E-Forum on Full Cost Accounting of Food Wastage:
Week 5, 18 November – 24 November
Biodiversity and Ecosystems

Week five of the E-Forum addresses food wastage impacts on biodiversity and ecosystems.

Food wastage impacts on Biodiversity and Ecosystems

Phase I of the Food Wastage Footprint (FWF) project estimated the impact of food wastage on biodiversity along three indicators: deforestation rate, species threat level (according to the IUCN Red List) and the Marine Tropic Index (MTI)[1]. It mostly qualitatively assessed the correlation between food wastage source regions and the occurrence of deforestation, agricultural threats to bird and amphibian species, and fish stock depletion. This captured some trends of food wastage occurrence and pressures on biodiversity but did not allow for some commodity-differentiation.

In Phase II, an approach to derive quantitative information on food wastage impacts on biodiversity and ecosystems is being developed. For this, different indicators related to the pressure of agricultural production (and therefore from the part that is wasted) on biodiversity and ecosystems could be considered (cf. Table 1). These indicators cover the five main drivers of biodiversity loss according to the framework from the Millennium Ecosystem Assessment (MEA, 2005), namely "habitat change", "climate change", "over exploitation", "pollution" and "invasive species".

Table 1: Examples of potential indicators for the impacts of food wastage on biodiversity and ecosystem services (entries shaded in green are used for cost quantifications in the model, cf. table 2 below)

Main driver of Biodiversity loss/Ecosystem changes	Indicator of pressure from agricultural production
Climate Change	Global Warming Potential
Habitat Change	Deforestation potential
	Drainage of wetlands
	Land use change from pastures to arable land
	Low biodiversity in agricultural landscapes due to monocultures
Over-Exploitation	Grassland degradation
	Fisheries depletion
	Wild species depletion via over-harvesting (e.g. natural medicines, pharmaceuticals, mushrooms)
	Salinization due to irrigation water extraction
	Depletion of aquatic ecosystems due to irrigation water extraction
	Soil fertility losses due to soil organic carbon losses
Pollution	N-eutrophication from N deposition in various ecosystems (incl. marine)
	P-eutrophication from P2O5 deposition in various ecosystems (incl. marine)
	Acidification from NOx deposition in various ecosystems (e.g. from biomass burning)
	Acidification of oceans due to CO2 emissions
	Pesticide deposition in various ecosystems (incl. marine)
Invasive Species	Effectiveness of import control and quarantine measures
	Trade of agricultural[2] products and inputs (seeds)
	Disturbance of the self-regulation capacity of ecosystems

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[1] The Marine Trophic Index (MTI), using mean trophic levels, has been developed to measure the decline in abundance and diversity of fish high in the food chain. This index communicates a measure of species replacement induced by fisheries and a declining value indicates depletion of fisheries.

[2] Trade of non-agricultural products is even more important as seeds and individuals of invasive species can travel on any transport means. But given the topic of the project, we focus on agriculture.

In the current model, the indicators are assessed at the national level only; a sub-national, ecosystem-location based hotspot analysis is therefore not possible. Commodities lost or wasted after the production phase should ideally be traced back to their country of production to determine the impacts of their production phase. As detailed trade flows have not been modeled in this first assessment, global average production impact numbers will be used to model the production phase impact of these lost/wasted commodities. The global average numbers will be specific for each commodity.

Besides the issue of finding enough data to quantify the impacts of these pressure indicators on biodiversity and ecosystems, two particular methodological challenges need to be pointed out. First, the effect of certain drivers depends on their own pre-existing level: additional greenhouse gases (GHGs) emitted due to food wastage, for example, results in higher damages if there is already a big quantity of GHGs in the atmosphere while damages from the same amount of emissions will be lower in a situation of low GHGs concentrations. The quantifications made in this project are based on average values only and thus disregard such marginal effects of stock changes at a given stock size. "Regime switches" are a particular relevant aspect of this challenge. For fisheries, for example, a moderate harvest quota may not greatly affect big populations, but for populations at the edge of the size where they stop to be self-sustained, even a moderate harvesting quota can lead to extinction. Second, double-counting needs to be avoided. Deriving the costs of GHGs emissions (cf. week 2) by means of the social costs of carbon already covers the impact of agriculture on ecosystems and biodiversity via its GHGs emissions. This should not be added again to the equation.

