Valuing the impact of food:

Towards practical and comparable monetary valuation of food system impacts

A report of the Food System Impact Valuation Initiative (FoodSIVI)

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CASE STUDIES OF FOOD SYSTEM IMPACT VALUATION SUMMARY

Nine monetary food system impact valuation studies conducted by the public and private sector show the variation in practice in footprint, models and data, and valuation methodology. The case studies show precedents for pricing uncertainty.

Overall, the case studies show that impact valuation can highlight social costs and benefits from food system activities which are not considered in the market.

Valuation at global, project, and product scale are covered. The studies are divided into social cost and marginal abatement value. A social cost study estimates the total economic value loss or gain to society due to an issue such as food loss or waste. A marginal abatement value study estimates the abatement of social costs achieved per unit of a product or practice compared to a baseline.

The first three case studies concern global activities. The studies are complex, first order estimates, admitting large errors bars. Costs of the global food system are divided roughly equally between health, environmental and social. External costs from carbon represent one third of the costs from the global food system.

Valuations across case studies are not directly comparable. Even though they have similar impact pathways, they have different boundaries, different models of those pathways, and different choices of footprints. Different valuation factors are used. Confidence intervals for quantity calculations and marginal valuations are estimated in literature sources, but no case study combines them into an uncertainty estimate for the impact valuation. Some of the estimates are based on multi-linear regression with unclear assumption about errors and low fitness statistics, giving low confidence.

Life cycle analysis (LCA) is used in many of the case studies for environmental footprints. Software allows a representation the full impact pathway of a product or practice in LCA, which is standardised at least to structural level in LCA even though individual LCI models are not directly comparable due to different scopes and boundaries. The case studies show that valuation factors implemented in LCA software can be used to monetise impact.

It is argued that even though the marginal abatement value may be high, that does not mean that a sustainable product or practice offering abatement is in demand. Low quantity of uptake of those products or practices means low reduction of food system impact. Total abatement value is of greater concern to government and investors, which requires multiplying marginal abatement value by demand. The market drives demand, so demand for abatement is linked to internalisation.

One of the major uncertainties in demand is whether abatement measures such as dietary changes will be realised. Dietary changes are necessary to reach global footprint targets. It is recommended that demand projection in broad commodity categories be considered in a food system non-financial accounting standard.

Demand projections are illustrated by looking at scenarios for replacing animal protein by plant protein.The uncertainty in forward demand can be part of the risk pricing. If there were a mechanism to internalise the social or abatement costs, then the risk price would reduce with the reduced uncertainty in total abatement meeting food system transformation targets. Risk to society of status quo in unsustainable products would be transferred to venture investment for sustainable alternatives by risk pricing and internalisation.

CONTENTS

CASE STUDIES OF FOOD SYSTEM IMPACT VALUATION

A range of global, project and product valuation studies already conducted by the public and private sector illustrate the components of valuation: footprint, other drivers of capital change, capital change, impacts considered, parity and discounting. In many cases the valuation parameters such as discount rate and parity are contained in valuation factors, obtained from literature or third parties.

The case studies all involve monetised valuation and footprint metrics covering more than one environmental, social or health issue, e.g. not just carbon emissions. Each is published as a peer-reviewed article, a publicly available report, or featured in an annual sustainability report. All the studies use an estimate (not the same one) for the cost of carbon. Human capital changes such as health impacts have limited coverage. Natural capital changes have the most coverage. Comprehensive coverage of impact is an aspiration for true cost and impact valuation studies which, realistically, needs to be driven by further demand from users[1].

The studies are divided into social cost and marginal abatement value. A social cost study estimates the total economic value loss or gain to society due to an issue such as food loss or waste. A marginal abatement value study estimates the abatement of social costs achieved per unit of a product or practice compared to a baseline. That unit might be kg of product, or ha of farmland under alternative practice, compared to the same kg of a baseline product or the same ha farmland under baseline practice. The baseline practice is usually an industry standard practice.

Social cost case studies

The first three case studies concern global activities. Social costs due to environmental and social changes from the inputs, activities, and outputs associated to food lost or wasted per year feature in the first case study. Social costs due to environmental changes from the inputs, activities, and outputs of global poultry, beef and dairy production feature in the second case study. Both studies are complex, first order estimates, admitting large limitations in data and valuation methodology. Each though provide an estimate of the order of the externalised costs of the food system as a whole and their potential distortion of the optimality of the economies in which they occur. These social costs contrast to the second set of marginal abatement value case studies. The latter represent products or practices that could reduce the social cost if the alternative products or practices were substituted for baselines.

The third social cost case study involves a simpler estimation of the social cost associated to combined environmental, social and human health changes caused by the global food system. The first two social cost case studies do not consider human health effects of consumption.

[1] SDSN and BCFN, *Fixing the business of food: the food industry and the SDG challenge*, Barilla Center for Food & Nutrition (Parma, Italy, 2019), https://www.fixing-food.com/media/pdf/Fixing-the-Business-of-Food---Report.pdf.

1: FAO valuation of food loss and waste

A 2014 FAO study valued environmental and social externalities attributed to the production and purchasing of food that is not consumed (food loss and waste)[2]. It noted 2012USD 1 trillion per year of financial losses directly from lost market value of the lost and wasted food, and estimated external costs from the lost and wasted food at 2012USD 700 billion for environmental externalities and 2012USD 900 billion (b) for social externalities per year. In the breakdown of costs per year notable amounts were 2012USD 394b from GHG emissions, and 2012USD 396b and 333b respectively of well-being loss from the contribution to conflict and lost livelihood.

Scope: global food system (geographic/organisational) food loss and waste over one year (temporal), and all inputs-activities-outputs of the full supply chain including disposal (value chain).

The global social cost of food loss and waste is a complex undertaking, and considerable thought was given to boundaries, availability of data and estimates, and relevant pathways of impact. Uncertainty was acknowledged by an order of magnitude calculation. Despite not including several categories of capital change effects which could have increased the social cost, it is hard to determine if the social cost estimates provide a lower bound due to uncertainty in the costs that were included.

Pathways: (see Figures 2-4 of the FAO report) climate change, nutrient pollution, pesticide use and subsequent effects on drinking water quality and biodiversity from growing food not consumed. Land use change was considered for soil erosion and ecosystem loss through deforestation. Water use for irrigation was an additional social stress through water scarcity. Effects on produced and financial capital from input costs not converted into revenue (including water use) along the food value chain. Social and human capital changes (effects of conflict, livelihoods changes, and health effects) factor through environmental changes (climate change, soil degradation, pesticide use) per below.

Models and data: FAOSTAT, AQUASTAT, SOL-m model to allocate global food wastage volume to ha of production per country per commodity, nitrogen and phosphorous application per country per commodity, and GHG emissions. Various estimates of marginal social costs from literature. OECD and WorldBank estimates for country population and income. Discounting of lock-in impacts uncertain in literature estimates, except for the social cost of carbon. The future scenario consideration is implicit in social cost of carbon estimations.

Economies: Measures a mixture of direct economic costs and income of individuals in national economies. Spatial parity is mixed in different components, mostly using benefit transfer.

Valuation method: Linear approximation of the welfare difference between a forecast (using an equilibrium model that can incorporate externalities) of the current global economy measured with present food loss and waste and an optimal economy with an optimal level of food loss and waste. That is, estimation of marginal social cost per footprint metric considered (shadow price or valuation factor) that such a model would calculate, multiplied by the change in quantity of each footprint metric, added together to obtain (total) social cost. Changes in footprint quantities are directly related to changes in the quantities of food lost or wasted (the activities). The linear approximation cannot include non-linear social cost change. Some total cost estimates are used and added to the linear approximation. Care was taken to minimise or acknowledge correlation in the calculation of marginal costs associated to footprint quantities.

Quantities: In practice the optimal level of food loss and waste was set to zero. Using previous FAO estimates on regional food loss and waste per commodity per year, production loss and post-production waste volumes were allocated per country per commodity per year. SOL-m, FAOSTAT, AQUASTAT were used to translate the volume changes to tonnes GHG emissions globally, ha per country and per commodity of production, m^3 of water use for irrigation per country, and ha forests not converted to agriculture production per country. Estimates were also required for tonnes of soil lost from erosion, and units of toxicity exposure from pesticides per country per year.

[2] FAO, *Food wastage footprint: full-cost accounting*, Food and Agriculture Organization of the United Nations (Rome, 2014).

Footprints: The quantity calculation attributed to food loss and waste changes in ha/commodity/country, ha forest/country, m^3 water/country, t soil eroded/country, t CO2-eq. This footprint could be broken down further to kg of nitrogen (N) or phosphorous (P) applied /ha, pesticide applied/ha. Instead kg/ha application of N, P and pesticide was absorbed into the marginal social costs. Since marginal social costs per footprint unit and footprint are multiplied together, and then added, the result is equivalent.

Marginal social costs: Estimation of shadow prices used a mix of valuation techniques, summarised in Table 2 in the FAO report. All monetary values were converted to USD2012. We describe several calculations to illustrate the range.

Carbon: $/t CO2-eq, Stern Review estimate for social cost of carbon which includes: discount rate; IPCC equity weighting between countries experience impacts; and IPCC A2 scenario applied to the PAGE model. The social cost of carbon was the only calculation performed with dependence on the footprint of other sectors.

Ecosystem services: $/ha forest/country from TEEB biodiversity database (ESVD) values for forest that was lost to produce food lost or wasted. Benefit transfer was used to obtain marginal cost for equivalent countries not within the TEEB database.

Biodiversity: biodiversity losses from nutrient pollution /kg N and P applied from a UK study, pesticide from UK and Thailand study. Benefit transferred to other countries and country N and P application /ha used.

Water scarcity: country specific values of social cost from water use due to water scarcity, see next case study.

Social and human capital changes from environmental changes: Well-being valuation. Involved a linear regression of an indicator of well-being against income and environmental changes (factored through health damage, livelihood loss and conflict). Using this linear regression income change and environmental change were substituted to find the amount of percentage income gain that provides the same level of well-being indicator as the environmental change. Income percentage (GDP/capita) regression uses data from the UK, while environmental regression factors through a global well-being survey that has respondents from 55 countries (which were pooled into non-OECD and OECD and then applied to each nation according to whether they were non-OECD or OECD). The marginal social cost was calculated by multiplying the GDP/capita income percentage from a unit change in the environmental factors chosen (soil erosion and pesticide use) by nominal GDP of that nation in USD2012.

The regression coefficients were incredibly small, small R^2, unknown normalcy of errors, and the potential for many correlates of erosion and livelihoods or conflict, indicates large uncertainty between the environmental factors and compensatory income percentage. Multiplying by GDP (of the order $>10^{11}$ for most countries) creates large amplification of that uncertainty.

Total social costs: Global pollinator services were valued at 2012USD 330b from a cited study, and the loss of services attributed to produced food lost or wasted was 8% of that figure. Financial losses included to governments of subsidies given for growing the wasted food.

Private costs: of lost revenue from waste across nations are compared by exchange rates to 2012USD. Production loss and post-production waste volumes are allocated per country per commodity per year and multiplied by country producer prices or trade prices. As noted in the FAO report, the market value of wasted food (the greatest value loss is at consumption, which also has the highest percentage of volume of wasted food in wealthy countries) and losses to governments of subsidies applied to growing additional food, were not reduced by financial gain to producers (many in non-wealthy countries) and the economy they lived in of growing the wasted food. The lost revenue was also not offset by health costs (positive and negative) of the additional food were it to be consumed.

The FAO study uses mostly spatial and contextual marginal social costs for footprints other than emissions, at country level (the basis of FAOSTAT, income and water scarcity data) and in the context of producer and trade prices, and N, P and pesticide applications, per commodity per country.

2: TEEBAgriFood valuation of livestock production

A 2017 study conducted by Wageningen University & Research (WUR), the companies TruCost and TruePrice, and commissioned by TEEB, analysed poultry, beef and dairy production systems for the assessment of the impact of global livestock production systems on human systems and ecosystems[3]. Of the capital changes valued, the study found beef production caused losses from natural capital changes at 2015USD 1.5 trillion, dairy milk 2015USD 0.5 trillion, and poultry 2015USD 0.26 trillion. Poultry's costs post-production would be higher due to a smaller proportion of costs from production (estimated at 78% for beef, 65% for dairy milk and 29% for poultry). Land-use change and GHG emissions were responsible for >84% of the costs for beef and dairy. FAOSTAT estimates the farm-gate value of beef, dairy milk, and poultry products in 2015 at USD2015 0.3, 0.25 and 0.2 trillion resp.

The study has a "top-down" valuation using TruCost's EEIO model and "bottom-up" using True Price's method. The valuations are compared on p. 52 of the WUR report for natural capital changes, system boundaries, and valuation methods. Figures above are from the "top-down" study. We examine it here.

Scope: global poultry beef and dairy production (geographic/organisational) per year (temporal), for inputs-activities-outputs of production (not processing, retail, nor consumption).

The study considered costs and benefits from both natural and produced capital changes. The global social cost of livestock is a complex undertaking, and consideration was given to boundaries and relevant pathways of impact up to the specification of the TruCost model. Uncertainty was not discussed outside of Table 2.3 in the WUR report which indicating ranges for valuation factors across countries.

Pathways: (see Figure 1.2 and Figure 2.2 of the study), from the study p. 41 "Natural capital costs are calculated considering the impacts from the production inputs to the farm gate. Those impacts have been split by supply chain impacts (upstream) and operational impacts (farming)" GHG emissions from energy production and non-energy sources, e.g. methane from livestock and nitrous oxide from soil processes and fertiliser input, for farming activity and upstream supply chain contribute to climate change. Energy use, fertiliser and pesticide application in farming activity and upstream supply chain air pollutants with human health effects. Fertiliser run-off (N and P) pollution of water basins resulting in loss of ecosystem services. Pesticide application creates soil pollution with ecosystem and human health effects. Land use change was considered for ecosystem services loss of ecosystems converted to agricultural land. Water consumption leading to scarcity, human health costs and property value loss.

Benefit of provision of beef, dairy milk and poultry meat for downstream economic activity and human consumption (26% of global human protein consumption and 13% of total calories). Benefit of manure as fertiliser (65% of the total quantity of nitrogen, and 63% of total phosphorus, applied globally in 2000).

Models and data: Used Trucosts' EEIO (Environmentally Extended Input-Output) model based on the US economy. It attaches natural capital valuations to direct operations, in this case farming, and indirect operations, in this case the inputs to farming. Marginal valuations and the determination of quantities ("LCA, international databases, company disclosures", etc.) are different for the direct and indirect component[4]. FAO data used to determine 2015 production quantities per commodity (cattle meat, dairy milk, poultry meat) per country. Future scenario consideration in the valuation is implicit in social cost of carbon. Farming estimates use country specific data where available, and global average where data is incomplete. No distinction within nations of the different externalities produced from different farming production systems. Inputs and the externalities they produce are not disaggregated into origin of production and potential trade from another country.

Economies: Welfare measures a mixture of damage costs from ecosystem services and human health costs to individuals in national economies. Spatial parity is mixed in different components and not fully specified. PPP used to derive global average for inputs.

[3] W. Baltussen et al., *Valuation of livestock eco-agri-food systems: poultry, beef and dairy.*, Wageningen University & Research, Trucost & True Price (Wageningen, 2017).

