Economic valuation of environmental costs of soil erosion and the loss of biodiversity and ecosystem services caused by food wastage

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Abstract

Food wastage costs society far more than the direct economic loss of US$ 750 billion per year. When food is discarded, all embodied natural resources are wasted, too. The aim of this study is to estimate global environmental costs of soil erosion and the loss of biodiversity and ecosystem services caused by food wastage. Firstly, environmental indicators and their quantities such as soil erosion rates, N, P and pesticide inputs and land use changes to agricultural production were assessed through a literature review. After an extrapolation of this data, cost estimation studies about the indicators were used to apply benefit transfer method. Results were calculated by the multiplication of quantities and costs of indicators, by the food wastage volumes and their land occupation factors. Global environmental costs of water erosion resulted in US$ 18 billion globally and total costs of biodiversity and ecosystem services loss account for US$ 4.5 billion.

Introduction

One third of food produced is lost or wasted within the food supply chain from agricultural production to the consumer (Gustavsson, Cederberg et al. 2011, Kummu, de Moel et al. 2012). Food wastage is defined as the sum of food loss and food waste (FAO 2013). Developing countries lose more than 40% of food post-harvest or during processing because of the storage and transport conditions (Gustavsson, Cederberg et al. 2011). Industrialized countries have lower producer losses, but at the retail or consumer level more than 40% of food may be wasted (Gustavsson, Cederberg et al. 2011). The direct economic loss of this food wastage accounts for US$ 750 billion per year (FAO 2013). That calculation is based on producer prices only and is equivalent to the GDP of Switzerland. Already this number shows that food wastage has grown into a serious problem. But these are not the costs the society pays truly. Food, which is produced but not eaten represents wasted resources and has a range of additional environmental and socio-economic impacts causing external costs. 1.4 billion hectares (ha) of land are occupied by food wastage (FAO 2013). That is 30% of the world's agricultural land and corresponds for example to the country areas of China, Mongolia and Kazakhstan together. Resources, including water, land, energy, labour and capital are wasted on this agricultural land, as well as greenhouse gas emissions, which arise and contribute to global warming and climate change. The carbon and water footprint, as well as the land occupation/degradation and the potential biodiversity impact, have been assessed in a previous study by FAO (FAO 2013). These assessments base on food wastage volumes estimated by Gustavsson, Cederberg et al. (2011), are made qualitatively, and do not include any costs.

It is not certain how much investment into food wastage mitigation will be efficient from a societal point of view. Therefore, social and environmental impacts of food wastage have to be assessed and monetized globally, first. In a further step results can be used for cost-benefit analysis to identify policy priorities for mitigation measures and to internalise these external costs into prices. Assessing

total social and environmental costs of food wastage within the whole food supply chain (FSC) at global scale has not been done before. This master thesis contributes one part to the monetary valuation of the environmental impacts. It is linked to a project conducted by the Research Institute of Organic Agriculture (FiBL) in collaboration with the Food and Agricultural Organisation (FAO) of the United Nations. The allotted time for the thesis allowed assessing the impacts soil erosion, biodiversity loss and (3) changes in ecosystem services and their costs (see Figure 1).
Therefore, the central research question addressed in this paper is:
How high are the global environmental costs of soil erosion and the loss of biodiversity and ecosystem services caused by food wastage?
The impacts to assess in this study are located mainly at the agricultural production stage. For that reason the master thesis is focused on this FSC stage.

External costs caused by agriculture

Several studies have been conducted to assess the external costs either of one specific impact of agriculture or of its total environmental impacts. Pretty, Brett et al. (2000) assessed in a trans-disciplinary study the total external environmental and health costs of modern agriculture in the UK. They analysed a variety of datasets to assess cost distribution across sectors and calculated the annual total of external costs by UK agriculture in 1996 to be £2343 million, equivalent to £208/ha agricultural land. Tegtmeier and Duffy (2004) estimated external costs of agricultural production in the United States including natural resources, wildlife and ecosystem biodiversity and human health by reviewing literature. Total external costs are estimated at $5.7 to $16.9 billion (£3.3 to £9.7 billion) annually. Using 168.8 million hectares of cropland in the US, external cost per cropland hectare is calculated at $29.44 to $95.68 (£16.87 to £54.82) and are much lower than the results of Pretty, Brett et al. (2000). Engström, Wadeskog et al. (2007) assessed the environmental impact from Swedish agriculture, including up- and downstream effects. They showed that the most important impact beside eutrophication, is the use of non-renewable resources, but they did not assign any costs.
Tegtmeier and Duffy (2004) and Pretty, Brett et al. (2000) used a similar framework for assessing the costs. Damage costs were assessed in the categories damage to water resources, soil resources, air resources, to wildlife and biodiversity, and to human health (Tegtmeier and Duffy 2004). Pretty, Brett et al. (2001) assessed the total external costs of agriculture in the UK, US and in Germany by using the same framework again. However, literature review made it visible that most studies are not comparable since the estimations of external costs were made for different impacts and with different methods. The range of different value and cost assessment methodologies is huge. An Overview over the different valuation techniques is presented in Table 1.

