Supplement S1.

Cleaning of bi-national trade data from re-exports to establish direct links between producers and consumers of primary crop commodities – method description

Bi-national commodity trade data taken from the COMTRADE database (United Nations, 2013) were cleaned from re-exports by constraining commodity exports of each country by its domestic crop production as computed by the Global Crop Water Model GCWM (Siebert and Döll, 2010). This is important to establish direct links between producers and consumers of goods as required by the virtual water flow and footprint concepts. The international trade flow net is very complex and many national trade partners act as importers and exporters of the respective goods. It is important to ensure that the virtual water content of a commodity remains similar to the content at the point of crop production and is not altered in the analysis through re-exports. These intermediate trade flows, caused by re-exports, should therefore be removed from the commodity flow net. Commodities, their global production according to GCWM, and their bi-national trade flows before cleaning for re-exports according to COMTRADE and after application of the cleaning procedure are reported in Table 1 of this supplement.

The basic assumption used to reduce as much as possible the re-exports in the commodity flow net was that commodity exports of each country are constrained by the crop production of the respective country. If crop exports of a country are larger than its crop production, then the difference between both quantities represents re-exports (commodities imported from somewhere else and re-exported to other countries). The corresponding commodity flow was then deleted from the flow net and new commodity flows created between the countries from which the commodity was imported and the countries to which the commodity was exported.

The procedure is illustrated in Figures 1 and 2. It shows the production of a commodity in different countries and bi-national commodity flows between countries. The upper parts of figures 1 and 2 represent examples of the original bi-national trade flows while the lower parts show the commodity flows after application of the cleaning procedure. Country C represents a re-exporter in the upper parts because its domestic crop production is smaller than its commodity export (outgoing flows to country B). Therefore the commodity flow to country B was reduced to the domestic production (20 in Figure 1 and 30 in Figure 2) and, as compensation, new commodity flows of the same amount created between countries from which country C imports the commodity (country A in Figure 1, countries D and E in Figure 2) and the country to which the commodity was exported (country B). When the re-exporting country imported commodities from more than one country, the newly established commodity flows were in the same proportion than the imports from these countries before (see Figure 2). It was necessary to repeat the cleaning procedure in an iterative process until for each country the outgoing flows no longer exceeded the domestic production, because in many cases commodity flow chains according to the bi-national trade flows contained more than one re-exporter (e.g. coffee exports from Belgium to Germany which both are re-exporters).

Application of the cleaning procedure did not alter commodity production and commodity consumption (production + inflow – outflow) of the respective countries. However, it reduced commodity flows between countries (from 160 to 120 in the example shown in Figure 1 and from 320 to 230 in the example shown in Figure 2).

It should be noted that the assumptions made here resulted in a conservative estimate of re-exports since we assumed that the domestic crop production of the specific countries goes preferential to exports. In re-exporting countries (country C in Figures 1 and 2) the whole domestic commodity production is exported (to country B in Figures 1 and 2). Domestic consumption of re-exporting countries is either 0 (Figure 1) or completely based on the commodities imported from other countries (Figure 2). Furthermore we assumed that commodity flows between two countries can go into both directions (e.g. the flows between countries A and B in Figure 1). For some commodity flows this may be realistic, e.g. when fodder wheat of low quality is flowing in the one direction and bread wheat of high quality is flowing into the other direction. In other cases these flows also may represent re-exports.

References

Siebert, S., and P. Döll (2010). Quantifying blue and green virtual water contents in global crop production as well as potential production losses without irrigation. Journal of Hydrology 384(3-4): 198-217.

United Nations (2013). United Nations Commodity Trade Statistics Database (UN COMTRADE). http://comtrade.un.org/, last access 27/01/2013.

Table 1. Commodity classification according to GCWM and COMTRADE (HS1996); crop production (mean 1998-2002) according to GCWM; bi-national commodity flows before and after cleaning for re-exports (mean 1998-2002).