[4] Details of data and model in TruCost, *Top-down methodology TEEB Animal Husbandry*, TruCost (London, 2016), http://www.teebweb.org/wp-content/uploads/2017/08/Top-down-methodology_TEEB-Animal-Husbandry_v2.pdf.

Valuation method: Estimation of marginal social cost per footprint metric (shadow price or valuation factor), multiplied by the change in quantity of each footprint metric, added together to obtain total social cost. Changes in footprint quantities are related to beef, poultry meat and dairy milk production in 2015 and inputs to that production. Country specific marginal social costs applied to production operation footprint, while global averages applied to input footprint. Discounting of lock-in impacts uncertain in literature estimates, except for the social cost of carbon.

Quantities: FAO data used to determine production quantities per commodity (cattle meat, dairy milk, poultry meat) per country. Country specific "environmental matrix" applied to farming sector per country per models and data above to calculate direct quantities of t GHG emissions t air pollutants, m^3 water consumption, t water pollutants, t soil pollutants, ha land use change, resulting from the production quantities. Inputs from other sectors are calculated differently than the farming sector. Proportion of flow per subsector of the economy into farming production is from the IO model (the proportions are derived from the US economy). Then quantities of emission, pollutants, etc. above are assigned per value of subsector ("environmental intensities"), which is the EE part of the EEIO model. The assignment itself is proprietary information.

Footprints: The quantity calculation attributed to beef, dairy milk and poultry production: t CO2-eq emissions (CO2 CH4 N20), t air pollutants (NH3, SO2, NOx, VOCs, PM10), water consumption m^3, t water pollutants (from fertilizer application), t soil pollutants (from pesticide application) and ha land-use change per country in 2015 from farming and inputs to farming. Separated between farming activity and farming inputs, as the two different footprints are multiplied by different marginal social costs.

Marginal social costs: All monetary values were converted to USD2015. Determination of marginal social costs described in the reference in footnote 4. We describe several calculations to illustrate. The uncertainty in footprint and marginal social costs is unknown as EEIO method proprietary and linear regressions used in valuation unpublished. Uncertainty in land-use the most relevant.

Carbon: $/t CO2-eq, 2015USD 128 social cost of carbon (SCC), using the 95th percentile estimate for a 3% discount rate from the US IWGSCC study distribution of SCC estimates.

Air, soil and water pollutants: Attribution of human health loss from air, water and soil pollutants is obtained in DALYs from specific LCA or literature, then a stated preference study (for air pollution across 9 EU countries) is used to specify a monetary value of a DALY. Attribution of ecosystem loss from air, water and soil pollutants is obtained in proportion of species disappearing (PDF) from LCA databases. Monetary value of PDF determined by a linear regression factoring through NPP, i.e. a regression of value against NPP and then NPP against PDF. Regression tests of fit unreported. Average marginal social cost for 65 pesticides is used as the marginal social cost for pesticide application.

Water quality (eutrophication): Attribution of water quality loss from N and P to effect on waterfront house prices and human health. Treatment costs for safe drinking water direct treatment cost and human health costs of unsafe drinking water in DALYs. Costing of DALYs same as pollutants. Average value used for nitrogen, nitrate, phosphate and phosphorous.

Land-use: $/ha ecosystem loss/country. 10 ecosystems considered, with total loss assumed. Costs sourced from TEEB biodiversity database (ESVD).

Water use and scarcity: Effect of water abstraction on ecosystems using same linear regression method factoring through NPP as per pollutants. Effect of water use on water scarcity from a method in literature in DALYs[5]. The method is based on a calculation which is non-linear in water extraction, quadratic in HDI (larger uncertainty in the relationship between HDI and DALYs for low values of HDI) and linear between DALYs and malnutrition rates with low R^2. Costing of DALYs same as pollutants.

Marginal private benefits: Downstream benefit of provision of beef, dairy milk and poultry meat valued through market prices of commodities (China, US, Brazil prices). Benefit of manure valued through market price of fertiliser with equivalent N provision (requiring data on market prices and literature on equivalence).

[5] S. Pfister, A. Koehler, and S. Hellweg, "Assessing the Environmental Impacts of Freshwater Consumption in LCA," *Environmental Science & Technology* 43, no. 11 (2009), https://doi.org/10.1021/es802423e.

3: FOLU valuation of the global food system

A 2019 Food and Land Use Coalition (FOLU) study valued inefficiencies and environmental and health social costs of the global food system and compared them to an estimate of the market value of the global food system[6]. It estimated 2018USD 1.3 trillion of economic losses directly from inefficiency (fertiliser overapplication and food loss and waste) in 2018, 6.6 trillion in human health costs, 1.5 trillion costs from GHG emission and 1.7 trillion from natural capital costs. In total 2018USD 11.9 trillion of externalised costs and inefficiencies in 2018 versus an estimate of the market value of the global food system of 10 trillion.

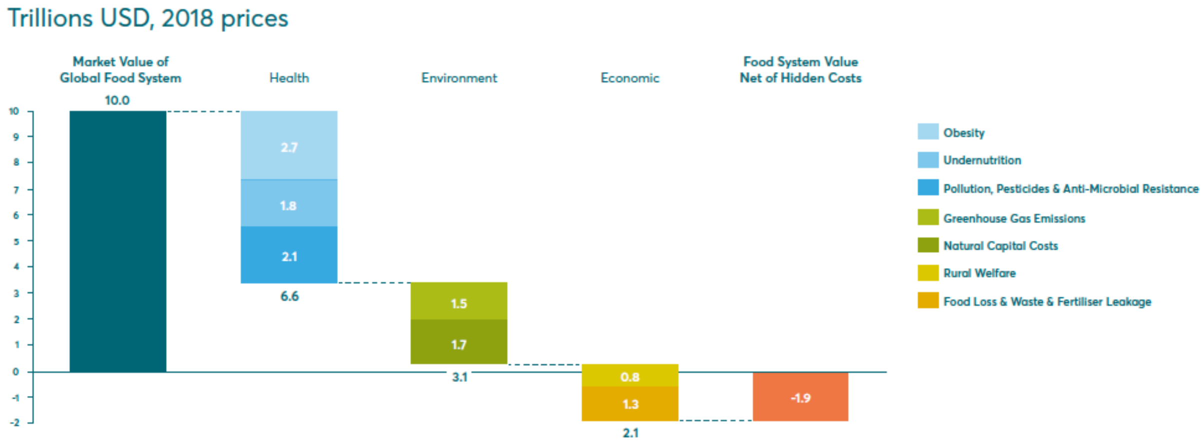

Figure 26: Valuation of the global food system incorporating inefficiencies and environmental and health social costs (Source: Exhibit 2 p. 13 FOLU, *Growing Better: Ten Critical Transitions to Transform Food and Land Use*).

Scope: global food system (geographic/organisational) inefficiencies and environmental and health social costs over one year (temporal), and all inputs-activities-outputs (value chain).

The global social cost of food is a complex undertaking. The “hidden costs” study in the 2019 FOLU report used global averages. The estimates were still broadly in-line with those case studies. Two scenarios were considered into the future, not for the estimation of lock-in impacts, but for comparison of the costs now, and costs in 2030 and 2050 for “Current Trends” and “Better Futures” (described on p. 26 of the FOLU report). Uncertainty acknowledged through order of magnitude estimate.

Pathways: (see Section 2.3 from p. 37 of the FOLU report) malnutrition as overconsumption leading to obesity and under-consumption leading to child growth failure. Air pollution from the production and cooking of food with human health effects. Pesticide exposure pathways of inhalation (workers), soil and drinking water contamination and vegetal consumption with human health effects. Use of antibiotics in production leading to an increase in anti-microbial resistance (AMR) with human health effects. GHG emissions from global food and agricultural system contributing to climate change. Water consumption leading to water scarcity. Agricultural practices resulting in loss of soil biodiversity and soil ecosystem services. Forest and mangrove loss of services from agriculture and aquaculture. Attribution of agriculture to global pollinator losses and exploitation of fisheries leading to lower yields. Low income of agricultural workers leading to rural poverty. Food loss and waste and fertiliser over-application as lost private revenue and cost, respectively.

Models and data: University of Washington Institute for Health Metrics and Evaluation (IMHE) Global Burden of Disease (GBD) database. Literature on DALYs for pesticide exposure. RAND model on lost labour costs factoring through DALYs from AMR. FAOSTAT, AQUASTAT. IIASA’s GLOBIOM model was used to project food production in the future scenarios, and as a data source for regions at risk of water scarcity. GHG emissions from 2019 IPCC report. Estimates from literature, WorldBank, etc.

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[6] FOLU, *Growing Better: Ten Critical Transitions to Transform Food and Land Use, The Global Consultation Report of the Food and Land Use Coalition.*, Food and Land Use Coalition (New York, 2019), https://www.foodandlandusecoalition.org/global-report/.

Scenarios: World Bank "Shockwaves" study and SSP2 used for exogenous setting of IIASA's GLOBIOM model to project production of agricultural commodities, prices, and land-use to 2030 and 2050. With the production projection, the recalculation of footprint quantities from that production can be conducted. Scenarios also set some future marginal social costs (for example the economic measure GDP/capita is a pure exogenous setting as the scenarios set global GDP and population growth).

Economies: Measures a mixture of direct global economic costs and global GDP losses from DALYs. Spatial parity is globally utilitarian, global GDP is calculated by PPP and then global GDP/capita.

Valuation method: See Annex B p. 14 of FOLU Report. Mixture of total social and private costs, marginal social and privates costs multiplied by quantities, and "rural welfare" which can be described as an abatement costing (it only appears to be an financial inefficiency if the social costs of low rural welfare could be internalised and low wages with social costs became more expensive than high wages without). Most of the calculations involve two or three term products following the attribution of quantity change and marginal value of quantity change. See FOLU report for adjustments to the calculations for the "Current Trends" and "Better Futures" scenarios to 2030 and 2050.

Quantities: DALYs attributed to food system through GBD database and literature. t CO2-eq attributed in 2019 IPCC report. Total water use, pesticide application and N and P fertiliser use from FAOSTAT, with percentage of N and P lost from Yara study of leakage. A literature study is used to attribute total ppl in rural poverty employed in agriculture. Literature studies used for ha deforestation and mangrove lost due to agriculture and aquaculture. Attribution of agriculture to degraded land in ha from GLASOD.

Footprints: DALYs (due to high-BMI, child growth failures, air pollution, and pesticide exposure), t Co2eq, m^3 water, ha degraded land, ha forest, ha mangroves, ppl rural population in poverty, t N and P fertilisers.

Marginal social costs: Used a mix of sources, see Table 3, Annex B of FOLU Report. We describe several calculations to illustrate the range. All in 2018USD.

Health: $/DALY is GDP/capita.

Ecosystem services: $/ha forest, $/ha mangrove, $/ha soil from TEEB database (ESVD) and literature.

Water scarcity: $\$/m^3$ TruCost value used, multiplied by 0.25 from GLOBIOM estimate that 25% of all water extracted for agriculture is from a location at risk of water scarcity.

Total social costs: Pollinator and fish yield losses per 2014 FAO Food Loss and Waste study, except that attribution is to total production not lost production. Total lost labour productivity due to AMR from RAND model, and literature source for 22% AMR attributed to global food and land-use system. Eutrophication total cost used from 2014 FAO study above.

Marginal abatement costs: Rural welfare as calculated in the FOLU report is an abatement cost. It is the cost of the global population reaching the World Bank poverty line of $5.50/day rather than a calculation of the social costs of poverty. The assumption is the social costs of poverty would be abated by this level of income. The marginal abatement is calculated at $5.50 x 0.4 x 365.25 /pp rural in poverty/yr (40% is the average rural poverty gap).

Carbon: $/t CO2-eq, USD2018 100 as the average range of marginal abatements costs over 2020-2050 from 2017 Carbon Pricing Leadership Coalition High-Level Panel on Carbon Pricing report[7].

Private costs: (Total) Total production value of food from FAO and that could have been increased by 32% (production inefficiency of food loss and waste). (Marginal) Average price of N and P fertilisers $/t, World Bank, which were then multiplied by footprint of t respective fertiliser wasted (production inefficiency). Average value of production from grassland and pasture (FAOSTAT), multiplied by yield loss fraction from degradation, which was then multiplied by footprints of degraded agricultural land.

The FOLU study uses no spatial and contextual marginal costs and quantities. It had no estimate of uncertainty.

[7] From a submission to the Commission by C. Hood (2017) https://www.carbonpricingleadership.org/report-of-the-highlevel-commission-on-carbon-prices

The case study valuations are not directly comparable. There is no direct way to restrict the global study to livestock or food loss and waste and derive, even by substitution, the result of the first two studies from the third. The restriction of the food waste study to livestock, and restriction of the livestock study to loss and waste, will arrive at different values. Even though they have similar impact pathways and scope, they are different in boundaries, different in terms of the substantiated model of those pathways and allocation of footprint, and different values used for valuation factors. Valuation starts variously at what would be called a pollutant, a midpoint, and an endpoint level in LCA, see the discussion in Food System Impact Valuation in Practice on ambiguity. A short modelling study by experts would be required to compare them.

There are some common quantity estimates and marginal costs used between the studies. Land use by SOL-m and water scarcity from TruCost's adaption of a literature model is common between the TEEB Agrifood and FAO food waste study. LCA (SimaPro agri-footprint and EcoInvent) used for GHG and air pollutants footprints in the FAO and TEEB AgriFood study are shared by corporate marginal abatement valuations below. There are some considerations for *de facto* standardisation of impact valuation through private providers (TruCost features in most commissioned studies so far), which we discuss further in Implications. Comparability is not using the same value, but the ability of the user of the valuation to substitute different sets of values in and out of studies, which means standardising structure of shadow prices and footprint quantities. Quantity calculations do not need to be the same either (EEIO is top-down in the sense of whole industry flows between sectors, where LCA is bottom-up in the sense of reconstructing pathways of impact from activities). Variability in calculations enters into the uncertainty in quantity, and then uncertainty in the full valuation, and can be captured in risk pricing, as long as there is the ability to map the footprints used to those set by the accounting framework or set by the use case.

We have not directly compared studies using EEIO models. A report of the Danish Environmental Protection Agency examined Novo Nordisk's EP&L using EEIO and lists general strengths and weaknesses, with recommendations[8]. There are data sources for input-output with higher resolution than economic sectors[9].

The 2014 FAO study's use of the Stern Review social cost of carbon figure and TruCost's use of the US IWGSCC 95th percentile figure in the 2017 TEEB study for the social cost of carbon are examples of added risk premium. Both values are higher than the median and average value of social cost estimates, acknowledging the uncertainty and the risk it entails[10]. For global decision-making under the uncertainty in climate change, given that climate change is a once-occurring process with high global economic consequences, using the expected or

[8] COWI, *Assessment of potentials and limitations in valuation of externalities*, The Danish Environmental Protection Agency (Copenhagen, 2014).
[9] D. Moran, M. Petersone, and F. Verones, "On the suitability of input–output analysis for calculating product-specific biodiversity footprints," *Ecological Indicators* 60 (2016), https://doi.org/https://doi.org/10.1016/j.ecolind.2015.06.015.
[10] J. C. J. M. van den Bergh and W. J. W. Botzen, "A lower bound to the social cost of CO2 emissions," Perspective, *Nature Climate Change* 4 (2014), https://doi.org/10.1038/nclimate2135; R. S. Pindyck, "The social cost of carbon revisited," *Journal of Environmental Economics and Management* 94 (2019), https://doi.org/https://doi.org/10.1016/j.jeem.2019.02.003; M. Adler et al., "Priority for the worse-off and the social cost of carbon," Article, *Nature Clim. Change* advance online publication (05/22/online 2017), https://doi.org/10.1038/nclimate3298; R. S. J. Tol, "On the Uncertainty About the Total Economic Impact of Climate Change," *Environmental and Resource Economics* 53, no. 1 (2012), https://doi.org/10.1007/s10640-012-9549-3. CPLC, *Report of the High-Level Commission on Carbon Prices*, Carbon Pricing Leadership Coalition (Washington DC, 2017), https://www.carbonpricingleadership.org/report-of-the-highlevel-commission-on-carbon-prices.

average value, which is valid for statistically frequent events with, individually, small global economic consequences (insurance of automobile accidents for example), is inappropriate[11].