Table 1: Economic valuation techniques (Liu, Costanza et al. (2010), Farber, Costanza et al. (2002), Adhikari and Nadella (2011))

Revealed-preference approaches	
	Market price: Valuations are directly obtained from what people are willing to pay for the service or good, because they buy it.
	Travel cost: Valuations of site-based amenities are implied by the price people pay to enjoy them (e.g. train ticket to recreation services)
	Hedonic methods: The value of a service is implied by what people are willing to pay for the service through purchases in related markets (e.g. air quality, scenic beauty, cultural benefit).
	Production function: Service values are assigned from the impacts of those services on economic outputs (e.g., increased shrimp yields from an increased area of wetlands).
State-preference approaches	
	Contingent valuation: People are directly asked their willingness to pay or accept compensation for some change in ecological service (e.g. willingness to pay for cleaner air).
	Conjoint analysis: People are asked to choose or rank different service scenarios or ecological conditions (e.g. choosing between wetlands scenarios with differing levels of flood protection and fishery yields).
Cost-based approaches	
	Replacement cost: The loss of a natural system service is evaluated in terms of what it would cost to replace that service.
	Avoidance cost: A service is valued on the basis of costs avoided, or of the extent to which it allows the avoidance of costly averting behaviours, including mitigation (e.g., clean water reduces costly incidents of diarrhoea).
	Damage costs: Costs to repair damage to nature (e.g. water treatment because of pollution caused by agricultural production)
Other approaches	
	Benefit transfer: A widespread and cost-effective valuation technique, mainly if there is not enough time to do a primary study. Cost/value calculations at a primary study site are taken to estimate the cost/value at a policy site.

The valuation of external costs or ecosystem services is controversial due to methodological and measurement problems (Pretty, Mason et al. 2002), but the role of monetary values is important, because it has an influence on public opinions and policy decisions (Pretty 2008). Economic valuation of ecosystem services and biodiversity can illustrate to society in general and policy making in particular that biodiversity and ecosystem services are scarce and that their decline or degradation has associated costs to society (TEEB 2010).

Framework used for the assessment

Food wastage leads to the fact that less food is available for consumption and this causes an increase of production. The additional production is either reached by land use changes (when croplands and pastures extend into new areas, replacing natural ecosystems) or by intensification (when existing lands are managed to be more productive). Some outcomes are a higher use of physical capital (e.g. machinery, buildings), higher fertilizer and pesticide input, and higher water use or deforestation rate (see Figure 1). Therefore, the direct consequences for the environment are land occupation, soil erosion/degradation, air and water pollution and deforestation. The direct impacts lead to further impacts such as biodiversity loss, changes in ecosystem services and climate change.

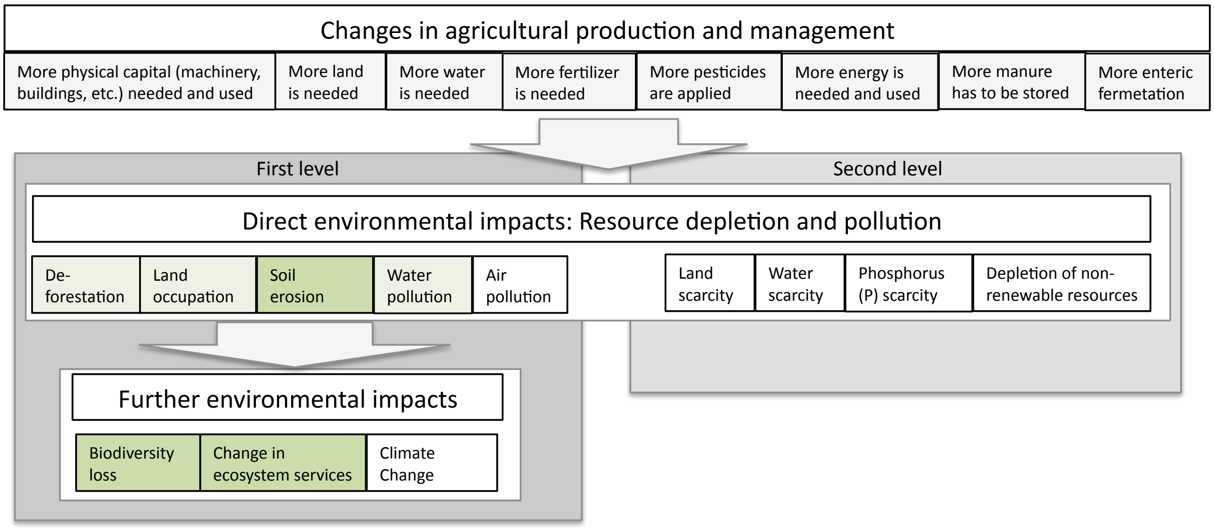

Figure 1: Environmental impacts of food wastage in agricultural production (adapted from Schader, Müller et al. (2013))