Social costs of food wastage impacts on biodiversity and ecosystem services

As in the previous inputs to the E-forum, Figure 1 below presents examples of the different aspects of ecosystem and biodiversity valuation in the Total Economic Value (TEV) Framework. For this topic, in principle, the full range of use (albeit mainly indirect) and non-use values can be covered (large rectangle), depending on the different values covered in the cost estimates used. In this project, we focus on the direct and indirect use value, though (small rectangle).

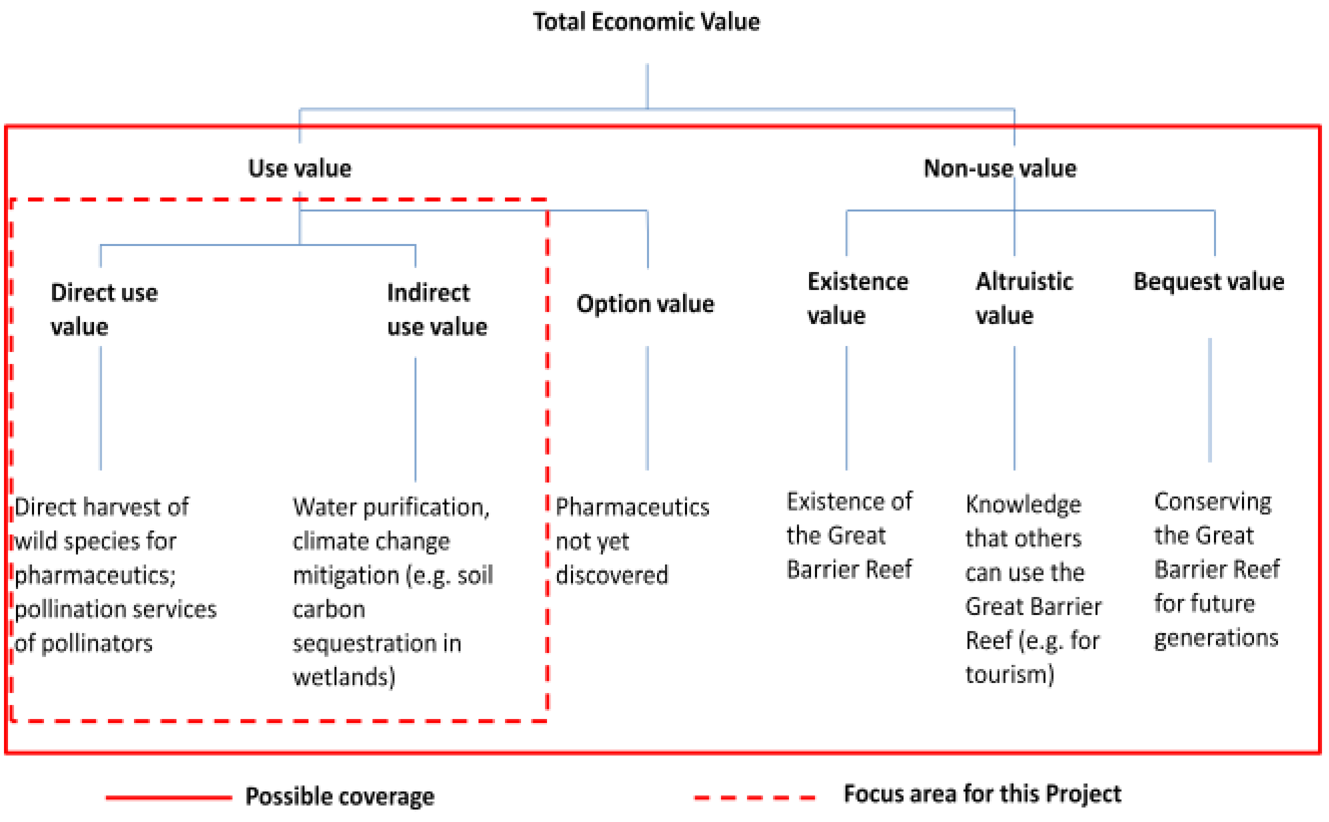

Figure 1: TEV for biodiversity and ecosystem services, displaying some examples of the different values.

