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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The market value of the global food sector is underpinned by costs externalised to society. Internalising those costs through improved products and practices, information and intervention can lead to a significant contribution to food system transformation and opportunity for leading companies. Valuations of food system impacts to account for the costs and make them economically visible can be a key component of internalisation. The report provides background on food system impact valuation and examines whether the way that carbon is costed in terms of social and abatement costs can be adjusted to estimate the costs of food production, processing and consumption. Nine case studies from the global food system to products highlight the variation in methods used. Recommendations are made toward a model of shadow prices and a food system non-financial accounting standard.

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FoodSIVI is a collaborative initiative between academia, industry and civil society to promote standardised and pre-competitive monetary valuation of environmental, social and health impacts of food systems. FoodSIVI's overall purpose, working with other impact valuation and true cost accounting initiatives, is to champion **food system transformation through internalisation of the food system's environmental, social and health external costs**. It aims to:

- Improve and operationalise impact valuation methods, promoting the development of standardised and comparable valuations.
- Create a network to initiate and promote uses of food system impact valuation.
- Promote the inclusion of environmental, health and social data in food information and technology systems and undertake research on the utilisation of such systems for impact valuation.

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EXECUTIVE SUMMARY

What is the cost of the food we eat? What is the value of the sustainable products and practices in the food sector? Here cost doesn't mean just the price at the market or the supermarket. It also means the costs of climate change, ecological dead zones from nitrogen run-off, air pollution, water scarcity, rural poverty and preventable death and disease from obesity, diabetes, hunger and stunting. These costs are incurred through the production, processing and consumption of the food we eat. These costs aren't included at the cash register, but they are being paid nonetheless. We pay for them, both directly and indirectly, through health costs, social costs, lost productivity, lost quality of life, conflict, and increasing scarcity.

Yet, it is food that provides us with the calories and nutrition we need, connects culture, brings family and friends together, delights us with taste and much more. The decreasing cost of food has allowed money left over in household budgets to be spent on other needs and activities, further increasing value. So how do we balance these short-term and private values with the longer-term and externalised costs taking their toll on nature, the communities of workers producing and processing food, human health, and more?

The costing of carbon describes how activity, measured by carbon footprints, is translated into a monetary estimate of the cost of carbon production. We produce too much carbon and putting a cost on it enables the introduction of incentives and encouragement to reduce our footprint.

This report examines food impact costing, and whether the way that carbon is costed in terms of social and abatement costs can be adjusted to estimate the longer-term and externalised costs of food production, processing and consumption. Social costs are the damage that would result from producing the footprint. Abatement costs are the cost to reduce the footprint. The conclusion overall is that social and abatement costing can be adjusted to food, but that the food context has some considerable complications, which also suggests the need for co-ordinated responses.

We do not need to produce less food globally, and we do not want to lose the immediate value food brings, but we need to produce food with a lower global footprint. Besides carbon footprints, the water, nitrogen, land-use, unhealthy food consumption and other footprints of food globally are considerable. These footprints and their consequences are accelerating, evolving into multiple crises. A growing number of scientific reports recommend the need for a food system transformation to halt and reduce impact. The purpose of food impact costing is the same as carbon costing, to enable economic correction and incentives to reduce footprints. The corrections and incentives may be indicators to influence food consumers or the financers of the food sector, government regulations and taxes, or a range of other measures.

Footprint is not universally bad. It is likely that developing countries need to increase their application of nitrogen as well as their efficiency of applying nitrogen. The impact on social and human well-being depends on where and how a footprint is occurred. Footprint and impact are not the same. Environmental, social and nutrition science is concerned with the how, the how much, and the consequence of footprint. Economics is concerned with balancing short-term private gain against external and/or long-term value loss for social and human well-being.

High level reports from the EAT-Lancet Commission on healthy diets from sustainable food systems in January 2019, the FABLE consortium in July 2019, and the Intergovernmental Panel on Climate Change (IPCC) in August 2019 have laid the foundation for global footprint targets. Work on food system valuation, in terms of the underlying basis for social and abatement costing, is part of the follow-on from the high-level reports to investigate what can guide economic contributions to food system transformation towards those targets.

The report examines the steps of valuation outlined in leading impact frameworks. Based upon the examination, the inherent ethical choices, uncertainties in costing, and on the variation observed across nine case studies, the report concludes and suggests the following:

- That abatement costing be further developed for two reasons: one, to inform costs of tangible action and economic trajectories for food system transformation; two, to improve (cost-effectiveness) measures of the value provided by sustainable food products and practices to accelerate investment in them and other incentives.
- That a footprint protocol solidifying what to measure and how to track reduction be developed by a consortium of intergovernmental and institutional actors and experts (a societal process), in collaboration with the food sector. The protocol and subsequent steps should lead ultimately to a food system non-financial capital accounting standard which guides footprint accounting and formalises impact pathways, similar to the ecosystem component of the UN System of Environmental Experimental Accounting. The UN body, UNEP, produces an annual report on the progress toward carbon emission targets called "The Emissions Gap Report". Global progress to food transformation targets could also be reported. There are many environmental pollutants, and many social consequences associated to the food system, but the footprint protocol should identify and deal only with those of major global concern, and others left to local processes.
- That there is enough scientific work to formalise food footprint and targets. The gap is in the political and societal process.
- That carbon neutral is an important aspiration for the food sector in line with food system transformation targets, but an integrated form of impact neutrality should be promoted to emphasise aspiration to meet the multiple dimensions of food system transformation targets.
- That, given unavoidable ethical choices and order of magnitude uncertainties inherent in both social and abatement costing, a societal process building on private starts and national handbooks should compile, set and update shadow prices associated to food footprints. A shadow price is the estimate of the cost of one more unit of footprint produced. The costs incurred by society differ depending on where the impact and footprints occur so there will be many shadow prices. A practical model for using the shadow prices required is described, as are non-linear corrections to impact costing for scarcity and interactions created by food's multiple footprints, and risk-based corrections because of the uncertainty.
- That having a set of established and regularly updated shadow prices takes ethical choices in the costing of societal impact away from individual businesses

and consultants. Leaving business to compete on footprint reduction. The report also suggests that uniformity and availability of the difficult to calculate shadow prices will enhance comparison of impact costings leading to enhanced use.

- The high-level reports mentioned, particularly the EAT-Lancet Commission on healthy diets from sustainable food systems, advocate strongly for the need for an intergovernmental body to inform food system impact (an "IPCC-for-food"). Such a body would be a natural home, or focus at least, for establishing a footprint protocol and the societal process leading to setting and updating shadow prices. National governments can adapt pricing, but given the quantities of footprint embodied in food trade crossing many national borders, the shadow prices stimulate and benchmark pricing for impact costing involving global value chains.

In suggesting the above to overcome the complications in food impact costing, the report is not suggesting that the application and uses of food impact costing should wait until an "IPCC-for-food" is formed. Food system transformation is identified by high-level reports as urgent. Steps toward a food footprint protocol and developing social and abatement costings should proceed under the umbrella of food economic policy with the caveats noted in this report and others. As should uses of impact costing to advocate change to consumers, guide impact investing, and challenge government to adjust subsidies and financial incentives. Shaping these steps and uses to align toward an accounting standard and societal process for shadow pricing are improvements toward practical and comparable food system impact valuation.

KEY MESSAGES

Food system impact valuations can align the market dynamics of food and agricultural toward the social and human well-being targets of food system transformation.

Building on private starts and national handbooks a societal development and review process should set shadow prices to bring credibility, comparability, and reduce other barriers to use. This would overcome the complexity in calculating shadow prices for quantities associated to food system impact and accelerate the uses that will have the most effect on reducing impact.

Carbon is estimated to produce less than one-third of global food system social costs. A food system non-financial capital accounting standard would guide what to measure and disclose in terms of other footprints, guide transacting the contributions to value and impact along the food and agriculture sector's complex value chains and provide a standard set of quantities on which to base shadow prices. This would enable tracking of global footprint reduction targets, and disclosure and offset opportunities similar to carbon disclosure and offset.

SUMMARY

There are many reports now on the impacts of food systems and its multiple dimensions. Besides CO2-eq emissions, the food system is the main cause of global land-use change, biodiversity loss from pesticide and nutrient application, and renewable and non-renewable water extraction. Agricultural communities and workers are associated to poverty, social stress and high accident and suicide rates. Dietary risk factors are now the largest global cause of preventable disease and death. Antibiotic use and emergence of exotic pathogens from animal production are additional human health concerns. Recent studies suggest that costs from natural, social and human capital changes due to the activities of food system equate to 11% of global GDP. This outweighs the market value of the global food sector. Most costs are external and less than one-third of the costs are associated to CO2-eq emissions.

Internalising costs through market measures, improved products and practices, information, and intervention, could lead to a significant contribution to food system transformation. It could also be a significant opportunity for leading companies. The science on the impact of food systems is clear but the economic response remains marginal. Market incentives and investment in malnutrition, diabetes and obesity, regulations for water use and nutrient pollution, food policies, uptake of Pigouvian taxes, subsidy changes, and other corrective measures remain disproportional to the impact. Food system science is pointing in one direction but, on present course, our economic system is heading in another. Impact valuations provide an estimate of the costs, and benefits, from food system activities. They account for impacts not costed into market transactions. Impact valuations can guide where internalisation and incentives are required and in what amount.

The costing of carbon describes how activity, measured by carbon footprints, can be translated into a monetary estimate of the longer-term and externalised costs of carbon production. This report examines food impact valuation as social and abatement costing of externalised costs of food production, processing and consumption. Costing carbon, which the report reviews, involves ethical choices such as intergenerational equity and large uncertainty. Similar ethical aspects and uncertainties for social and abatement costs associated to food's production, processing and consumption are examined. Another major complication to social and abatement costing is that food impacts have multiple footprints and the impact from a footprint such as water or nitrogen waste is heavily dependent on where the footprint is incurred and on the manner of extraction or waste. Setting footprint reduction targets and costing the reduction is further complicated by trade-offs and co-benefits. That is, one footprint or impact may increase, or decrease respectively, as another is reduced.

The complications lead the report to recommend a footprint protocol, formalising impact pathways, and a process for setting and updating marginal social and abatement costs with estimates of their uncertainty. A model is suggested using marginal social or abatement costs. Non-linear corrections for scarcity and interactions between food's multiple footprints are indicated, and risk-based corrections using estimates of uncertainty.

Before considering marginal social and abatement costing the report places them in context. Using footprints as quantities to link impact and activities in the food sector is not a universal approach. The report breaks down valuation according to a common process in impact frameworks to avoid duplicating existing frameworks. It places social and abatement costing within the breakdown. To help bridge food system science and economic theory the report also discusses the economic theory of change and the evidence that costing impact will contribute to food system transformation.

In more detail, the report makes three contributions to valuing the impact of food:

1) Background to make the link between food system science and contributions to food system transformation from economic change. Correcting market dynamics by estimating

impacts not costed into market transactions can align financial gains with gains in human and social well-being. The explanation of the economic theory of change given in the report is simple. More linking with welfare economics, economic valuation, and accounting, could be considered in subsequent studies.