The case studies show that there is precedent and acceptance in food system impact valuation of using higher marginal valuations adjusted for risk.

Spatial parity across economies is not overt for any of the case study valuations. Parity is mixed in with valuation factors, so it is difficult to separate out directly equity concerns for social costs and benefits in different economies and non-financial capital flows between economies which may hide substitutions. To test equity concerns, comparable valuations would have the capacity to substitute alternative parities. A similar comment applies to discounting. For the case studies though, the marginal social cost of carbon is the only valuation factor used that admits lock-in impacts. The ability to compare discounting for comparison of the treatment of intergenerational equity reverts, for the case studies, to the ability to compare the different social costs of carbon used. The marginal social costs of carbon used can be swapped in and out of each of the studies easily because it is used as a multiplication factor of carbon footprint. With a caveat, as the FOLU study used an abatement cost for carbon with a target of not exceeding 2 deg C global warming. Abatement costing with this target, that is the cost for the actor to abate the contribution of one tonne of CO2-eq to welfare loss from exceeding 2 degrees, is different than the full social cost of climate change as discussed in Food System Impact Valuation in Practice.

The studies also reveal the complexity of uncertainty estimates. Evidenced, firstly, by the fact that no case study attempted uncertainty estimates, given, in most cases, in confidence intervals on quantity and marginal valuation estimates in the literature sources. Secondly, some of the estimates are based on multi-linear regression with unclear assumption about errors and low fitness statistics, giving low confidence in confidence intervals. A modelling exercise by experts would be required to re-examine the distributions underlying some of the most common shadow prices and quantities; it would be non-trivial (footnote 10 lists selected academic papers for the distribution and risk pricing of the uncertainty in the social cost of carbon).

The 2014 FAO study provided the most acknowledgment on the first order approximation of dynamic modelling of economies inherent in using footprints and marginal valuation factors. The estimate of the financial efficiency loss of food loss and waste as lost value from revenue used in the 2014 FAO study and in the 2019 FOLU study either implies all production loss is pushed into consumption waste, or an increase in food consumption with attendant health costs (positive and negative) of the additional food. An alternative description of efficiency would be to have the same meeting of demand of food products, but, due to reducing food loss and waste, less agricultural supply and even less inputs. Whether this is an efficiency gain, or an internalisation into the supply chain of the social costs of wasted food, depends on estimates of agricultural sector revenues and input costs. It would change the structure and value of agricultural inputs.

We note other social cost case studies: valuation of Irish dairy[12]; a global valuation of crop and livestock production in 2015 (with boundary broader than beef, poultry meat and dairy milk),

[11] Chapter 6, Y. Y. Haimes, *Risk Modelling, Assessment, and Management*, 2nd ed. (Chichester, UK: Wiley, 2004). S. Dietz, "The Treatment of Risk and Uncertainty in the US Social Cost of Carbon for Regulatory Impact Analysis," *Economics* 6, no. 18 (2012).

[12] W. Chen and N. M. Holden, "Bridging environmental and financial cost of dairy production: A case study of Irish agricultural policy," *Science of the Total Environment* 615 (2018), https://doi.org/10.1016/j.scitotenv.2017.09.310.

again by TruCost through a commission from the FAO[13]; the MARCH valuation of global health costs attributed to the food system; and, the Sustainable Food Trust report on the Hidden Costs of UK Food[14]. Chapter 7 of the TEEB AgriFood Scientific and Economic Foundation report provides more examples of case studies at local scales and reduced scopes than the three discussed here, categorised to illustrate a cross-section of individual valuation methodologies (damage costs, revealed preferences, stated preference, etc.).

Marginal abatement case studies

The 2019 FOLU report *Growing Better: Ten Critical Transitions to Transform Food and Land Use, The Global Consultation Report of the Food and Land Use Coalition*, performed the valuation of "hidden costs" (a mixture of social, abatement and private financial costs) in Case Study 3. It also performed abatement costing under "investment requirements" to abate (or save for the already existing abatement costs of rural welfare and carbon, or recover for private costs) to a target that coincides with the "economic prize", that is, the difference between hidden costs in the "Current Trends" scenario and hidden costs in the "Better Futures" scenario in 2030 and 2050 (Figure 27). The "economic prize" is an example of a global impact target, as in the discussion of footprint and impact targets in Food System Impact Valuation in Practice.

Figure 27: Economic prize of the amount of hidden costs that could be saved in the "Better Futures" scenario to 2030 and 2050 in the 2019 FOLU study. Investment requirements were the estimates in the study of the costs to receive the benefit of the economic prize. (Source: Exhibit 1, p. 10, FOLU, *Growing Better: Ten Critical Transitions to Transform Food and Land Use, The Global Consultation Report of the Food and Land Use Coalition, 2019).*

The actions to be invested in, described in Chapter 5 of the 2019 FOLU study, are, roughly, examples of abatement mechanisms. The economic prize is the total abatement value. Some of the investments result in internalisation to the food system of the hidden costs. The business opportunities represent an upper valuation of the financial gains in the transition: some parts of economic sectors will be losing financial value as adapting or new ventures gain financial value through taking up the opportunities.

Following current practice in impact valuation we indicate the marginal abatement value offered by an alternative business product, substituting a supplier, or changing an activity. Here marginal means per unit of quantity. The unit might be kg of product, or ha of farmland

[13] FAO, *Natural Capital Impacts in Agriculture: Supporting Better Business Decision-making*, Food and Agriculture Organization of the United Nations (Rome, 2015). p. 5: "This report assesses impacts from the farm gate back along the upstream supply chain, which includes the production of agricultural inputs such as energy and feed. The natural capital costs associated with crop production in this study represent nearly USD 1.15 trillion, over 170 percent of its production value, whereas livestock production in this study produces natural capital costs of over USD 1.81 trillion, 134 percent of its production value [total livestock]…The highest combined operational and supply chain costs of natural capital impacts in this study have been attributed to beef production in Brazil (USD 596 million) and the USA (USD 280 million), as well as pork production in China (USD 327 million)."

[14] FAO, *Methodology for valuing the Agriculture and the wider food system Related Costs of Health (MARCH)*, Food and Agriculture Organization of the United Nations (Rome, 2017). I. Fitzpatrick and R. Young, *The Hidden Cost of UK Food*, Sustainable Food Trust (Bristol, 2017).

under a management practice. The unit might be per company where society and investors have the choice in substituting market share and financial shares.

Marginal abatement value for the case studies involves the sum of differences in social costs from one unit of the alternative product or practice compared to the baseline product or practice. Multiplied by the quantity of that product or practice the marginal abatement value would indicate the total abatement value of avoided social costs (or saved abatement costs and private costs if the valuation has mixed marginal social and abatement costs). In economics the marginal abatement value means the social benefit from one unit more of substitution of the baseline product or practice by the alternative; as discussed in Food System Impact Valuation in Practice. The next section discusses the demand for abatement products and practices. Summing the different social and abatement costs and the private costs, which, ideally, are specific to region and context, is problematic if some of them are negative. It implies the costs that are positive are substitutable for the costs that are negative. This is discussed further in Implications.

The marginal abatement value is variously called the total value, the total economic value, or the true value per unit of product or practice or company.

In the absence of least cost abatement portfolios for food system footprint reduction targets, another measure of abatement value is considering marginal abatement benefits and marginal abatement costs. Comparing them is social cost-benefit analysis or welfare-based cost benefit analysis[15]. Determining what are costs and what are benefits for society has some ambiguity. Is the production of emissions a cost or a negative benefit from an original activity (was it part of the outlay or part of what was received)? Substituting amounts between benefit and cost because of the ambiguity changes the benefit-cost ratio. The ratio is changed by less if benefits outweigh costs and negative benefits are transferred into positive costs, e.g. emission costs are treated as outlay rather than negative benefit received. The ratio is changed by more if benefits outweigh costs and positive benefits are transferred to negative costs, e.g. payment of a carbon tax from increased revenue is treated as an offset of outlay on emissions. An accounting standard would have to resolve the ambiguity.

A simple measure for value to society is the magnitude of the value of all negative impacts be considered the outlay costs and the magnitude of the value of all positive impacts be considered benefits received. This separation and their comparison in a ratio would avoid assumptions about substitutability in summation of values with different signs.

Marginal abatement value, benefits and costs are relative to value to whom and to a baseline. The case studies chose the perspective of society including the value chain.

To be clear, the following six case studies calculate the reduction in social costs per kg of product, or ha farmland under alternative practice, etc., compared to the same kg of a baseline product or the same ha farmland under baseline practice, etc. The business products or services that offer abatement value, or abatement compared to abatement costs, become attractive ones for procurement, incentives, or investment, for reduction of impact. They will increase in value during internalisation (economic correction sponsored by value correction) versus the baseline. For examples of value corrections to consider, see business value drivers or business implications in the Capital Protocols[16].

[15] M. Adler and E. Posner, "Rethinking Cost-Benefit Analysis," *Yale Law Journal* 109, no. 2 (1999), https://doi.org/10.2307/797489.
[16] p. 14, S&HCC, *Social & Human Capital Protocol*, Social & Human Capital Coalition, World Business Council for Sustainable Development (Geneva, 2019), https://docs.wbcsd.org/2019/02/Social_and_Human_Capital_Protocol.pdf. p.9 NCC, *Natural Capital*

The baseline might be the same company, practice or product at a previous time[17]. In the 2019 FOLU study the baseline is framed by the "Current Trends" scenario and the alternative is framed by the "Better Futures" scenario.

The terms "hidden cost" and "abatement" imply correcting a damaged or less than optimal baseline. Framing effects aside[18], they were chosen given the perspective of this report, which is to identify contributions of comparable impact valuation to food system transformation. The description of "Current Trends" in the FOLU study is not a good position for society. There are many elements of the global food system that are good for society and transformation should be designed to make them even better, so "cost" and "abatement" are not fully accurate. They are used in a net sense. Other framings such as societal value or impact instead of costs, and value creation instead of abatement value, have been used in other contexts. In the scope of food system transformation, what is important is understanding the relationship between social costs in total produced by the food system and abatement measures offered through an economic system as reduction of those social costs.

This section refers to abatement value (change in welfare loss) not cost-effective footprint abatement (change of quantities associated to welfare loss). The two are linked as discussed in Food System Impact Valuation in Practice. A product or practice at the marginal abatement cost offers a quantity of footprint abated per unit of that product or practice. The economic value of that quantity of footprint abated is the abatement value.

Protocol: Food & Beverage Sector Guide, Natural Capital Coalition (London, 2016), https://naturalcapitalcoalition.org/natural-capital-protocol-food-and-beverage-sector-guide/.

[17] p. 30, S. Vionnet and J.-M. Couture, *Measuring Value - Towards New Metrics and Methods*, Quantis and Ageco (Switzerland, 2015).

[18] A. Tversky and D. Kahneman, "The framing of decisions and the psychology of choice," *Science* 211, no. 4481 (1981).

4: Marginal abatement by supplied commodity: Nestlé valuation of reduction in the social cost of palm oil supply[19]

Nestlé collaborates with New Britain Palm Oil Limited (NBPOL) and the Earthworm Foundation on responsible sourcing of palm oil in Papua New Guinea (PNG) and the Solomon Islands. The aim is to deliver on three areas of Nestlé Commitments, which also align with priorities of NBPOL and the Earthworm Foundation: avoiding deforestation, improving the livelihoods of employees, suppliers, and the local communities, and improving Water, Sanitation and Hygiene (WASH) of employees, suppliers, and the local communities. The palm oil is used, among others, in Nestlé Germany for confectionary (KitKat) products, and in the Maggi business.

Using information published by NBPOL in its annual sustainability report 2017[20], the impacts of the interventions on the ground were valued in monetary terms at 2017USD 192 /tonne produced palm oil.

Scope: supply of PNG palm oil commodity (geographic/organisational). Assessment of natural, social and human health capital changes over four years (temporal) including NBPOL operations and upstream suppliers (between 3.5%-32.2% of fruit produced by smallholder farmers across 6 sites) (value chain). The spatial scope of the assessments covers the operating area of NBPOL, that is, 86829ha of palm oil plantations and 9483ha of high carbon stock (HCS) conserved land, mainly in PNG, with less than 10% of operations in the Solomon Islands. No downstream distribution or customer organisations have been included, and the consumer phase has been excluded. The timeframe covers up to the 2017 annual NBPOL sustainability report (data until the end of 2017 with most programs starting data collection in 2013). The impact the NBPOL sustainability programs have been compared to a baseline palm oil production which is assumed to follow only legal minimum requirements.

Nestlé's valuation assessments are still in early stages. Methodologies have been simplified to obtain a first result. No sensitivity or uncertainty assessments have currently been implemented, and future impacts such as ongoing benefits of WASH initiatives have not been discounted – these might be implemented in future versions of the assessment.

Internal use: for NBPOL to better understand the way they do business, for Nestlé to optimize the impacts of Nestlé Responsible Sourcing activities, and for Earthworm Foundation to better understand how to measure the impact of their work on communities.

External use: can enable communication across value chains to emphasize the benefits of responsibly sourced palm oil (e.g. with other suppliers or retailers). Can enable communication teams to tangibly demonstrate the contribution to the total abatement of social costs or the true benefit-cost (to society) of such programs, e.g. with authorities or key opinion leaders.

Pathway of capital change: The study considers changes in natural and human capitals:

- The holding of HCS conserved forest (p. 28 NBPOL SR 2017) allows carbon capture and avoidance of carbon release in forest, and retention of ecosystem services of forests, such as water filtration, biodiversity preservation, medicinal and recreational services, compared to another supplier holding no HCS conserved forest (the legal minimum).
- NPBOL conducts WASH social initiatives (p. 43 NBPOL SR 2017) reducing health impacts from lack of water and occurrence of cases of diarrhoea compared to a legal minimum supplier providing no initiatives. This was converted into human capital gains based on average OECD productivity.
- NPBOL pays a premium for palm fruits from its RSPO certified smallholders and pays employees above minimum wage (p. 44,48 NBPOL SR 2017), which improves livelihoods compared to a legal minimum supplier paying a minimum wage. Using health utility of income, an increase in life expectancy and quality was calculated and converted into human capital using OECD productivity.

Baseline supplied commodity: palm oil from legal minimum equivalent supplier (no conservation land holding, no carbon efficiency efforts, no RSPO premium, no WASH initiatives, PNG minimum wage).