Commodity (GCWM)		Commodity (COMTRADE HS1996)		Global production (Tg yr^{-1})	Bi-national commodity flows according to COMTRADE (Tg yr^{-1})	Bi-national commodity flows after cleaning for re-exports (Tg yr^{-1})
ID	Name	ID	Name			
1	Wheat	1001	Wheat and meslin	584.4	115.3	114.5
2	Maize for grain	1005	Maize (corn)	604.3	85.0	84.7
3	Rice	1006	Rice	680.9	29.4	24.7
4	Barley	1003	Barley	136.2	24.1	23.6
5	Rye for grain	1002	Rye	20.3	2.1	2.1
6	Millet	100820	Millet	25.9	0.3	0.3
7	Sorghum for grain	1007	Grain sorghum	55.6	7.9	7.8
8	Soybeans	1201	Soya beans	166.0	52.5	50.6
9	Sunflower	1206	Sunflower seeds	25.1	4.0	3.8
10	Potatoes	0701	Potatoes, fresh or chilled	311.8	9.3	9.0
11	Cassava	071410	Manioc (cassava), fresh or dried	162.4	5.7	5.2
15	Rapeseed	1205	Rape or colza seeds	36.8	9.9	9.7
16	Groundnut	120210	Groundnuts in shell not roasted or cooked	33.1	0.2	0.2
17	Pulses	0713	Vegetables, leguminous dried, shelled	53.8	8.9	8.5
18	Citrus	0805	Citrus fruit, fresh or dried	109.3	11.1	10.2
19	Dates	080410	Dates, fresh or dried	4.4	0.5	0.5
20	Grapes	0806	Grapes, fresh or dried	58.3	3.6	3.3
22	Cocoa	1801	Cocoa beans, whole or broken, raw or roasted	3.2	3.7	2.2
23	Coffee	090111	Coffee, not roasted, not decaffeinated	6.8	5.7	5.0