Several approaches are possible to arrive at cost estimates of the impacts of the pressure indicators listed above:
Approach 1**:** After defining the pressure indicators values, these pressures are linked to quantifiable biodiversity and ecosystem impacts. The costs of these impacts are then identified. This approach necessitates a detailed understanding of the highly complex relationship between the pressure indicators and the biodiversity and ecosystem impacts.
Approach 2: As the primary interest in this project lies on the costs of these impacts from food wastage, the step linking pressure and impacts does not necessarily need to be addressed explicitly. It is therefore possible to directly utilize existing cost estimates for the pressure indicators (as e.g. done with the use of social cost of carbon estimates for greenhouse gas emissions in the second week of this E-forum), therefore avoiding having to detail the link between pressure and impacts.
Approach 3: This starts at the ecosystems level rather than at the pressure level, estimating the relative importance of different drivers in the observed ecosystem and biodiversity changes. For this, the status of biodiversity and ecosystems need to be assessed, as well as the agriculture (or rather the share of it that goes wasted) contribution to these changes (e.g. 80% of deforestation is due to agriculture). The share of food wastage in those drivers is then derived by using the food wastage percentages for the various agricultural commodities. This finally results in some assessment of the contribution of food wastage to changes in the ecosystems and biodiversity. Estimating the costs of these changes (e.g. based on ecosystem services values) then allows an assessment of the respective costs of food wastage

Approach 1 is the most accurate and detailed approach, while approaches 2 and 3 don't fully capture the linkage between pressures and impacts. Approach 2 avoids detailing this linkage by referring to literature that provides direct costs data for the pressure indicators, while Approach 3 is based on the value of ecosystems and biodiversity lost and literature that provides assessments on how much agriculture contributes to these losses.

In this project, only some of the indicators listed in table 1 will be used, based on the parameters available in SOLm. Table 2 presents the proposed indicators and their measurement units. In particular, the driver "invasive species" is not taken up, as data availability and applicability in the SOL-model is very limited due to its reference to countries as basic geographic units.

Table 2: Indicators and valuation approaches for the impacts of food wastage on biodiversity and ecosystem services used in the project

Main driver of Biodiversity loss/Ecosystem changes	**Indicator of pressure from agricultural production**	**Measurement unit**	**Possibility of product-specific calculations in SOLm**	**Evaluation of share coming from food wastage**	**Calculation of the costs of Impacts on Biodiversity/ Ecosystems**
Climate Change	Global Warming Potential	CO2-eq	yes	directly linked to production	Approach 2, but already included in Social Cost of Carbon Calculation
Habitat Change	Deforestation	Hectares	yes	allocated to specific crop based on their area shares	Approach 2, but already included in the land degradation calculation
Over-Exploitation	Grassland degradation	Index for use intensity	yes	assigned to different animal types based on animal numbers (cattle units)	Approach 2, but already included in the land degradation calculation
	Fisheries depletion	kg of fish	no	Directly linked to production	Loss of fish population, approach 1 (as the linkage between harvests and depletion is direct)

Pollution	N-eutrophication	kg of surplus N	yes	directly linked to production	Approach 1 or 3
	P-eutrophication	kg of surplus P2O5	yes	directly linked to production	Approach 1 or 3
	Pesticides	Pesticide use intensity (amount of pesticides in agriculture unknown)	no	directly linked to production	Loss of pollinators, approach 3

The costs of the impacts of overexploitation of grasslands and deforestation on ecosystem services have already been assessed under the topic of "land use change" in the input paper on land use and land degradation. The costs of greenhouse gas emissions have been assessed in the input paper on climate change, where the notion of "social costs of carbon" has been employed, which is an aggregate cost estimate that also covers the effects on ecosystem services and biodiversity. These topics are not further discussed here in order to avoid double counting.

