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# Global footprints of water and land resources through China's food trade

Tariq Ali[a,b], Jikun Huang[a,b], Jinxia Wang[a], Wei Xie[a,*]

[a] China Center for Agricultural Policy, School of Advanced Agricultural Sciences, Peking University, No 5 Yiheyuan Road, Haidian District, Beijing 100871, China

[b] Center for Chinese Agricultural Policy, Institute of Geographical Sciences and Natural Resources Research, Chinese Academy of Sciences, Jia 11, Datun Road, Beijing 100101, China

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ABSTRACT

China's rapid increase in food imports has repercussions for China's and global resources. This study reviews the recent literature on China's virtual water and land trade through food trade, presents updated results for 2000–2015, and makes projections for 2030. The results show that the increased imports of virtual water and land have significantly eased pressure on these resources in China. Soybean imports have been the main contributor towards China's domestic savings of virtual water and land. China's food trade has increasingly contributed towards global savings of virtual water and land. Our projections suggest that the trend in savings of domestic and global virtual water and land will continue, with significant variations due to changes in resource use efficiency.

## 1. Introduction

China has largely ensured its food security despite the increase in demand for food due to an increase in population, higher levels of income, and changes in food consumption pattern. The biggest challenges of food supply in the last six decades in China were to meet the increasing food demand, resulting from: (i) increasing population, which increased by around 1% annually over 1978–2014, and (ii) rising per capita GDP, which increased by 9.7% annually over 1978–2014 (NBSC, 2015). The rising income has significantly increased the consumption of high-value products such as meats, dairy, and fruits. At the same time, China has also made tremendous progress in increasing agricultural production and nutritional status of its population (FAOSTAT, 2016). Despite its natural resource constraints, increase in China's food demand has largely been met by domestic agricultural production expansion, except for the demand for soybean (Huang, 2016).

However, in the past, China's agricultural expansion has been at the expense of environment and of sustainable development. Overdraft of groundwater has been one of the most serious problems in China. In 11% of the plain regions, groundwater extraction exceeded its sustainable levels (MWR, 2012). In the Hai River Basin, one of the major grain production regions in China, 91% of the area faces the problems of groundwater overdraft. Groundwater overdraft has resulted in issues such as groundwater table decline, land subsidence, and intrusion of seawater (MWR, 2016; MOEP, 2015). Soil degradation has also become a serious problem in many regions in China. Among other factors, unreasonable human utilization has caused degradation of 540 million ha (Mha) land, accounting for about 56.2% of the total national area (Long, 2013). Additionally, more than 50% of the total cultivated land has experienced land degradation (Li et al., 2011). Deng and Li (2016) estimated that the annual cost of land degradation reached US$ 37 billion in China in 2007 or about 1% of China's GDP. In terms of total resource use in agriculture, China's agricultural water withdrawal and cultivated land have increased 3.2% (from 378 $km^3$ to 390 $km^3$) and 5.4% (from 128 Mha to 135 Mha) between 2000 and 2015, which indicates increasing stress on these resources in China (FAOSTAT, 2016).

To meet the challenges of constraints in water and land resources, and of rising food demand, since the 1990s, China has partially but increasingly relied upon the international market to ensure its food supply. The previous studies showed that China, based on its comparative advantage, had expanded its food trade by increasing the import of land-intensive crops (e.g., cereal, soybean, edible oils, and sugar) and the export of labor-intensive products (vegetables, fruits, and processed foods) (Huang et al., 2010). By 2013, China's net food imports accounted for 6.7% of total food consumption (FAOSTAT, 2016). Given that trade in agricultural commodities is also an exchange of resources incorporated into the traded goods, there is a growing volume of recent literature on the impact of increased trade flows on hidden resources like water and land (Kastner et al., 2012; Kissinger, 2012). Regional differences in the quantity of water and land required

* Corresponding author.
*E-mail address:* xiewei.ccap@pku.edu.cn (W. Xie).

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to produce one ton of crop biomass, termed as virtual water content (VWC) and virtual land content (VLC), can be used to mitigate regional scarcity of water and land. Some studies have suggested that although China's agricultural trade is steered by economic and political reasons, China has unconsciously been importing virtual water (VW) and virtual land (VL). Such VW and VL trade has implications at both national and global levels. A handful of studies have analyzed China's footprint of water and land via food trade (Liu et al., 2007; Liu and Savenije, 2008; Dalin et al., 2012a, 2012b, 2014; Qiang et al., 2013; Shi et al., 2014; Chen and Han, 2015) with different temporal, regional and commodity coverage.

A better understanding of China's historical and future global virtual trade in water and land can help China and the rest of the world evaluate alternate policy options in the future. Therefore, we have designed this study with two major objectives: 1) to draw key conclusions from the literature on China's virtual water trade (VWT) and virtual land trade (VLT) via agricultural commodities trade; 2) to update and provide coherent and consistent results on VWT and VLT over the past decade, and for the future. We contribute to the literature by using better VWC parameters (Hanasaki, 2016) and consistent coverage of commodity types for different years, for both VW and VL trade. We have used country-specific VWC and VLC of the same product for each country. Thus, covering past and future periods in a coherent analysis would help assess the dynamics and effects of various policies, economic and physical factors in China on China's and the world's water and land footprints.