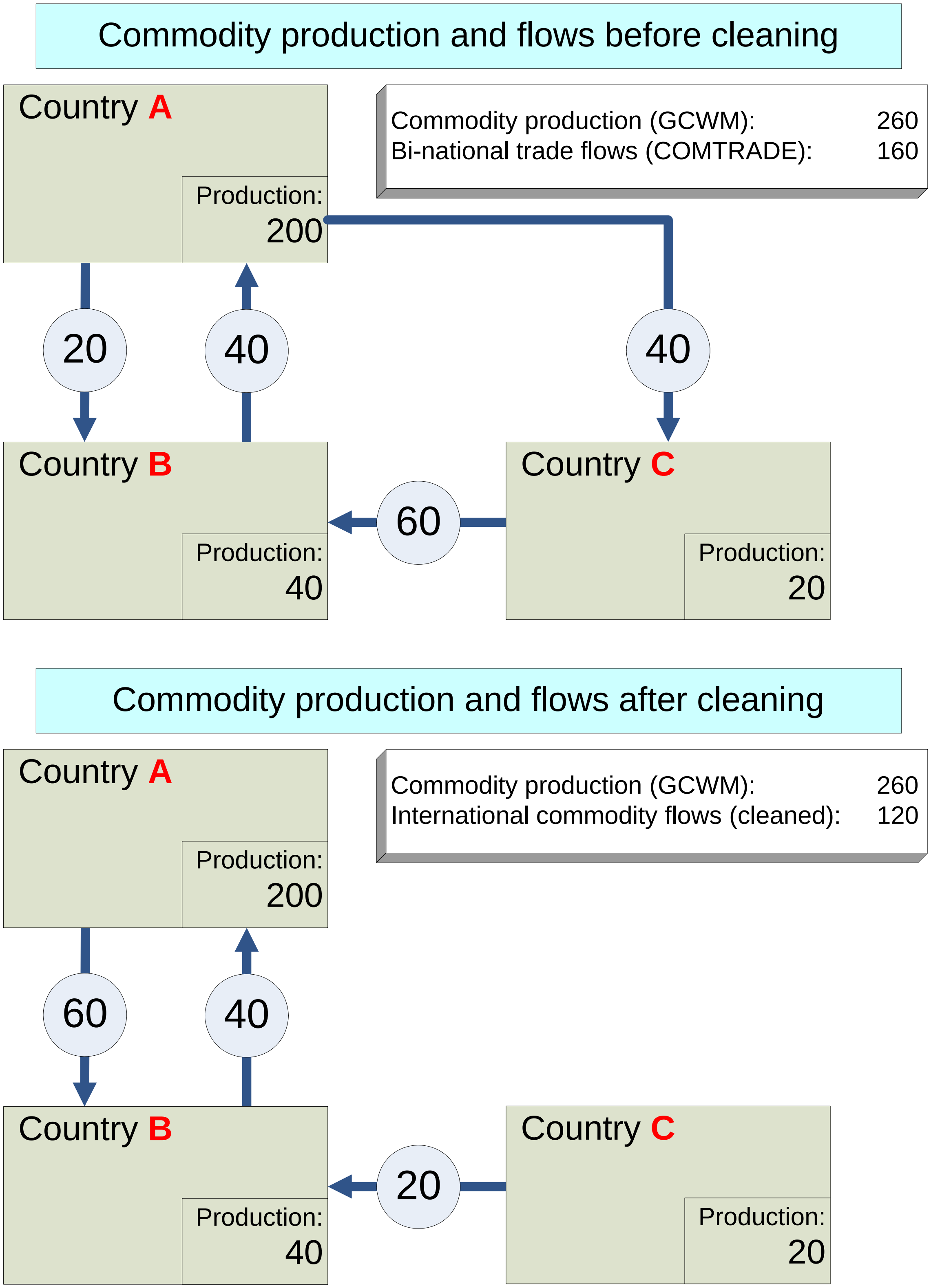

Figure 1. Commodity production in – and commodity flows between countries A, B, and C according to bi-national trade flows (top) and after cleaning of re-exports (bottom).