The costs of fisheries' overexploitation are assessed in World Bank and FAO (2008), Sumalia and Suatoni (2005), Hesselgrave, Kruse *et al.* (2011). Combining this with the share of wastage in fisheries allows assessing the contribution of food wastage to the fisheries sector. A key problem is the non-linear threshold-effects of depletion as already mentioned above, where relatively small contributions can push a fishery over the edge and lead to its extinction. A second topic in fisheries is discard of by-catch, i.e. of non-useful species. This affects different fisheries/ecosystems than the commercial ones and valuation thereof becomes relevant for endangered species. The valuation then needs to refer to the costs of population decline and extinction of endangered species.

Data on per kg N or P costs of ecosystem services and biodiversity losses due to nitrogen and phosphorous runoff are largely lacking, but there is some data on species loss due to N runoff in general. Bleeker, Hicks *et al.* (2011), for example, quantify the N impact on ecosystems. This can then be combined with the assessment of the values of ecosystems and their services presented by de Groot, Brander *et al.* (2012). This would allow some first cost estimate of these impacts.

Pesticide impact costs (incl. pollination) are provided by a range of publications.Leach and Mumford (2008), for example, report such costs differentiated per country (for USA, UK and Germany) and on the basis of costs per kg of pesticide used. Country-wise pesticide quantity data is not readily available. The data available in FAOSTAT is not currently complete enough and is not crop–specific. An assessment specific to pollination services could be attempted based on the study of Bauer and Wing (2010), which estimates the total costs of pollinator decrease. Combining this with values on the contribution of agriculture to pollinator decrease would allow some general assessment of the impact of food wastage on pollinators. This contribution is however difficult to quantify, albeit the correlation between intensive agriculture, pesticide use and pollinator decline is well established (Kremen, Williams *et al.*, 2002, Biesmeijer, Roberts *et al.*, 2006, Ricketts, Regetz *et al.*, 2008, Brittain, Vighi *et al.*, 2010, Cresswell, 2011, Garibaldi, Steffan-Dewenter *et al.*, 2011, Gill, Ramos-Rodriguez *et al.*, 2012). Early results from a recent initiative coordinated by FAO have shown that optimal pollination levels increase yields by an average rate of increase of 24%; conversely, yields are 24% decreased under non-optimal pollination conditions (such as monocultures and intensive use of agricultural chemicals).

Finally, some estimates are available for the protection costs for endangered species, or on the willingness to pay for species conservation (Shogren, 1997, McCarthy, Donald *et al.*, 2012). These values allow deriving some cost estimate based on the loss of species indicator used in Phase I, as it was then reported that on average, 66% of species loss had agriculture as one of their main driver. The numbers behind this estimate vary regionally and with species type. For a gross estimate, it is assumed that a third of food production is lost via food wastage. Food wastage would then be responsible for about 20% of species losses and, in consequence, for 20% of the related costs. This assessment is not linked to the single drivers according to the Millennium Ecosystem Assessment used above, as it is an aggregate assessment of the combined impacts of all drivers related to agriculture. There is therefore a risk of double counting. This issue will have to be investigated in more depth before proceeding to monetization.

Draft approach to the monetization of food wastage impacts on biodiversity and ecosystem services

Based on the approaches described above, we attempt some preliminary sample estimates of the costs of the impacts of food wastage on ecosystem services and biodiversity, avoiding double counting by not covering aspects already covered earlier as indicated in table 2. We address fisheries over-exploitation, N-runoff, and pollinator losses as a demonstration of the possible methodology.