- Comparable and agreed valuations of the major external costs introduced by the food system are likely to have the most effect on reducing impact. Comparable valuation is needed for external correction such as impact investing and government policy. As evidenced in the report by the variation in nine case studies, and the discussion of ethical choices and uncertainty implicit in valuations like the social cost of carbon, it is difficult presently to compare food system impact valuations.
- Economic theory indicates that internalisation by itself may not result in reduced food system impacts, or it may transfer the impact on social and human well-being to another sector rather than reduce it. Additional research is required on which economic changes to the food system will achieve reduction in impact. Research needed: i) estimates of the reduction in impact that could be achieved through efficiency gains in the present market; ii) dynamic economic modelling of the follow-on consequences from large fiscal or policy interventions suggested by impact and attribution studies, and iii) merit order curves, similar to abatement curves from climate science, with economic trajectories for food system transformation that consider co-benefits and trade-offs.
- Realising market corrections requires synergy between a triad of food system science, economics and users. A short survey of current activity around the triad shows a body of existing activity. A network can bring the triad closer together. Investment can enable the community to develop and promote measures for economic correction of food system impact at scale.

2) Advice on doing monetary food system impact valuations. Existing impact frameworks such as the Natural Capital Protocol and The Economic of Ecosystems and Biodiversity (TEEB) AgriFood Evaluation Framework use a natural, human and social capital approach. They describe monetary and non-monetary valuation of changes to capital due to the activity of business, government and society. The existing frameworks are aligned, describing similar steps such as setting the scope and acquiring data, but are not specific on comparable monetary valuation.

Based on the impact frameworks we phrase impact valuation in terms of footprint created by activities (quantities associated to impact such as tonnes CO2-eq emitted or kg reactive nitrogen leached), the capital change attributable to the footprint, and the value change from the capital change (Figure A on the next page). The activity might be the annual operations of a food company, the lifecycle of a food product, the production of a tonne of an agricultural commodity, or a change in farming practice. The impact valuation indicates the change in economic value due to the activity, factoring through the footprint quantities produced and changes to natural, social and human capital. Footprints become the quantities associated to increase or decrease in economic value. In economic theory quantities should either be produced or reduced to maximise economic value overall.

A shadow price, or marginal valuation, or valuation factor, is the estimate of the cost of one more unit of footprint produced or reduced, depending on whether the marginal valuation is a social or abatement cost respectively. Marginal valuations combine the attribution of capital changes and the value of the capital change together (Figure A on the next page).

Examination of the social and abatement costs of carbon and case studies finds fundamental ethical choices and a large amount of variation and uncertainty in the steps of an impact valuation. In choosing which footprints to include and associate to impact, in an actor calculating footprint, and particularly in estimating capital changes and economic changes.

Estimating economic value involves a monetary representation of social and human well-being which is often implicit in valuations. Parity is the choice of how to compare economic value between economies; usually national economies. Discounting is the choice of how to compare economic value between an economy now and an economy in the future. Monetary representation of welfare, parity and discounting are all ethical choices which are shown from literature studies to produce order of magnitude differences to marginal valuations. Some of these conclusions are from studies on the social cost of carbon, but the report considers the evidence of intergenerational effects in other dimensions of food impact such as obesity and rural poverty, and international effects embedded in food's global value chains. Choices of parity and discounting will likely result in potential order of magnitude differences in an overall food system impact valuation.

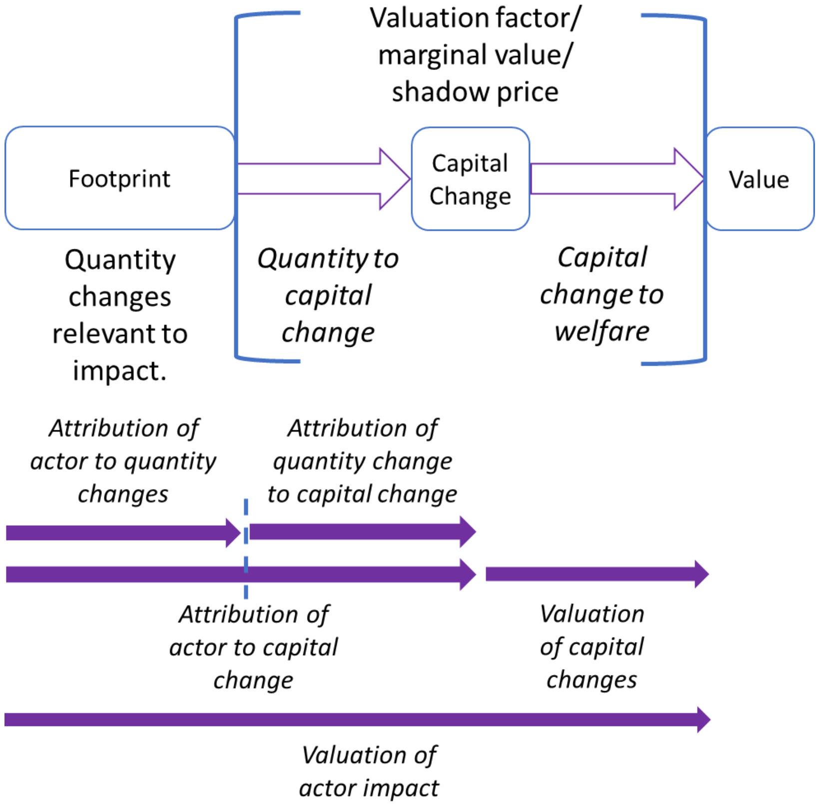

Figure A: the components of impact valuation, which is an estimate of the changes in economic value (the impact) due to an activity, factoring through the footprint quantities produced and changes to natural, social and human capital.

Most of our knowledge about capital changes comes from scientific models and observed or interpolated data. Examples of modelling are given, and evidence of variation produced by different models. The report outlines the complexity of the impact pathways associated to food's footprints. This can produce ambiguity and modelling uncertainty above the inherent error (goodness of fit) in models integrated to represent the impact pathway. The need and use of scenarios of socio-economic drivers and estimates of the total societal footprint is discussed.

Based upon examination of the inherent ethical choices, uncertainty in costing, and on the variation observed across the nine case studies, the report concludes and suggests the following:

- Comparable valuation that has the most effect on reducing impact will likely involve a limited number of use cases, but with frequent application. The limited number of use cases provides an opportunity to fix and standardise the scope and framing associated to those uses. That is, fixing the footprints and the impact pathways associated to the major external costs introduced by the food system. Fixing the footprint is the basis for consistent marginal valuation with respect to those footprints. The frequent application provides an opportunity to address the variability and uncertainty in marginal valuation.
- The variety of data, models, tools, scenarios, and valuation methods already used in impact valuation, and fundamental uncertainties in ethical choices as well as scientific estimates, make it unlikely that agreement can occur on single values or single methods for marginal valuations.
- Fixing single values would ignore the risk being passed to society by business inherent in the production of footprints. An improvement would be to consider the distribution of valuations and price the risk transfer to society within the impact valuation. The risk premium is how much society should "charge" to take on the uncertainty in impact associated to the footprint produced by a product, practice, or company.
- The nine case studies show the variation in practice in footprint, models and data, and valuation methodology, and a precedent for pricing uncertainty.
- Businesses have the same playing field if shadow prices and their uncertainty were agreed. This incentivises the food sector to contribute to a societal process for better information about impacts and valuation to reduce the uncertainty and so reduce the risk premium on shadow prices. The business also avoids the ethical choices implicit in choosing shadow prices.
- Businesses can compete on footprint reduction and on disclosure. Disclosure reduces the uncertainty in footprint. Through the pricing mechanism disclosure reduces the risk price. Calculating footprint is closer to the activity of the business itself. Methods for footprint calculation such as lifecycle analysis (LCA) are already well developed.
- Some challenges in doing valuation are not new to food systems. They include aggregation, double-counting, bias, error-bars, and substitution. If valuation is going to have traction toward reducing impact the challenges need to be addressed. Ambiguity and errors lead to mistrust and an inability of parties to subscribe to and use valuations. Some of the challenges cannot be solved. That is, the shadow prices will never be "correct". How to deal with them as issues in a consistent and agreed way is part of the rationale for risk pricing. Synergy between a triad of food system science, economics and users is as important for potential change in the food system as incremental improvements in modelling or economic growth projections.

Social and abatement costing

The costing of carbon considers both marginal social and abatement costs. These are two different marginal valuations. They lead to two different impact valuations when applied to the same footprint.

A marginal social cost is the change in economic value that would result if the footprint was produced. A marginal abatement cost is the cost incurred (which is also a change in economic value) to reduce the footprint. Reducing the footprint avoids incurring the social costs. Marginal abatement costs are usually derived from portfolios of abatement measures designed to achieve a footprint reduction target for the least cost.

Sustainable food and agricultural products, and companies incorporating sustainable practices or sustainable sourcing, offer abatement of footprint compared to their unsustainable counterparts. The additional cost of the sustainable products and practices is their abatement cost. In this view sustainable products and practices are abatement measures. The reduction in footprint from substituting the unsustainable product or practice is called the abatement. The social benefit associated to the abatement is called the abatement value.

An impact valuation using marginal social costs and abatement as footprint calculates the abatement value of the sustainable product or practices.

An impact valuation using marginal abatement costs and abatement as footprint indicates the cost-effectiveness of the sustainable product or practice as an abatement measure contributing to a footprint reduction target.

The two are complementary views of the value of sustainable food and agricultural products. Both can be used to set incentives.

Challenges in social and abatement costing for longer-term and externalised costs of food production, processing and consumption are reviewed in the report. Many of the challenges in social costing relate to discounting and uncertainty in models already discussed. Abatement costing does not avoid uncertainty however. Setting consistent footprint reduction targets across food's multiple footprints is difficult. High level reports from the EAT-Lancet Commission on healthy diets from sustainable food systems, the IPCC, and the FABLE consortium, have laid the foundation for global footprint targets. One of the major uncertainties is whether abatement measures such as dietary changes will be realised. Dietary changes are necessary to reach global footprint targets. Realising some abatement measures is therefore dependant on demand for sustainable products and practices. This demand depends on the response of business and consumers, which is uncertain.

At the risk of being obvious, total abatement of food system impacts are currently low because demand for abatement measures or the abatement they offer is low. The most useful measure for society and governments is total abatement which is needed to calculate abatement portfolios and determine societal marginal abatement costs. The total abatement offered is the marginal abatement multiplied by the quantity sold in the market (in terms of units of sustainable product substituting a less sustainable counterpart). Calculating total abatement therefore depends on projecting demand.