It is worth pointing out that this study is focused on impact of China's food trade on footprints of water and land resources. Water/land saving with trade scenario indicates that more water/land would have to be used if there would be no trade.

The remainder of the paper is organized as follows. Section 2 reviews the literature for key findings. Section 3 describes the most recent (2000–2015) trends in China's trade in VW and VL, embodied in major food commodities. Section 4 contains our projections of China's food trade and corresponding flows of virtual water and virtual land. Section 5 concludes the paper with policy and research recommendations.

## 2. Key findings from existing literature

### 2.1. Virtual water trade

At the global level, agricultural commodity trade has helped save water resources. Literature contains different estimates on the amount of water saved via commodity trade, due to varying methods and crop/product coverage. Still, most of the studies have pointed towards water savings (Fader et al., 2011; Dalin et al., 2012a, 2012b). For example, Chapagain et al. (2006) estimated that agricultural trade saved 352 $km^3$ of global water resources in 2002, which was equivalent to 6% of the global water use in agriculture that year. Dalin et al., (2012a, Dalin et al., 2012b estimated that international food trade led to 8% savings in global fresh water withdrawal in 2005.

For China, VW trade has been growing at a rapid pace since late 1990s. According to Liu et al. (2007), the annual total virtual water imports of all the 32 crops increased steadily from an annual average of 32.0 $km^3$ (accounting for 7.7% of agricultural water withdrawal) during 1981–1990 to 44.9 $km^3$ (accounting for 11.5% of agricultural water withdrawal) during 1991–2004. A more recent study by Shi et al. (2014) shows that annual total VW imports (for 27 primary crops covered) increased from 33 $km^3$ in 1990 to 148 $km^3$ in 2009, which were 26.3% and 39.8% of China's agricultural water withdrawal in respective years. However, during 1990–2009, the annual total VW exports of all crops remained almost constant, ranging between 12.7 $km^3$ in 1990 and 16 $km^3$ in 2009. As a result, total net VW imports due to agricultural trade have been increasing continuously. Net VW import increased from about 78 $km^3$ in 2004, to a staggering 138 $km^3$ (accounting for 37.1% of China's agricultural water withdrawal) in 2009 (Shi et al., 2014). In contrast, for both agricultural and industrial trade during 1996–2005, China had 23 $km^3$ average annual net exports of VW (Hoekstra and Mekonnen, 2012). As pointed out earlier, estimates from these studies have slight differences due to different commodity coverage and parameters used.

A few major crops have been responsible for the rising trend of VW trade for China. Since the 1990s, except for a few years, more than 95% of VW imports consisted of soybean, cereals, and edible oils (Liu et al., 2007; Shi et al., 2014; Zhuo et al., 2016). For soybean, China was a net exporter until before 1996. However, due to increasing imports caused by higher domestic demand and by liberalizing soybean trade since China's joining of WTO in 2001, China's import of Soybean has significantly increased. On the other hand, China also exports many agricultural products such as vegetables, fruits, tobacco, and tea; these exports contributed to the rising trend of total VW export.

In the recent past, geographic distribution and trading partners for China's VW trade have been evolving rapidly. China's total number of virtual water trading partners has increased from 34 in 1986 to 159 in 2009. Generally, Asia, Europe, and Africa are China's net VW export partners. The Americas and Oceania are China's net VW import partners, from whom China imported much larger volumes of VW than that it exported. Further analysis of VW trade network shows that it is heterogeneous and highly polarized, with eight big partners accounting for more than 85% of China's VW trade (Shi et al., 2014).

More importantly, China's agricultural trade has also been saving domestic and global water resources. China's domestic savings of water increased from 16.5 $km^3$ per year during the period 1961–1980 to 30.6 $km^3$ per year during 1991–2004 (Liu et al., 2007). More recently, China's domestic savings of water due to agricultural trade increased from 33 $km^3$ in 2000 to 138 $km^3$ in 2009 (Shi et al., 2014). These estimates are quite similar to findings of Zhuo et al. (2016), who reported that China saved 108 $km^3$ of VW in 2008 due to international crop trade. Domestic water savings in 2009 were equivalent to 37% of China's irrigation water use in that year (Shi et al., 2014).

China's role in global water savings through agricultural trade has been significant. During 1998–2001, China contributed around 24% to the total global water savings (263 $km^3$) related to agricultural trade (Fader et al., 2011). Trade in Soybean has been a major contributor towards global water savings, mostly due to increase in China's imports from the more efficient producers (United States, Argentina, and Brazil). In 2007, China's trade in Soybean was responsible for a significant part (36%) of the total global water savings associated with major food commodities (Dalin et al., 2012a, 2012b).

