Supporting Information

##

## Overview

The following chapters provide details on the data sources and methods used for the calculation of land use, biomass flows and HANPP between 1883 and 2007 on the level of all single land and biomass categories entering the final data set. All data sets are based on primary data from national statistics (Kaiserliches Statistisches Amt 1884-1917; StRA 1918-1848; Destatis 1950-2013; SZS 1950-1989), which were digitalized for every fifth year. Some of the statistical data were already available in secondary literature (Hoffmann et al. 1965; Franzmann 2013; Franzmann 2012a; Franzmann 2012b). In these cases the exact data sources are indicated in the text.

In order to guarantee consistent post-WW II territorial extent for the entire study period, we excluded in our calculation the provinces of East-Prussia, West-Prussia, Posen (West-Prussia since 1925), Silesia, Upper-Silesia, Lower-Silesia and Alsace-Lorraine before 1945, and we included Pomerania as well as parts of Brandenburg (Pomerania 24.7%, Brandenburg 69.5%).

## Land use change

### Cropland

Cropland includes areas planted to annual and perennial crops and temporary fallow land. Statistics before 1927 only documented areas planted to the most common crops, such as cereals, fodder crops and potatoes, but lacked documentation for other crops. Thus the category “other crops” was introduced and it was calculated by subtracting all reported crop areas and fallow land extent from total cropland. The share of these areas to total arable land increased from 16% in 1883 to 22% around 1900 and decreased to 18% by 1938. From 1883 to 1930, no provincial data on the extent of fallow land were available and we used data for the total German Empire instead. Thus the share of fallow land to total cropland for the German Empire was used to calculate fallow land extent in this time period.

### Grassland

Grassland consists of permanent meadows and pastures. From 1883 to 1932, when no provincial data on grassland extent were provided by the national statistics, we assumed that the share of grassland to the territory (in 2013 borders) was equal to the share of grasslands to the entire territory of the Germany Empire.

### Forest land

Refers to all areas covered with natural forests and forest plantations. All data were taken from the national statistics, between 1950 and 2007 data for West Germany were taken from Franzmann (2013).

### Settlement areas

Settlement areas after WW II were taken from Franzmann (2013). These values include inland water, which was subtracted and added to the category “other land”. From 1927 to 1931 data were taken from the national statistics and before 1927 the mean per capita demand of settlement area from 1927 to 1933 was used.

### Other land

Other land is calculated as the remainder of total land area and all other land use categories. It consists of inland water bodies, wetlands, permanent snow and ice, permanent rocks, and other un-used land.

## Harvested NPP (HANPPharv)

### Cropland harvest

Cropland harvest exists of all primary and secondary (used and unused crop residues) harvest flows. Agricultural statistics usually report only primary harvest, e.g., the merchantable parts of a plant in fresh weight. In a first step, we converted primary crop production reported in fresh weight by the national statistics into carbon units by using crop-group specific water content ratios (Table S1) and considering a carbon content of 50% of oven-dry biomass. Then we extrapolated total plant biomass from primary crop production using harvest factors listed in Table S1. All factors are based on previous work by Krausmann et al. (2008; 2013), who calculated harvest factors based on Wirsenius (2000, 2003) and Evans (1996). Krausmann et al. (2008; 2013) considered decreasing trends of harvest factors from 1900 to 2007 owing to technological advancements and plant breeding. The amount of crop residues was then calculated by subtracting primary production from total plant biomass. The share of used to un-unused residues was calculated through crop specific recovery rates. Until 1960 we assumed that a certain share of residues was used for all crop groups, thereafter we only assumed used residues for cereal crops.

For several crop-groups information on harvest factors was lacking. For these crops we assumed that total plant biomass per unit of area equals the mean value of plant biomass per area of all other crops for which harvest factors were available. Crop residues were then calculated by subtracting primary crop harvest from total plant biomass. Harvest on areas planted to “other crops” was calculated by applying the mean harvest per area of all other crop types for which data were available.

