IM)-82.4% (IM+B) and 97.9% (IM)-95.2% (IM+B), respectively (Table 1). A relatively small effect, especially as China is already increasing its international imports, and as the government recognizes the need to complement domestic food supply with foreign products (*3*). However, the corresponding agricultural expansion in other nations might have negative environmental consequences there, affecting land and water resources, even if major trade partners (e.g. Brazil and the U.S.) have a significantly more water-efficient agriculture than China (*2*).

Reducing irrigation would likely come at a small financial cost, mostly devoted to farmers support (e.g. by government transfers, such as ecological compensation) and additional foreign food imports. We found that the overall effects of IM+B scenario are a 1% increase in China’s cropping revenue (by 25.6 billion Yuans/yr, SI Appendix, Table S7) and an 11% increase in cost of foreign imports (by 29.1 billion Yuans). The national cropping revenue increase results from income loss due to production decline in provinces where irrigated land is cut, compensated by a larger income increase in the rest of China, due to higher crop prices. Importantly, we find that China would save 14.8 km^3/y of irrigation water while increasing national cropping revenue (+1%, IM+B scenario). The provincial income loss in the most stringent scenario (IM+B), mainly in Inner Mongolia and Hebei, could thus be transferred domestically. The farmers compensation could also be funded through some of the important water conservation investments planned in China (*30*).

Financial means to implement changes in irrigation practices as explored here are largely available. The Chinese government's 2011 N°1 Document outlined a plan to expedite water conservation development and to achieve sustainable management of water resources within this decade (*36*). It plans to bring total investment in solving water problems to four trillion yuan (U.S.D. 635 billion) in the next 10 years. Political will is shifting in favor of environmental protection, but implementation, governance and integrated management are still lacking (*30*). It is too early to know whether such funds could be directed to farmers abandoning unsustainable irrigation, but specific references have been made to focus on water scarce areas and to convert irrigated cropland to conservation areas, in a section of the 2013 N°1 Document (The Institutional Development of Ecosystem Civilization (*4*)). Subsequently, a "Special planning program for integrated water use for Beijing-Tianjin-Hebei" is in preparation under the umbrella of the national development strategy of "Integrated Development of Beijing-Tianjin-Hebei", initiated in 2014. In September 2014, these provinces released government guidelines stating that, besides improving agricultural water use efficiency, other measures reducing agricultural water use are also critical. Suggestions include conversion of cropland to conservation areas, adoption of drought-tolerant varieties (with specific subsidies for farmers in Hebei (*37*)), conversion of irrigated land to rain-fed land, and water pricing according to local water scarcity. Such measures may well benefit the country in the near future, and many more will be needed to successfully address China's extensive water problems.

Materials and Methods

The Chinese domestic and foreign VWT networks are built for years 2010, 2020 and 2030 under three policy scenarios: baseline, irrigation reduction in Inner Mongolia, and irrigation reduction in both Inner Mongolia and the greater Beijing area. Here we analyze results for year 2030. In China's VWT network, each node represents a province or the rest of the world (ROW), and each link between a pair of nodes is directed by the direction of trade and weighted by the volume of virtual water involved in the traded commodities. The ROW node can be directly linked only with the four main trading harbor provinces of Guangdong, Shanghai, Tianjin and Liaoning. We use two main pieces of information to construct the VWT network in each year and scenario: the detailed inter-regional food trade, downscaled to inter-provincial level, and the virtual water content of each commodity in all provinces. We build the VWT (kilograms of water) network by multiplying the traded volume of a specific commodity (kilograms of product) by the VWC of that commodity (kilograms of water per kilograms of product) in the province of export. The VWT flows corresponding to direct international imports and to domestic trade of foreign commodities are obtained by multiplying the trade volumes by the VWC of the corresponding commodity in the ROW (see SI Appendix).