The World Bank/ FAO report (2008) evaluate the loss economic benefits due to over fishing at around USD50 billion/ year due to overexploitation of fisheries and therefore underperformance of fisheries. As FAO (2013) estimates the global fish wastage to be about 20%, gross estimate of the loss economic benefits due to fish wastage, contributing to fisheries overexploitation, is USD10 billion/year. This estimate excludes consideration of losses to recreational fisheries and to marine tourism. The losses attributable to illegal fishing are not included. The estimate also excludes consideration of economic contribution of dependent activities such as fish processing, distribution and consumption. It excludes the value of biodiversity losses and any compromise to the ocean carbon cycle. This suggests that the losses to the global economy from unsustainable exploitation of living marine resources substantially would exceed USD50 billion per year. On the other hand, this number may be over-estimating the true losses, as no market effects of extra landings (if the fishing potential was fully realized) are considered and the value of this additional catch has been calculated by the price realised for the actual quantities caught. An increase of fish quantities might however lead to price decreases.

A global assessment of N runoff into protected areas is attempted in Bleeker, Hicks *et al.* (2011), which identify about 10% of these areas receiving more than 10 kg N/ha/y which is chosen as some gross aggregate critical benchmark above which changes in ecosystem services and biodiversity may occur, based on some experimental studies. These 10% correspond to about 100 million ha. Sources for these N entries into ecosystems are agriculture and the energy sector. Bleeker, Hicks *et al.* (2011) provide values that already have been made comparable globally and no further benefit transfer is thus needed. Using an average value of about USD3000/ha/y for terrestrial biomes, this amounts to critical impacts on areas that deliver a total in ecosystem services of about USD300 billion/y. How much value is lost due to this N entry, is however not known. For some areas, it will be up to 100%, while for others, it may be close to negligible. Assuming an average of 20% value loss (just for illustration), and about 85% of the nitrogen stemming from agriculture (Boesch, 2002) and using the share of food wastage in total production from (FAO, 2013), this results in a contribution from food wastage of about USD20 billion, somewhat less than 3% of the pure economic estimate of food wastage given in (FAO, 2013). It has to be emphasized that this is a very gross and preliminary estimate. Further refinement will likely lead to an increase, as coastal and marine biomes with considerably higher per ha values have not yet been accounted for while some hot spots for N deposition (e.g. China) cover such. Furthermore, this assessment is based on N inputs to the protected areas only.

According to Bauer and Wing (2010), a total global pollinator losses would lead to economic costs of about USD330 billion. This number cannot be further refined for regions and commodities and we thus assume a global share of food wastage in agricultural production of a third. Furthermore, the global situation does not face a total pollinator loss but a decrease only. Using the 24% losses due to pollinator decrease referred to above, this share of costs could be used for a first gross estimate. If pollinator loss would be fully due to agriculture, food wastage would then be responsible for about USD30 billion. Given that there are other drivers but agriculture is the most important one, we may assume a value of USD20-25 billion. Clearly, this has to be further refined, in particular on regional scale, and regarding the contribution of agriculture. Also, the model behind the data used here looked at pollinators complete extinction, results from the extinction of only a fraction of the pollinators thus needs to be addressed in more detail, in particular as the relationship between pollinator losses and economic impacts likely is not linear.

Questions for Discussion

- This Paper presents a set of potential indicators to assess the food wastage impact on biodiversity and ecosystems. Do you think that key quantifiable indicators are missing? If so, do you know of any quantification study we could work with?

- Three potential approaches to value the impacts of food wastage on biodiversity and ecosystems are presented. How do you judge those and do you see/know of alternative approaches?
- What do you think about the first attempts at the monetization exercise?
- How to deal with threshold effects, i.e. the fact that marginal impacts on ecosystems and biodiversity strongly depend on the pressure already present? What does this mean for the identification of impacts from food wastage?
- Is potential double counting of effects prevented in the way biodiversity and the other environmental impacts have been addressed? How to avoid double counting?

References

Bauer, D. M. and Wing, I. S. 2010. Economic Consequences of Pollinator Declines: A Synthesis. *Agricultural and Resource Economics Review* 39(3): 16.

Biesmeijer, J. C., Roberts, S. P., Reemer, M., Ohlemueller, R.,Edwards, M., Peeters, T.,. Schaffers, A, Potts, S. G., Kleukers, R., Thomas, C. D., Settele J. and Kunin W. E. 2006. Parallel declines in pollinators and insect-pollinated plants in northwest Europe. Britain and the Netherlands. *Science* 323(5785).