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[19] This case study description was contributed by Urs Schenker, Nestlé.
[20] NBPOL, *Sustainability Report 2016/2017*, New Britain Palm Oil Group (Papua New Guinea, 2017), http://www.nbpol.com.pg/?page_id=231. Nestlé Responsible Sourcing

Models and data: Data published in the 2016/2017 annual sustainability report of NBPOL. Complementary data collected on site where required. Background databases were used to convert inputs (e.g. ha of forest preserved) to outcomes such as DALYs based on scientific literature, the Global Burden of Disease, or existing LCA databases.

Economies: Measures a mixture of direct global economic costs (social cost of carbon) and local welfare changes connecting to the catchments, communities and ecosystems around the NBPOL sites. Spatial parity implicit in social cost of carbon, and average OECD productivity was assumed for all countries to convert increased health into human capital. PPP conversion used for PNG incomes.

Valuation method: Monetary valuations have been developed based on relevant literature, e.g. PwC 2016 methodology in climate change, the OECD average productive value of GDP per hour worked, the Novartis health-utility of income assessment[21]. Given the exploratory nature of this assessment, different valuation techniques have sometimes been mixed.

Quantities: Forest conserved results in avoided carbon emissions of 280000 t CO2-eq per year. This is based on avoiding expanding plantations into high carbon stock (HCS) land. Increased efficiencies on plantations and in mills compared to baseline (reduced fertiliser application, replanted oil palm and mill fuel and electricity) calculated at carbon abatement of 0.4 million t CO2-eq per year. Overall, forest conservation saves 0.68 million t CO2-eq per year. Furthermore, an enclave of 4552 ha for community use results in ecosystem services that have been valued for the community.

Reduction in cases of diarrhoea and outcomes of water availability from pre and post WASH intervention in villages were based on a previous study on benefits of WASH programs worldwide. Total hours of productivity saved equate to the annual labour of 320 people (pp). Reduction of diarrhoea disability-adjusted life years (DALYs) estimated at 9.42 DALYs/yr, which is equated to productivity saved of the annual labour of 9.42 pp. Furthermore, the reduced time to access water is estimated at 383500h for all people covered by water pumps, resulting in a productivity increase of 160pp.

NBPOL SR 2017 pays a premium of 13.7 2017PGK /t FFB. A harvest of 589524 t FFB by 16121 smallholder blocks combined with the premium is the income increase for smallholders. In addition, a similar premium above minimum wage (1.02 2017PGK/h) is paid to employees. Novartis health-utility of income multiplier of 0.86 used for Papua New Guinea (Vionnet & Haut 2018) and PGK converted into 2017USD using a PPP based exchange rate of 0.48 2017USD / 2017PGK.

Footprints: t CO2-eq, ha forest, t FFB smallholder production, # employees, productivity saved (pp)

Marginal social costs: marginal valuations used

Carbon: 2017USD 80 /t CO2-eq from 2016 PwC study

Ecosystem services: 2017USD 5604 ha/yr

Health utility of income: 2017USD 5.66 /t FFB for smallholders, 2017USD 1011 /yr for employees.

Productivity: 2017USD 36955 /pp

Total abatement value: 115 million 2017USD / year for production of crude palm and palm kernel oil based on NPBOL operations in 2016/2017 compared to baseline. Total breaks down into

Natural capital benefits

- Avoided carbon emissions due to HCS preservation: 22.4 million 2017USD per year
- Avoided carbon emissions due to carbon efficiencies: 32 million 2017USD per year
- Retention of ecosystem services in enclave: 25.5 million 2017USD per year

Social and human capital benefits:

- Health impacts and time savings of water pumps provided: 6.3 million 2017USD per year.
- Health utility of increased income: 19.2 million 2017USD per year

Marginal abatement value: Per tonne of palm oil (crude palm oil and palm kernel oil) produced, the sum of natural and social benefits amounts to 192 2017USD/tonne.

[21] S. Vionnet and S. Haut, *Measuring and valuing the Social Impact of Wages - The Living Wages Global Dataset and the Health Utility of Income*, Valuing Nature (Switzerland, 2018), https://88d654fa-5953-4a9f-9041-afc185319bc3.filesusr.com/ugd/fe1a77_ec38381c9f1e4754a2312e157d5b7d58.pdf.

5: Marginal abatement by practice: Syngenta and Multifunctional Field Margins[22]

Syngenta, together with Arcadis and Bioversity International developed a position paper “Multifunctional Field Margins: Assessing the benefits for nature, society and business” to estimate the most important natural and social capital benefits provided to farmers and local communities by Multifunctional Field Margins (MFFMs)[23]. MFFMs are established and managed vegetated strips of marginal farmland alongside field boundaries and waterways[24]. The position paper documents 20 natural capital and environmental benefits, along with 15 social capital benefits. Estimated average monetary benefits of MFFMs varies from 1600 2012USD/ha/yr (for ha of MFFMs with flowers, grasses, and shrubs margins) to 4000 2012USD/ha/yr (for ha of MFFMs with connected tropical forests).

Scope: agricultural land use across 9 projects in 9 countries (geographic/organisational) and natural and social capital changes per year (temporal). The spatial scope covers nine crop-growing MFFMs projects across nine countries (approximately 7929 ha of grassland MFFMs, 414 ha of woodland MFFMs, 4947 ha of tropical forest MFFMs, benefiting as estimated 3.15m ha of farmland): MFFMs for cropland in Germany, UK, USA and Canada, MFFMs in fruit orchards in Belgium and S Korea, MFFMs for rice fields in China; riparian and wildlife corridor in lowlands and woodland MFFM in highland coffee plantation in Columbia; riparian tropical forest MFFMs for land under soy in Brazil. Project level data is collected yearly for ha of farmland implemented and benefitted by the MFFMs projects. Social and upstream economic benefits discussed (Table 3A of the position paper), e.g. MFFMs inputs seeds and training, but no upstream input comparisons with baseline.

The study identified natural and social capital benefits of MFFMs through literature review (70+ scientific papers) and interviews with the 9 projects’ partners and stakeholders, conducted by Arcadis. It matched literature findings and interview results to evaluate and document benefits. A sample of ecosystem services were given a monetary value (USD/ha/yr), based on availability of monetary estimates and commercial relevance. External review by Bioversity International.

Internal use: to inform internal decision-support systems, shape Syngenta’s commercial offering and improve value chain collaboration.

External use: to stimulate discussion amongst farmers, other value chain players and researchers about the benefits of biodiversity and how they can be valued in a simple and compelling manner. Improving measurement and valuation will lead to an understanding of the impact of MFFMs on farming and food production; supporting risk assessment and investment.

Pathways: Natural and social capital changes from improving biodiversity through MFFMs. MFFMs facilitate the movement of seeds and animal species, reduce soil erosion, and attract pollinators and predatory invertebrates as natural pest control that could improve crop yield and/or quality. Qualitative natural and social capital benefits listed in Tables 2 and 3 of the position paper. Six benefits (pollination services, prevented soil erosion, water filtration and retention, recreation & aesthetics, carbon sequestration and climate regulation) were selected for monetisation. MFFMs were categorised with different levels of vegetation (and local ecosystems and climates) into the biomes of grassland, woodland, and tropical forest MFFMs, providing context to impact. Five out of six services were natural, but the natural services result in additional changes to produced and financial capital and social and human capital. These additional links in the pathway beyond the ecosystem services chosen are implicit in the valuation factors used, e.g. from de Groot et al. (2012).

Baseline: ha marginal agricultural land not established as MFFMs. No data on baseline ecosystem services, so no additional benefits were assumed for non-MFFMs practice.

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[22] This case study was contributed by Varun Vats, Syngenta.

[23] Syngenta, Arcadis, and Bioversity International, *‘Multifunctional Field Margins’ Assessing the benefits for nature, society and business; a position paper.* (2018), https://www.syngenta.com/~/media/Files/S/Syngenta/2018/MFFM-Assessing-the-benefits-for-nature-society-and-business.pdf.

[24] N. R. Haddaway et al., "The multifunctional roles of vegetated strips around and within agricultural fields," *Environmental Evidence* 7, no. 1 (2018), https://doi.org/10.1186/s13750-018-0126-2.

Models and data: Data collected on ha with MFFMs in grassland, woodland, and tropical forest biomes for Syngenta by projects. Valuation factors from literature used (see Table 5b of the position paper)

Economies: Measures a mixture of direct global economic costs (carbon sequestration) and local welfare changes connecting to the catchments, communities and ecosystems around the MFFMs sites. Spatial parity implicit in social cost of carbon and global averages from de Groot et al. (2012)[25].

Valuation method: Monetary valuations have been developed based on relevant literature, e.g. IPCC, IPBES, Table 2 de Groot et al. (2012). The values in Table 2 de Groot et al. (2012) are meta-values averaged across studies using different valuation techniques (market, damage costs, stated and revealed preferences, etc.). They use PPP to obtain a global average across the studies then divided by global total ha of biome. MFFMs benefits will be highly variable on geospatial location and MFFMs services are adding on to existing services. Absolute provision of services on agricultural land is reasonable because of the low provision of most intensively farmed land (except for food provision). The intention of global values in the de Groot et al. (2012) was to use benefit transfer to translate to specific sites. Benefit from MFFMs being immediately adjacent to agricultural land is unclear in the figures in de Groot et al. (2012). Assuming for every 3ha of MFFMs 100 ha of agricultural land gets productivity benefits (the average MFFM occupies 3% of the agricultural field) from specific increase in services of water storage, filtration of nutrient run-off, and climate regulation from the proximity of MFFMs, the average economic value of MFFMs /ha may be higher. The position paper called for more research to examine extended benefits.

Table 5C of the report discusses the limitations of the ability assess monetary amounts specific to spatial location and context of the MFFMs. Uncertainty in classifying actual MFFMs into the 3 biomes, and that other benefits and costs in impact pathways were omitted due to uncertainty, was discussed in the limitations.

Quantities: Carbon sequestration /ha calculated by IPCC estimates in sequestration from change in biomass, for forest and woodland 3.29 t/ha/yr of carbon and grassland 5 t/ha/yr (an average for establishing MFFMs and MFFMs being maintained). Multiplied by 3.67 to convert to CO2eq.

Footprints: ha of MFFMs implemented. CO2eq t/ha/yr sequestration.

Marginal social benefits: $/ha/yr from MFFMs. In 2012USD.

Pollination services: 946 average estimated from IPBES assessment report and discounted to 2012.

Soil erosion prevention: de Groot et al. (2012) (Table 2) database global value per biome (Grassland: 44, Woodland: 13, Tropical Forest: 15).

Water filtration and storage: de Groot et al. (2012) (Grassland: 60, Woodland: n/a, Tropical Forest: 27).

Climate regulation: de Groot et al. (2012) (Grassland: 40, Woodland: 7, Tropical Forest: 2044).

Recreation and aesthetics: de Groot et al. (2012) (Grassland: 193, Woodland: 7, Tropical Forest: 867).

Carbon sequestration: 20$/t CO2-eq internal estimate.

Private benefits: (Marginal) Mixed within values from de Groot et al. (2012) (some are direct market pricing), making it difficult to determine value chain benefits downstream and upstream.

Marginal abatement value: Sum of marginal social benefits to obtain approximately 1200 USD/ha/yr (woodland MFFMs), 1600 USD/ha/yr (for MFFMs with flowers, grasses, and shrubs margins) and 4000 USD/ha/yr (with connected tropical forests).

Marginal abatement cost: MFFMs incurs costs to establish and then maintain them. Farmers invests time and capital and lose marginal farmland for production. Proactive and targeted maintenance of MFFMs are required to ensure the expected benefits. For example, for flower margins, farmers need to and invest in the appropriate seed mixtures and the machinery needed to sow it.

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[25] R. de Groot et al., "Global estimates of the value of ecosystems and their services in monetary units," *Ecosystem Services* 1, no. 1 (2012), https://doi.org/10.1016/j.ecoser.2012.07.005.

6: Marginal abatement by intervention: GCC-ER stunting reduction

A 2013 study under the "Grand Challenges Canada Economic Returns to Mitigating Early Life Risks Project" (GCC-ER) outlined the economic rationale for investments in the 1000 days after conception that reduce stunting[26]. 2011 estimates indicate 165 million children in low- and middle-income countries were stunted, the majority in Asia (28% prevalence) and Africa (40% prevalence). The framework of the study provides a conceptual impact pathway from intervention to benefits through each life-stage, and literature review provides attribution data for malnutrition across multiple countries. Wider economic benefits of intervention accruing through life-stages and across the individuals would represent social benefits and abatement of social costs from a counter-factual of no intervention.

Estimates of benefit-cost ratios for a set of nutritional interventions to reduce stunting were derived in the study. Country-specific benefit-cost ratios for investments that reduce stunting in 17 high-burden countries range from 3.6 (DRC) to 48 (Indonesia) with a median value of 18 (Bangladesh) (Table 2 in Hoddinott et al. (2013)).

The monetary value of reduced stunting is pegged to income accrual in the valuation, p. 75, Hoddinott et al. (2013). The framework (Figure 28) and valuation is applicable to GDP/capita accrual from stunting changes in a cohort of children, which can be representative of net welfare improvements in the wider economy (data might be more difficult to find or fit than income data).

Scope: intervention (package of products and practices) to all children in target country (geographic/organisational) with social and human health capital changes over lifetime (temporal), see Figure 28, including social and societal economic interaction, i.e. good and services received by and provided by child through lifetime (value chain). The spatial focus is on high burden countries: DCR, Madagascar, Ethiopia, Uganda, Tanzania, Kenya, Sudan, Nigeria, Yemen, Nepal, Burma, Bangladesh, Pakistan, India, Vietnam, Philippines, Indonesia.

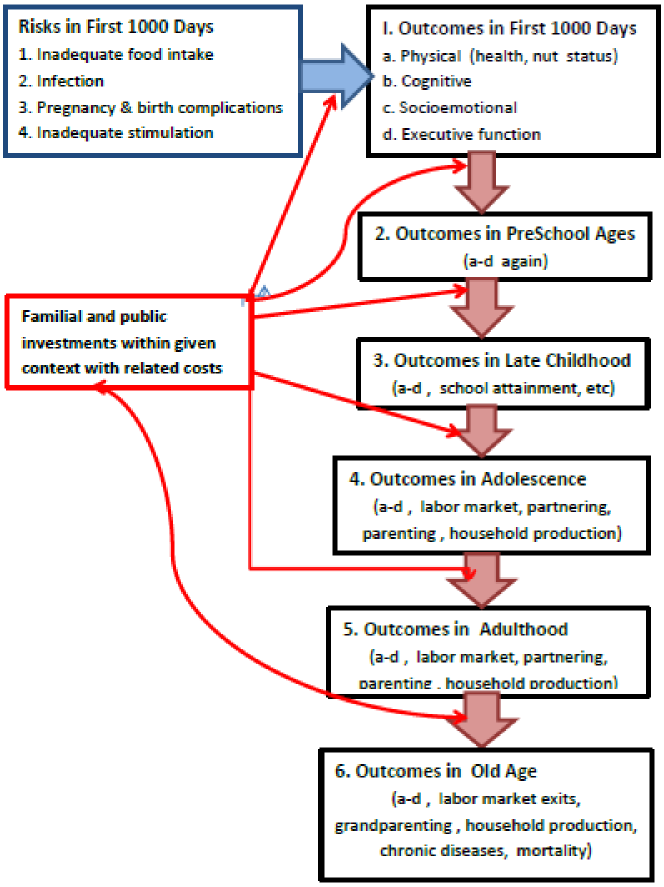


Figure 28: Lifecycle or impact pathway with benefits from later life stages (Source: Hoddinott et al. (2013))

External use: to communicate to development and Finance and Planning officials of high burden countries: "countries that want to generate and sustain broad-based wealth are likely to find that scaling-up these nutritional interventions to be some of the best investments they can make", p. 70, Hoddinott et al. (2013).