### 2.2. Virtual land trade

International trade in agriculture can play an important role in compensating for land scarcity, especially in countries with scarce land endowments. Globally, trade during 1998–2002 saved about 41 Mha land annually, which was about 5% of cultivated land (Fader et al., 2011). The global agricultural system can be more productive if trade is directed from countries with higher yields to countries with lower yields. For example, in comparison to a hypothetical self-sufficient world, agricultural trade pattern in 2001 raised global land productivity by 5% (Fader et al., 2011).

There are very few studies focusing on China's VL trade. In this paper, we summarize the major findings from a recent study by Qiang (2013), which indicates China has been importing significant quantities of VL via its agricultural trade in 6 main crops. Virtual land imports of China grew from 1.2 Mha (equivalent to 0.93% of China's cultivated area or 0.73% of crop sown areas) in 2000 to 33 Mha (27.1% of China's cultivated area or 20.8% of crop sown areas) in 2009. For the past fifteen years, the average cropping intensity index (sown area/ cultivated land) in China has been around 1.25. For simplicity, we will hereafter only compare land savings with cultivated land. Exports of VL have been fairly constant over the same period, ranging between 4 Mha to 5 Mha (Qiang, 2013).

Over the years, different crops have been responsible for China's trade in VL. Cereals dominated total virtual land imports from 1986 to 1996, accounting for 57.6% of the total VL imports. Since 1996, VL imports via oil crops increased dramatically (accounting for 82.2% of the total VL imports), reaching 26.64 Mha in 2009. Soybean was the major driver behind this surge. From the export side, cereals, vegetables, and fruits have been the major land exporting products over 2000–2009 (Qiang et al., 2013). Moreover, China's VL imports have not only grown but have also diversified in the last two decades, with 43 partners in 1986 to 62 in 2009. Between 1986 and 1996, China mostly imported VL through wheat from North Americas. However, after 1995, South Americas became the major source of China's VL, with 12.49 Mha imports in 2009 (Qiang et al., 2013).

China's crop trade has also been saving considerable quantities of virtual land for China. During 1986–2009, China's domestic savings of land changed from negative (−4.4 Mha) to positive (28.9 Mha). During 1994–2002, China's domestic savings of land due to crop trade were steady at around 7.8 Mha per year. However, the domestic savings increased rapidly to attain a value of 28.9 Mha in 2009, mainly due to an increase in imports of oil crops (mostly soybean) (Qiang et al., 2013).

China's contribution to global land savings through crop trade changed from negative to positive from the early 1990s, indicating that China's domestic land productivity was higher than that of its trading partners in the early period. However, later changes in the composition of China's imports resulted in increased contribution to global land savings, which reached 8.81 Mha in 2009 (compared to −0.3 Mha in 1990). Soybean and oil crop products were the largest contributors to these savings, with an annual average land savings of 3.27 Mha (Qiang et al., 2013). Nevertheless, during 1986–2009, China's cereal and fiber imports contributed to global land loss, with an annual average loss of 0.86 Mha and 0.48 Mha, respectively. Land productivity has been the key factor in determining whether China's trade would induce savings/losses to global land use. It is noted that these results cannot be generalized as they: i) lack enough support from literature; ii) are based on older estimates; iii) fail to present a more recent evolution.

## 3. Recent trends in China's virtual water and virtual land

In order to capture the impact of China's food trade on VW and VL in more recent years, we selected six major food crops (rice, wheat, maize, soybean, fruits and vegetables), and three livestock sectors (poultry, beef and pork). In China, more than 95% of calories are supplied through these commodities (FAOSTAT, 2016). A brief discussion of methodology is presented in Appendix A.

Our results show that China's recent food trade has brought an unprecedented increase in the country's net imports of VW. During 2000–2015, China's food trade has been responsible for an average of 54.8 $km^3$ of net VW imports annually. Starting with a mere 6.9 $km^3$ in 2000 (equivalent to 1.8% of China's agricultural water withdrawal in 2000), China's Net VW imports have risen to 120.1 $km^3$ in 2015 (equivalent to 30.7% of China's agricultural water withdrawal in 2015). Increasing imports of Soybean have been the key factor behind this strong surge in net VW imports; Soybean accounted for about 88% of net VW imports in 2015 (Fig. 1A). Interestingly, in 2000, maize contributed negatively to China's net VW imports (−11.8 $km^3$). Approaching 2010, net VW imports via maize had switched from negative to positive (Fig. 1A). Note that contributions of rice and wheat towards net VW imports have turned positive from negative. Fruit and vegetable trade has been contributing negatively to China's net VW imports; however, the value of negative contribution has been decreasing since 2010, mainly due to a decrease in exports of fruits, and partly by improvements in water productivity. China's net VW imports of meat (poultry, beef and pork) turned positive from around 2012 (Fig. 1A), signifying the increasing consumption of animal proteins by Chinese population, attributable to improved economic conditions and changing food preferences.