Demand projections are illustrated by looking at scenarios for replacing animal protein by plant protein between the "Current Trends" (worst case/status quo) and "Better Futures" (best case/vision) scenarios of a September 2019 Food and Land Use Coalition Report: "Growing Better: Ten Critical Transitions to Transform Food and Land Use". The uncertainty in forward demand can become part of the risk pricing. If there were a mechanism to internalise the social or abatement costs, then the risk price would reduce (as would mean shadow prices toward effective prices) with the reduced uncertainty in total abatement meeting food system transformation targets. In this way risk to society of status quo in unsustainable products is transferred to venture investment (through the internalisation mechanism) for sustainable alternatives.

Observed impact valuations in case studies consider abatement value. That is, they use marginal social costs in the impact valuation. Abatement costing has further technical complications mentioned in the report, but it should be further developed for two reasons: one, to inform costs of tangible action and economic trajectories for food system transformation which is connected to point 1) above; two, to improve cost-effectiveness measures of the value provided by sustainable food products and practices to accelerate investment in them.

Model

Spatial and contextual distinction in shadow prices is essential. The social cost of carbon avoids this because of its global impact. Other shadow prices, for example for water, nutrient pollution, and malnutrition, are very dependent on context. The social cost(s) of obesity, like carbon, have intergenerational components. Carbon has a clear footprint unit (t CO2-eq emitted). Additional research will be required to develop footprint and impact pathways with spatial and contextual distinctions for social and health impacts. The report provides an argument for practical impact valuation to have spatially and contextually explicit footprints up to broad boundaries such as food basin, ecosystem, catchment, agricultural land use, etc. currently used in global modelling. Though the resolution is coarse, the spatial and contextual detail suggested will still guide initial and effective corrections to incentivise footprint reduction.

The report outlines a linear approximation to estimating economic value change from footprint changes. The shadow price for that footprint quantity (e.g. CO2-eq emissions or water extracted in a specific catchment) is multiplied against the footprint incurred. The result is then summed across all the footprint quantities. This linear approximation is the basis for using marginal valuations. It captures the impact valuation method used in every case study observed. Non-linear corrections to impact costing for scarcity and interactions created by food's multiple footprints are indicated. A practical model for risk pricing is also sketched, which replaces terms in the linear model with random variable equivalents (uncertain shadow prices, uncertain footprints, etc). It is described how correlations between shadow prices, and other factors such as economic growth trajectories related to discounting, need to be included. A risk-based correction to an impact valuation can be calculated to account for uncertainty in shadow prices and correlations in impact.

The linear model is agnostic to whether the marginal valuations are social or abatement costs. The report discusses why marginal social and abatement costs should not be used together.

3) Implications and arguments for a food system non-financial capital accounting standard. The report collates a table of the methods, data, and models, described through the report. It concludes by listing implications for impact reporting in the food sector, efficiency in footprint reduction and offset markets. The same section summarises the argument for a consortium of intergovernmental and institutional actors and experts to develop a footprint protocol and set and update shadow prices for food impact costing.

One of the implications relates to the trend to report on "total" or "true" value by adding up social and private benefits related to wages and revenue and subtracting natural and social capital costs. The subtraction is implicit in the linear model. Often social costs are incurred on the other side of the world from the social benefits; it is extremely unclear if they are substitutable which is what the subtraction implies. Keeping benefits and costs spatially and contextually distinct and investing in methods to understand and implement their substitution would avoid mistrust from society that valuations are obscuring the balance sheet. While one of the advantages of valuation is to put things into monetary terms to make them more comparable, this does not imply everything is exchangeable for money without an appropriate use of parity. Without further consideration or agreement it is unclear why purchasing power parity, based on substitution of money for produced goods, is appropriate for exchange of value in other capitals.

One recommendation the report makes is to use inequity statistics to report alongside totals of natural, social and human capital costs. The statistics are based on the temporal, spatial and contextual detail provided by shadow prices in the model outlined. Three forms of equity are suggested. First, intergenerational equity as the amount of impact occurring in present time periods compared to later time periods. Second, the certainty of costs compared to the uncertainty in benefits. Third, national transfers of costs from natural, social and human capital changes to benefits from produced capital changes.

Forms of the linear model are already used in lifecycle analysis software. The suggested second order non-linear corrections could also be implemented in lifecycle analysis software. The use of software and private methods for shadow pricing could become *de facto* standardisation without investment in a societal process. This risks bias in valuations which may systematically under or overestimate cost of impacts. The result would be too much or not enough economic adjustment. A staged process is recommended of pragmatic solutions that can sponsor business and government uses. This graduates to a societal process for agreed valuations with increasing use.

There is no standard scheme of food system footprints equivalent to carbon footprints yet, and few disclosure and offset opportunities equivalent to carbon disclosure or carbon offset. While the food sector is increasingly discussing carbon neutrality, an integrated form of impact neutrality across health and other impact dimensions is not prominent. A food system non-financial capital accounting standard would guide what to measure and disclose in terms of footprint and provide a set of quantities on which to base shadow prices. The report argues that the SEEA-EEA, the ecosystem component of the UN System of Environmental Experimental Accounting, and the Sustainability Assessment of Food and Agriculture systems (SAFA) terminology from the Food and Agriculture Organization (FAO), offer a blueprint and basis for a standard that:

- has a footprint protocol agreeing the spatially and contextually explicit footprints needed to incentivise footprint reduction and track progress toward food system transformation targets
- defines the format required for a database of shadow prices associated to the footprint quantities
- formalises impact pathways through which major impacts occur (exchanges and contributions between footprints, capitals, footprint to capital and capital to human well-being relevant to impact).
- is supplemented by scenarios for estimating lock-in impacts and projecting demand of categories of sustainable food products.

With an accounting standard, existing features of the market can be used for disclosure of footprint. For example, certification of sustainable products could be associated to footprint ranges. Calculating footprint is within the competitive space.

The report discusses global footprints targets, which have been identified in recent high-level reports of the EAT-Lancet Commission and the FABLE consortium. A footprint protocol would allow progress toward global footprint reduction targets for the food system to be tracked, while also informing context specific economic corrections and incentives.

INTRODUCTION

By conventional financial reckoning the food sector is a highly efficient and valuable sector. It produces high volumes of food at historically low costs to consumers with increasingly lower marginal inputs. However, a barrage of scientific reports from the Intergovernmental Panel on Climate Change (IPCC) in August 2019, the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services in March 2018 (IPBES), the Global Burden of Disease in April 2019 (GBD), The Economics of Ecosystems and Biodiversity (TEEB) for Agriculture and Food in 2018, Food and Land Use Coalition (FOLU) in September 2019, and the EAT-Lancet Commission on Healthy Diets from Sustainable Food Systems in January 2019, provide significant evidence that this financial position is underpinned by a global net consumption and degradation of natural, social and human capital[1]. They are culminations of over a decade of escalating calls for food system transformation.

By conventional financial reckoning the food sector is a highly efficient and valuable sector… account for social costs from impacts on natural, social and human capital and it becomes expensive, inefficient, and an economic, and potentially existential, risk to society.

The social costs of the impacts to natural, social and human capital identified by the scientific community are currently not costed into the activity of the food sector. Account for the social costs and the financial position of the current food system is transformed. It becomes expensive, inefficient, and an economic, and a potentially existential, risk to society. As part of the TEEB Business Coalition initiative, the consulting company TruCost found that the food sector was responsible for over 40% of the total economic cost of the global top 100 business environmental externalities[2]. A similar analysis by KPMG estimated the food sector's externalised environmental costs over 200% of sector profits[3]. With an estimated 12% of the globe's land surface being used for crop production and

[1] "Consumption" here means a reduction in the quantity of capital, while "degradation" here means a reduction of quality. There are a range of these terms for diminishing flows of capital services depending on the type of capital. Later we refer to changes in quantity and quality of capital, or simply capital change. IPCC, *IPCC Special Report on Climate Change, Desertification, Land Degradation, Sustainable Land Management, Food Security, and Greenhouse gas fluxes in Terrestrial Ecosystems*, Intergovernmental Panel on Climate Change (2019), https://www.ipcc.ch/report/srccl/. IPBES et al., *The IPBES assessment report on land degradation and restoration*, Secretariat of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (Bonn, Germany, 2018), https://doi.org/10.5281/zenodo.3237392. A. Afshin et al., "Health effects of dietary risks in 195 countries, 1990–2017: a systematic analysis for the Global Burden of Disease Study 2017," *The Lancet* 393, no. 10184 (2019), https://doi.org/https://doi.org/10.1016/S0140-6736(19)30041-8. TEEB, *TEEB for Agriculture & Food: Scientific and Economic Foundations*, UN Environment (Geneva, 2018). 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/. W. Willett et al., "Food in the Anthropocene: the EAT–Lancet Commission on healthy diets from sustainable food systems," *The Lancet* 393, no. 10170 (2019), https://doi.org/https://doi.org/10.1016/S0140-6736(18)31788-4.

[2] "Externality" meaning an economic cost or benefit arising from the transactions of a set of economic actors, e.g. costs of climate change to society not paid for in the transaction between producer and consumer when GHG emissions occur during production (or consumption). A glossary is on p. 8 of this report. The proportion of 48% of the cost of the global top 100 business externalities due to the food sector, and only 25% due to energy sector, with a ratio of economic costs of impacts to revenue of 180%, is calculated from Table 7.1 of TruCost, *Natural Capital at Risk: The Top 100 Externalities of Business*, TruCost PLC (London, 2013), https://www.naturalcapitalcoalition.org/wp-content/uploads/2016/07/Trucost-Nat-Cap-at-Risk-Final-Report-web.pdf.

[3] KPMG calculated, using TruCost data on food producers within 800 companies, the figure of 224% economic costs of impacts to EBITDA: p.10 KPMG, *A new vision of value*, KPMG International

26% used for livestock grazing, the scale for biodiversity loss, soil degradation and nutrient pollution from land use alone is immense[4]. Health impacts valued by annual preventable costs of malnutrition (obesity, diabetes, stunting, etc.) range in conservative estimates from 1 trillion US 2014 dollars in the United States to 5 trillion US 2014 dollars globally (over 6% of global GDP in 2014)[5]. The 2019 Food and Land Use Coalition (FOLU) *Growing Better: Ten Critical Transitions to Transform Food and Land Use* report estimated the environmental, social and health costs of the global food sector at approximately 11% of global GDP[6]. This outweighs the market value. The FOLU report also highlighted the opportunity for leading companies in reducing those costs.

The evidence is that the value loss created by the food system will likely be greater than the financial value produced and be borne by those that benefitted little from the value created. It becomes an imperative to set in motion private and public levers to reduce the external costs of food systems. Impact valuations provide an estimate of the costs, and benefits, from food system activities. They

> Value loss created by the food system will likely be greater than the financial value produced… Valuations that account for externalities not costed into market transactions can be a key component of change.

Cooperative (Netherlands, 2014), https://assets.kpmg/content/dam/kpmg/pdf/2014/10/a-new-vision-of-value-v1.pdf.