**Table S1: Water content factors, harvest factors (1900, 1930, 1960, 1980, 2000) and recovery rates (1960, 2000) of the main crop groups planted in Germany from 1883 to 2007**

|  |  |  |  |
| --- | --- | --- | --- |
|  | Water content | Harvest factors(share of residue to primary crop) | Recovery rates |
|  | ***%*** | ***1900*** | ***1930*** | ***1960*** | ***1980*** | ***2000*** | ***1960*** | ***2000*** |
| Cereals  | 14 | 1.31  |  1.31  |  1.27  |  1.10  |  1.00  | 0.89  |  0.70  |
| Roots and tubers  | 78 | 1.31  |  1.31  |  1.27  |  1.10  |  1.00  | 0.32  |  |
| Sugar crops  | 77 | 0.71  |  0.71  |  0.68  |  0.59  |  0.54  | 0.32 |  |
| Pulses  | 10 | 1.31  |  1.31  |  1.27  |  1.10  |  1.00  | 0.32 |  |
| Fodder crops  | 20 | 1.33 |  1.33 |  1.33 |  1.33  | 1.33  | 0.32 |  |
| Permanent crops  | 81 |  2.75  |  2.75  |  2.75  |  2.68 |  2.50  | 0.32 |  |

### Harvest on grassland

Harvest on grassland includes harvest on permanent meadows and pastures, through mowing and foraging and through livestock grazing. While hay harvest was reported in the national statistics, grazed biomass was calculated by applying a grazing gap approach, where the annual amount of grazed biomass is defined as the difference between annual feed demand of all livestock species and annual feed supply. Different procedures were used in order to calculate feed demand separately for the single livestock species (Table S2).

Feed demand for cattle was calculated through two ways: (1) cattle carcass weights and (2) milk yield of milk cattle. The higher result of the following two equations was used as final cattle feed demand:

*Equ. 1:* Feed intakemeat [kgDM/head/day] = 0.036361 \* carcass weight [kg/animal] + 1.702006

*Equ. 2:* Feed intakemilk [kgDM/head/day] = 0.00155 \* mild yield [kg/animal/yr] + 4.8375

Milk yields and carcass weights were taken from the FAO statistical database from 1961 to 2007 (FAO 2013). Before, data on milk yields were calculated from data on milk production provided by Hoffmann et al. (1965) and numbers of milk cows provided by Franzmann (2013). Carcass weights before 1950 were taken from the national statistics for the years 1913, 1926 and 1936 by calculating the weighted average of all slaughtered cattle categories (e.g. bulls, cows, calves) and their carcass weights.

Feed demand of pigs and poultry was calculated through feed efficiency ratios, in which feed demand is calculated according to input-output efficiency ratios applied for annual pig and poultry meat production and poultry egg production. Meat and egg production in tons were provided by the national statistics and feed efficiency ratios were taken from (Krausmann et al. 2008; Krausmann et al. 2013). We assumed that feed efficiency in 1960 was 40% lower than in 2000 and that the 1883 ratios were 10% lower than in 1960 owing to improved fodder quality and animal breeding (refer to Krausmann et al. 2008; Krausmann et al. 2013). Values in brackets are values for former East Germany.

Feed demand of sheep, goats, horses, buffaloes, asses and mules was assumed to stay constant over time, using feed demand factors provided by (Krausmann et al. 2008; Krausmann et al. 2013).

Table S2: Feed demand per animal species and year

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| ***animal nr./ species*** | ***Units***  | **1883** | **1900** | **1940** | **1960** | **1980** | **2000** |
| **Cattle** | tC/head/yr | 1.3 | 1.4 | 1.5 | 1.7 (1.6) | 2.0 (1.9) | 2.7  |
| **Horses** | tC/head/yr | 1.8 | 1.8 | 1.8 | 1.8 | 1.8 | 1.8 |
| **Asse and mules**  | tC/head/yr | 1.1 | 1.1 | 1.1 | 1.1 | 1.1 | 1.1 |
| **Sheep** | tC/head/yr | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 |
| **Goats** | tC/head/yr | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 | 0.3 |
| **Pigs** | tC/head/yr | 0.1 | 0.1 | 0.1 | 0.15 (0.14) | 0.2 (0.2) | 0.3  |
| **Poultry [1000]** | tC/head/yr | 28.23 | 28.2 | 32.3 | 25.1  | 47.9  | 37.7 |

Feed supply consists of fodder crops harvested on cropland, hay harvest from grassland, crop residues used for fodder and market feed. Market feed refers to the amount of fodder (primary and processed) purchased from the world market. We considered crop residues used as fodder only for cereals, and we considered a constant share of 15% fed to animals over the entire time period studied.