Since 2000, the geographic sources of net VW imports for China have also changed considerably. Around 2004, South America surpassed North America as the main source of China's net VW imports (Fig. 1B). Since then, the difference between net VW imports from South and North Americas has been increasing, mainly due to the increased imports of Soybean from Brazil and Argentina. Net VW imports from Australia and New Zealand have seen a significant surge in 2014–2015, mainly due to the increased imports of beef. In the last few years, an increase in maize imports from Eastern Europe has also contributed towards an increase in net VW imports from this region. China's exports of fruit and vegetable to East Asia and South East Asia are the major sources of China's negative net VW imports to these regions. In recent years, however, the negative net VW imports from these two regions have been steadily decreasing. As described earlier, lower volumes of exports and improved water productivity of fruits production in China are the main reasons for this decrease.

China's trade in VL, due to the food trade, has increased significantly; it has followed the trends in VW trade closely. During 2000, 2005, 2010 and 2015, China's net VL imports were 1.7 Mha, 9.2 Mha, 19.4 Mha, and 31.6 Mha respectively. These net VL imports were respectively equivalent to 1.3%, 7.6%, 15.9%, and 23.4% of China's total cultivated area during the respective years. China's net VL imports due to soybean experienced a staggering increase of 618% between 2000 (4.1 Mha or equivalent to 3.2% of total cultivated area) and 2015 (29.6 Mha or 21.9% of total cultivated area) (Fig. 1C). The contribution of China's trade in maize towards net VL imports was lowest in 2003 (−3.4 Mha), which subsequently changed to positive values from 2010 onwards. During 2000–2015, trade in rice and wheat also contributed to net VL imports of China, by a smaller degree. China's net balance in VL due to fruit and vegetable has been negative over the past 15 years (Fig. 1C).

In terms of geographic distribution, South America and North America are the two major sources of net VL imports for China, contributing 18.7 Mha and 11.5 Mha in 2015, respectively (Fig. 1D). Trade with East Asia has been contributing negatively to China's VL imports, with a decreasing trend in recent years. Australia and New Zealand have been contributing smaller, but positive quantities to net VL imports to China. For the most part of the last 15 years, Europe has been contributing negatively to China's net VL imports. The year 2014–2015 was an exception as China diversified its trade by importing soybean and maize from Eastern Europe, particularly from Ukraine and the Russian Federation.

Our results show that China's net imports of both VW and VL have significantly saved these resources for China (Table 1). China's food trade in 2000 saved 18.3 $km^3$ of its domestic water (equal to 4.9% of irrigation water used in 2000). In 2015, the amount of domestic savings of water was 215.5 $km^3$ (equal to 55.0% of irrigation water used in 2015). Soybean import saved 199.2 $km^3$ of water in 2015. It is noted that due to unavailability of rain water use, we compare water savings with irrigation water use. In reality, the water saving ratios will be lower than these ratios.

In the past 15 years, China's domestic savings of land have increased 13 times, from 3.6 Mha in 2000 to 46.7 Mha in 2015. In comparison to the total cultivated area, the domestic land savings increased from 2.8% in 2000 to 34.6% in 2015. One of the implications of domestic land savings is that in 2015 alone, China would have to increase its current soybean harvested area by more than 6 times to produce its imports on its own territory. These figures, particularly the recent ones, are quite significant when taken in the context of land scarcity and increased pressure from other uses of agricultural land in China. The land saved due to food trade could be left for natural vegetation or other non-cropland uses.