Functional relationships in Figure 28 (described in the on-line Appendix of Hoddinott et al. (2013)) represent an attribution process of outcomes at later life-stages to outcomes in the first 1000 days (which are affected by the footprint of the intervention). Valuation of outcomes from life-stages combined with the attribution of the intervention to outcome changes at life-stages are an impact valuation.

[26] J. Hoddinott et al., "The economic rationale for investing in stunting reduction," *Maternal & Child Nutrition* 9, no. S2 (2013), https://doi.org/10.1111/mcn.12080.

Pathways: The study considers changes in social and human capitals. Section 2 of Hoddinott et al. (2013) with evidence from literature in Section 3 describe the attribution of interventions to capital changes. We illustrate by summarising some descriptions from Section 2 and 3. Investments from two sources (familial or private sources such as family-provided food and care and public) can mitigate four risk factors: inadequate food intake in terms of both macro and micro-nutrients; infection; complications during pregnancy and birth and inadequate stimulation and nurturing. Outcomes in the next (preschool) life-cycle stage reflect the outcomes of the first 1000 Days, investments at the preschool life-cycle stage with random or demographic factors such disease and socio-emotional stimulation, complemented by investments in the next preschool life-cycle stage such low public day care services may require parents to spend more resources on private alternatives (substitution). The outcomes of the pre-school ages (stage 2) are produced by the outcomes of the First 1000 Days (stage 1) plus familial and public investments with a random term. And so on to stage 5, where outcomes are featured that are known to predict adult well-being (reflected in income in the study) and private investment in life-stages of children stages 1-4. Literature indicates, for example, positive regression between height and earnings, negative regression between cognitive development and learning and income, positive regression between stunting and chronic disease. Income effects described in Section 4 of Hoddinott et al. (2013).

Baseline: progression of identical cohort through life-stages with no stunting intervention in Stage 1.

Models and data: model developed in study with evidence and data from literature. Evidence from Bhutta et al. (2013) study across 36 countries that stunting reduced by 20% with intervention package with cost estimates[27]. Percentage may change with national factors.

Economies: Private benefits (income accrual) in national economies.

The attribution function based on Figure 28 was not utilised for the valuation in the study. Valuation methods that were applied were simpler.

Valuation method: Assumption of an uplift in income (11%/capita) over lifetime due to the moving a child in a cohort at Stage 1 from a binary state of stunted to not stunted. Derived from a Guatemalan cohort study that an individual stunted in stage 1 was predicted, as an adult, to have 66 percent lower per capita consumption. From studies mentioned the intervention package is attributed to a 20% change in the cohort from stunted to not stunted. Assuming only 90% of income gains (as consumption increase) are realised, 0.9x0.66x0.2 is approximated to 0.11 or 11%. Income benefits accruing through lifetime are discounted at 5% to the time of intervention.

Intergenerational effects would be represented in the dynamic process of the attribution function where adult outcomes (Stage 5) influence Stage 1 outcomes of the next generation.

Assumes that those households where stunting is prevalent (typically poor households) can accrue mean income benefits. This may not be true for high income inequality (study excluded Guatemala).

Uncertainty represented in a sensitivity analysis of benefit-cost ratio to a range of assumptions on discount rate (value accrual of the wider economy) and income growth from removal of stunting (Table 3 in Hoddinott et al. (2013)).

Quantities: Income growth rate applied to predicted per capita incomes of 2015 cohort of children per country.

Footprints: children in 2015 cohort/country

Marginal abatement value: Private benefit of 11% increase in predicted per capita income per country discounted to 2015 multiplied by proportion of stunted children in 2015 cohort/country.

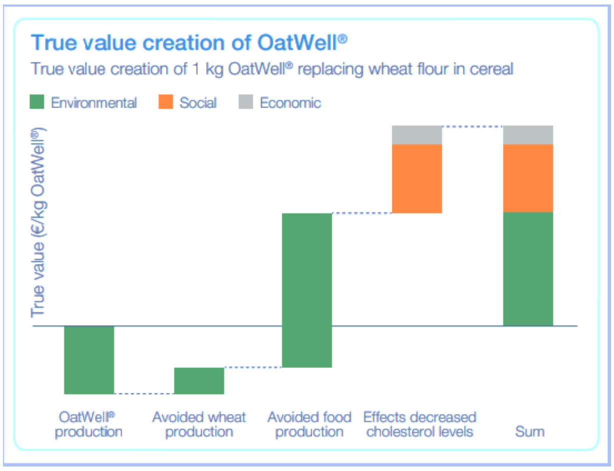
Marginal abatement cost: Table 1 in Hoddinott et al. (2013), purchasing cost of package/child.

Hoddinott et al. (2013), though discussing private benefits, provides a framework of valuation and attribution that can generalise to social benefit-cost.

[27] Z. A. Bhutta et al., "Evidence-based interventions for improvement of maternal and child nutrition: what can be done and at what cost?," *The Lancet* 382, no. 9890 (2013), https://doi.org/10.1016/S0140-6736(13)60996-4.

7: Marginal abatement by product: DSM and OatWell®[28]

DSM carried out a pilot of monetising the natural and human capital value of OatWell® replacing an equivalent kg of consumed wheat. OatWell® can replace wheat in food products such as bread, biscuit, and cereals.



The study valued the natural capital costs of production of OatWell® and natural and human capital benefits compared to an equivalent kg of consumed wheat. The results indicated that OatWell® incurred more natural capital costs in production than wheat, but this was offset by the consumption benefits of OatWell® being more filling (less consumption of other food products) and having additional health benefits to wheat consumption. The valuation showed a marginal abatement value of 75 2015€ in natural capital costs and 8 2015€ in human capital per yr per kg.

Natural capital benefits and costs and the health benefits were valued in separate studies. True Price conducted environmental costings initially, but for the purpose of later discussion we report on the application of CE Delft pricing attached to SimaPro. Health valuation conducted internally by DSM.

Scope: DSM food product (organisational) natural and human capital changes over lifecycle of production and health effects after 10 years of consumption (temporal) including upstream (ingredients), manufacturing, and downstream consumption (value chain) per kg product. The OatWell® product is sourced in North Europe, manufactured in Sweden and consumed across Europe. Health impacts incurred across Europe. Livelihood benefits from value-add of OatWell® predominately in Sweden. Environmental impacts incurred where OatWell® ingredients are produced and abated where replaced wheat and food not consumed due to satiation are produced (spatial).

The location of environmental costs is known from DSM's LCA production and sourcing data. This translates to less uncertainty in the natural capital costs of OatWell® production from the potential (through LCA and depending on the quality of the databases) to be spatially and contextually specific. Where abatement of natural capital costs of the replaced wheat and the avoided food consumption is occurring is uncertain (the latter depending on the diet of OatWell® end-consumers). Global figures are appropriate to use but uncertainty in the marginal abatement value is present due to uncertainty in the baseline (which translates to the marginal abatement value which is a difference).

Internal use: explore valuation to identify and pursue market segments that have the most direct value creation and commercial success for specific products. Compare natural and social valuation approaches independently by different groups to gain alternative perspectives.

External use: DSM Integrated Annual Report 2015, p. 70.

Pathways: The study considers changes in natural capital and human capitals. Effects are detailed in the LCA analysis and CE Delft environmental prices[29]. LCA attributed OatWell® production to approximately midpoint quantities in the ReCiPe conceptual model, and CE Delft valuation factors are applied to midpoint quantities in C02-eq, land use, water eutrophication, air pollution, human toxicity (pesticide), and acidification (damage to ecosystems). Research suggests that OatWell® helps lower cholesterol levels, control blood glucose and increase satiation[30]. Health effects of lower cholesterol

[28] This case study description was contributed by Henk Bosch, DSM.
[29] Detailed description of impact pathways in Section 5 and 6 of S. de Bruyn et al., *Environmental Prices Handbook EU28 Version*, CE Delft (Delft, The Netherlands, 2018), https://www.cedelft.eu/en/publications/2113/envionmental-prices-handbook-2017.
[30] R. Barone Lumaga et al., "Sugar and dietary fibre composition influence, by different hormonal response, the satiating capacity of a fruit-based and a beta-glucan-enriched beverage," *Food Funct* 3, no. 1 (2012), https://doi.org/10.1039/c1fo10065c.

were valued in the study. Increased satiation effect modelled by food not consumed.

Baseline: OatWell® replacing an equivalent kg of consumed wheat after 10 years of consumption.

Models and data: LCA model built in DSM LCA software (SimaPro) with environmental data in LCA databases (e.g. oat production and replaced wheat from Danish LCA Food database). Percentage replacement of a specific average diet of other foods due to satiation from literature. The replaced diet was assumed to be 30% bread, 40% potatoes, 20% ham and 10% spinach as percentages of average 2200 kcal intake. EcoInvent and Danish Food LCA database were used for attributing replaced diet footprints and cooking energy to midpoints units. DALYs for cardiovascular disease (CVD) sourced from WHO. Change in CVD DALYs attributed to consumption of the beta-glucans in OatWell® sourced from EFSA. DALYs value from Dutch sources (RIVM).

The CE Delft EU-28 handbook adapts the EU funded NEEDS model of impact pathways to calculate shadow prices[31]. Detailed model of European emission sites, atmospheric dispersal across Europe, dispersion to receptor sites where a receptor (human or ecosystem) receives a dose. Models associate the dose to an impact (such as mortality or ecosystem service loss) and a monetary value (years of lost life calculated by stated preference or other methods and valuation of ecosystem changes through PDF fraction mentioned earlier, see p. 70 of the CE Delft Handbook). It also includes pricing of air pollution damage to crops. 20 years of EU funded projects underly the pricing mechanism for the EU, and the costing is highly specific to population, ecosystem and crop distributions in the EU.

Economies: Measures a mixture of direct global costs (carbon) and EU environmental costs in €. US diet study results assumed for EU consumers of OatWell®. EU environmental costs are used for source environmental costs where wheat and replaced food were produced (which equates to a parity choice).

Valuation method: LCA software (SimaPro) calculates environmental footprints /kg of OatWell® product against the equivalent wheat. The footprint is multiplied by the marginal valuation factors from CE Delft handbook EU-28. Discounting uses the ReCiPe characterisation (CE Delft handbook Appendix A), which, except for carbon costing, is a mix of non-discounted 20-year span of damage and non-discounted 100-year span (land-use) The characterisation also increases or decreases scope in some impact pathways. For carbon a discount rate of 3.5% is used[32]. For the health study the health valuation estimated the reduction of direct treatment costs attributed to consumption (for constipation) and change in CVD DALYs attributed to OatWell® multiplied by DALYs monetary value.

CE Delft presents prices at three levels, which equate to LCA inventory, midpoint and endpoint levels. Weighting factors derived for the EU from ReCiPe are used to create consistency between the environmental prices at inventory, midpoint and endpoint levels (see discussion of ambiguity p. 96). Combining the individual impact pathway models used in the CE Delft handbook and ReCiPe weights associates footprint quantities to multiple mid-points which are then valued.

Quantities: calculated within LCA and per data above.

Footprints: see for example Table 2.2 in ReCiPe 2013 report or Table A.4 in CE Delft handbook.

Marginal social costs: See CE Delft environmental prices for other environmental prices.

Carbon: EU-28 version uses lower, central, and upper marginal abatement costs of t CO2eq based on Dutch and European emissions targets. The central value of 57 2015€/t assumes costs for efficient reduction path of 40% reduction target in 2030 and 65% in 2050. It includes 18% VAT.

Health: 75000 2015€/DALY average of values from RIVM. Health care cost reduction.

Marginal abatement value: Sum of marginal social costs times footprint from one kg of OatWell®, marginal social benefits from replaced wheat and avoided food consumption. Health benefits and avoided health costs added.

The OatWell® study uses EU environmental prices, spatial and contextual health costs, and some contextual quantities.

[31] Appendix B, de Bruyn et al., *Environmental Prices Handbook EU28 Version*.
[32] R. Aalbers, G. Renes, and G. Romijn, *WLO-klimaatscenario's en de waardering van CO2-uitstoot in MKBA's*, Centraal Planbureau (CPB), Planbureau voor de Leefomgeving (PBL) (Den Haag, 2016).

8: Marginal abatement by product: Evonik Feed Supplement[33]

The product line Animal Nutrition of Evonik Nutrition & Care GmbH produces essential amino acids for feed additives for dairy cows, poultry, swine and aquaculture. The technically produced amino acids DL-methionine (MetAMINO®), L-lysine (Biolys®), L-threonine (ThreAMINO®), L-tryptophan (TrypAMINO®), and L-valine (ValAMINO®) are identical to those from corn, wheat or soy. Supplementing feed with amino acids enables reduced use of plant based proteins (soy, rapeseed meal, etc.) in feed, combined with significant reduction of nitrogen emissions from manure and water consumption.

The environmental impact of the production of 1 tonne live weight (LW) broiler (chicken meat) with (AA suppl.) and without (no AA) supplementation[34] was monetised. Four impact categories known to relate to agriculture and livestock were chosen as focus categories: Global Warming Potential (GWP), Acidification Potential (AP), Eutrophication Potential (EP), and Land Use. Environmental impacts related to 1 tonne of LW broiler without supplement are higher across all impact categories relating to the cost decreases in the impact valuation (Figure 29). The marginal abatement value per 1 tonne LW broiler of supplement is USD2014 188 (519 environmental costs without supplement versus 331 with). The main reason for the decrease is a lower use of plant-based protein in feed like soybean meal and a higher feed conversion ratio. The main difference comes from the GWP and EP categories.