[4] J. Bruinsma, *World agriculture: towards 2015/2030: an FAO perspective* (London: Earthscan, 2003).;P. Conforti, "Looking ahead in world food and agriculture: perspectives to 2050," (2011), http://www.fao.org/docrep/014/i2280e/i2280e.pdf.; H. Steinfeld et al., *Livestock's long shadow: environmental issues and options* (Rome: Food and Agriculture Organization of the United Nations (FAO), 2006).; FAO, *The state of food and agriculture 2009 : livestock in the balance* (Rome: Food and Agriculture Organization of the United Nations, 2009). IPCC, *IPCC Special Report on Climate Change, Desertification, Land Degradation, Sustainable Land Management, Food Security, and Greenhouse gas fluxes in Terrestrial Ecosystems*. IPBES et al., *The IPBES assessment report on land degradation and restoration*., Key Message B6.

[5] p. 38 Credit Suisse Research Institute, *Sugar consumption at a crossroads*, Credit Suisse AG (Switzerland, 2013), http://archive.wphna.org/wp-content/uploads/2014/01/13-09_Credit_Suisse_Sugar_crossroads.pdf., US$1 trillion as 30% of 3.3 trillion, coming from the estimate 30-40% of the US$3.3 trillion spent annually on US healthcare goes toward obesity and diabetes, see also US$660billion from US obesity alone (which is 20%) on p. 18 of R. Dobbs et al., *Overcoming obesity : an initial economic analysis*, McKinsey Global Institute (Washington, D.C., 2014), http://www.mckinsey.com/insights/economic_studies/how_the_world_could_better_fight_obesity. The McKinsey and Credit Suisse sources give the same estimate of US$1 trillion for obesity and diabetes. A 2014 refence to US$3.5 trillion and 11% global GDP is on p. 50 of IPES-Food, Unravelling the food-health nexus: addressing practices, political economy, and power relations to build healthier food systems, 2017, Global Alliance For The Future of Food and IPES-Food. World GDP (nominal) in 2014 was approximately US$75 trillion according to CIA, *The CIA World Factbook 2014*, Central Intelligence Agency (New York, 2013)., making US$3.5 trillion in 2014 about 4% of Global GDP. Estimates on the economic costs of undernutrition are US$1.4-2.1 trillion on p. 5 of the 2013 report FAO, *The State of Food and Agriculture 2013* (Rome: Food Agriculture Organization of the United Nations, 2013). http://www.fao.org/3/i3300e/i3300e.pdf. Adding global obesity costs of US$2.8 trillion from Dobbs et al., *Overcoming obesity : an initial economic analysis*. p. 1 and diabetes costs give an estimate of around 2014US$5 trillion. See also M. Tremmel et al., "Economic Burden of Obesity: A Systematic Literature Review," *International journal of environmental research and public health* 14, no. 4 (2017), https://doi.org/10.3390/ijerph14040435. Malnutrition valuations in FOLU, 2019, based on Afshin et al., "Health effects of dietary risks in 195 countries, 1990–2017: a systematic analysis for the Global Burden of Disease Study 2017." result in a figure of 5~6% nominal global GDP.

[6] FOLU, *Growing Better: Ten Critical Transitions to Transform Food and Land Use, The Global Consultation Report of the Food and Land Use Coalition.* https://blogs.worldbank.org/voices/do-costs-global-food-system-outweigh-its-monetary-value

account for externalities not costed into market transactions. Economic valuations which include externalities, so that markets can internalise them and incentivise a sustainable food system producing healthy nutritious food, can be a key component of change. Regulation, market, investment…all the mechanisms that exist, that are already highly developed for rapidly responding to financial gain and loss of value, could and should be brought to bear on reducing food impact.

Further argument for the case for true-cost, or full-cost, accounting for the food sector is made in the TEEB AgriFood Scientific and Economic Foundations Report[7]. Existing impact frameworks such as the Natural, and Social & Human, Capital Protocol and TEEB AgriFood Evaluation Framework use a natural, human and social capital approach to capture external costs[8]. They describe monetary and non-monetary valuation of changes to capital due to the activity of business, government and society. This report provides specific background and recommendations on advancing the practice of comparable monetary valuation of food system impacts. The existing impact frameworks are aligned. They are designed for universal application and describe steps for valuation such as setting the scope and acquiring data. They are not specific on comparable monetary valuation, however. The Protocols place no emphasis on comparability since they focus on internal decision-making within companies. This report does not consider universal application. The emphasis is on comparable valuations of the major external costs introduced by the food system for a limited number of uses aimed at contributing to food system transformation.

The term valuation in this report will mean an economic valuation – a monetary estimate. The term is used more broadly in both the TEEB framework and the Protocols[9], see p. 32 for alignment with the two frameworks. Monetary estimates are contentious. The report discusses a range of ethical considerations and sources of uncertainty in valuations. Monetary estimates do not imply ownership rights and amounts for exchanging ownership rights or responsibilities. For example, valuing changes to a river basin, positive or negative, does not imply that rights to any financial value produced by the river basin can be purchased for that amount or that an actor can pay that amount elsewhere in the economy in compensation for damaging the basin.

> The practical challenges of impact valuation are not academic. They can lead to significant underestimation, or overestimation, of [the cost of impacts].

The ability to compensate value loss and gain across capital stocks using money is a feature of financial capital but is limited for non-financial capital. This is one of the challenges that need to be addressed for comparable impact valuations. The practical challenges of impact valuation are not academic. They can lead to significant underestimation, or overestimation. In the case of underestimation of long-term and major issues as climate change and generational health impacts, society would find it has not abated enough impact. When the social costs increasingly start to be revealed, society receives a bill for a cost it thought it had covered with less time to pay the outstanding amount. For overestimation, society has incentivised alternative economic trajectories along with their opportunity costs that are not optimal. The result is a loss to livelihoods and economic development.

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[7] TEEB, *TEEB for Agriculture & Food: Scientific and Economic Foundations*.

[8] NCC, *Natural Capital Protocol*, Natural Capital Coalition (London, 2016). 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.. S. Whitaker, "The Natural Capital Protocol," in *Debating Nature's Value: The Concept of 'Natural Capital'*, ed. V. Anderson (Cham: Springer International Publishing, 2018).

[9] TEEB, *TEEB for Agriculture & Food: Scientific and Economic Foundations*. Chapter 7

Ambiguity in a valuation, non-disclosure, or a financial and accounting error, parallel for non-financial positions as the same issues would for financial positions. A financial balance sheet claiming revenue in place of profit would lead to significant error in the financial position of a company. Claiming positives without subtracting the underpinning cost or service provided by nature or society, or overvaluing offsets of negative externalities, lead to significant differences accounting for impact. Ambiguity and errors lead to an inability of parties to subscribe to and use valuations to discriminate company or product performance. Accounting and reporting developed throughout the 20th century to counter fraud and create a baseline of trust and comparison on which financial markets could operate and accelerate. Non-financial accounting must do the same, otherwise it becomes another ecolabel or another corporate responsibility exercise.

Accounting developed to counter fraud and create a baseline of trust and comparison on which financial markets could operate and accelerate. Non-financial accounting must do the same, otherwise it becomes another corporate responsibility exercise.

Potential ideological positions on either side of the uncertainty, or error, in an impact valuation are an add to the recipe for lack of confidence and use. The side against overestimation of the impact would usually be established business, laissez faire approaches, conservative governments and vested capital. The side against underestimation of the impact would usually be civil society, progressive governments and business, precautionary approaches, and advocates for food system transformation. Ideological positions combine with the inherent uncertainties in valuations of changes in non-financial capital for a further lack of confidence[10]. Monetary valuation raises additional ideological divisions on what can be valued and by whom.

Reports such as present one, with both business and civil society sponsors, argue for a common basis for valuations within specific uses. The aim is to increase confidence and use.

The ethical choices implicit in impact valuation and the large uncertainty lead the report to recommend a footprint protocol, formalising impact pathways, and a process for setting and updating marginal social and abatement costs with estimates of their uncertainty. A model is suggested utilising marginal social or abatement costs, with the potential for risk-based corrections using the estimates of uncertainty.

A process for performing impact valuation and an examination of that process, starting p. 45, applies to any set of material issues. A material issue in the private sector is a valuable aspect to specific stakeholders which are impacted by the activities of the food system actor. However, most of the challenges, and most of the need for comparable and agreed monetary impact valuations, lie in material issues for society as a whole as the stakeholder (Table 1, p. 24). These issues are where the largest opportunities exist, both for change in impact on society, and for those leading companies positioned for fundamental change within the sector. These issues indicate the major external costs introduced by the food system. Most of the emphasis in this report is on impact on society.

The need for comparable and agreed monetary impact valuations lie in material issues with society as stakeholder. These issues are where the largest opportunities exist, both for change in impact on society, and for those leading companies positioned for fundamental change within the sector.

[10] The array of estimates for the social cost of carbon illustrate: 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. 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.

Scope of the report

To summarise, the focus of the report is on a narrower scope within the setting of impact frameworks:

- Monetary valuation of changes in natural, social and human capital due to the activities food system actor, or the costs of avoiding those changes (an impact valuation).
- Comparable and agreed impact valuation associated to the major external costs introduced by the food system.

Table 1 on p. 24 lists a set of issues likely to represent the major external costs associated to the food system. This report recommends using valuation factors, or shadow prices, for spatial and contextual footprints linked to external costs. It argues for a spatial and contextual resolution to footprints that balances practical calculation with error in estimating impacts. It argues for a process to set and update valuation factors. Providing a list of recommended valuation factors or footprint metrics is beyond the scope of the report. Presently, without the process described and the resources to enable it, listing recommended valuation factors would result in no different outcome in terms of agreement and comparability than the array of valuation factors already in use.

This report is designed to complement two other reports within a broader initiative on true cost of food systems. The first, by IDEEA Group, is guidance for a general TEEB AgriFood evaluation without the emphasis on monetisation. The second, by TMG-ThinkTank for Sustainability and Soil & More Impacts, serves to inventory methods, databases, and case studies for true cost analysis within the TEEB AgriFood Evaluation Framework. The review of case studies and an inventory of methods mentioned in this report, compiled on p. 170, focusses on monetised and comparable valuations.

Users of the report

The report can assist the present and potential user groups of comparable and agreed monetary impact valuations:

Companies (food retailers, food manufacturers, agricultural producers, agricultural input suppliers)

Presently there are no standards [for impact reporting]. Companies develop their own format, their own methodology, or engage consultants, making it very difficult to compare between their non-financial positions.

- Impact valuations are used in reporting non-financial positions. They are monetary estimates of the impacts of changes in natural, social and human capital due to the annual operation of a company, usually in comparison to their financial position. The reports are variously called Impact statements, Impact reports, Integrated Profit & Loss, etc. For example, the Olam Integrated Impact Statement and Eosta's pilot IP&L[11]. Presently there are no standards. Companies develop their own format, their own methodology, or engage consultants, making it difficult to compare between their non-financial positions[12].