The results also demonstrate that China's food trade can signifi-

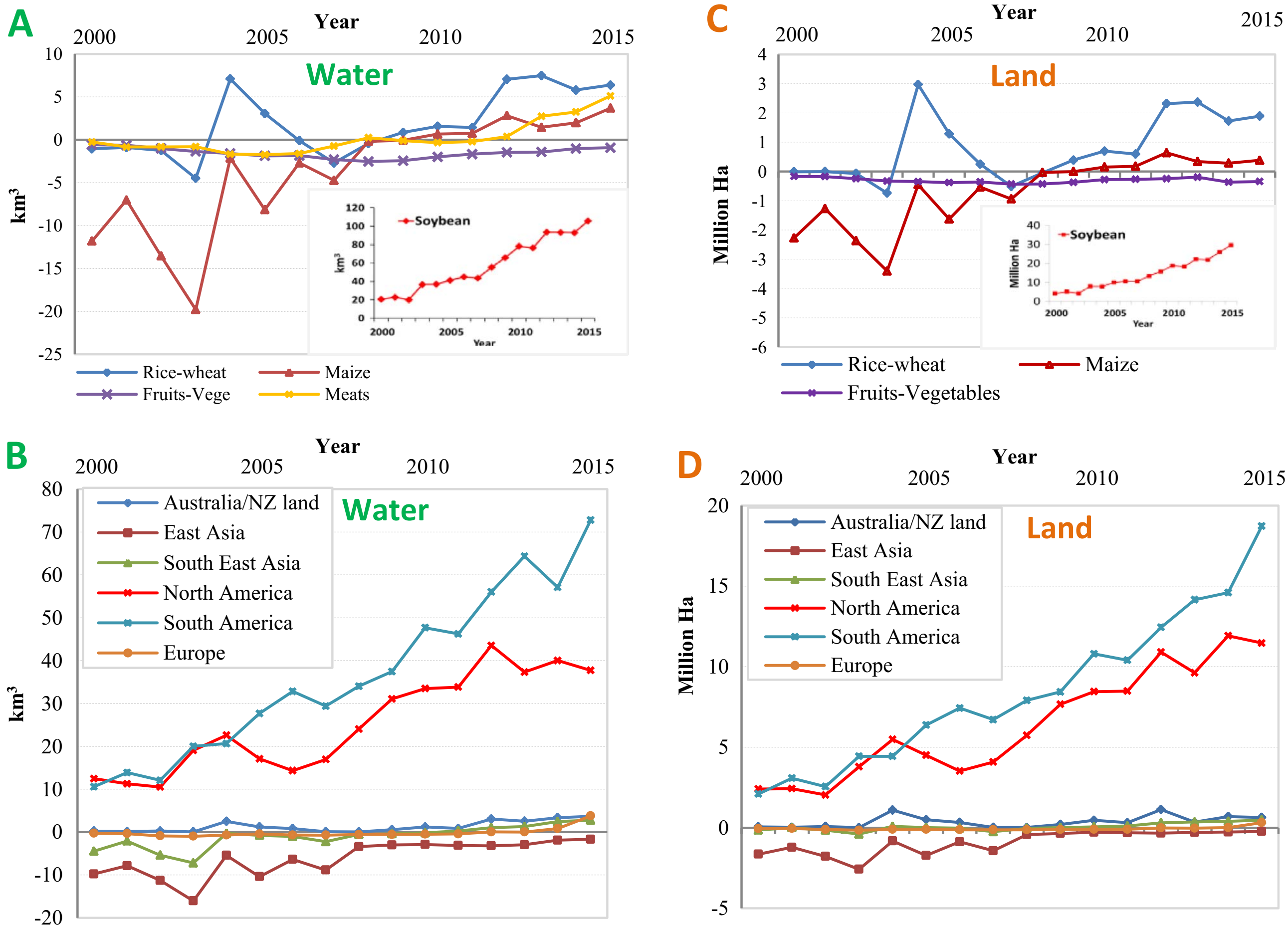


**Fig. 1.** China's net virtual water and land imports via major food commodities (Panels A and C) and from different regions (Panels B and D) in 2000–2015 .

**Table 1**
Contribution of China's food trade to domestic and global savings of water and land, 2000–2015.
Source: Authors' calculations

| Year | Domestic savings | | Global savings | |
|---|---|---|---|---|
| | Water ($Km^3$) | Land (Mha) | Water ($Km^3$) | Land (Mha) |
| 2000 | 18.3 | 3.6 | 11.4 | 1.9 |
| 2005 | 61.4 | 14.1 | 28.8 | 4.9 |
| 2010 | 140.1 | 31.0 | 62.0 | 11.7 |
| 2015 | 215.5 | 46.7 | 95.4 | 15.2 |

cantly contribute to global water and land savings if China's water and land productivity is higher/lower than those of its export/import partners. Overall, China's food trade is leading to increased savings of both water and land at the global level (Table 1). Global savings of water increased 9 times from 11.4 $km^3$ in 2000–95.4 $km^3$ in 2015. Global land savings due to China's food trade have also increased over this period: 1.9 Mha in 2000, 11.7 Mha in 2010 and 15.11 Mha in 2015. The major reason behind the increasing contribution of China's food trade to global water and land savings is the increasing volume of net imports of soybean and maize from South and North America.

Our estimates show 52.3 $km^3$ and 116.1 $km^3$ water savings for China in 2004 and 2009 respectively, as compared to 77 $km^3$ (Liu et al., 2007) and 138 $km^3$ (Shi et al., 2014) for the same years. The results differ mainly due to differences in VWC parameters used for estimations. For China's domestic land savings, our estimates are 14.1 Mha and 25.6 Mha for 2005 and 2009, respectively, which are on the lower side than 19.1 Mha and 28.9 Mha in the same period estimated by Qiang et al. (2013). The difference is mainly because our study covers only food crops whereas Qiang et al. (2013) also covered some non-food crops. For the overlapping periods, our estimates for global savings of water and land are quite comparable to the estimates in existing literature.