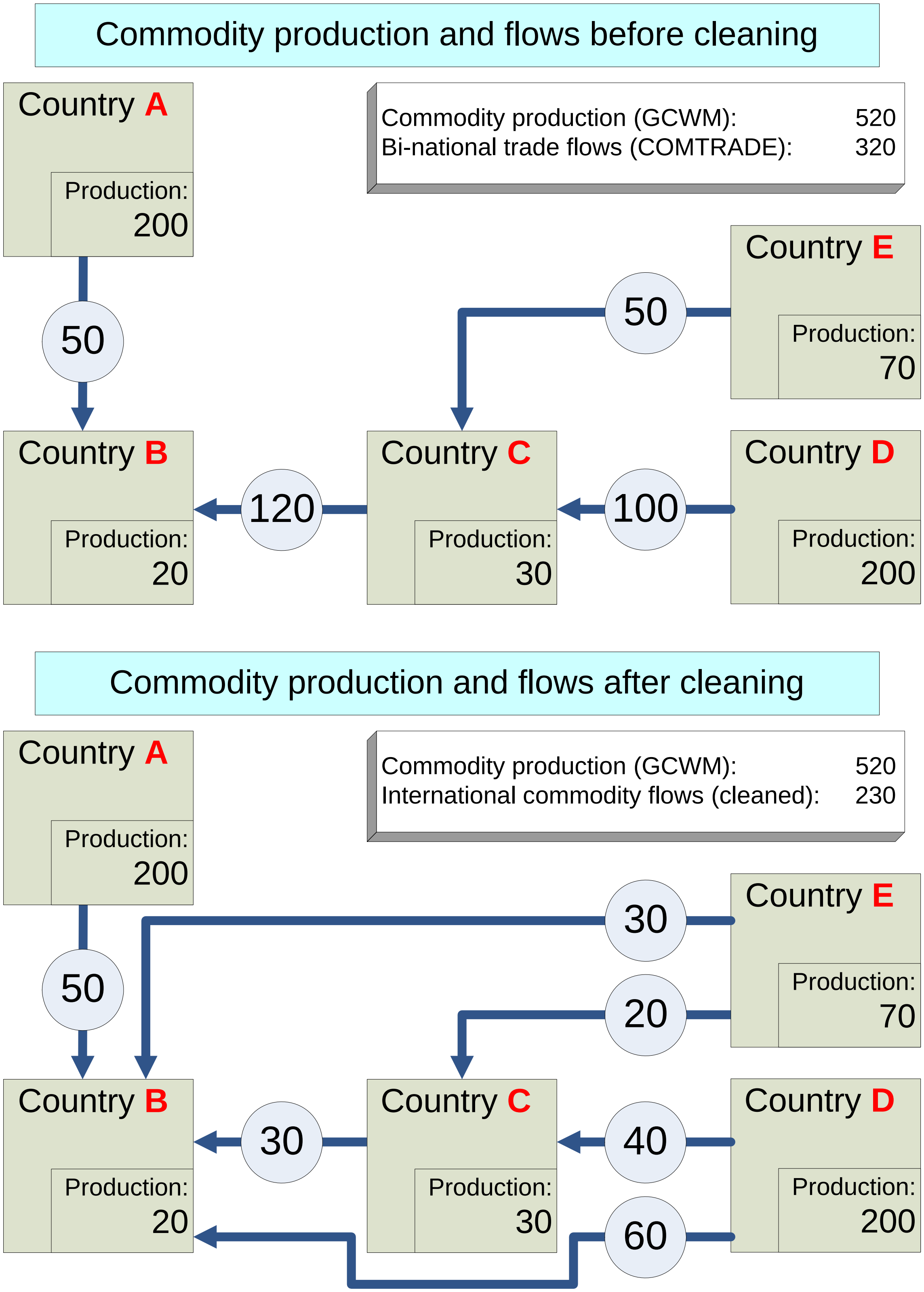

Figure 2. Commodity production in – and commodity flows between countries A, B, C, D, and E according to bi-national trade flows (top) and after cleaning of re-exports (bottom).

Supplement S2.

Calculation of grid cell specific virtual water flows and water footprints of cities – method description

1 Calculation of domestic commodity and virtual water flows

Domestic commodity and virtual water flows represent flows between grid cells belonging to the same country. For each country and each of the 19 commodities we computed first the per capita consumption of commodities produced in the same country $CONSD\_CAP_{crop,country,year}$ (kg cap^{-1} yr^{-1}):

$$CONSD\_CAP_{crop,country,year} = (PROD_{crop,country,year} - EXPORT_{crop,country,year}) / POP_{country} \qquad (1)$$

where $PROD_{crop,\ country,\ year}$ was the production of the commodity in the specific country and year (kg yr^{-1}) according to the Global Crop Water Model GCWM (Siebert and Döll, 2010), $EXPORT_{crop,\ country,\ year}$ the total export of the commodity to other countries in the specific country and year (kg yr^{-1}) according to the international commodity flow net cleaned for re-exports (see Supplement S1), and $POP_{country}$ the total population per country (cap) in year 2000 according to the HYDE-database (Klein Goldewijk et al., 2010). We assumed therefore that the per-cap consumption of the commodities is the same for all people belonging to the respective country. Next we computed for each grid cell, commodity and year the total consumption of commodities produced in the respective country $CONSD_{crop,\ cell,\ year}$ (kg yr^{-1}) as the product of the per capita consumption $CONSD\_CAP_{crop,country,year}$ and the population per grid cell POP_{cell} (cap):

$$CONSD_{crop,cell,year} = CONSD\_CAP_{crop,country,year} * POP_{cell} \qquad (2)$$

Then a balance $BALD_{crop,\ cell,\ year}$ (kg yr^{-1}) between crop production $PROD_{crop,\ cell,\ year}$ (kg yr^{-1}) and consumption of the commodity produced in the respective country $CONSD_{crop,\ cell,\ year}$ (kg yr^{-1}) was computed for each grid cell, year and commodity:

$$BALD_{crop,cell,year} = PROD_{crop,cell,year} - CONSD_{crop,cell,year} \qquad (3)$$

This balance was positive in the major production regions and negative in highly populated grid cells (e.g. cities) where the consumption prevailed. Please note that calculation of the total balance for an entire country would result in the amount of the respective commodity exported in that year to other countries $EXPORT_{crop,\ country,\ year}$ (see Equations 1-2). Production surpluses and deficits within each country were then levelled out by iteratively allowing commodity flows across larger and larger distances (across 2x2, 4x4, 6x6, 12x12, 24x24, 48x48, 72x72, 108x108, 144x144, 180x180, 216x216, 240x240, 360x360, 432x432 grid cells) and finally the whole country. These flows were recorded and corresponding virtual water flows of green and blue water computed by multiplying the commodity flow (kg) with the blue and green virtual water content in the source grid cell and corresponding year (l kg^{-1}).