Bleeker, A., Hicks, W. K., Dentener, F., Galloway, J. and Erismana, J. W. 2011. N deposition as a threat to the World's protected areas under the Convention on Biological Diversity. *Environmental Pollution* 159(10): 9.

Boesch, D. F. 2002. Challenges and opportunities for science in reducing nutrient over-enrichment of coastal ecosystems. *Estuaries* 25: 744-758.

Brittain, C. A., Vighi, M. and Bommarco, R. 2010. Impacts of a pesticide on pollinator species richness at different spatial scales. *Basic Appl Ecol* 11: 10.

Cresswell, J. E. 2011. A meta-analysis of experiments testing the effects of a neonicotinoid insecticide (imidacloprid) on honey bees. Ecotoxicology 20: 9.

de Groot, R., Brander, L., van der Ploeg, S., Costanza, R., Bernard, F., Braat, L., Christie, M., Crossman, N., Ghermandi, A., Hein, L., Hussain, S., Kumar, P., McVittie, A., Portela, R., Rodriguez, L. C., ten Brink, P. and van Beukering P.2012. Global estimates of the value of ecosystems and their services in monetary units. *Ecosystem Services* 1(1): 50-61.

FAO .2013. Food wastage footprint- Impacts on natural resources, Summary Report, FAO, Rome.

Garibaldi, L. A., Steffan-Dewenter I. and C. Kremen. 2011. Stability of pollination services decreases with isolation from natural areas despite honey bee visits. *Ecol Lett* 14: 1062-1072.

Gill , R. J., Ramos-Rodriguez, O. and Raine, N. E. 2012. Combined pesticide exposure severely affects individual- and colony-level traits in bees. *Nature* 491(105–108).

Hesselgrave, T., Kruse, S. and Sheeran, K. A. 2011. The hidden cost of overfishing to commercial fishermen: a 2009 shanpshot of lost revenuew, ecotrust.

Kremen, C., Williams, N. M. and Thorp, R. W. 2002. Crop pollination from native bees at risk from agricultural intensification. *Proc. Natl Acad. Sci. USA* 99: 16812–16816.

Leach, A. and Mumford, J. 2008. Pesticide environmental accounting: a method for assessing the external costs of individual pesticide applications. *Environmental pollution* 151(1): 139-147.

McCarthy, D. P., Donald, P. F., Scharlemann, J. P. W., Buchanan, G. M., Balmford, A., Green, J. M. H., Bennun, L. A., Burgess, N. D., Fishpool, L. D. C., Garnett, S. T., Leonard, D. L., Maloney, R. F., Morling, P., Schaefer H. M., Symes, A., Wiedenfeld, D. A. and Butchart, S. H. M. 2012. Financial Costs of Meeting Global Biodiversity Conservation Targets: Current Spending and Unmet Needs. *Science* 338(6109): 4.

MEA .2005. Millennium Ecosystem Assessment: Ecosystems and Human Well-being: Synthesis. Washington DC, Millennium Ecosystem Assessment.

Ricketts, T. H., Regetz, J., Steffan-Dewenter, I., Cunningham, S. A., Kremen, C., Bogdanski, A., Gemmill-Herren, B., Greenleaf, S. S., Klein, A. M., Mayfield, M. M., Morandin, L. A., Ochieng', A. and Viana, B. F. 2008. Landscape effects on crop pollination services: are there general patterns? *Ecology Letters* 11: 499–515.

Shogren, J. F. .1997. Economics and the Endangered Species Act. *Endangered Species Update* 14(1&2): 2.

Sumalia, R. U. and Suatoni E. 2005. Fish Economics: The Benefits of Rebuilding U.S. Ocean Fish Populations Fisheries Economics Research Unit.

World Bank and Food and Agriculture Organization. 2008. The Sunken Billions. The Economic Justification for Fisheries Reform. Agriculture and Rural Development Department. The World Bank. Washington DC.