The inter-regional trade of agricultural products was obtained from the CHINAGRO economic model (*17*), for 4 major crops (corn, rice, soybean, and wheat) and 3 livestock products (ruminant, pork and poultry). The comprehensive model is a 17-commodity, 8-region general equilibrium welfare model. It comprises 6 income groups per region, with farm supply represented at the level of 2,433 administrative units (virtually all counties), and accommodates for every county outputs of 28 products and 14 land use types in cropping and livestock production. Consumption is depicted at the regional level, separately for the urban and rural populations, and domestic trade is inter-regional (see SI Appendix). We apply a linear programming optimization procedure (*39*) to downscale the inter-regional trade matrices to inter-provincial trade matrices, by minimizing the total cost of trade for each commodity (see details in SI Appendix). The optimization constraints ensure the consistency with inter-regional trade simulated by CHINAGRO and the balance of commodity supply and demand in each province (involving production, consumption, storage change, other uses and trade flows), including foreign and domestic goods. In addition, foreign commodities appear in each province trade balance, but we allow their net export to be no larger than China's foreign import, while net export of domestic commodities is bounded by the local production. Finally, international trade flows through the four harbors (in Shanghai, Tianjin, Liaoning and Guangdong) is exogenously imposed, based on reported data (*40*) and projections. Foreign countries are represented as an aggregate in this model.

The VWC (kilograms of water per kilograms of product) of raw crops is defined as the evapotranspiration (ET) during a cropping period (kilograms of water per square meter) divided by the crop yield (kilograms of crop per square meter). It thus accounts for crop water consumption. Variability of a crop's VWC across Chinese provinces is mainly driven by differences in climate and technology affecting local ET and crop yield (see Ref. (*6*) for further details on commodities VWC in China). The VWC of unprocessed livestock products is defined as water consumption per head of livestock (kilograms of water per head), involving feed's VWC, drinking and cleaning water, divided by the livestock production per head (kilograms of meat per head). The virtual water content value of each commodity was calculated using provincial crop yield estimates from CHINAGRO (*17*) (for rainfed and irrigated lands) and ET simulated with the H08 global hydrological model (*18, 41*). The ET simulation used GMFD meteorological forcing data (*42*), which cover the whole globe at 0.5° spatial resolution, from 1948-2008 at a daily interval, the average from 2003-2007 was used in this study (circa 2005), to isolate the effects of policy and socio-economic changes from climate change effects - the latter are not considered here. Even though global warming is projected to increase evaporative demand by 2030 (IPCC), the combined effect of various climate changes (precipitation, temperature, heat stress, CO2 fertilization, etc.) and climate-vegetation feedbacks on crop yield and ET remains highly uncertain (IPCC AR5, Newlands et al 2012). In this paper, we focus on the effects of future socio-economic changes and specific agricultural scenarios. For each crop, the rainfed and irrigated harvested areas (*43*) were fixed circa year 2000, for which detailed gridded data is available, and then scaled in each year/scenario by using the cropland percent changes estimated by CHINAGRO. Gridded ET simulation results (0.5 ° spatial resolution) are then aggregated by province, using the provincial rainfed and irrigated areas simulated by CHINAGRO. Finally, VWC is estimated by dividing this provincial ET by the provincial yield calculated by CHINAGRO for each crop and cropland type (i.e. rainfed and irrigated cropland). We also use these yields to estimate the VWC of livestock feed. The hydro-economic consistency is thus ensured via H08 VWC simulations relying on CHINAGRO provincial crop yield and surface of irrigated and rainfed cropland in each province, year, and scenario.

Trade-induced water savings from a trade relationship represent the amount of water that is saved (if positive) or lost (if negative) by trade, compared with an autarky situation. Water savings (losses) are induced by a relationship in which the exporter is relatively more (less) water-productive than the importer (water-productivity being measured by the VWC of the traded commodity in the region, see SI Appendix).

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Figures and Tables

Scenario	Area	Δ Irrigation water consumption (km^3)	Δ Corn self-sufficiency ratio (percentage points)	Δ Wheat self-sufficiency ratio (percentage points)	Δ Soy self-sufficiency ratio (percentage points)
	In. Mongolia	-5.2			
IM	China	**-7.7**	-1.8 [84.3%]	-0.3 [97.9%]	-0.2 [21.4%]
	In. Mongolia	-5.2			
	Beijing	-0.2			
IM+B	Tianjin	-0.3			
	Hebei	-5.7			
	China	**-14.8**	-3.6 [82.4%]	-3.0 [95.2%]	-0.7 [20.9%]

Table 1: Differences in irrigation water consumption (all products combined), by area, and in China's self-sufficiency ratios for three major crops, between each scenario and the baseline (year 2030). Number in brackets indicate the self-sufficiency ratio in each scenario. Note that in IM+B scenario, about $15km^3$ of freshwater are saved (14% decrease in irrigation water consumption), without significantly altering China's food self-sufficiency (by 4.2% for corn, the largest decrease).