The monetization of soil erosion, biodiversity loss and changes in ecosystem services (see Figure 1, impacts marked in dark green) will be the contribution to the whole FAO project, where the shown framework was used. Deforestation, land occupation and water pollution is marked in a light green because these impacts are partly included in the assessment of biodiversity loss and changes in ecosystem services. To ensure, that no double counting occurs within the project, emissions to the air and water are part of the impact ‘climate change’. This includes the CO_2 emitted by deforestation or land use changes, and other greenhouse gases (GHG) produced by agriculture. One exception is eutrophication induced by nitrogen (N)- and phosphorous (P)- fertilizer, which cause the biodiversity loss. This part of water pollution is taken into account for this study.

Methodology

The aim of the project done by FAO and FiBL is the monetization of all environmental and social impacts caused by food wastage. Total environmental costs caused by food wastage (EC_TOTAL_i) were calculated as the sum of each single environmental impact (EC_{ik}) defined in the framework (see Figure 1). Not only the sum of the global costs of each impact can be calculated, but also the sum of total environmental costs per country. It can be seen as a matrix with countries and environmental impacts where costs can be accumulated vertically and horizontally.

$$EC\_TOTAL_i = \sum_k EC_{ik} \qquad \forall i \qquad (1)$$

EC_TOTAL = total global environmental costs caused by food wastage (US$/year)

EC = costs for environmental impact (e.g. deforestation, soil erosion) in US$/year

k = index of environmental impacts

i = index of country

All calculated costs in this study are given in 2012 US dollars (US$).

The methodological approach for EC of soil erosion and the biodiversity and ecosystem loss was defined after an extensive literature review. Method was split into the five steps 1) Country-specific assessment of environmental indicators in physical units, 2) Extrapolation of assessed physical units, 3) Assessment of monetary valuations of physical units, 4) Applying benefit transfer for an extrapolation, and 5) Calculation of the costs caused by food wastage.

An overview of the approach is shown in Table 2. The two impacts biodiversity loss and changes in ecosystem services were merged, because they are strongly linked. Biodiversity loss compromises the provision of goods and services made available by ecosystems. Therefore these two impacts are handled together or are even considered as one.

Table 2: Overview of methods

Steps	Soil erosion	Biodiversity and ecosystem service loss	
		Intensification	Higher use of agricultural land
1) Assessment of environmental indicator in physical units	Soil erosion rate in t/ha/year	N-, P- and pesticide use (in kg active ingredient per ha and year)	Land use change (ha/year)
2) Extrapolation of environmental impacts to countries where no data are available	Because assessed data for single countries was not complete, the gaps are filled with regional or global averages		
3) Assessment of monetary valuation of physical units	Costs per ton eroded soil (On- and off-site costs and sub-groups)	Costs per kg of N, P, pesticide used	Difference in ecosystem value caused by land use change
4) Applying benefit transfer	An adjusted unit value transfer approach will be used. Adjustment for differences in income levels using Gross Domestic Product (GDP) and Purchase Power Party (PPP) as correction factors for the different countries		
5) Calculation of the costs caused by food wastage	Existing land occupation factors multiplied by the food wastage volumes were to calculate the share of costs caused by food wastage. The factors depend on regions and commodities and are based on Gustavsson, Cederberg et al. (2011)		

Available data determined the choice of the environmental indicators. A distinction between intensification and additional land use for agriculture was made for the biodiversity and ecosystem loss. Existing studies about soil erosion rates could not indicate a correlation between agricultural intensity and soil erosion. Thus, for this master thesis it was assumed that no additional soil erosion is caused by intensification.

According to Sala, Stuart Chapin et al. (2000) and the Millennium Ecosystem Assessment (MA 2005) the most important determinants of changes in biodiversity at the global scale are changes in land use, atmospheric CO_2 concentration, pollution, climate, and biotic exchanges (deliberate or accidental introduction of plants and animals to an ecosystem). Land use changes and water pollution caused by fertilizer and pesticides are considered as the main threats out of these drivers on biodiversity loss. To mitigate double counting, changes in atmospheric CO_2 and climate are assessed within the other environmental impacts (see framework Figure 1). The cost calculations for the three (five) environmental indicators in the columns are done with three equations. Equation 2 was used for the soil erosion costs. Equation 4 was used to calculate the costs for biodiversity and ecosystem service loss caused by intensification and Equation 5 was used for the losses by land use changes. A detailed explanation follows in the sections to come. Since the methodological *Steps 2, 4* and *5* are identical for each environmental indicator they are explained in the section about soil erosion cost. The other two subchapters are limited to the *Steps 1* and *3*, where the assessed data through literature review is described.