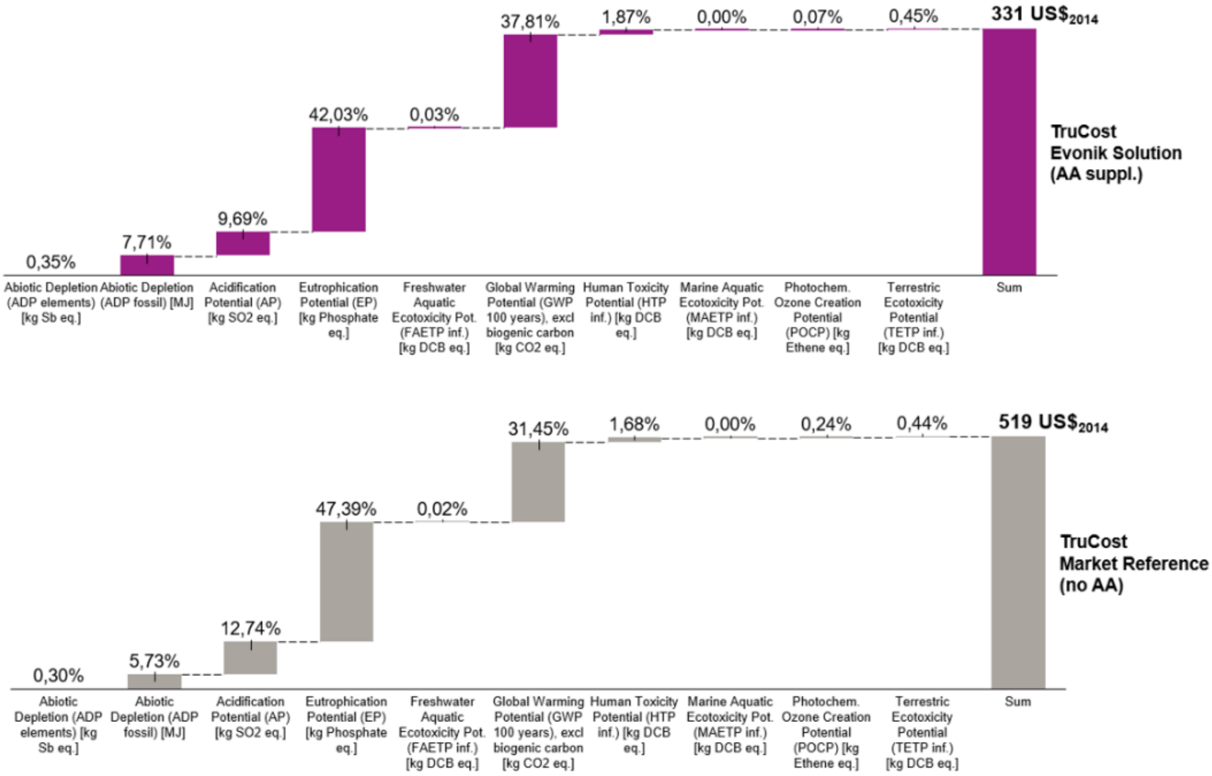


Figure 29: Lower marginal environmental costs 1 tonne LW broiler produced with supplement

Land Use outside of contribution to emissions could not be valued due to lack of implementation in GaBi LCA software.

Scope: Evonik feed supplement (organisational) abatement of natural capital costs over lifecycle (temporal) of the production of 1 tonne of chicken live weight at farm gate in Germany. Including displacement in upstream raw materials, amino acid manufacturing Europe and USA, feed manufacturing and chicken production (Germany). Slaughtering, retailing, and impacts associated to

[33] This case study description was co-authored with Dr. Michael Binder and Aurélie Wojciechowski, Evonik Nutrition & Care GmbH.

[34] E. Kebreab et al., "Environmental impact of using specialty feed ingredients in swine and poultry production: A life cycle assessment1," *Journal of Animal Science* 94, no. 6 (2016), https://doi.org/10.2527/jas.2015-9036.

meat consumption (downstream) have not been included in this study. Raw materials are produced across Europe and North and South America, with capital changes and abated capital changes in those locations (geographic).

Internal use: portfolio steering and internal strategic decision-making.

External use: external communication along the value chain and setting standards for industry associations.

Pathways: Pathways are detailed in the publication Kebreab et al (2016) up to impact categories (midpoint) and in TruCost environmental prices[35] from midpoint to natural and human capital changes. Evonik's LCA attributed production with and without supplements to approximately midpoint quantities, or impact categories, in the CML LCA method (CML 2013) with an emphasis on GWP, including emissions from Land Use Change, AP, EP[36]. With supplement pathway involves additional production and transport (of amino acids and feed), which is offset by displacement of without supplement feed ingredients and requiring less feed. Additional benefit included is credit for manure storage and application with reduced N and P leakage subtracted by costs of manure application.

Baseline supplied commodity: 1 tonne LW broiler (chicken meat) without supplementation.

Models and data: Environmental data collected in Evonik LCA software (GaBi) using Kebreab et al (2016) description of production. GaBi database, supplemental LCA databases and literature estimates for aspects of amino acid production and feed preparation were used to populate the LCA model. Uncertainty from footprint to CML midpoints acknowledged in original study with geospatial variation through 3 scenarios in different markets (US, Brazil, EU). Manure credits and application based on IPCC and literature. For the valuation study LCA data used with geographic specification as follows: Corn grains (European average); Winter wheat grains (Germany); Rapeseed meal (European average); Rapeseed oil (European average); Mono calcium phosphate (European average); Salt (European average); Limestone flour (Germany); Methionine (Belgium); Threonine (Hungary); Soda (European average); Soy bean meal (Brazil); Lysine (USA).

Valuation method: LCA software (GaBI) calculates difference in environmental footprints per 1 tonne of LW broiler with and without supplement. The footprint is multiplied by TruCost valuation factors implemented in GaBI are global weighted averages. Uncertainty in valuation as per description of TruCost valuation factors in the TEEB AgriFood livestock study.

Economies: Measures a mixture of direct global costs (carbon) and global weighted averages in USD 2014. Country specific environmental costs that are calculated by TruCost by benefit transfer by adjusting parameters are turned into a weighted averages by PPP GDP.

Quantities: calculated within Evonik LCA and per data above. Double counting removed for manure displacing conventional N and P application. Land use change assessed in LCA using ReCiPe 2016 midpoint.calculation, others are CML impact categories.

Footprints: for the four focus categories (GW, AP, EP, LUC): 2683 (AA suppl.) versus 4887 (no AA) kg CO2eq/t LW; 32 (AA suppl.) versus 65 (no AA) kg SO2eq/t LW; 14 (AA suppl.) versus 26 (no AA) kg Peq/t LW; 3894 (AA suppl.) versus 5693 (no AA) crop eq/y/t LW.

Marginal social costs: See TruCost marginal social costs estimates in TEEB AgriFood livestock study.

Carbon: TruCost uses US IWGSCC 95th percentile social cost of carbon estimate with 3% discounting.

Marginal abatement value: USD2014 188 per 1 tonne chicken LW.

Evonik feed additives replace oil seeds and this replacement is cost neutral when the feed miller runs properly calculated feed formulations. The Evonik study uses global marginal environmental costs and some contextual quantities (3 scenarios). As per DSM study uncertainty in baseline because of uncertainty in origin of displaced feed products.

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[35] TruCost, *TruCost's Valuation Methodology*, TruCost (2015), https://www.gabi-software.com/fileadmin/GaBi_Databases/Thinkstep_Trucost_NCA_factors_methodology_report.pdf.
[36] J. B. Guinée, *Handbook on life cycle assessment: operational guide to the ISO standards* (Dordrecht; Boston: Kluwer Academic Publishers, 2002).

9: Marginal abatement by project: Social Return on Investment Farmer-Managed Natural Regeneration Project, Ghana

World Vision Australia piloted a social return on investment (SROI) approach to the Talensi Farmer-Managed Natural Regeneration (FMNR) Project[37]. From the report p. 22. "FMNR is often promoted for its ability to provide rural communities with timber and improve arable soils. In this study, FMNR's contribution to livestock health, psychosocial wellbeing and household access to "wild" consumables such as indigenous fruits, traditional remedies, bush meat and construction materials (thatching and rafters) also created significant value. Yet, because these benefits are not easily measured in economic terms, they may have been invisible or under-valued in previous studies of FMNR compared to more tangible outcomes such as provision of firewood, soil improvement and crop protection."

Adapted from the 2013 report p. 4: for World Vision's investment of funds, staff and technical input investment of 2012US$323,816, the estimated value created by the project between 2009 and 2016 is estimated at 2012US$5,500,000, with a SROI ratio of 6:1 by year three (end of the project) and 17:1 by 2016. Sensitivity analysis was conducted in the study to examine the uncertainty in the SROI ratios.

Scope: World Vision project to rebuild household resilience amongst subsistence farming communities in Talensi District in the Upper East Region Ghana (geographic/organisational) natural, social and human health capital changes over 3 years of project and benefits projected to 7 years (temporal) with externalities (value chain). The project focused on benefits and costs to nine communities in Talensi containing a population of approximately 12,000 people in 1,472 households.

Internal use: an evaluation approach for World Vision projects.

External use: communication on return on investment to funders.

Pathways: The study considers changes in natural capital leading to value creation for produced, social and human capitals. To reverse deterioration of soil fertility and the natural resource base, the project focused on restoring multipurpose indigenous trees to farmland and community managed forests. Mainly benefits associated to livelihoods with some human health benefits. Income effects included: savings from food purchases, revenue from wild resources to sell, increased productivity of livestock and crops. Health effects: fuel-efficient stoves and additional quantity and diversity of food. Human & social benefits: enhanced status and community participation of farmers, especially women.

Figure 30: Project site (Source: Weston (2013)).

The only natural capital change valued by itself was carbon sequestration, which came from tree stocks in FMNR forest sites that were not harvested or used for burning. Increased natural capital stock (tree stocks in FMNR forest sites), was valued for addition to farmer and community resilience through the surveys. Seeing benefits at the initial investment sites (n=180), neighbouring households (n=1292), assumed to also be baseline, voluntarily adopted FMNR practices.

Duration of benefits were assumed to occur for six years (the last two of the project and then four years subsequently). See drop-off rate in uncertainty considerations below. Costs were considered as time spent on FMNR management versus and externalities of the project itself, and what that time would have produced social or economic benefit in the baseline. Attribution of changes to the project were

[37] P. Weston, Food Security and Climate Change Team World Vision Australia, and R. Hong, *Talensi Farmer-Managed Natural Regeneration Project, Ghana: Social Return on Investment Report*, World Vision Australia (2013), http://fmnrhub.com.au/wp-content/uploads/2013/10/SROI-Report_Low-Resolution.pdf.

also considered; some communities had other land management practices in place that may have contributed to observed benefits.

Baseline: Talensi District household in a community without FMNR practices.

Models and data: Quantitative household survey (n=104 investment households, n=154 neighbours, n=142 baseline). Annual surveillance of FMNR forest sites.

Economies: Measures a mixture of direct global economic costs (social cost of carbon) and local welfare changes to the communities with intervention households. Localised project with no assumed effects outside Talensi District beside carbon sequestration. 8.9% discount rate used (Ghana's inflation and projected inflation at time of study), the justification of which is described, p. 13 "Given the week-to-week and year-to-year subsistence needs of households in northern Ghana, this high rate is a fair reflection of farmers' need to prioritise short-term results over long-term benefits."

Valuation method: Private benefits (wild resources for sale or exchange, etc.) were directly estimated from data collected at project site. Stated preference and revealed preference valuations turned the household surveys into monetary values. Monetary valuations reported as totals in report.

Uncertainty in benefits were considered in the report. The social cost benefit-ratio is sensitive to drop-off rates (households reverting to baseline practices), change in prices for resources benefitting from FMNR (particularly wood and livestock prices), and attribution to FMNR. Current condition of the subsistence farmers was mostly known, so the baseline had less uncertainty in quantities and the benefits more uncertainty. The results were also sensitive to the voluntary adoption by surrounding households, which, because of the short time scale, is partly included in drop-off rates.

Footprints: n/a as totals estimated in report and valuation results of survey not published.

Social benefits:

Health: 2012US$ 250k (5% of total benefits)

Social and Human outside Health: 2012US$ 430k (8% of total benefits)

Carbon sequestration: 2012US$ 600k (5% of total benefits)

Tree stock (community): 2012US$ 6.5m (56% of total benefits)

Private benefits:

Income benefits (households in community): 2012US$ 1.4m (26% of total benefits)

A breakdown of benefits shows that the different household and community valuations place the greatest proportion of value increase in assets in the form of trees and livestock. There is some trade-off between carbon sequestration, the livestock value and the community asset of tree stocks (56% of total benefits), if those community assets represent an economic buffer of wood that can be harvested and sold. Some of the trade-off is avoided in the short time scale of benefits; if the livestock value is received within the 7 years and the economic buffer of tree stock were utilised after the 7 years. Selling the trees though, especially for uses which release the sequestered carbon, creates trade-off between sequestration value and the market value of the tree stock. Psycho-social benefits of the existence of the buffer up until the buffer is utilised are not in trade-off. The low carbon cost used (it is unclear if 2012US$ 12 /t C or 12 /t CO2-eq is assumed) means that potential double counting amounts to little change. A carbon cost as used in other case studies (around 2012$ 120 /t CO2-eq for example) would value carbon sequestration equal to the economic asset of tree stock. Despite the equal value on paper, without an internalisation mechanism for the community to be rewarded for that sequestration it is unlikely that the sequestration and the market value of tree stock are substitutable.

Total abatement value: the intervention occurred in 180 households and the estimate of financial, social and human value produced was 2012US$ 5.5 million.

Marginal abatement value: Value produced by project 2012US$ 30555 /household.

Marginal abatement cost: Actual cost of project 2012US$ 323,816 with 2012US$ 90,871 in-kind contributed by community. Which averages to 2012US$ 2304 /household.

The marginal abatement valuations are not directly comparable as they use product or practices that are not direct substitutes for each other, e.g. tonnes of livestock production versus packages of nutrition interventions. The context of the user determines their substitutability. A procurer clearly wants similar physical properties for the supply chain (for example substituting feed with supplemented feed). A subsistence community in Africa will not substitute unrewarded carbon sequestration in a community landscape for the financial value of selling the wood if financially stressed. An impact investor or government looking to substitute and aggregate into a portfolio at company, project or sector level will consider products (shares, commodities, etc.) and practices substitutable up to very broad economic parameters such as total abatement value and total abatement cost.

From the societal perspective of a sustainable global food system, marginal abatement opportunities need to be compared to understand the contribution of the abatement that the product or practice offers to total social costs.

The marginal abatement value can be compared by other units or other denominators than the marginal abatement cost when the products or practices share common quantities. For example, comparing livestock products on a marginal abatement value per kg protein basis[38].

Assuming a context where marginal abatement products or practice are substitutable then the comments on comparability from the social cost case studies apply. Footprints are associated to quantities in different parts of the impact pathway, and different valuation factors used. Comparison of marginal abatement value would require deconstruction into a comparable footprint and the application of comparable marginal social and private costs (in the footprint units). Examining the case studies, positive contributions compared to baselines are not across the same categories of benefit. It is also unclear, without reading into the detail of the individual studies, if negative effects from substitution were disclosed. A rationale is required why the product or practice was approximately equivalent (no economic value difference) to the baseline in other categories of impact. Incomparability and inclusion or exclusion of benefits and costs are standard issues raised in a large literature on cost-benefit analysis[39].

Understanding if the marginal abatements complement each other or displace each other at scale is also difficult as there are no formalisation and harmonization of pathways of impact.

LCA is highly developed for environmental sources of capital change and several endpoints that influence welfare (human health, species loss and resource depletion). An LCA calculates the inventory (LCI) for a product or practice (a functional unit) against a baseline. LCA has several standard methods and aspects such as midpoint impact categories that could also represent components of a standardised footprint for food system impact valuation. Valuation factors such as CE Delft environmental prices act on LCA inventories or midpoints.

In practice the inventory or midpoints are not spatially or contextually specific, but it is possible in terms of the LCI flow model. The limitation is the LCI data which may not be available for a context or spatial category at the resolution discussed in Food System Impact Valuation in Practice[40]. LCI models represent the calculation from the functional unit (the product or practice displacing a baseline) to an inventory, then LCIA (CML or ReCiPe) calculates from

[38] The TEEB AgriFood Case Study on livestock introduces the term “natural capital intensity” for natural capital cost per kg of protein across beef, dairy milk and poultry meat, p. 18 Baltussen et al., *Valuation of livestock eco-agri-food systems: poultry, beef and dairy.*

[39] R. Frank, "Why is cost-benefit analysis so controversial?," *Journal of Legal Studies* 29, no. 2 (2000).