## 4. Future scenarios

For analyzing the impact of China's food trade on VW and VL in future, we project China's food trade from 2015 to 2030 based on recursive dynamic method of Global Trade Analysis Project (GTAP) model (Hertel, 1997) and its latest database in 2011. Three scenarios are formulated for China: i) Reference scenario (S0): in addition to assumptions on average annual growth of GDP (5.5%) and population (0.14%) over 2015–2030, we also assume that annual growth of crop yield for China will range from 0.3–1.87% for different crops and 0.2% for livestock based on the historical trends; ii) Scenario 1 (S1): on top of S0, irrigation efficiency (defined as the ratio of the amount of water consumed by the crop to the amount of water supplied through irrigation) in China will be improved by 0.5% annually; iii) Scenario 2 (S2): on top of S0, irrigation efficiency in China will be improved by 1.0% annually. For estimation of VW and VL trade, we adopted the same methodology as we did in the previous section (Appendix A).

Our projection about food supply, demand, and trade in 2030 showed that while China will be almost fully sufficient in rice and wheat, consumption of animal proteins will increase remarkably due to higher income. Expansion of livestock production with rising meat demand will result in large imports of feed grains into China. For example, maize import is projected to increase from 4.7 million tons in 2015 to 39.8 million tons in 2030; self-sufficiency in maize will fall from 97% in 2015 to 85% in 2030. Meanwhile, soybean imports will continue to increase, and will reach 124.6 million tons in 2030 as compared to the current levels of 81.7 million tons in 2015. On the other hand, fruit and vegetable will maintain distinct net exports advantage. For meats, China will have relatively high self-sufficiency in pork and chicken. For beef, there will be a marginal drop in self-sufficiency; an increase in demand will result in some increase in beef's imports.

Under reference scenario in 2030, the net imports of VW and VL embodied in China's food trade will be considerably higher than the current levels. Particularly, in comparison to 2015, China's total net imports of VW will increase from 120.1 $km^3$ to 158.1 $km^3$ and that of VL will increase from 31.6 Mha to 49.4 Mha in 2030. The increase in net imports of both VW and VL is caused by the significant increase in the volume of soybean and maize imports; although the total net VW and VL imports are partially offset by lower VWCs and VLCs, which in turn is governed by improved yields in 2030. In 2030, the ratio of contribution of maize towards total net VW imports and net VL imports, in comparison to soybean (two major contributors), will increase significantly. During 2000–2015, contribution of maize was either negative or negligible in comparison to soybean's contribution towards total net VW imports and net VL imports. However, in 2030, net VW imports and net VL imports from maize will be 1/5th and 1/8th of the contributions from soybean, respectively (Fig. 2A). Net VW imports from Europe will increase from 3.8 $km^3$ in 2015, to 23.6 $km^3$ in 2030, mainly due to an increase in maize imports (Fig. 2B). This indicates some degree of diversion of China's net VW imports away from South and North Americas.

In 2030, net VW imports, embodied in food trade, will save substantial portions of domestic water and land for China. Under reference scenario, total domestic savings of VW in 2030 will be 301.8 $km^3$ (77.1 % of irrigation water used in 2015) as compared to 215.5 $km^3$ in 2015 (55.0 % of irrigation water used in 2015) (Table 2). China's food trade will also contribute strongly to domestic savings of land, viz., 66.2 Mha (49.2% of total cultivated area in 2015) in 2030 as compared to 46.7 Mha (34.6% of total cultivated area) in 2015. In comparison to 2015, contributions from rice and wheat to domestic savings of VW and VL will decrease, while the contribution from soybean and maize will increase significantly. On the other hand, the negative contribution from fruit and vegetable will also increase.

In 2030, global effects of China's food trade on VW and VL will also be much higher than those in 2015. Total global savings of VW and VL in 2030 will increase from 95.4 $km^3$ to 143.6 $km^3$ and from 15.2 Mha to 16.8 Mha as compared to 2015 levels, respectively (Table 2). China's future food trade patterns show that soybean will be the major contributor towards global savings of VW and VL in 2030. Positive contributions of beef trade towards China's domestic VW savings will not be fully translated into global savings of VW. This can be explained as there will exist quite small differences in water productivities of beef production between China and its trading partners in 2030.

**Table 2**
Contribution of China's food trade to domestic and global savings of water and land in 2030.
Source: Authors' calculations

| Scenarios | Total water used[a] ($Km^3$) | Water savings ($Km^3$) | | Land savings (Mha) | |
|---|---|---|---|---|---|
| | | Domestic | Global | Domestic | Global |
| Reference | 869.3 | 301.8 | 143.6 | 66.2 | 16.8 |
| S1 | 834.0 | 287.9 | 129.5 | – | – |
| S2 | 811.5 | 279.0 | 120.4 | – | – |

Note: Effect of livestock sectors on virtual land trade is disregarded in view of negligible amount of trade and difficulty to obtain reliable data on VLC for livestock.
[a] Only for the production of the commodities covered in this study.