2 Calculation of commodity flows and virtual water exports to other countries

The procedure to level out positive and negative commodity balances within the specific countries described before stopped when all negative grid cell balances were levelled out by positive commodity flows from surplus regions. As described before, the remaining surplus represented the quantity of the commodity exported to other countries (see Equations 1-3) and the corresponding grid cells with remaining positive balances represent the regions in which the exports to other countries were produced. Virtual water exports to other countries were then computed by multiplying the remaining positive balances in each export grid cell by the blue and green virtual water content computed with GCWM for the specific year.

3 Calculation of commodity imports from other countries and corresponding virtual water flows

Commodities imported from other countries were distributed in proportion to population per grid cell, thus it was assumed that per capita consumption of imported commodities was the same in all grid cells belonging to the same country. Related virtual water flows were determined by multiplying the commodity flow with the respective blue and green virtual water content in the exporting regions computed as described in section 2.

4 Calculation of net virtual water flows and virtual water flows to cities

Net commodity - or virtual water balances were computed for each grid cell, year and commodity by accounting positively for commodity or virtual water flows into the corresponding grid cell (imports from other countries and inflow from other grid cells of the same country) while accounting outflows (exports to other countries and outflow to other grid cells of the same country) negatively. Flows to grid cells belonging to the selected cities (Table 1) were recorded separately to derive additional information like source regions of the flows or (flow weighted) mean distances of the source regions.

References

Klein Goldewijk, K. , A. Beusen, and P. Janssen (2010). Long term dynamic modeling of global population and built-up area in a spatially explicit way, HYDE 3.1. The Holocene 20(4): 565-573.

Siebert, S., and P. Döll (2010). Quantifying blue and green virtual water contents in global crop production as well as potential production losses without irrigation. Journal of Hydrology 384(3-4): 198-217.

Table 1. Coordinates (decimal degrees) of center points of 5 arc-minute grid cells assumed to belong to the cities of Berlin, Delhi and Lagos.

Cell number	Berlin		Delhi		Lagos	
	Latitude	Longitude	Latitude	Longitude	Latitude	Longitude
1	52.6250	13.2917	28.8750	77.1250	6.8750	3.2083
2	52.6250	13.3750	28.7917	77.0417	6.8750	3.2917
3	52.6250	13.4583	28.7917	77.1250	6.7917	3.2083
4	52.5417	13.1250	28.7917	77.2083	6.7083	3.2083
5	52.5417	13.2083	28.7917	77.2917	6.7083	3.2917
6	52.5417	13.2917	28.7083	76.9583	6.7083	3.3750
7	52.5417	13.3750	28.7083	77.0417	6.6250	3.2083
8	52.5417	13.4583	28.7083	77.1250	6.6250	3.2917
9	52.5417	13.5417	28.7083	77.2083	6.6250	3.3750
10	52.5417	13.6250	28.7083	77.2917	6.6250	3.4583
11	52.4583	13.1250	28.7083	77.3750	6.6250	3.5417
12	52.4583	13.2083	28.7083	77.4583	6.5417	3.1250
13	52.4583	13.2917	28.6250	76.9583	6.5417	3.2083
14	52.4583	13.3750	28.6250	77.0417	6.5417	3.2917
15	52.4583	13.4583	28.6250	77.1250	6.5417	3.3750
16	52.4583	13.5417	28.6250	77.2083	6.5417	3.4583
17	52.4583	13.6250	28.6250	77.2917	6.4583	3.1250
18	52.4583	13.7083	28.6250	77.3750	6.4583	3.2083
19			28.6250	77.4583	6.4583	3.2917
20			28.5417	76.8750	6.4583	3.3750
21			28.5417	76.9583	6.4583	3.4583
22			28.5417	77.0417	6.4583	3.5417
23			28.5417	77.1250	6.3750	3.1250
24			28.5417	77.2083	6.3750	3.2083
25			28.5417	77.2917	6.3750	3.2917
26			28.5417	77.3750	6.3750	3.3750
27			28.4583	77.0417		

Cell number	Berlin		Delhi		Lagos	
	Latitude	Longitude	Latitude	Longitude	Latitude	Longitude
28			28.4583	77.1250		
29			28.4583	77.2083		
30			28.4583	77.2917		
31			28.3750	77.2083		
32			28.3750	77.2917		
33			28.3750	77.3750		