[40] C.-K. Rebecca et al., "Life cycle assessment needs predictive spatial modelling for biodiversity and ecosystem services," *Nature Communications* 8 (2017), https://doi.org/10.1038/ncomms15065. Land Use: B. Vidal Legaz et al., "Soil quality, properties, and functions in life cycle assessment: an evaluation of models," *Journal of Cleaner Production* 140, no. P2 (2017), https://doi.org/10.1016/j.jclepro.2016.05.077.

that inventory to midpoints or endpoints. CE Delft valuation factors have the capacity to calculate from inventory, midpoints, or endpoints to monetised values. This chain represents the full impact pathway of a product or practice in LCA, which is standardised at least to structural level even though individual LCI models are not directly comparable (different scopes and boundaries). TruCost valuation factors implemented in GaBi software calculate from CML impact categories, essentially equivalent to ReCiPe midpoints, to monetised values[41].

Development of a food systems accounting framework would determine a footprint that should be interoperable in the environmental categories of LCI with inventory or midpoint levels. The LCI flow model calculating the inventory would then be within the "calculating the footprint" scope of valuation in the accounting framework, and part of the concern of business disclosure rather than attribution of footprint to capital changes and valuation of capital changes. Standardising disclosure of how business operations are associated to footprint using LCI models would be challenging without standardising LCI models of priority interventions for food system transformation. An accounting framework should be, through methods in data science such as ontologies, interoperable with standards in LCA.

On treatment of uncertainty, sensitivity analysis as seen in several of the marginal abatement value case studies is per case and not standardised. It is unclear how to aggregate the results of robustness derived from sensitivity analysis or compare the uncertainty between two valuations with only sensitivity analysis in the individual studies. Whereas it is well established how to add, subtract, multiply and divide not necessarily independent uncertain marginal abatement values and costs when represented by random variables.

The 2018 CE Delft environmental prices EU-28 handbook briefly addresses uncertainty in Annex C.2. It was considered in the underlying 2008 NEEDS models. The EU NEEDS project introduced a reasonable use of lognormal approximation for the value distribution for the same reasons as explained in Food System Impact Valuation in Practice, essentially the multiplicative nature of first order approximation where footprint, attribution of footprint to changes and valuation of capital changes are a conditional sequence. The lognormal distribution is the limit distribution for products of random variables like the normal distribution is the limit distribution for sums of random variables. NEEDS analysed the uncertainty in pricing from data and provided an application where the standard deviation could be applied for the uncertainty in benefit transfer of the EU valuations to a non-EU country. The valuation was increased during benefit transfer because of the uncertainty in whether the EU models of impact applied. This is a precedent of using risk pricing.

A centrality argument was made in the CE Delft handbook. That is, if the environmental cost per unit of pollution is incurred frequently and the variation underlying the valuation uncertainty was independently allocated to the occurrences (small amounts of emission compared to total emission across many independent cases of emission), then the central limit theorem applies and the total costs to society are approximated well by the environmental price for that pollutant (as a proxy for the mean of the distribution of uncertain environmental prices) times the total quantity of emission.

The centrality argument seems unlikely to hold, though, for all the footprint quantities and impact pathways resulting in food system impacts. To be clear, this narrower scope on the

[41] The EU H2020 REFRESH project focusses on LifeCycle Costing (LCC) of LCA for EU food waste: J. Davis et al., *Generic strategy LCA and LCC : Guidance for LCA and LCC focused on prevention, valorisation and treatment of side flows from the food supply chain* (2017 2017), http://urn.kb.se/resolve?urn=urn:nbn:se:ri:diva-27973.. See also M. Pizzol et al., "Monetary valuation in Life Cycle Assessment: a review," *Journal of Cleaner Production* 86 (2015), https://doi.org/10.1016/j.jclepro.2014.08.007.

external costs of the food system is not the focus of the CE Delft or other national handbooks on environmental prices.

On the independence assumption, for carbon cost, it is unclear why emissions from production in The Netherlands in 2019 get reabsorbed into the global economy in a future world where carbon had say 2015USD 20/tCO2-eq impact, and emission from production in Germany in 2019 gets reabsorbed into the global economy in a future world where carbon had say 2015USD 200/tCO2-eq impact. The emissions from The Netherlands and Germany in the same year contribute to the same causal mechanism for the same future world. Their impact is drawn from the same lottery not different lotteries for the social cost of carbon.

The other issue is bias in the environmental prices (acknowledged in the CE Delft Handbook). That is, the potential for under- or over-estimation of the mean of the revealed present and future costs and benefits from environmental pollution. The use of valuation mechanisms based on individual preferences is likely to under-estimate impact for food system external costs. The individual is likely to have difficulty conceiving the context of the trade-off in markets affected by global large quantity changes in footprints.

The final issue is correlation between variation in valuation factors and variation in footprints, e.g. spatial variation. Greater marginal costs than the average in a location which is also associated to greater footprint than the average at that location results in positive correlation, or lesser marginal costs associated to greater footprint results in negative correlation. Either the spatial variation of valuation factors has to be very low, or the footprint associated to impact across regions and contexts has to be very uniform, or generally they have to be uncorrelated, to estimate the total value as the average environmental price multiplied by the total footprint. Positive correlation means the product of the average environmental price and total pollution will *underestimate* the social cost, and negative correlation that the product will *overestimate* the social cost.

Under or over estimation is the risk in setting single valuation factors without consideration of the variation in the impact associated to quantities of footprint occurring in different regions and contexts.

There are many other abatement value case studies under the umbrella of Social Return on Investment. Some interventions in TEEB case studies involving agriculture and aquaculture can be seen in terms of abatement[42].

Aligning social cost and marginal abatement case studies

From the societal perspective of a sustainable global food system, the value to society of abatement products and practices is the total abatement value they supply toward total societal costs (social and private costs outside of the value chain)[43] as well as private benefits in the value chain.

[42] http://www.teebweb.org/resources/case-studies/

[43] For the purposes of this section, we will absorb costs outside of the value chain into the term societal cost. We recall social cost is economic damage (the economy is not providing the full value it could with the present market: it is not optimal because of quantities of footprint not fully factored into the present market), abatement of a social cost is a market value that could be paid now to avoid that economic damage, and a private cost is usually a market value paid by economic actors. Technically the social costs can include all private costs, but we are separating out the private costs to the economic actors inside the value chain of the abatement product or practice. Societal costs and benefits are external to the value chain. Internalisation turns a societal cost or benefit into a private cost or benefit in the value chain.

Abatement demand

The value to society of abatement products and practices requires both the marginal abatement value and the quantity of demand for those products and practices. Significant marginal abatement for products that do not sell, or practices that are not taken up, are useless not only for actors in the agri-food sector but for society as well. The quantity of uptake, or abatement demand, is partly a function of the benefits and costs in the value chain, and if internalisation is present in the market, then partly a function of the societal costs as well.

Valuations of marginal abatement value that do not discuss demand projections leave society to guess on the total abatement value. Society can offer demand projections, saying what it needs in terms of achieving total abatement, but whether that matches with the actual demand realised within the economic system is uncertain.

The marginal abatement value is a signal of potential value to suppliers and procurers in the value chain. For marketing purposes, value propositions, ventures, or other purposes this may be sufficient. Accounting for total abatement value or total abatement requires estimating how suppliers and procurers act on that information.

Demand and internalisation

Procurers, in markets corrected or not corrected by internalisation, will determine demand and so the total abatement achieved by sustainable products, services and practices.

The procurer occupies a position in the value chain that separates the value chain, from the procurer's perspective, into them as actor, upstream and downstream. From the procurer's perspective, the components of a marginal abatement value are valued differently depending on the occurrence in the value chain of private and external value and cost. Where private and external value and cost occur has different considerations for demand.

An accounting standard should consider whether components of marginal abatement value should be reported separately for a product or activity positioned in a value chain. Marginal abatement value should be retained as a vector of values that reports where private costs and benefits are incurred in the value chain and from what location in the value chain costs are externalised.

Many of the societal costs are not directly converted into financial benefit or cost through being sold or consumed. The transfer happens through internalisation. Internalisation, roughly, should be observed in a shift of costs from the external (to the value chain) component to internal to the value chain components.

Marginal private benefits to the value chain upstream and downstream are realised in the market while only the internalisation of societal costs (related to externalities to the value chain) are realised in the market. In economics terms, internalisation of societal costs provides market price signals. The relevant components (Figure 31):

Internalisation of societal costs and benefits upstream either reduces the cost of the abatement product or practice, or increases the cost of the baseline, which reduces the price difference (the market price in the market with internalisation), thereby increasing demand for the abatement product or practice.

Internalisation of societal costs and benefits downstream, and for the actor, increases the value of the abatement product or practice to the procurer, increasing demand.

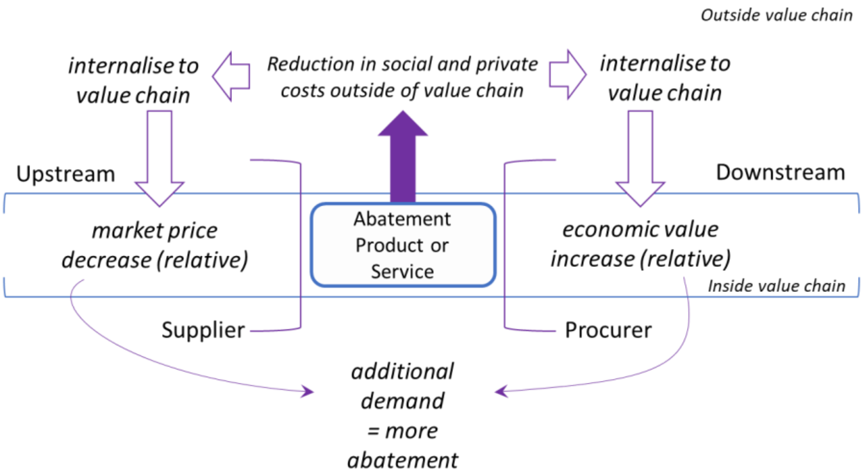

Figure 31: Demand for products or services as a function of abatement of societal costs factors through internalisation into the value chain of that product or service

When internalisation into the value chain is not present, then the marginal abatement cost is the current market price and demand is the demand function of the market price and the upstream effects of the economic value in the value chain. The total abatement value offered to society by supplying sustainable products would then be based on financial efficiency those products offer to the present market.

The present market has already internalised some food system externalities by virtue of consumer and investor values about sustainability. Positive externalities are likely to already be internalised. A classic economic study estimates the internalisation of pollination services[44]. Surveys of food purchases in developed countries routinely place purchase price of food products as the major factor in choosing between alternative however. Purchase price is usually well above environmental and social issues[45]. Present internalisation is likely not creating enough demand to address food system impacts. Demand and price signals are changing. Several national farmers federations and large companies have announced carbon neutral targets[46] (an internalisation) in response to demand signals from investors, society, and consumers.

Internalisation is also mixed in the valuation factors. Some are direct market estimates or damage costs (private benefits or costs) inside and outside the value chain, others are production function based which represent potential benefits in the value chain, some are willingness-to-pay or avoid, some are aggregates across approaches. Willingness-to-pay or avoid is not actual payment into the economic system based on those preferences, or

[44] S. N. S. Cheung, "The Fable of the Bees: An Economic Investigation," *The Journal of Law & Economics* 16, no. 1 (1973).

[45] DEFRA, *Food Statistics Pocketbook*, Department for Environment, Food and Rural Affairs (York, UK, 2015); I. Vermeir and W. Verbeke, "Sustainable Food Consumption: Exploring the Consumer “Attitude – Behavioral Intention” Gap," *Journal of Agricultural and Environmental Ethics* 19, no. 2 (2006), https://doi.org/10.1007/s10806-005-5485-3. J. L. Lusk and B. C. Briggeman, "Food Values," *American Journal of Agricultural Economics* 91, no. 1 (2009), http://ezproxy-prd.bodleian.ox.ac.uk:2084/stable/20492417.

[46] https://www.theguardian.com/environment/2019/sep/10/no-need-to-cut-beef-to-tackle-climate-crisis-say-farmers; https://www.theland.com.au/story/6315052/proactive-farming-sector-key-to-australia-meeting-carbon-targets/ ; https://www.nestle.com/media/pressreleases/allpressreleases/nestle-climate-change-commitment-zero-net-emissions-2050

adjustment of taxation and government spending based on those preferences, so the level of internalisation from preferences is unclear[47].

Adding together societal costs and private costs in the value chain when both are positive or both are negative is an indicator of value. They cannot really be subtracted as private costs in the value chain (which are reflected in the market value) and societal costs (reflected in the economic value) are not directly substitutable except through internalisation or a mechanism for internalisation. The difference between the marginal societal costs and the private costs in their influence on demand trajectories is the distortion inherent in externalities. It is also a manifestation of the economic maxim that abatement value is larger than the abatement price (determined in the market by the demand and supply of abatement).

In summary, even though the marginal abatement value may be high (high value for society), that does not mean that a sustainable product or practice offering abatement is in demand. Low quantity of uptake of those products or practices means low total abatement of social costs, which is an issue for society. The market drives demand, so demand for abatement is linked to internalisation.

Projections of abatement demand

The total abatement that products and practices offer to total societal costs gives signals to government and the investment community on what classes of product and activities offer the most efficient and effective abatement. Total abatement value requires multiplying the marginal abatement value per unit by a demand projection of units of baseline substituted by the alternative.

The demand projection may be historically based, for example a forecast from historical data on the growth and substitution of sustainably sourced palm oil, or the replacement of animal dairy products by plant-based dairy products, etc.

To have comparable total abatement valuations the projections would have to be comparable. The supplementation of scenarios in a food system accounting standard would contain implicit projections for broad categories of commodities, food products, and activity such as land use. Specifying those implicit projections could serve as a basis for comparable demand projections relevant to food system impact.

Broad market projections and opportunities for abatement are likely best developed with publicly supported models alongside market research. Considerations are complicated and the projections would need regular updates. An example of a complication would be abatement quantity caps and factors which change the marginal abatement value and cost. For example, there are only so many locations where the abatement benefits of FMNR project sites (case study 9) will be at the level estimated in case study 9 for the same marginal cost. Broad demand projection in a shared-use standard will control some sources of variability. Business can invest in the process and have the same playing field regarding a range of broad projections. Business can compete on disclosure and developing abatement opportunities aligning with demand.

Including scenarios in marginal abatement costing is now common and best practice (see p. 102, e.g. WOL scenarios incorporated into the CE Delft EU-28 environmental prices). Models such as GLOBIOM can break footprint targets down into commodities and activity like land

[47] J. Loomis, "What's to know about hypothetical bias in stated preference valuation studies?," Article, *Journal of Economic Surveys* 25, no. 2 (2011), https://doi.org/10.1111/j.1467-6419.2010.00675.x. F. B. Norwood and J. L. Lusk, "Social Desirability Bias in Real, Hypothetical, and Inferred Valuation Experiments," *American Journal of Agricultural Economics* 93, no. 2 (2011), https://doi.org/10.1093/ajae/aaq142.

use at a spatial resolution useful for valuation. The SOL-m model achieves the same end (the footprint in case study 1 was that from global food loss and waste). These are likely an appropriate resolution for scenarios for commodity demand and at scale agricultural practices that could support an accounting standard.