The Sustainable and Organic Livestock Model (SOL-m) is used to perform the extrapolation of data on environmental indicators to all different countries, to apply benefit transfer and to do the multiplication by food wastage volumes and land occupation factors (methodological step 2, 4 and 5 of Table 2). SOL-m is a physical mass balance model, which covers the global food system, containing land use and livestock activities (Schader, Muller et al. 2012). It was developed by FiBL and had already been used to estimate food wastage footprints such as GHG, water, land occupation and biodiversity (FAO 2013). The model is also used to calculate scenarios for the future and particularly global effects of food wastage or mitigation measures on food availability and environmental impacts. It is also possible to assign environmental costs or impacts to specific commodities or/and regions.

Soil Erosion costs

Equation 2 was used to calculate the soil erosion costs ($EC_{i, Soil\_ersosion}$). The variables for the calculation are explained in detail in the following sections and are structured in the same five methodological steps (see Table 2). Soil erosion rates for each single country (e_i) result from *Step 1*) and *2)*, and the country-specific costs of soil erosion per ton (c_i) were assessed and calculated in *Steps 3)* and *4)*. The variables annual food wastage volumes (w_i) and land occupation factor (f_i) are explained in Step *5)*. The summation of the four multiplied variables over all countries leads to the global soil erosion costs caused by food wastage.

$$EC_{i, Soil\_ersosion} = \sum_i (e_i * c_i * w_i * f_i) \qquad \forall i \qquad (2)$$

$EC_{Soil\_ersosion}$ = global costs for soil erosion caused by food wastage in each country (US$/year)

e = annual soil erosion per hectare caused by agriculture (t/ha/year)

c = soil erosion costs per ton (US$/t)

w = annual food wastage (t/year)

f = land occupation factor (ha/t of wasted food)

i = index of country

1) Country-specific assessment of environmental indicator in physical units

To assess the annual soil erosion rates per hectare all available literature was considered. Soil erosion is a physical process that is naturally occurring throughout the existence of Earth. Severity and frequency depend on different factors such as soil type, wind and precipitation, topography and land management (Barrow 1991). Agriculture is the single largest contributor to soil erosion. Up to now, external costs of waterborne erosion have been studied and quantified more than those of windborne erosion (Tegtmeier and Duffy 2004). Literature review showed that a distinction between types of land use is necessary due to the big differences in erosion rates. Data availability made it possible to distinct between cropland and grassland. Therefore, soil erosion rates were classified in water and wind erosion, and in crop- and grassland. Water erosion rates on cropland were assessed for 60 countries and data for 14 countries was available on grassland. The rates for cropland range from 0.1 to 565 t/ha/yr (Lal, Hall et al. 1989, Tattari and Rekolainen 2006), and those for grassland range from 0.01 to 29.4 t/ha/yr (Darmendrail, Cerdan et al. 2004). Wind erosion rates on cropland were assessed only for five countries with a span from 0 to 41 t/ha/yr

2) Extrapolation of assessed physical units

The assessed country-specific data by literature review was extrapolated to all other countries. This data was used in Equation 2 as the occurring soil erosion caused by agriculture (e_i) (in Equation 4 as $b_{i,m}$, and in Equation 5 as $l_{i,m}$).

Regional averages were assigned to those countries where no primary data was available. The sub-regions used are shown in Table 1.

Table 3: Sub- regions used for extrapolation of averages

Africa	Americas	Asia	Europe	Oceania
Eastern Africa	Northern America	Central Asia	Eastern Europe	Australia/ New Zealand
Middle Africa	Central America	Eastern Asia	Northern Europe	Melanesia
Northern Africa	Caribbean	Southern Asia	Southern Europe	Micronesia
Southern Africa	South America	South-Eastern Asia	Western Europe	Polynesia
Western Africa		Western Asia		

Water erosion rates of 60 different countries were assessed and extrapolated to the 180 countries registered by the United Nations. For five regions no country-specific data was available, and therefore, other averages had to be assigned. The Eastern African average was used for all middle African countries, West African average was assigned to Northern African countries and Central American average was used for all South- Eastern Asian countries. It is assumed that the chosen averages represent the regions better than just the global average. Global average of water erosion was assigned to Eastern Asia and to Oceania only.

3) Assessment of monetary valuations of physical units

Several studies have been conducted to assess soil erosion costs all over the world (see Table 4). To illustrate the range for annual soil erosion costs per ton, assessed costs were divided by the soil erosion rates. Lowest costs per hectare were divided by lowest soil erosion rates and highest costs by highest rates. Results range from 0.3 to 331.7 US$/ha (disregarding any inflation rates) and most of them are limited to on-site costs.