[11]Eosta's pilot IP&L: Eosta et al., *True Cost Accounting for Food, Farming & FInance*, Soil & More International (Hamburg, 2017). Olam Integrated Impact Statement is not yet publicly available. See https://www.olamgroup.com/content/dam/olamgroup/investor-relations/ir-library/annual-reports/annual-reports-pdfs/olam-annual-report-fy18_strategy_report.pdf#page=112

[12] 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-

- Internal risk assessment. Companies use internal carbon prices and scenarios to stress test their operations against potential introduction of legislation on carbon pricing in the economy[13]. Pricing from food impact valuation enables a more comprehensive risk assessment for the food sector.

Governments

- External costs of the food sector pose significant risk to society. Valuations, such as the social cost of carbon, estimate the non-optimality of economic performance and growth if the externalities are not internalised[14]. National governments subsidise foods that they, or other governments, pay for again in additional national healthcare costs. Valuations are not determinations of the best policy. Evaluation and decision making under uncertainty are wider topics involving ranking of options[15]. They enable mechanisms for internalisation and indicate where correction is required.
    - Fiscal intervention to correct optimality of a national economy. The amount of correction is informed by valuations. For example, Pigovian style taxation, and adjustment of tariffs and subsidies according to impact. Sugar taxes and meat taxes are fiscal interventions[16].
    - Regulation and incentives. For example, the proposed UK Environmental Land Management Scheme replacing EU basic farm payments where farmers who provide the greatest (environmental) benefit will receive the largest public funded payments[17].

> National governments subsidise foods that they, or other governments, pay for again in national healthcare costs

- Appraisals and evaluations, e.g. UK Treasury Green Book and the UK Social Value Act. Comparisons of policy options, tenders, and major project spending, that require consideration of environmental and social benefits and costs.
    - Public procurement of food. In the EU-28 about 5% of the food services revenue is for public catering (€25 billion in 2017), similarly about 5% of food production revenue is for public self-catering (€57 billion in 2017)[18].

Business-of-Food---Report.pdf. Reporting standards such as GRI and IIRC do not require comparable impact statements, e.g. "the primary thrust of <IR> [is] to enable each organization to tell its own value creation story" p. 23 IIRC, *Capitals Background paper for <IR>*, International Integrated Reporting Council (IIRC). Association of Chartered Certified Accountants (ACCA). Netherlands Institute of Chartered Accountants (NBA). (London, 2013), https://integratedreporting.org/wp-content/uploads/2013/03/IR-Background-Paper-Capitals.pdf.

[13] https://www.cdp.net/en/climate/carbon-pricing

[14] Chapter 7 (Box 10) discusses the economic dimensions of climate change and land particularly in the context of agriculture in IPCC, *IPCC Special Report on Climate Change, Desertification, Land Degradation, Sustainable Land Management, Food Security, and Greenhouse gas fluxes in Terrestrial Ecosystems*. See Table 7.2 and subsequent analysis in the same on policy and intervention options.

[15] M. Adler, "Cost-Benefit Analysis and Social Welfare Functions," in *Oxford Handbook of Ethics and Economics.*, ed. M. D. White (Oxford UK: Oxford University Press, 2019).

[16] S. W. Ng et al., "Did high sugar-sweetened beverage purchasers respond differently to the excise tax on sugar-sweetened beverages in Mexico?," *Public Health Nutrition* 22, no. 4 (2019), https://doi.org/10.1017/S136898001800321X. M. Springmann et al., "Health-motivated taxes on red and processed meat: A modelling study on optimal tax levels and associated health impacts," *PLOS ONE* 13, no. 11 (2018), https://doi.org/10.1371/journal.pone.0204139.

[17] D. Helm, "Agriculture after Brexit," *Oxford Review Of Economic Policy* 33, no. suppl1 (2017), https://doi.org/10.1093/oxrep/grx010.

[18] S. Calderia et al., *Public Procurement of Food for Health: Technical report on the school setting*, European Commision and Maltese Presidency (Malta, 2017).

Civil society

- Valuations bridge communication and advocacy for food system transformation with consumers in terms of costs, and with the governments in terms of economic governance and fiscal and regulatory policy. For example, Sustainable Food Trust's report on "The Hidden Cost of UK Food"[19].
- Comparable impact valuations allow ranking of food companies based on environmental, social and human health performance – a "total impact scorecard". Companies are responsive to ranking initiatives, e.g. WWF Palm Oil Buyers Scorecard.

Investors

> Impact valuations are a direct way for investors to compare environmental, social and human health performance of food companies.

- Environmental and Social Governance (ESG) criteria and performance. Comparable impact valuations directly compare environmental, social and human health performance of food companies.
- Portfolio building. Comparable valuations can be aggregated to understand impact performance of a portfolio[20].
- Impact performance can be built into bonds. Valuations can be used as criteria, or set levels of return, based on impact performance. If built on comparable agreed valuations, investors could understand the relative value between different impact bonds and have confidence in impact reduction achieved.

Food system impact valuation community

- Contribution to development of products, including footprint metrics and marginal valuations.

Consultants

- Many accounting and economic services firms now perform true value or impact valuations on behalf of companies, governments and civil society[21].

Offset markets

- Carbon markets allow carbon trading. Trading theoretically increases economic opportunities, economic activity, and overall efficiency of emissions reduction. Carbon as a globally tradeable commodity is possible because of carbon's global impact. One tonne of carbon saved from emission anywhere in the world reduces the impact everywhere in the world. For food systems, CO2-eq emission is not the only footprint of concern. Offset markets are more complicated and more local for water, for nutrient pollution, for community damage, and for human health. For food system impact beyond CO2-eq emissions the spatial and contextual footprints and valuation factors recommended in this report have applications in offset markets.

[19] https://sustainablefoodtrust.org/articles/hidden-cost-uk-food/

[20] p. 23 A. Millan, B. Limketkai, and S. Guarnaschelli, *Financing the Transformation of Food Systems Under a Changing Climate.*, CGIAR Research Program on Climate Change, Agriculture and Food (Wageningen, the Netherlands, 2019), https://hdl.handle.net/10568/101132.

[21] KPMG True Value https://home.kpmg/nl/en/home/services/audit/sustainability/true-value.html; EY Total Value https://www.ey.com/Publication/vwLUAssets/ey-total-value-impact-valuation-to-support-decision-making/$FILE/ey-total-value-impact-valuation-to-support-decision-making.pdf; PWC Total Impact Measurement & Management https://www.pwc.com/gx/en/services/sustainability/total-impact-measurement-management.html; Impact Institute https://www.impactinstitute.com/; etc.

Chapters 9 and 10 of the TEEB AgriFood Evaluation Framework, *TEEB for Agriculture & Food: Scientific and Economic Foundations*, discuss further uses of impact valuation and true-cost accounting.

Structure of the report

The sections of the report are outlined below. Progressing from the why of monetised and comparable impact valuations to the practice and the implications:

- Economic theory of change
    - *Why and how impact valuation can create change in the food system*
- Alignment with impact frameworks
    - *"Measure and Value" within the TEEB Agri-Food Framework and the Natural, and Social & Human, Capital Protocols*
- Valuation in practice
    - *Carbon costing as an introduction to marginal social and abatement costing of carbon footprints*
    - *Components of an impact valuation based on footprint, capital changes and valuation of the capital changes, superimposed on the "Measure and Value" steps*
    - *Consideration of marginal social and abatement costing for food system impact valuation, including inherent ethical choices and uncertainty*
- Case studies
    - *Examples of food system impact valuations and an illustration of the variation in marginal social and abatement costs and footprints chosen*
- Methods
    - *A discussion on the development of impact valuation, arguing for the movement toward spatial and contextual footprints and marginal valuations*
    - *An inventory of the data, models and methods mentioned in the report for footprint and impact calculation*
- Implications
    - *Challenges in the practice of impact reporting, being aware of them so they can be covered in the present and addressed in the future*
    - *Equity statistics to be reported alongside impact reporting concerning substitution of economic value*
    - *Efficiency in footprint reduction and offset markets*

Glossary

The TEEB AgriFood Evaluation Framework, and the Natural and Social & Human Capital Protocols, consider capitals as a broader notion of resources. Resources which themselves provide goods and services that interact with human production and consumption. Value and social and human well-being have a long history of discussion and conceptual development in economics. Valuations are usually in terms of social and private costs from welfare economics. A few associations are required between terms used in the capitals framework and terms from economics.

<u>Abatement cost:</u> monetary cost to reduce social costs from capital change. Can also refer to the minimal monetary cost to reduce social costs to a certain level given a costed portfolio of actual or potential abatement measures.

> <u>(Marginal) abatement cost of carbon (MAC):</u> the minimal cost to reduce social costs from the emission of an additional tonne of CO2eq over a specified emissions target.

Implies a costed portfolio of actual or potential measures that can avoid or sequester CO2-eq emission.

Accounting: can relate to physical or inventory accounting, e.g. changes in in the quality and quantity of capital due to actor activity. Can relate to monetary accounting, e.g. the monetary valuation of inventories. Valuation is the step from physical to monetary accounting; it is not immediate for non-financial capital. We keep the conceptual distinction between physical and monetary accounting.

Attribution: capital change due to the activities of a set (an individual or group) of food system actors.

Capital: a source of value having the attributes of quantity and quality.

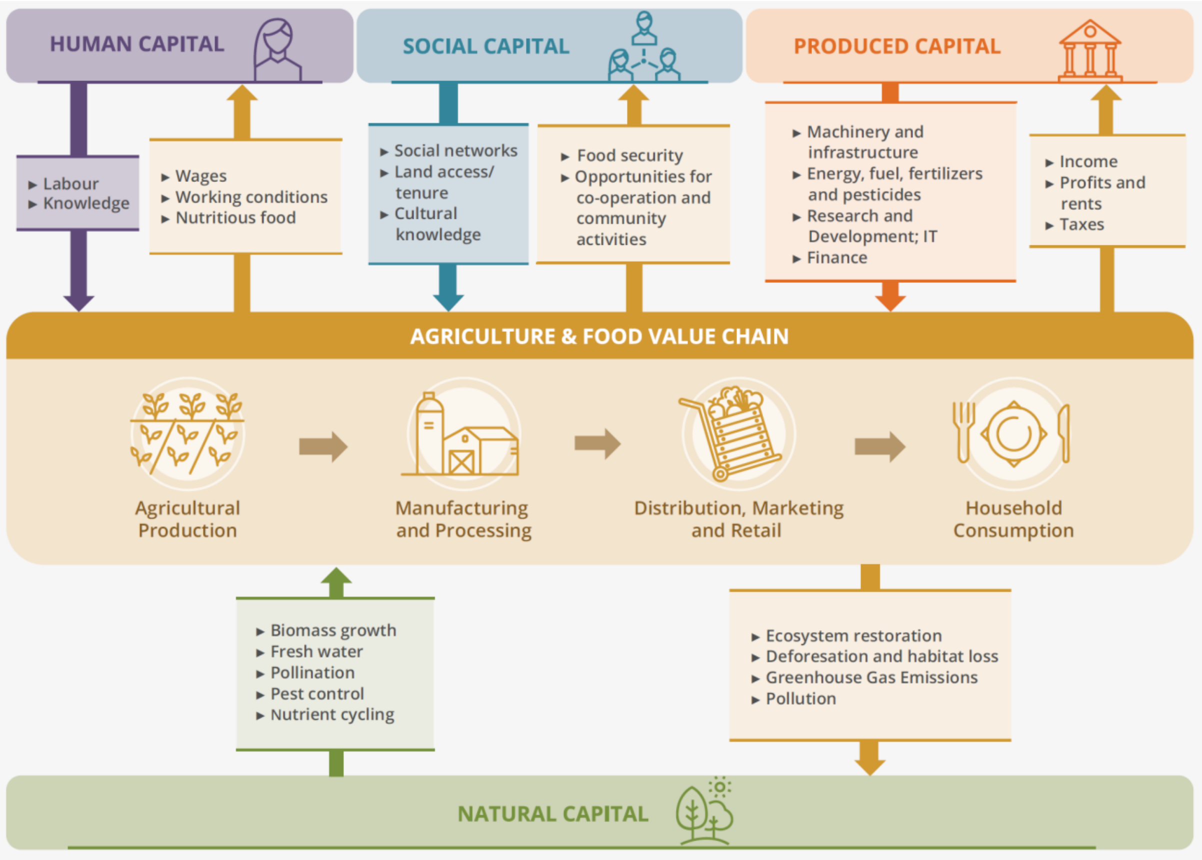

Figure 1: Value flow and capital stock exchanges in the food system (Source: TEEB, *TEEB for Agriculture & Food: Scientific and Economic Foundations* p. 12)