The current ability of food system science to project demand and different scenarios of internalisation resides mainly in the inputs, activity, and outputs of agricultural production. We have few integrated models of consumption for food product demand projection. We also have few models of financial capital flows, e.g. sinks of revenue from production and consumption, to understand the transfer of local harms in production and consumption to local benefits from taxation on earnings, etc[48].

In projecting the future, or spatially extrapolating demand changes from study sites and markets to other sites or markets, demand projection introduces uncertainty. As an example, the large uncertainty in predicting production responses, and consumer responses including affordability[49], lead to different abatement value offered by substitution of high intensity animal production for low intensity animal production or plant-based production (Box 1).

For practice changes such as MFFMs and FNMR, uncertainty in demand projection includes why they might not work or not be taken up at scale. The failure and unintended effects of many interventions despite apparent high social benefit-cost ratios are well documented[50]. The Institute for Sustainable Development and International Relations (IDDRI) has developed projection scenarios for abatement of carbon offered by scaling organic farming[51].

Uncertainty in total abatement value comes from an uncertain marginal valuation and uncertain demand multiplied together. Assuming uncertainty in the two terms is uncorrelated, the mean total abatement is the numerical product of the mean marginal abatement and mean demand projection. However, the standard deviation of the product is dominated below by the product of standard deviations (in the uncorrelated case), and the orders of magnitude add. The tail of products of random variables lengthens in general. The assumption that uncertainty in the marginal valuation and the demand projection are uncorrelated needs to be examined, as (uncertain) marginal abatement values are sometimes derived as averages of (uncertain) total abatement divided by a known or uncertain quantity from historical information or a study.

[48] New studies of value add in global value chains for food and agriculture point to concentration of value-add in China and Germany: J. Greenville, K. Kawasaki, and M.-A. Jouanjean, *Dynamic Changes and Effects of Agro-Food GVCS, OECD Food, Agriculture and Fisheries Papers, No. 119*, OECD Publishing (Paris, 2019). https://www.oecd.org/agriculture/topics/global-value-chains-and-agriculture/

[49] K. Hirvonen et al., "Affordability of the EAT-Lancet reference diet: a global analysis," *The Lancet Global Health* 8, no. 1 (2020), https://doi.org/10.1016/S2214-109X(19)30447-4.

[50] D. Lovallo and D. Kahneman, "Delusions of success: How optimism undermines executives' decisions," *Harvard Business Review* 81, no. 7 (2003). M. K. Muth et al., "The Fable of the Bees Revisited: Causes and Consequences of the U.S. Honey Program," *The Journal of Law & Economics* 46, no. 2 (2003), https://doi.org/10.1086/377290. R. Bourne, "'Market failure' arguments are a poor guide to policy," *Economic Affairs* 39, no. 2 (2019), https://doi.org/10.1111/ecaf.12346. F. Ackerman, L. Heinzerling, and R. Massey, "Applying Cost-Benefit to Past Decisions: Was Environmental Protection Ever a Good Idea?," *Admin. L. Review.* 57 (2005), http://scholarship.law.georgetown.edu/facpub/323/. J. Madeley and M. Robinson, *When aid is no help : how projects fail, and how they could succeed* (London: Intermediate Technology Publications, 1991).

[51] P. M. Aubert, M. H. Schwoob, and X. Poux, *Agroecology and carbon neutrality in Europe by 2050: what are the issues? Findings from the TYFA modelling exercise*, IDDRI Study (Paris, 2019), https://www.iddri.org/sites/default/files/PDF/Publications/Catalogue%20Iddri/D%C3%A9cryptage/201904-ST0219-TYFA%20GHG.pdf.

Box 1: Demand projection illustration. Alternative animal or plant meat and dairy shares of consumption

The "Better Futures" scenario in the 2019 FOLU study *Growing Better: Ten Critical Transitions to Transform Food and Land Use, The Global Consultation Report of the Food and Land Use Coalition* contains demand projections of substitution of alternatives, and changes in overall demand, compared to the baseline projection in "Current Trends". "Better Futures" is a normative scenario[52], meaning it projects demand which achieves the targets in 2030 and 2050 described in the scenario and the FOLU report.

Modelling in the "Better Futures" scenarios shows downward pressure on food prices. This is mainly the result of exogenous hypotheses in the "Better Futures" future scenario (p. 26, assumption 6) on what consumers will demand, i.e. consumers will demand the EAT-Lancet reference diet, or they respond to fiscal pressure designed to create that demand profile. The FOLU report describes what the value could be for abatement opportunities. To understand the uncertainty, other plausible demand trajectories would be included. Normative scenarios represent plausible internalisation scenarios but, for accounting estimates, and for projecting forward where we are likely to be versus where we want to be to achieve targets, they are not the only ones.

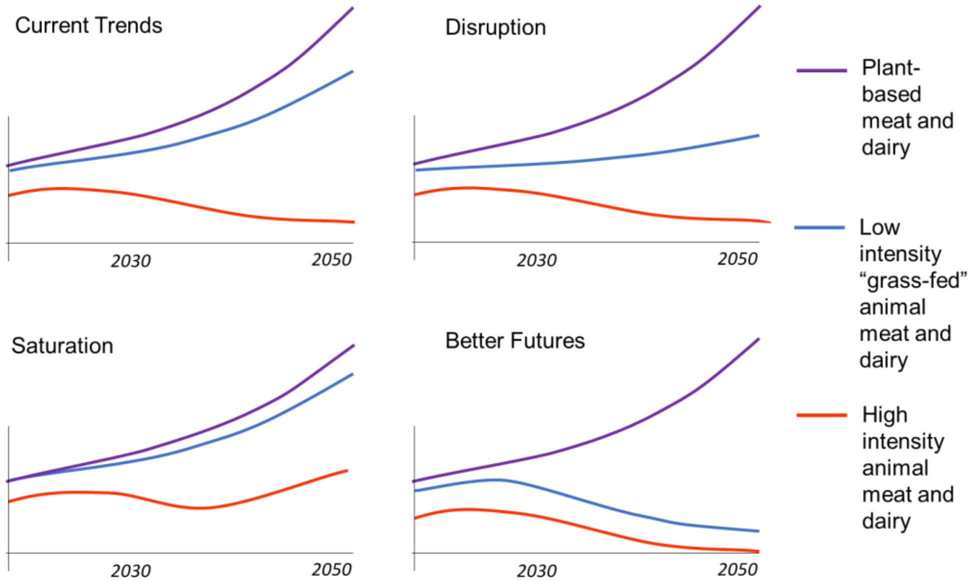

Figure 32: Alternative animal or plant meat demand projections as share of total. Illustrative only. Current Trends and Better Futures indicative of scenarios from FOLU report only. Current trends projects forward high growth in plant-based meat and dairy consumption displacing a share of low growth in the much larger animal-based retail market. It assumes low intensity or sustainable intensification displacement of high intensity production. Better Futures targets the Eat-Lancet Planetary Health diet. Disruption is based on speculative market reports of low growth in animal meat and dairy, with plant-based absorbing 50% market share by 2050. Saturation represents a richer world where US-EU production is replaced by a sustainability trend but middle-income countries, Brazil, Russia, India and China (BRIC) capitalise on higher costs in US-EU production by retaining and increasing high intensity production. Early and rapid movement in EU-US on sustainable animal production results in a flattening of the plant-based market, which is further flattened by richer global consumers outside high income countries increasing consumption of animal products.

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[52] K. Wiebe et al., "Scenario development and foresight analysis: exploring options to inform choices," *Annual Review of Environment and Resources* 43 (2018), https://doi.org/10.1146/annurev-environ-102017-030109.

In the "Better Futures" scenario achieving the EAT-Lancet reference diet is an assumption about substitution of animal protein by plant-based protein. Figure 32 contains examples of alternative trajectories to explore the uncertainty in demand. The FABLE report *Pathways to Sustainable Land-Use and Food Systems. 2019 Report of the FABLE Consortium* expresses some country-specific pathways of commodity use, consumption, and practice, based on abatement targets[53]. These pathways could also be the basis for demand trajectories under internalistion.

Figure 32 considers alternative animal or plant meat and dairy demand projections as share of total value. It is illustrative only, to indicative different possibilities for demand. Crude assumptions are made such as normalisation between scenarios to the same total quantity of protein consumption. The scenarios labelled Better Futures and Current Trends are only indicative of the FOLU scenarios in terms of plant-based diets. Better Futures assumes increased protein supply from oceans, which is not represented. Current Trends projects forward 5-10% real growth/yr in the 2019US$ 30-40 billion global retail plant protein market displacing some of the 1.5-3% real growth/yr in the 2019US$ 1.5 trillion global retail animal protein market (with a mean 10% displacement by 2050)[54]. Current Trends assumes that low intensity or sustainable intensification of animal production displaces high intensity[55]. Disruption is based on speculative market reports of low or nil growth in animal meat and dairy, with plant-based substitutes absorbing 50% market share or greater by 2050[56]. Saturation represents US-EU transition to sustainable production but middle-income countries, Brazil, Russia, India and China (BRIC) capitalise on higher costs in US-EU production by retaining and increasing high intensity production. Early and rapid movement in the EU-US on sustainable animal production results in a flattening of the plant-based market, which is further flattened by richer global consumers outside high income countries increasing consumption of animal products[57].

Demand changes in meat and dairy, and production responses in the US, EU, Brazil, China, Russia and India, are critical for projections of the sustainability of the future global food system. Estimates of technology changes to increase yield and sustainable production are insufficient to meet unchanged demand[58]. The EU and the 5 countries listed are responsible for greater than 50% of global animal meat and milk produced and consumed (FAOSTAT).

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[53] p. 28: FABLE, *Pathways to Sustainable Land-Use and Food Systems. 2019 Report of the FABLE Consortium.*, International Institute for Applied Systems Analysis (IIASA) and Sustainable Development Solutions Network (SDSN) (Laxenburg and Paris, 2019).

[54] OECD and FAO, *OECD-FAO Agricultural Outlook 2019-2028* (Paris: OECD Publishing, 2019). FAIRR, *Plant-based profits: investment risks & opportunities in sustainable food systems*, Farm Animal Investment Risk & Return (London, 2018). These figures are rough calculations only. Assumes displacement of equivalent retail products and constant real prices equating market value growth with consumption growth https://www.mckinsey.com/industries/agriculture/our-insights/alternative-proteins-the-race-for-market-share-is-on; https://www.gfi.org/marketresearch?utm_source=blog&utm_medium=website&utm_campaign=marketresearch; https://www.kerry.com/europe-en/resources/kerrydigest/2019/the-state-of-the-global-plant-based-protein-market; https://www.greenmatters.com/p/dairy-alternatives-market-growing

[55] T. Garnett et al., "Sustainable intensification in agriculture: premises and policies," *Science* 341 (2013), https://doi.org/10.1126/science.1234485. H. C. J. Godfray and T. Garnett, "Food security and sustainable intensification," *Philosophical Transactions of the Royal Society of London B: Biological Sciences* 369, no. 1639 (2014), https://doi.org/10.1098/rstb.2012.0273.

[56] https://www.atkearney.com/retail/article/?/a/how-will-cultured-meat-and-meat-alternatives-disrupt-the-agricultural-and-food-industry;

[57] B. L. Bodirsky et al., "Global Food Demand Scenarios for the 21st Century," *PLOS ONE* 10, no. 11 (2015), https://doi.org/10.1371/journal.pone.0139201.

[58] B. Bajzelj et al., "Importance of food-demand management for climate mitigation," *Nature Clim. Change* 4, no. 10 (2014), https://doi.org/10.1038/nclimate2353. p.172 :OECD and FAO, *OECD-FAO Agricultural Outlook 2019-2028*.

Ensuring consistency between demand projections and marginal valuation factors is a potential contribution of an accounting framework. Uncertainty in demand may appear to be an additional complication even though it has appeared already in the discussion in Food System Impact Valuation in Practice. It is part of the uncertainty in attribution of capital changes conditional on footprint. Having no demand trajectories would create even more uncertainty.

Bringing context of demand to marginal abatement will be the most powerful statement of potential value; what government and investment actors aiming to reduce total impacts of the food system should look for in impact valuation of companies, products, practices and programs.

Disclosure and certification

The case studies included many of the same causes of impact. While this is expected from the repeated presence of LCIA and TruCost studies there is an underlying consensus on environmental and health issues. It is likely a footprint protocol as a step toward a food system non-financial accounting standard can align the footprint units and make interoperable a range of valuation methods with a common set of footprints. The valuation factors and the detail underneath the footprint metrics can change or be updated with evolving scientific opinion on sustainability assessment for food systems. The update process can include more comprehensive coverage of societal impacts as needed.

Outside of global social cost studies (case studies 1-3), calculating the footprint is within the domain of producers, manufacturers, and retailers. Credible and comparable valuations still depend on the ability to certify the footprint calculation and understand what variation in reported footprints may have been caused by the methods used to calculate them.

Case study 4 involved an RSPO certified supplier of palm oil. Certification offers a distinction in footprint compared to baselines upon which calculations can potentially be based. If certification (with spatial and contextual qualifications) can be associated to an accounting standard, and associated to a reliable amount or distribution of footprint abatement compared to the baselines that the certified products substitute, then existing certification could be attached to credibility and calculation of footprint.

Disclosure of footprint may be only to the external user, for inclusion in a valuation from which internalisation benefits are received. For example, a bond issuer uses a digital ledger to increase certification of footprint reduction achieved for bond purchasers, or a financer links certified disclosure and abatement to discounted finance.

Open disclosure, or reporting to society at large, contributes to the understanding of progress to targets. Information on total footprints also feeds into updating valuation factors and the metrics associated to a common accounting framework. As before, society as the bearer of many of the externalised costs needs to see footprint reduction achieved. An equivalent to the Carbon Disclosure Project (CDP)[59] for food systems would enable tracking of footprint abatement trajectories and comparison with global monitoring of stocks by national and international institutions. Unlike the CDP the footprint disclosure for food systems would be broken down spatially and contextually and based on the boundaries in a food system non-financial accounting standard. Another advantage of a CDP equivalent for food system footprint is complementarity with potential offset markets. Automatic registration of offset

[59] https://www.cdp.net/en ; D. C. Matisoff, D. S. Noonan, and J. J. O'Brien, "Convergence in Environmental Reporting: Assessing the Carbon Disclosure Project," *Business Strategy And The Environment* 22, no. 5 (2013), https://doi.org/10.1002/bse.1741; E.-H. Kim and T. Lyon, "When Does Institutional Investor Activism Increase Shareholder Value?: The Carbon Disclosure Project," in *The B.E. Journal of Economic Analysis & Policy* (2011).

transactions, even if companies transact taking on a footprint burden from upstream suppliers or within its own operations, can increase visible exposure and provide a traceable account of footprint calculation. With disclosure comes potential value over competitors when footprint reduction is internalised into the market.

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PREVIOUS SECTION: 6. FOOD SYSTEM IMPACT VALUATION IN PRACTICE

Valuing the impact of food:

Towards practical and comparable monetary valuation of food system impacts

A report of the Food System Impact Valuation Initiative (FoodSIVI)

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NEXT SECTION: 8. DEVELOPMENT AND INVENTORY OF METHODS