Table 4: Cost estimations of soil erosion

Study	Country/ area	Soil erosion costs (US$/ha/year)			Cost type	Soil erosion rates used for calculation	Costs per ton of soil eroded
		Min	Mean	Max			
Dregne and Chou (1992)	World		3.5		on-site		
Pimentel, Harvey et al. (1995)	USA		275[1]		on-site and off-site	17	16.2
Riksen & Graaff, 2001 in Telles, Guimarães et al. (2011)	EU (4 members)		60.36		on-site		
Rodrigues (2005) in Telles, Guimarães et al. (2011)	Brazil, Goias	38.39		165.73	on-site and off-site	1.1 to 4.4	34.9 to 37.6
Telles, Guimarães et al. (2011)	Brazil, Santa Catarina	14.83		24.94	on-site	1.04 to 8.9	2.80 to 14.26
Hein (2007)	Spain, Puentes	5.12		66.54	on-site	7.1 to 206.9	0.32 to 0.72
Telles, Guimarães et al. (2011)	Brazil, Sao Paulo	28.32		72.65	on-site		
Kuhlman, Reinhard et al. (2010)	EU (25 members)	165.85		409.1	on-site	0.5 to 10	40.91 to 331.7

Although the study by Pimentel, Harvey et al. (1995) is almost 20 years old, it is still the most detailed assessment of soil erosion costs, and therefore, was investigated more closely. That the soil erosion rate used for this calculation has been criticised by Crosson, Pimentel et al. (1995) does not affect the costs, when they are calculated per ton of soil eroded. Since the range of different cost categories is far beyond all other studies and appears to be almost complete, the cost calculations done by Pimentel, Harvey et al. (1995) were taken to apply benefit transfer and used for the further steps.

To split water erosion and wind erosion, the fractions (10/17 and 7/17) are used to calculate the specific on-site costs (see Table 5).

Table 5: Used soil erosion costs for benefit transfer in *Step 4* (Pimentel, Harvey et al. 1995)

Cost type	Sub group	Total costs (millions US$/year)	Water erosion (millions US$/year)	Wind erosion (millions US$/year)
Erosion rate	t/ha/year	17	10	7
On-site costs (replacement costs)	Water	7'000.00		
	Nutrients	20'386.00		
Total		27'386.00	16109.40	11276.60
Off-site costs (damage costs)	Wind erosion c	9'632.50		9632.10
	Water erosion	7'381.00	7381.00	
Total off-site costs		17'013.50		

[1] Calculated from total soil erosion costs of 44000 million USD divided by 160 million hectares used by Pimentel et al (1995)

Total costs (on and off-site) US_{1994}\$/ha/year	44'399.50	23490.40	20909.10
Total area (million ha)	160.00	160.00	160.00
Costs US_{1994}\$/ha/year	274.90	146.80	130.70
Cumulative Inflation rate untill 2012[2]	0.55	0.55	0.55
Costs US_{2012}\$/ha/year	429.80	226.40	202.40
Costs US_{2012}\$/t/year	25	22	29

4) Applying benefit transfer method for an extrapolation

Benefit transfer method was applied to extrapolate the costs from the chosen studies at the study site to all other countries, called policy sites. A unit value transfer with adjustment for income differences will be used in this thesis. The common adjustment factors are Gross Domestic Product (GDP) and Purchase Power Party (PPP). To calculate the environmental costs at the policy site (C_p), costs at the study site (C_s) are divided by the GDP_{PPPs}, which is corrected by the PPP, and multiplied by the GDP_{PPPp} at the policy site:

$$C_p = C_s * (GDP_{PPPp} / GDP_{PPPs}) \qquad (3)$$

The C_p of of each single country can be found in Equation 2 as the soil erosion costs per ton (c_i), in Equation 4 as the costs per unit input such as N, P or pesticide ($x_{i,m}$) and in Equatoin 5 as the ecosystem value decrease from forest to agricultural land ($d_{i,j}$).

The advantage of this type of value transfer is, that data for the adjustment factors are available and it is a cost effective method.

Most recent GDP_{PPP}'s are taken from the World Bank (WB 2013), and in the majority of cases, this is the data from 2012.

5) Calculation of the costs caused by food wastage

The last methodological step contains the multiplication of the costs (results of step 2 multiplied by results of step 4) by the annual food wastage in tons and by the land occupation factor in hectare per ton of wasted food to get the share, which is caused by food wastage. Food wastage volumes data (w_i) from Gustavsson, Cederberg et al. (2011) were already taken to estimate the land occupation factor (f_i) which is commodity and region specific (FAO 2013). It reflects the hectares of land used to produce uneaten food. The authors made the assumption in the quantification of land occupation that products consumed in a sub-region are produced in the same region (FAO 2013). For example, land occupation related to wheat wasted in Europe was calculated with the land impact factor of 1 ton of wheat produced in Europe.