Improvements in irrigation efficiency in China will reduce the impact of China's food trade on domestic and global savings of VW. Particularly, if China can improve its irrigation efficiency by 0.5% annually (under S1 scenario), the domestic savings of VW will be 287.9 $km^3$, which is −4.6% less than the reference scenario with no irrigation efficiency improvements. The impact of irrigation efficiency improvements on global savings will be more conspicuous in percentage terms, decreasing by −9.8% from 143.6 $km^3$ to 129.5 $km^3$. Under S2 scenario, if China manages to improve its irrigation efficiency by 1% annually through 2015–2030, domestic and global savings of VW will decrease by −7.6% and −16.2% as compared to the reference levels, respectively.

Our future analysis also shows that improvements in irrigation efficiency by China will benefit China's agriculture more as there will be less water required for crop production. In particular, under S1 and S2 scenarios, China will use 35.3 $km^3$ (from 869.3 $km^3$ to 834 $km^3$) and 57.8 $km^3$ (from 869.3 $km^3$ to 811.5 $km^3$) less water, respectively, than the reference scenario (Table 2).

## 5. Conclusions and discussions

China's water and land resources are scarce, and this scarcity has been getting severe over time (Jiang, 2009; Liu et al., 2013). Competition with other uses has reduced agricultural water withdrawal from 83% of total water withdrawal in 1990 to 65% in 2005 (Aquastat, 2016). Sustainable food production could be threatened if this trend continues in the future. Similarly, land scarcity constrains food production in China and has led to growing concerns about China's domestic food security and impacts on global food markets (Liu and Savenije, 2008). China has only about 0.09 ha of cultivated area per capita, compared to the world average of 0.20 ha (World Bank, 2016).

China has been promoting trade liberalization, particularly since joining WTO in 2001, and has entered into several free trade agree-

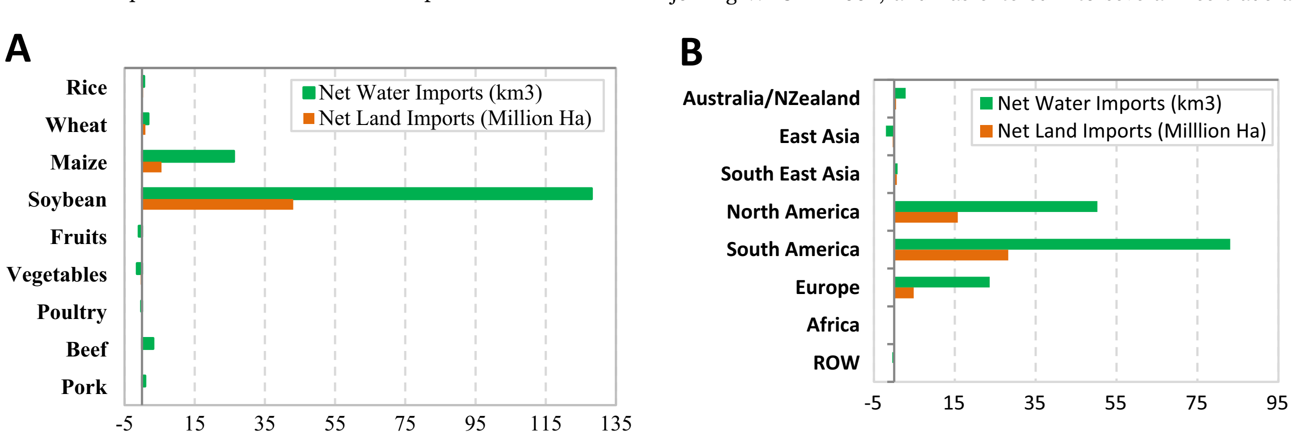


**Fig. 2.** Reference scenario of future: China's net water and land imports through different food commodities (A) and from different regions (B) in 2030.

ments (FTAs). Since the start of this century, liberalized trade and increasing food demand, mainly due to rising income, have been driving China's food trade to grow at a significant rate. China has signed and implemented 14 FTAs with different nations like Australia, Republic of Korea, ASEAN countries, and Pakistan. Since 2013, China has also been promoting its trade relations with neighboring countries and beyond, under the land and maritime Silk Road initiative.

Unequal distribution of water and land resources among countries further highlights the importance of using trade for taking complete advantage of global water and land resources, and decreasing the regional extent of resource scarcity. China, with about 20% of world's population, has only about 6% of global water resources and 8% of global cultivated land. Under these situations, achieving food self-sufficiency and enhancing sustainable development of domestic agriculture are major challenges for China.

Recognizing the challenges, China has tried to solve its resource constraints partially through international trade. In the last 15 years, due to virtual water trade through food trade, China's domestic savings of water have increased 12 folds. This trade also saved increasing quantities of water at global scale. For land resources, analysis of China's food trade over 2000–2015 shows that China's food trade has helped it save significant amounts of domestic and global land resources. According to our future projections, food trade will continue to save increasing levels of domestic and global water and land resources in 2030. However, water savings at domestic and global arenas will vary according to changes in China's irrigation efficiency during the next 15 years. In addition to relying on international trade in agriculture, China can also effectively ease pressure on its domestic water sources by improving irrigation efficiency in agricultural production.