The TEEB AgriFood Evaluation Framework (Figure 1), following the UN Inclusive Wealth Report, Dasgupta (2015), and the International Integrated Reporting Council (IIRC) Task Force[22], considers four categories of capital:

natural capital: the limited stocks of physical and biological resources found on earth, and of the limited capacity of ecosystems to provide ecosystem services;

[22] Definitions of the four capitals quoted from TEEB, *TEEB for Agriculture & Food: Scientific and Economic Foundations*. UNEP, *Inclusive wealth report 2018 : measuring progress towards sustainability* (Cambridge: Cambridge University Press, 2018). See also P. Dasgupta, "Disregarded capitals: what national accounting ignores," *Accounting and Business Research* 45, no. 4 (2015), https://doi.org/10.1080/00014788.2015.1033851. IIRC, *Capitals Background paper for <IR>*. NCC, *Natural Capital Protocol*; S&HCC, *Social & Human Capital Protocol*.

produced capital: all manufactured capital, such as buildings, factories, machinery, physical infrastructure (roads, water systems), as well as all financial capital and intellectual capital (technology, software, patents, brands, etc.);

social capital: encompasses networks, including institutions, together with shared norms, values and understandings that facilitate cooperation within or among groups;

human capital: the knowledge, skills, competencies and attributes embodied in individuals that facilitate the creation of personal, social and economic well-being.

There is some variability on how to arrange a taxonomy of capitals. If we refer to produced and financial capital together, it will mean we highlight financial capital categorised within produced capital.

Capital change: net change in quantity and quality of capital stock. Also called an outcome in the TEEB AgriFood Evaluation Framework.

CO2-eq: Carbon dioxide equivalent represents the amount of CO2 that would have the same global warming potential (radiative forcing) when measured over 100 years in the atmosphere of a given greenhouse gas.

Compensatory transfer: a transfer of economic value (loss) from one set of economic actors to another set (gain) for which the losing actor(s) are willing to accept a financial value in compensation from the gaining actors.

Dependency: private cost or benefit to one set of economic actors from capital changes due to the activities of another set of economic actors.

Dependency valuation: monetary measurement of the dependency of one set of economic actors due to the activities of all economic actors.

Economy: a system of actors producing, exchanging, and consuming goods and services, utilising capital to produce economic value.

Economic efficiency: optimal production of economic value from capital in an economy.

Economic value: that which economies seek to produce. Has a long philosophical history. Associated to welfare in welfare economics in that economic efficiency seeks to maximise welfare of economic actors and society. Welfare is measured in terms of utility of actors and social welfare functions, which are not generally monetary. In a perfect market, prices and quantities resulting from frequent transactions of economic actors in that market result in optimal welfare (First Welfare Theorem). Market failures like externalities means that market prices and quantities may not represent optimal welfare. A wider measure of welfare would include more social and human well-being indicators. Distinct from financial value.

Economic valuation: monetary estimate of economic value. For comparison with financial value. A financial value can be an economic valuation. An amount in an economic valuation cannot necessarily be substituted with the same amount in another economic valuation. This would be equivalent to exchanging economic value (welfare) which may raise or lower total economic value, e.g. the social welfare function is not invariant under the substitution. An implication is that an amount in an economic valuation cannot necessarily be substituted with an amount of financial value. Monetisation of costs and benefits does not necessarily imply substitution of costs for benefits.

Externality (negative): capital change with an external cost due to the activity of a set of economic actors but not borne by them directly (the social costs exceed the private costs to that set of economic actors from capital changes due to their activities). A boundary is implied in an externality, it is external with respect to the set of economic actors.

Externality (positive): capital change with an external benefit due to the activity of a set of economic actors but not received by them directly (the social benefits exceed the private benefits to that set of economic actors from capital changes due to their activities).

Financial capital: ownership of financial value (assets such as stocks, deposits, bonds, etc.) that can produce, of itself, value flows. Some financial assets derive financial value from association to other capitals (stocks represent financial value of produced capital, derivatives are linked to physical commodities, etc.). Quality of financial capital can include return rate and risk. Financial capital changes can result in changes in financial value and, through impact, changes in economic value.

Financial efficiency: optimal production of financial value from capital in an economy.

Financial value: monetary amount calculated from prices and quantities in a market. Market value is financial value.

Food sector: agri-food sector, and agriculture sector, fisheries and food & beverage sector, are used synonymously.

Food system: A food system gathers all the elements (environment, people, inputs, processes, infrastructures, institutions, etc.) and activities that relate to the production, processing, distribution, preparation and consumption of food with outputs to and inputs from produced, natural, social and human capital (Figure 1). Called eco-agri-food system in the TEEB AgriFood Evaluation Framework.

Footprint: quantities that produce non-financial capital changes which then produce impact. Called the actor's impact drivers in the Protocols. It is a subset of flows in the TEEB AgriFood Evaluation Framework. The footprint of a food system actor is not the only driver of impact. Impact valuations will differ depending on the footprint of other businesses and society. Impact valuations will also differ depending on exogenous drivers such as population growth, urbanisation, social and political dynamics. For example, the social cost of carbon depends on a choice of emission scenario, biophysical responses, and socio-economic scenario. Footprint accords with familiar terms such as carbon footprint and water footprint.

Impact (on welfare): change in welfare from capital changes. TEEB and the Protocols consider impact on human well-being which is treated as synonymous to a wider sense of welfare.

Impact assessment: as per impact evaluation. Some studies labelled impact assessments refer to impact on capital, meaning measurement of the capital change not the welfare change.

Impact evaluation: measurement of the impact attributable to food system actor(s), not necessarily monetary.

Impact valuation: monetary measurement of the impact attributable to food system actor(s). Equivalently, valuation of the change in economic value from capital changes due to food system actor(s).

Internalisation (of an externality): adjustment affecting the transactions of a set of economic actors (taxes, subsidies, better information, re-allocation of quantities, self-dependencies, etc.) which reflects the external benefits and costs from those transactions before adjustment. The intention of internalisation is that financial efficiency (optimising financial value) in the adjusted market is closer to economic efficiency (optimising economic value).

Investment: utilisation of financial capital to increase quantity or quality of capital stock.

Material issue: a valuable aspect to specific stakeholders which is impacted by the activities of food actor(s). In the TEEB AgriFood Evaluation Framework, a dimension of well-being under impact. Area of protection in lifecycle impact assessment (LCIA).

Material issue for society: globalised impact or material issues of local or regional impact occurring concurrently and with a present or future effect on global value flows.

Non-compensatory transfer: a transfer of economic value (loss) from one set of economic actors to another set (gain) which is not compensatory.

Parity: a means to compare economies for equivalence of economic or financial value; e.g. exchange rates compare financial capital between national economies, purchasing power parity compares consumption of produced goods between national economies, Ramsay discount rates compare future economies with present economies, etc.

PPP: purchasing power parity, which is the rate at which the currency of one country would have to be converted into that of another country to buy the same amount of goods and services in each country. Based on bundles of good and services set and tracked by the World Bank International Comparison Program.

Private benefit: increase in economic value to a set of economic actors from a capital change. Estimated in monetary terms by an economic valuation of the increase.

Private cost: decrease in economic value to a set of economic actors from a capital change. Estimated in monetary terms by an economic valuation of the decrease.

Self-dependency: private cost or benefit to a set of economic actors from capital changes due to the externalities of that same set of economic actors, e.g. a food company's activities are attributed to obesity and diabetes, which raises health insurance (the externality), which raises the costs of health insurance that the food company pays on behalf of employees. As another example, a food company's emissions create environmental change, lowering yields globally of certain commodities which it uses, which increases price from its suppliers due to reduced global supply. Equivalently, a private cost or benefit of a set of economic actors that would not exist without external costs produced by that set of economic actors.

Shadow price (of a footprint quantity): change in economic value from capital changes due to one additional unit of the footprint quantity.

Social benefit: increase in economic value to society from a capital change. Estimated in monetary terms by an economic valuation of the increase.

Social cost: decrease in economic value to society from a capital change. Estimated in monetary terms by an economic valuation of the decrease.

> (Marginal) social cost of carbon (SCC): the social cost resulting from capital changes due to the emission of an additional tonne of CO2-eq. The social cost of carbon is a marginal social cost, meaning social cost per unit of a quantity, see shadow price.

Stock: a quantity of capital.

Value flow: economic value produced from capital, a combination of its quality and change in quantity.

Values: Alignment of economic systems with value systems is outside the scope of the report. For the report's purposes values are defined by economic value. In the TEEB AgriFood Evaluation Framework value is defined already by conceptual economies and economic and financial value: "the worth of a good or service as determined by people's preferences and the trade-offs they choose to make given their scarce resources, or the value a market places on an item".

Measuring all the capital changes due to activities of the food system would be difficult and unnecessary in terms of correcting the major market failures. Material issues for society represent beliefs based, in the case of food systems, on scientific consensus about what components of activities in the food system produce the most difference in economic value for society. Concentrating on those issues restricts the measurement of capital changes and footprints to those believed to be causing most of the impact.

ECONOMIC THEORY OF CHANGE SUMMARY

Matching supply and demand in markets provides a dynamic to what humans produce and consume. Whether it is the local farmer market, the supermarket, or the Chicago Mercantile Exchange. Present activities in the food sector that lead to external costs from damaging nature, communities and human health, are largely determined by markets. The economic theory of change is that factoring external costs into markets leads to changes to food system activities with reduced impact. Factoring external costs into a market is called internalisation.

Internalising the external costs can have winners and losers. Unable to compete, companies and industries that are not able to adapt when external costs are internalised are replaced by new ventures or industries that provide greater value in the adjusted market.