The costs for biodiversity and ecosystem service loss caused by intensification

Equation 4 was used for the biodiversity and ecosystem service costs caused by intensification ($EC_{i,B\_intensification}$). The amounts of fertilizer and pesticides applied in agricultural production per country

[2] Cummulative inflation rate: http://www.usinflationcalculator.com/inflation/historical-inflation-rates/

($b_{i,m}$) result from step 1 and 2, and the country-specific environmental costs per unit of one input active ingredient ($x_{i,m}$) were assessed and calculated in steps 3 and 4. The variables annual food wastage volumes (w_i) and land occupation factor (f_i) are explained in methodological step 5 of the section Soil erosion costs. The summation of the four multiplied variables over all countries leads to the global soil erosion costs caused by food wastage.

$$EC_{i,B\_intensification} = \sum_m (b_{i,m} * x_{i,m} * w_i * f_i) \quad \forall i \qquad (4)$$

$EC_{B\_intensification}$ = global costs for biodiversity loss caused by intensification due to food wastage in each country (USD/year)

b = fertilizer or pesticide use (kg /(ha*year))

x = environmental costs per unit (USD/kg)

w = annual food wastage (t/year)

f = land occupation factor (ha/t of wasted food)

i = index for country

m = index for input (N,P, pesticide)

Step1)

The use of the fertilizer N and P, as well as applied pesticides were assessed in this master thesis. Data for fertilizer use has already been integrated in SOL-m and was taken from FAO (2013). Data about pesticide applications was taken from Schreinemachers and Tipraqsa (2012), because it was a data assessment which covered 115 countries and is the most up to date study, which has been peer-reviewed.

Step 3)

Not many studies exist about environmental costs per unit pesticide or fertilizer. For the fertilizer costs, calculations from Glendining, Dailey et al. (2009) are used in this thesis. It is the only peer-reviewed study available, which includes biodiversity loss costs for both N and P. They calculated the costs for biodiversity loss caused by eutrophication to be GB£ 0.011 per kg N applied and GB£ 0.12 per kg P applied. With a cumulative inflation rate of 29% for GB Pounds from 2000 till 2012 and an exchange rate of 0.63, costs per kg fertilizer applied in 2012 dollars are US$ 0.024 and US$ 0.26.
Costs for biodiversity loss per kg pesticide applied are taken from Leach and Mumford (2008). They calculated external costs by using two different cost category schedules in a matrix. Cost categories used by Pretty, Brett et al. (2000) are shown in columns and those used for the environmental impact quotient of pesticides (EIQ) explained in Kovach, Petzoldt et al. (1992) showed in horizontal lines (see Table 6). When costs within the biodiversity categories are summed, costs for pesticide range from US$ 1.84 to US$ 3.23 per kg applied.

Table 6: External costs of pesticides calculated by Leach and Mumford (2008) in 2012 US$[3]

	Pesticides in sources of drinking water	Pollution incidents, fish deaths and monitoring costs	Biodiversity wildlife losses/	Landscape/ cultural/ tourism value	Bee colony losses	Acute effects of pesticides to human health	Sum
Applicator effects	0.79					0.44	1.23
Picker effects	0.79					0.09	0.88
Consumer effects	4.76			0.94		0.03	5.74
Ground water	0.79	0.58					1.38
Aquatic effects	0.79	0.58	0.23				1.59
Bird effects			0.23	0.38			0.60
Bee effects			0.07	0.18	0.18		0.44
Beneficial insect effects			0.23	0.38			0.60
Sum of Above	7.94	1.15	0.74	1.89	0.18	0.55	12.45

Costs for biodiversity and ecosystem service loss caused by land use changes

To calculate the additionally costs for biodiversity loss caused by land use changes ($EC_{i,\ B\_land\ use\ change}$) Equation 5 is used. Land use changes from forest to agricultural land ($l_{i,m}$) result from step 1 and 2, and the country-specific value decrease per hectare changed land ($d_{i,m}$) were assessed and calculated in steps 3 and 4. The variables annual food wastage volumes (w_i) and land occupation factor (f_i) are explained in methodological step 5 of the section Soil erosion costs. The summation of the four multiplied variables over all countries leads to the global soil erosion costs caused by food wastage.

$$EC_{i,\ B\_land\ use\ change} = \sum_j (l_{i\,j} * d_{i,j} * w_i * f_i\ ) \qquad \forall i \qquad (5)$$

$EC_{B\_land\ use\ change}$ = global costs caused by land use changes in each country (USD/year)

l = land use change (ha/(ha*year))

d = costs as the difference in ecosystem value (e.g temperate forest to cropland) (USD/ha)

w = annual food wastage (t/year)

f = land occupation factor (ha/t of wasted food)

i = index for countries

j = index for type of land use change (tropical, temperate or boreal forest to cropland)

Step 1)

Changes from forests to agricultural land were taken from FAO (2013). A global annual forest area loss of 5.6 million hectares was calculated by averaging the changes over the last five years. Simultaneously, arable land and permanent crops areas expanded with a rate of 4.2 billion hectares per year. Permanent meadows and pastures decreased almost as fast as forest, with 5 million hectares per year. Variation of these land use change rates is huge when considering the different regions.