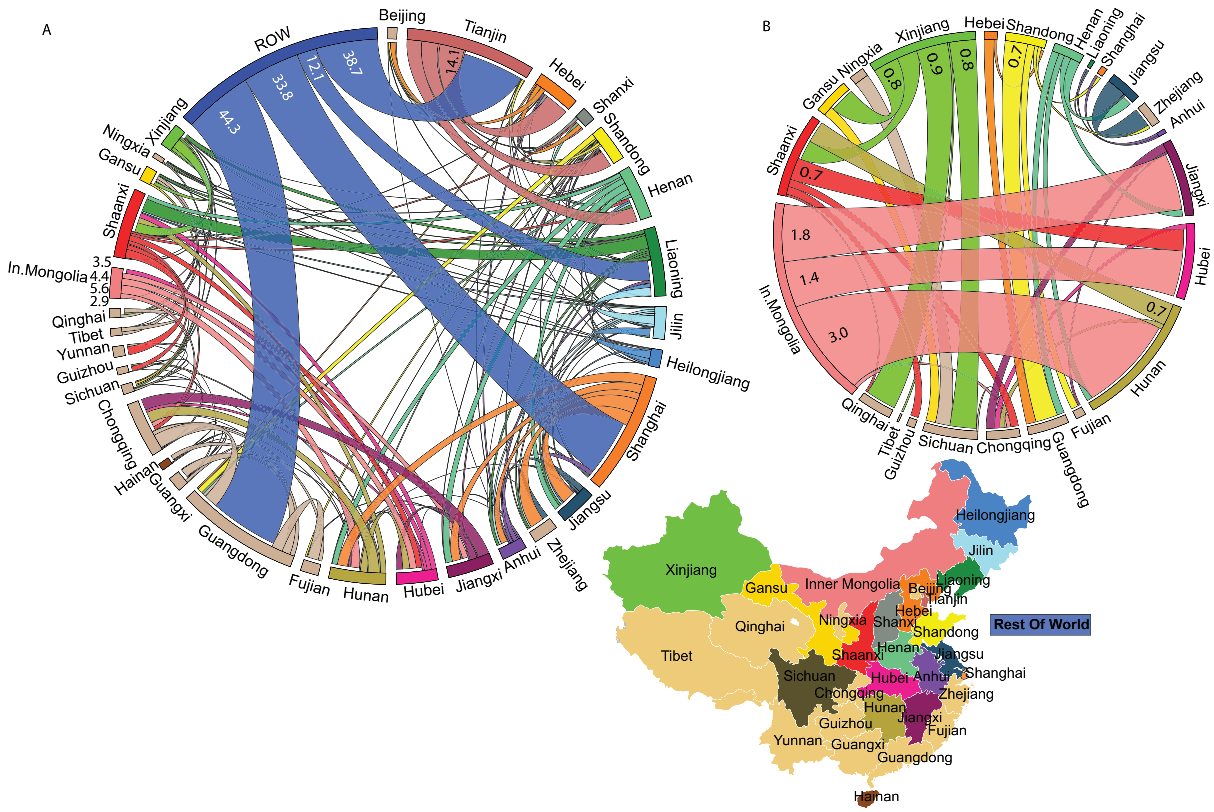

Figure 1: Virtual water trade between Chinese provinces and the ROW (A, 445 km^3), and trade-induced losses of blue water - from rivers, reservoirs and aquifers - (B, 16.9 km^3), in 2030 under BL scenario. Numbers indicate the volume of water in cubic kilometers, and the link color corresponds to the exporting province. The map at the lower right provides a key to the color scheme. Note that China's international imports account for 30% of all VWT. Inner Mongolia exports induce the largest *blue* water losses across provinces (6.4 km^3). This graphics are created using a network visualization software (*38*).