Impact valuation estimates the external costs in order to inform internalisation. Impact valuation can also indicate who incurred the costs and what food system activities they originate from.

The economic theory of change is a theory. It is not clear how business and consumers will respond to reintroduced costs, and what will be the follow-on effects for other sectors. Removing one food system impact may create another impact which is larger. This is called the theory of second best.

There are many mechanisms for internalisation. From awareness raising to interventions such as taxation. Three categories of internalisation are found relevant to impact valuation and impact reduction:

- No internalisation or already internalised. Reduction is a by-product of pursuing efficiencies in the existing market.
- Internalisation through dependency on capital changes and external costs. Reduction results from an internal correction in food companies or consumer groups costs and benefits due to the consequences they experience. The food sector adjusts itself.
- Internalisation through value correction or intervention. Reduction results from an external market adjustment.

The aim of harnessing market dynamics is that impact reduction becomes a by-product of efficiencies in the adjusted market. Comparable impact valuation has uses in the first two categories but is needed particularly for the third category.

The report finds it unclear what available efficiencies and present dependencies will contribute to global food system impact reduction targets identified by the scientific community. It recommends research to understand the amount of reduction in impact available through efficiencies and dependencies in the present market, and what must be achieved through interventions. It also recommends more research on: i) dynamic economic modelling of the follow-on consequences from large fiscal or policy interventions in the food system suggested by impact and attribution studies; and ii) economic trajectories for food system transformation.

Realising market corrections requires synergy between a triad of food system science, economics and users. A short survey of current activity around the triad shows a body of existing activity. Some of the hurdle to realising market corrections lies in establishing a network bringing the triad closer together, and investment that enables the community to develop and promote measures for economic correction of food system impact at scale.

ECONOMIC THEORY OF CHANGE

That impact valuation can reduce the impacts of food systems rests on an economic theory of change.

In welfare economics the purpose of an economy is to maximise economic value from the utilisation of capital. Economic value has a long philosophical history. Following the approach of the TEEBAgriFood Framework and the Natural and Human Capital Protocols we use economic value synonymously with welfare and human well-being in a broad sense[23]. The conventional sense of welfare is the satisfaction of aggregated individual utilities by produced goods. Even the conventional sense of welfare can indicate that market failures created by the food system can lead to a lower economic value than might otherwise be possible, and that internalisation of the external costs produced by the food system could lead to higher economic value.

Externalities and economic efficiency

Financial markets operate to achieve a market price where the quantity of goods and services supplied matches the quantity of goods and services demanded. Matching supply and demand give financial markets a natural dynamic which can be harnessed.

However, the dynamic of markets, which leads to maximising profit to individual firms and economic value (benefit) to consumers involved in those transactions (market surplus), can lead to increased financial value but may not lead to increased economic value to society.

Capital changes caused by activities associated to transactions may affect others not involved in the transaction. The positive changes in economic value to society from the capital changes are called the social benefits, and the negative changes the social costs. Similarly, positive and negative changes to those involved in the transaction are called the private benefits and costs. A negative externality is when the social costs exceed the private costs to that set of economic actors from capital changes due to their activities, similarly for positive externality. A boundary is implied in an externality, it is external with respect to the set of economic actors involved in the transaction. The external costs and benefits (the difference between the social costs and benefits and the private ones) have been produced by the

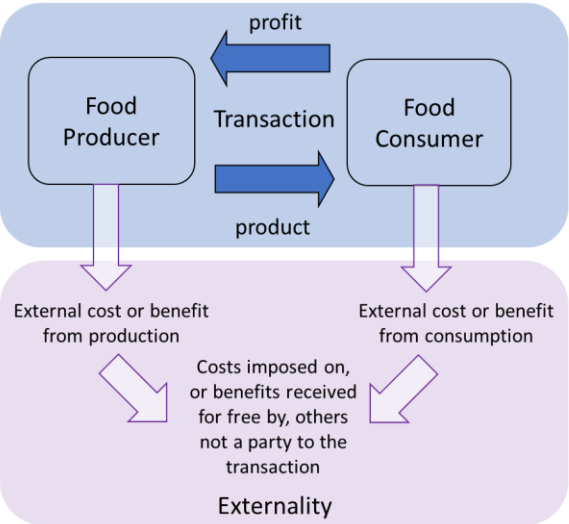

Figure 2: External cost or benefit

[23] p. 6: B. Sandelin, H.-M. Trautwein, and R. Wundrak, *A short history of economic thought*, 3rd ed. (London: Routledge, 2014); J. A. McGregor and N. Pouw, "Towards an economics of well-being," *Cambridge Journal of Economics* 41, no. 4 (2016), https://doi.org/10.1093/cje/bew044; R. K. Turner, I. Bateman, and D. W. Pearce, *Environmental economics : an elementary introduction* (New York-London: Harvester Wheatsheaf, 1994). S. Parks and J. Gowdy, "What have economists learned about valuing nature? A review essay," *Ecosystem Services* 3 (2013), https://doi.org/https://doi.org/10.1016/j.ecoser.2012.12.002. P. Dasgupta, *Human Well-Being and the Natural Environment* (Oxford: Oxford University Press, 2002). The concept of total economic value which includes the broad sense of welfare and intrinsic value is applied in the ISO 14008:2019 standard on monetary valuation of environmental impacts https://www.iso.org/obp/ui/#iso:std:iso:14008:ed-1:v1:en.

activity of a set of economic actors but are not borne by them directly[24].

Economists distinguish between financial, or market, efficiency and economic efficiency. The presence of externalities means that movements to maximise market surplus (a financial efficiency gain) may not lead to increased economic value to society (an economic efficiency gain). A market failure is when a financial efficiency gain from the transactions of a set of economic actors is not an economic efficiency gain.

Externalities are not the only market failures. Poor information means the actors may not realise their own missed private benefits and costs, or actors may not behave in ways that accord with measures of economic value associated to rational behaviour. These factors distort transactions (price, supply, demand in market) so that the dynamics of the market may result in a financial gain which is not a gain in economic value. Healthcare costs as a result of food consumption provide examples of consumer difficulty in assessing economic value to themselves, see footnote 26. Most of the focus of impact valuation is on external costs produced by food system actors, rather than correcting consumer assessment of private costs and benefits.

Internalisation reflects the external benefits and costs from the transactions of that set of economic actors back into their private benefits and costs (taxes, subsidies, better information of dependencies on externalities, re-allocation of quantities, etc.). The intention of internalisation, and correcting market failures in general, is that financial efficiency (optimising financial value) in the adjusted market is closer to economic efficiency (optimising economic value), and the natural dynamic in markets is harnessed to produce change that increases economic value.

That is the general theory. We provide examples of externalities and efficiency gains with the food system and food system transformation in mind[25]. The question is whether internalisation that reduces the impacts of the food sector can be achieved by the food sector itself because of its dependencies on its own external costs, or whether external corrections are required.

Financial efficiency gain in the transactions of food system actors may result in the reduction of food system impacts without internalisation. Changing to LED bulbs saves electricity costs for a firm above the original purchase of the light and produces the same light. This lowers input costs with no change in the quality or quantity of the output products that are consumed. A food processing factory which uses food waste to produce energy is a financial efficiency gain for the company if the saved electricity and waste disposal costs outweigh new infrastructure costs. Voluntary reduction of packaging with lower net cost without losing properties of storage and consumer acceptability is a financial efficiency gain for the company and the consumer. Farmer education where the same yield with the same quality can be obtained with less fertiliser, and so less fertiliser input costs, is a financial efficiency gain for the farmer.

Decreasing food loss and waste, where the cost of the measures to prevent harvest or stock loss and waste are outweighed by the sales value of the saved harvest or stock is a financial efficiency gain for the value chain. An app connecting food consumers to food that would be wasted and saving disposal costs to the producer is a financial efficiency gain for producer and consumer. The consumer voluntarily changing their demand away from fertiliser and water

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[24] D. W. Pearce and E. Barbier, *Blueprint for a sustainable economy* (London: Earthscan, 2000).
[25] C. Rocha, "Food Insecurity as Market Failure: A Contribution from Economics," *Journal of Hunger & Environmental Nutrition* 1, no. 4 (2007), https://doi.org/10.1300/J477v01n04_02. J. A. Caswell, "Rethinking the Role of Government in Agri-Food Markets," *American Journal of Agricultural Economics* 79, no. 2 (1997), https://doi.org/10.2307/1244166. T. M. Bachmann, "Optimal pollution: the welfare economic approach to correct market failures," in *Encyclopedia on Environmental Health.*, ed. J. Nriagu (Burlington: Elsevier, 2011).

intensive foods, such as intensively farmed beef and lamb, to lower input foods, at the same time food sector firms have the capacity to voluntarily alter production such that lower input costs cover the cost of transition, is a financial efficiency gain. In all cases, consumers get the same or higher value product, and the producer receives higher total profit. There are wider market implications to these changes, but, for the present discussion, the market is the actors involved in the transaction. Financial and economic efficiency depends on the boundary chosen for the transaction, the parties and activities associated to the transaction, and the calculation of costs and benefits for the parties.

In each of the examples, reduction in external costs associated to food system impact (social costs resulting from CO2eq emissions from production, nitrogen and phosphorus leakage from fertiliser, water use, etc.) occurs as a by-product of a financial efficiency gain in the narrow scope of business input costs and output consumption value. Private benefits are abating social costs.

It is not clear if enough financial efficiency gains are available now or in the future to reduce food system impacts to the targets that science considers sustainable.

Cost to third parties from CO2eq emissions during food production is currently an externality. Cost to third parties from nutrient changes in waterways from fertiliser run-off is an externality. Healthcare cost of consumption borne by public money in a third country to the taxes paid by production are an externality[26]. Cost or benefit to a community from use of infrastructure paid for by business from profits is an externality.

The external effect can be positive or negative. CO2eq emissions can have benefits through increased arability or plant growth in higher latitudes. The net social cost or benefit absorbed into present or future economies is the concern of impact valuation.

The term net already introduces an issue. For example, how can healthcare burden from poor diets paid in Samoa, a negative externality, be substituted by social benefits from taxes and wages, a positive externality, associated to revenue from products sold in Samoa received by parent firms in the United States? Unless the transaction of the purchase of the food products includes social costs and benefits, so that the transfer of an economic value loss in Samoa to an economic value gain in the United States is being accepted in the exchange by the Samoan consumer as the bearer of the negative externality, how is the commensurability of the external cost to one actor and the external benefit to another established? Only when the values are commensurable can one social cost be subtracted from another social benefit to obtain a net social benefit or cost. Economics has for over a hundred and twenty years (there are also references to the concept in Aristotle), and continues to, debate ideas about value and it features in discussions of value in exchange versus value in use[27].