[3] Calculated with an cumulative inflation rate of 14.7% Euro from 2006 till 2012 and an exchange rate of 0.809 http://search.worldbank.org and http://www.irs.gov/Individuals/International-Taxpayers/Yearly-Average-Currency-Exchange-Rates

Step 3)

The value of ecosystem services in monetary units is a tool to raise awareness and expresses the (relative) importance of ecosystems and biodiversity (de Groot, Brander et al. 2012).

Values used for this study were taken from Van der Ploeg and de Groot (2010) who assessed all existing studies and generated a database with more than 1300 values of biomes and their range of services. The sum of all services reflects the total economic value (TEV) a biome. It includes use values and non-use values. Use values consist of direct use values such as resource use or recreation, and indirect use includes for example regulating services. Non-use values contain option values bequest and existence values (TEEB 2010). The costs for land use changes were calculated as the difference from the original biome such as temperate or tropical forest to agricultural land. Table 7 shows some examples, which were used for the extrapolation.

Table 7: Economic values of biomes assessed by Van der Ploeg and de Groot (2010)

Country	TEV per hectare tropical forest (US$/year)	TEV per hectare temperate forest (US$/year	TEV per hectare grassland (US$/year)	TEV per hectare cropland (US$/year)
World	4048	444	341	135
Spain		4641	281	2621
China	4313	618	1429	1363
Australia	4558	686	527	208
United States of America		419	322	127

All values were adjusted to 2012 US$ by using the cumulative inflation rates of the original country and the exchange rates from World Bank (WB 2013).

Results

With total global water erosion of 4.5 billion tons annually caused by food wastage, environmental costs of US$ 18 billion were calculated. The annual costs of biodiversity and ecosystem service loss caused by pesticides result in US$ 0.9 billion. N and P fertilizer cause costs of US$ 0.7 and US$2.4 billion, respectively. A biodiversity and ecosystem service value decrease caused by land use changes from forest to cropland is estimated to be US$ 0.55 billion per year.

Soil erosion

Global average of water erosion on cropland and grassland is 14 t/ha/year. Global results and the seven countries with highest water erosion cost are shown in Table 8. The income corrected costs per ton by applying benefit transfer range from less than $1 to almost $30 per ton. The costs occurring in China are not much higher as in the United States, but the physical soil erosion is six times higher than the one in the US. The first seven countries account for more than 55% of global costs.

Table 8: Global costs and countries that cause the highest water erosion costs

Country	Total costs (million US$/year)	Water Erosion (million t/year)	Costs per ton (US$/t)
World	17,777	4,478	4
China	2,502	667	4
United States of America	2,212	103	22
India	1,546	940	2
Singapore	1,381	51	27
Japan	879	57	15
Australia	810	43	19
Brazil	779	151	5

Biodiversity and ecosystem service loss

Biodiversity loss caused by fertilizer and pesticide applications costs the society US$ 4 billion and is eight times higher than the calculated costs for ecosystem service loss caused by land use change. Table 9 shows the costs for pesticide, for N and P fertilizer again for the whole world and as the sum the seven countries causing the highest costs. The costs in the United States represent 20% of the total costs and Chinas cost correspond to 15% of the global biodiversity and ecosystem loss caused by food wastage. The seven countries account for more than 50% in each of the four columns.

Table 9: Costs of biodiversity and ecosystem service loss caoused by pesticides, N and P fertilizer

Country	Costs caused by pesticides (million US$/year)	Costs caused by N fertilizer (million US$/year)	Costs caused by P fertilizer (million US$/year)	Total costs (million US$/year)
World	925	700	2363	3988
United States of America	104	182	491	777
China	185	70	353	609
Brazil	31	38	152	222
Japan	15	22	145	184
Australia	13	51	118	183
India	47	22	89	159
Singapore	102	8	3	113

The costs for the land use change from forests to cropland result in an unexpected distribution. The extrapolation of the costs (value difference) led to a difference of US$10,000 between forest and cropland in the small state of Brunei Darussalam. Brazil attracts attention with the high change rate of 304,000 hectares per year caused alone by food wastage.