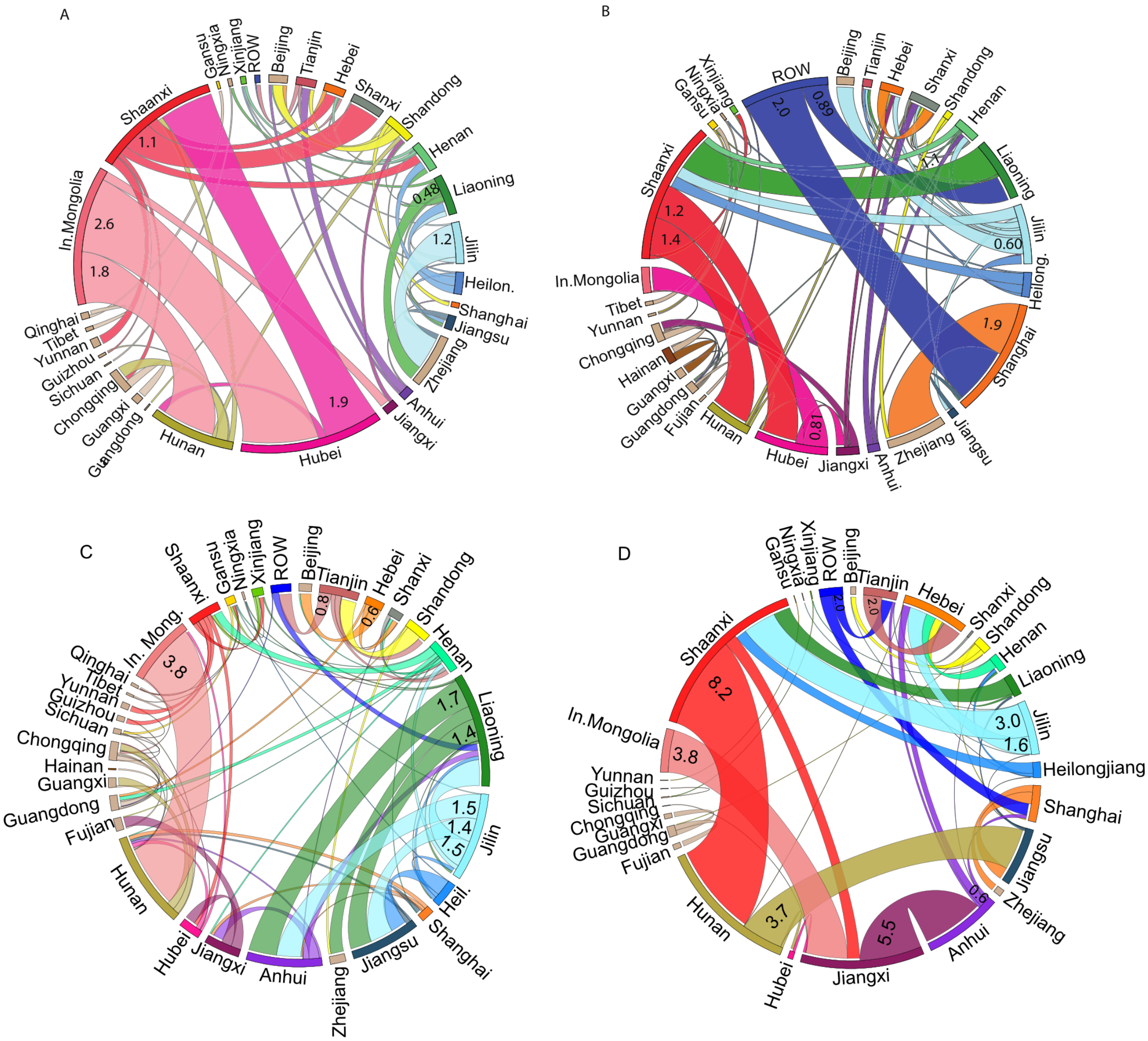

Figure 2: Negative (A,C) and positive (B,D) differences in China's domestic and international virtual water trade flows (km^3) in 2030, between IM scenario and the baseline (A,B) and between IM+B scenario and IM scenario (C,D). Inner Mongolia's virtual water exports decrease from 16.7 km^3 in the baseline to 12.1 km^3 in IM scenario (A) and foreign imports increase by about 3 km^3 (B). Beijing, Tianjin and Hebei's virtual water imports increase from 52.4 km^3 in IM scenario to 55.5 km^3 in IM+B scenario (D).