No data for market feed consumption before 1961 were available and information on the share of market feed consumed in East Germany was lacking between 1950 and 2007. Market feed consumption between 1961 and 2006 was taken from the FAO statistical database (FAO 2013), which also contains data on market feed consumption in former East Germany. In 1990, after the unification of East and West Germany, market feed consumption witnessed a steep decline along with the collapse of the livestock numbers in the former East Germany. Assuming that the decline of market feed after 1989 equals the share of market feed consumed in East Germany in 1988, we derived a share of 32% market feed consumption in East Germany. The index of poultry, pigs and cattle feed demand was used to model market feed consumption between 1950 and 1988 and between 1989 and 2007. Before 1961, data on market feed were lacking. We thus modelled market feed consumption from 1883 to 1960 by assuming that growth rates from 1945 to 1961 were similar to the growth rates between 1961 and 1970, and that in 1883 market feed was 45% of the 1945 level.

Before WWI we assumed that if harvest on grasslands exceeded actual productivity on grasslands, the surplus harvest fraction was dedicated to forest land. This assumption is based on previous work for historical accounts of biomass flows in Austria (refer to Krausmann 2001; Erb et al. 2013).

### Forestry harvest

Forestry harvest consists of all parts of biomass harvested or destroyed in the course of wood harvest, including roundwood and fuelwood removals, as well as all aboveground felling losses. From 1960 to 2007 data on harvest of forestry products, e.g., roundwood and fuelwood harvest, were taken from Franzmann (2012b). Franzmann (2012a) provided data on forestry harvest in East Germany. No forestry data were available before 1888. We therefore kept the value of 1888 constant for the preceding years. Before WWI surplus harvest on grasslands was dedicated to forest land (refer to chapter S2.2).

## Actual productivity (NPPact)

### Cropland

Actual productivity on cropland was extrapolated from harvest on cropland by multiplying harvested NPP with loss expansion factors (Table S3, after Krausmann et al. 2013).

Table S3: Loss expansion factors for cropland harvest

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **1883** | **1900** | **1930** | **1960** | **1970** | **1990** | **2005** |
| 1.27 | 1.25 | 1.23 | 1.19 | 1.18 | 1.14 | 1.14 |

# Auxiliary figures



Figure S1: Aboveground potential productivity (NPPpot) in East and West Germany from 1950 to 2007 in grams carbon per square meter of land.



Figure S2: Share of energy carriers to total consumption of primary energy in EJ on the German territory (changing boarders) from 1883 to 1973. Fuelwood consumption was taken from Hoffmann et al. (1965), all other energy carriers are taken from Schilling (1977).



Figure S3: Cereal yields (primary harvest without residues, constant 2007 boarders) per area land planted to cereals [gC/m2/yr] from 1883 to 2007.

|  |
| --- |
| a) |
| b)  |

Figure S4: a) Annual feed supply between 1883 and 2007, b) Livestock species in Mio heads per year, poultry in billion heads per year. a) and b) are shown in constant 2007 boarders.

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|  |

Figure S5: Net biomass trade in East and West Germany from 1961 to 1989. Net trade refers to imports minus exports of tons carbon per year. Values are shown in 5-year intervals.

|  |  |
| --- | --- |
| a) | b) |
|  |

Figure S6: a) Number of tractors per km2 of cropland per year in East and West Germany from 1950 until 1989, b) Livestock density [animals/km2/yr] in East and West Germany from 1950 to 2007.

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