Table 10: Costs of biodiversity and ecosystem services caused by land use change

Country	Land use change costs (millionUS$/year)	Deforestation (1000 ha/year)	Costs per hectare land use change (US$/ha)
World	550	2200	250
Brunei Darussalam	438	43	10174
Indonesia	36	89	407
Angola	35	25	1410

Lao People's Democratic Republic	30	14	2143
United Republic of Tanzania	28	85	328
Brazil	26	304	86
Cameroon	25	46	544

Discussion

A few countries are responsible for a big part of the costs that were assessed. China and the United States cause the highest costs assessed in this study. Both countries have high food wastage shares and therefore much agricultural land is occupied by food wastage

The results generated in the master thesis can be considered as lower bounds for the actual environmental costs, because different factors could not be considered due to lacking data. For instance, soil erosion caused by water is only a part of total soil erosion and biodiversity loss not only occurs because of a higher fertilizer and pesticide inputs or land use changes by cutting down forests. Since wind erosion data was only available fore five different countries, no extrapolation was made. The little available data showed that wind erosion rates are a bit lower than water erosion rates in these five countries, but costs are about 25% higher. There exist also other soil degradation types beside soil erosion. For example, annual productivity loss in agriculture caused by soil salinity in Algeria, Egypt, Lebanon, Marocco, Syria, Tunisia and Iran costs US$80 million in total. Assuming that a third of that is caused by food wastage it costs society nearly US$30 million in these seven countries. Different studies ascertain that economic calculations grossly underestimate the current and future value of natural capital. Real costs occur, when nature's goods and services are already lost, and it shows then that they had been undervalued (Pretty, Brett et al. 2000).

For soil erosion and biodiversity loss caused by intensification, cost data base on one primary study only. Beside the uncertainties within the chosen primary studies, benefit transfer can lead to additional inaccuracy. The unit value transfer implies the assumption that costs vary proportionally with GDP. Results at the policy site can at the most be as good as the results at the primary study site. Kaul, Boyle et al. (2013) assessed 1071 transfer errors reported by 31 studies and calculated a median of absolute error of 39% for all data and 33% with the outliers removed. The individual transfer errors range from nearly 0% to larger than 200%. Therefore, results presented in this paper are an approximation to the real costs and demonstrate a base of global results, which can be improved by updated and more primary studies. Additional primary studies reflecting for example soil erosion rates, and cost calculations per ton would improve and ensure the global results. Knowledge about wetlands and their conversion into agricultural land could complete the results further.

The relatively low results for land use change costs could be explained with the absence CO_2 emission costs in the calculation. When adding all the environmental costs, which were assessed in the project by FAO and FiBL, also CO2 costs will be taken into account.

Results represent how much environmental costs would be saved if no agricultural production would take place on the 1.4 billion hectares occupied and if no intensification would occur. These costs are further used to calculate the Net-Present-Value (NPV) for food wastage mitigations.

Generally it can be said, that reducing food wastage on consumer level will cause a decreasing demand and result in a lower agricultural production and therefore, lower environmental cost. The later a product is lost, the higher environmental costs are, because they add up during the FSC. Raising the consumer awareness with a campaign could be an efficient mitigation measure, because it operates at the end of the FSC. According to (BIOIS 2013) reducing household waste of dairy products and red and white meat sectors, as well as fruits and vegetables provide the greatest potential for reducing land demand in the EU .

Reducing food waste is a key step towards improving resource efficiency in the food system (BIOIS 2013). In order to meet the demand of a growing global population, agricultural production is not allowed to decrease. It is known that enough food is produced at the moment to nourish each single person on this globe, but it ends up at the wrong places. A central finding by Fader, Gerten et al. (2013) is that domestic crop production could theoretically replace imports and allow food self-sufficiency in many countries. This would shorten the food supply chains and food losses could probably be reduced.

The authors of the report "Turning Milestones into Quantified Objectives: Food waste" state that although food producers would seem to be negatively impacted by a food wastage reduction induced by decreasing demand, this would probably be more than compensated by the general overall trend of increasing food demand due to growing global populations and income (BIOIS 2013).

The EU Commission defined food waste reduction targets between 10% and 50% by 2020 compared with 2010. It has not been possible to identify a plausible food wastage minimum for all countries, because the estimated quantities currently generated vary so widely across EU member states and sectors (BIOIS 2013). Therefore countries would need to define their own targets. For example, the Netherlands have set a 20% target for 2015 (BIOIS 2013). Considering the case of United States or China, food wastage reduction of only 10% would already lead to high savings in external costs, because of the high food wastage shares.

Conclusion

Given that waterborne soil erosion causes US$18 billion in damages each year and assuming that wind erosion and other soil degradation types induce similar costs, a sum of $36 billion results. Adding the US$4.5 billion of biodiversity and ecosystem service loss leads to US$40 billion environmental costs caused by food wastage. With a world population of 7.2 billion, that makes annually US$5.5 per person. With 1.4 billion hectares occupied by food wastage production, costs to society are US$29 per hectare. Gustavsson, Cederberg et al. (2011) assessed 1.3 billion tons of edible food wastage. By dividing the costs of soil erosion, biodiversity and ecosystem loss by the 1.3 billion tons, US$30 per

ton food wastage could be spent for mitigation measures to still be efficient. When considering total environmental and social costs out of the framework (see Figure 1), a lot more money could be spent for campaigns to raise consumer awareness and causing a reduction of external costs.
Money affects peoples' decisions. Showing these monetary relations to policymakers and consumers can induce an action into the right direction, to a more sustainable management of our planet.

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