Thus, China can continue to use trade liberalization to promote sustainable development of agriculture, both at national and global levels. With the help of international trade in agriculture, China can effectively increase global production potential. Although in the future, China can decrease its trade in virtual resources by improving its resource productivities, the world would need additional quantities of these resources if China were to stop food imports in future. Therefore, in the future, implementing more FTAs can help China and other resource-scarce countries to supply adequate food for their populations and promote sustainable agricultural development at a global scale. Moreover, policy makers in China and other major players in the global food market should consider designing policies that encourage the imports of such commodities in which their domestic production has lower water and land productivities and exports of high water/land productivity crops.

Although this study analyzed impacts on virtual water and virtual land, trade in agriculture can also affect greenhouse gas emissions at national and global scales, which also needs attention in the future. The savings identified as a result of trade are also an environmental benefit, though the risk remains that total use of water and land may still grow so great that environmental problems will continue to be difficult to manage. In addition, for a more comprehensive analysis of the issue, future research could add more crops and their products, and consider changes in agricultural production technology. Better estimates of actual specific water use per crop through advanced hydrological models can help improve the accuracy of such studies' results.

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## Appendix A

*Methodology and data*

For calculating virtual water trade, we have used virtual water contents (VWC) parameters for major crops and livestock from Hanasaki (2016) that provided country specific annual VWCs for 1986–2005 period. We updated the VWC values from 2005 to 2015 by using changes in national crop yield as (Eq. (1))

$$VWC_{i,c,n} = VWC_{i,c,2005} * \frac{Y_{i,c,2005}}{Y_{i,c,n}} \quad (1)$$

where i= country; c=commodity; n=year; and Y=crop yield. Yield data are from FAO (FAOSTAT, 2016). This method has been used in other studies (Dalin et al., 2012a, 2012b) and relies on the finding that crop water productivity (CWP) for different crops, or the inverse of VWC, has a strong linear relation with crop yield (Liu et al., 2007b). Estimation of VWC values of crops for 2016–2030 for China is described earlier in Section 4. For the rest of the world, VWC values of crops for 2016–2030 are estimated using forecasts on water productivity from Rosegrant et al. (2002). The authors forecast that between 1995 and 2025, the water productivity of non-rice cereals will improve by 66% for developing countries and 40% for developed countries. We used these figures to estimate the annual change in country specific VWCs for all crops. For livestock sectors, the VWC values provided by Hanasaki (2016) were extrapolated to future years by assuming 1% improvement in water productivity for every five years. For fruit and vegetable, we used base year (2001) VWC for apples and tomatoes (Liu and Savenije, 2008) from Chapagain and Hoekstra (2004) and updated them by incorporating 1% annual improvement in water productivity. Virtual land contents (VLC) are calculated by using annual yields from FAOSATAT as (Eq. (2)):

$$VLC_{i,c,n} = \frac{1}{Y_{i,c,n}} \quad (2)$$

Virtual water imports ($VWI_{i,c,n}$) and exports ($VWE_{i,CHN,n}$) are calculated by multiplying VWC with imports/exports of China as (Eqs. 3 and 4):

$$VWI_{i,c,n} = M_{i,c,n} * VWC_{i,c,n} \quad (3)$$

$$VWE_{i,c,n} = X_{i,c,n} * VWC_{i,CHN,n} \quad (4)$$

where $M_{i,c,n}$ is the quantity of commodity i imported by China from country c during year n; $X_{i,CHN,n}$ is quantity of China's exports of each commodity i to destination c during year n; $VWC_{i,CHN,n}$ is China's VWC. Net VW import for China is givens as (Eq. (5)):

$$NVWI_{i,CHN,n} = VWI_{i,c,n} - VWE_{i,c,n} \quad (5)$$

China's domestic savings of water ($DWS_{i,CHN,n}$) can be obtained if we replace partner country's $VWC_{i,c,n}$ with China's $VWC_{i,CHN,n}$ in Eq. (3) and use it in Eq. (5).

China's contribution towards global savings/losses of water is the extra/less water that China might need to produce the same commodity domestically, as (Eq. (6)):

$$GWS_{i,c,n} = DWS_{i,CHN,n} - NVWI_{i,CHN,n} \quad (6)$$

Positive value of Eq. (6) indicates a net saving and vice versa. Total domestic and global water savings were computed by adding up savings from all commodities and all trading partners. The same method was adopted for calculating net virtual land imports ($NVLI_{i,CHN,n}$), domestic land savings ($DLS_{i,CHN,n}$), and global land savings ($GLS_{i,c,n}$) by replacing VWC with VLC in each of the above equations. A country can induce positive global savings of land if its domestic yields are lower than those of its importing partners, i.e. the host country will require more land to produce the same quantity of the crop domestically as compared to its trade partners.

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