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[26] Health care costs borne by the consumer of the food product is a private cost. The potential market failure in private costs to consumers is the lack of information or otherwise impairing the ability of the consumer to weight their own value between pleasure and sustenance in food consumption now and impaired health at a future time. When those private costs become a wider burden on social resources and have social effects, that is the externalised cost. In a publicly funded health system such as the UK NHS, healthcare costs become immediate social costs. An external cost in the US healthcare system would be rising health insurance through pooling risks and private costs, or crime and other social effects to support high private costs.

[27] Sandelin, Trautwein, and Wundrak, *A short history of economic thought*. Substitution between different forms of capital is discussed extensively in sustainable development economics, under “weak” and “strong” sustainability. Weak sustainability, which assumes the ability to substitute between produced and other capitals on the premise that the increased produced capital gains will later allow recover of damage to other capitals is highly contested: K. J. Arrow et al., "Economic growth, carrying capacity, and the environment," *Science* 268, no. 5210 (1995),

Valuations of external costs need to be careful about existing boundaries and existing transactions. Externalities and other market failures are well studied[28]. Economic actors pay taxes and governments use revenue to provide public benefits, e.g. an educated workforce and use of public infrastructure. Companies claiming social benefits from tax paid need to account for the social benefits they receive as well. Similarly, companies provide products to society. The value of those products to society (nutrition, pleasure, sustenance, etc.) are reflected in demand. Demand increases the marginal value received for output. Hence the value provided to society by companies is captured, probably in the most part, in revenue. A positive externality, by definition, must not already be captured in private costs or benefits. Asymmetry in positive and negative externalities is likely a feature of business. Present business practice seeks to capitalise on benefits provided and internalise them into revenue while externalising cost.

If the external costs of food systems outweigh the external benefits, and it is unlikely that financial efficiency gains available in the current market will significantly reduce external costs, then intervention can adjust financial efficiency gain to align with reducing food system impacts. Internalisation may or may not result in an increase in economic value overall, so it is a theory of change[29]. The details and context of the intervention need to be considered.

Internalisation reintroduces (some part of) the external costs into the consideration of private benefits and costs for the transactions of the food system actors that produced the external costs. The food system has long value chains, so where in that value chain and what form the internalisation takes in order to adjust production, demand and prices requires detailed consideration. It is becoming accepted by progressive businesses and civil society that the “true cost” of food is not being paid. It is still debated who and where in the value chain the “true cost” should be paid.

Subsequent private benefits and costs from a producer and consumer’s own externalities can reintroduce external costs back into their private benefits and costs. If subsequent private benefits and costs are considered, then market efficiency gains may drive changed behaviour to reduce externalities. Examples are when a food company’s outputs are attributed to obesity and diabetes, which raises health insurance (the externality), which raises the costs of health insurance that the food company pays on behalf of employees. The social costs of poor health also create lobbying costs for food companies, which may exceed the opportunity costs of changing production. As another example, a food company’s emissions create environmental change, lowering yields globally of certain commodities which it uses, which increases price from its suppliers due to reduced global supply. The subsequent private benefits and costs would not be present without the external costs (Figure 3 on p. 19).

These reintroductions are called dependencies in the Natural Capital Protocol, see also Section 2.3.2 of the TEEB AgriFood Scientific and Economic Foundations Report[30]. Change

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https://doi.org/10.1126/science.268.5210.520. G. R. Davies, "Appraising Weak and Strong Sustainability: Searching for a Middle Ground," *Consilience*, no. 10 (2013), www.jstor.org/stable/26476142..

[28] A. Marciano and S. G. Medema, "Market Failure in Context: Introduction," *History of Political Economy* 47, no. suppl 1 (2015), https://doi.org/10.1215/00182702-3130415. J. E. Stiglitz, "Markets, Market Failures, and Development," *The American Economic Review* 79, no. 2 (1989).

[29] The theory of second best means that market corrections in one sector when there are uncorrected market distortions in another sector may not lead to an increase in economic value overall: R. G. Lipsey and K. Lancaster, "The General Theory of Second Best," *The Review of Economic Studies* 24, no. 1 (1956), https://doi.org/10.2307/2296233.

[30] Business will also seek through market efficiency to reduce dependency on the externalised costs of business other than their own. Such a reduction does not necessarily reduce the externality for society. For example, shifting production to another country once capital is degraded (by others) in the present

in consumer demand due to raised awareness by civil society is also a dependency, e.g. antibiotic use, deforestation for palm-oil, etc. Externalities borne by economic sectors on which the food sector depends are dependencies. The more direct the dependency of the already monetised produced and financial capital on the external cost, the easier it is to value the externality. The Natural Capital Protocol discusses dependencies of businesses on natural capital with food sector examples[31].

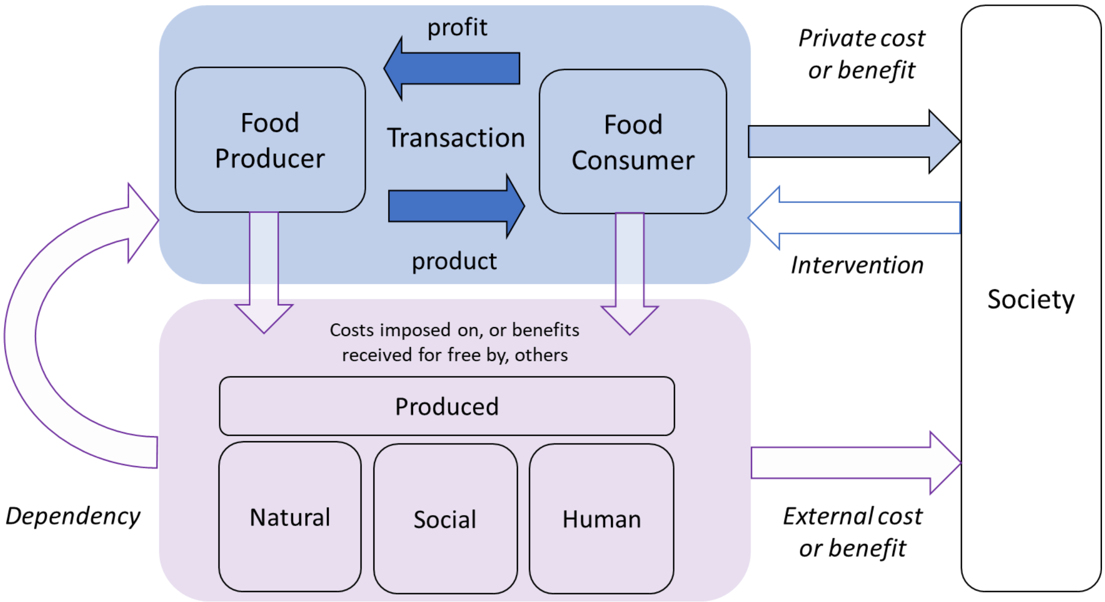

Figure 3: Internalisation of externalities through dependency or intervention

It is unclear, as it was for purely financial efficiency gains, if present or future feedbacks to the market of dependencies of food system actors on the external costs they create are sufficient to reduce food system impacts to the targets that science considers sustainable. With international trade and long value chains, there are many examples in the food system where external costs accrue in one location or community with weak dependency on private benefits in transactions of retailers and food consumers in other locations and communities. In the case of health insurance, the premium rise is pooled across all sectors. The premium rise as a private cost to the food company is unlikely to compare to the revenue from selling the food products.

Reputational damage, demand change, the threat of regulation, and investor concern appear to be the strongest feedbacks presently. Awareness raising of food system impacts by civil society performs a potential economic efficiency gain since demand change connects external costs to private benefits. As the disparity between costs and benefits becomes extreme, e.g. political insecurity in nations bearing external costs begins to create social costs for businesses or consumers receiving private benefits, the dependency strengthens. However, waiting for the dependency to manifest through very large welfare changes is less than optimal for maximising welfare.

location. Loss of taxes and value from production in the original locality which may or may not be compensated by taxes and production in the new locality become part of the cost of the original externality, in addition to the existing capital change. Unless the cost becomes linked to the externality producer, i.e. the externality producer has a dependency on their own externality, market efficiency may not provide a reduction of the externality to society.

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

When the dependency is a weak signal to revenue and cost the likelihood the externality will be internalised through dependency is low. In this case market efficiency gains cannot be harnessed to drive reduction in impact. When externalities accumulate at the societal level, then society intervenes in transactions to create a new dependency or amplifies existing dependencies (Figure 3). For example, the costs of CO2-eq emissions are uncertain and will occur over a long time period. Advocacy by civil society of the accumulated impacts of climate change increases the risk of being regulated or litigated, and reputational harm and revenue loss due to not responding to societal demand and value changes. As another example, a national government introduces an emissions tax, intervening in the market to reduce the externalities at the societal level. Governments and civil society are not the only interventionists concerned with accumulated effects of external costs. Investors experience accumulated effects. In terms of amplifying dependencies, nature intervenes through desertification, droughts, heatwaves, extreme weather. Communities intervene through riots and uprising.

Role of valuations in internalising externalities

Impact valuation estimates the external costs in order to inform internalisation. Impact valuation can also indicate who incurred the costs and what food system activities they originate from. The estimates can inform the calculation of private costs and benefits of the actors in the food system responsible for the costs. The estimates can also inform market corrections by external actors.

Value is uncertain, and it is estimated rather than known. It is unlikely that market price and proxies to market price are good estimators of marginal value for natural, social and human capital change of the scale of the impact of the food system.

Value is uncertain, and it is estimated rather than known. In the situation of frequently transacted goods in exchange markets with large amounts of information, and where externalities are mostly internalised (e.g. existing regulation or an established area of litigation), price multiplied by quantity becomes an estimator of value. It is unlikely that market price and proxies to market price are good estimators of marginal value for natural, social and human capital change of the scale of the impact of the food system. Proxies to market price are derived from valuation methods that estimate the trade-offs of individuals[32]. The trade-off is between the capital change and a monetary amount directly or between a capital change and market substitutes. When dependencies that affect individuals are uncertain and in-direct, and capital changes are occurring simultaneously globally, it unclear that individuals have either the information or the ability to assess trade-offs of equal economic value to society. Valuation of external costs is a challenge. Impact valuation in practice is discussed further from p. 48.

What is discussed here is that dependencies that are uncertain and indirect are prevalent for food system impact. The connection between those that produce the external cost (the source of impact) and those that bear it (the receiver of impact) is called the impact pathway. Impact pathways for the food system can be long and complex.

Three categories of internalisation for reduction of food system impacts from externalities have been discussed:

[32] National Research Council, "5: Economic methods of valuation," in *Perspectives on Biodiversity: Valuing its role in an everchanging world* (Washington DC: The National Academies Press, 1999). D. N. Barton et al., *Discussion paper 5.1: Defining exchange and welfare values, articulating institutional arrangements and establishing the valuation context for ecosystem accounting. SEEA EEA Revision. Version 25 July 2019.*, United Nations Statistics Division (New York, 2019).

- No internalisation or already internalised. Reduction is a by-product of market efficiency gain in the existing market.
- Internalisation through dependency on capital changes and external costs. Reduction results from an internal correction in food companies or consumer groups of costs and benefits. The food sector adjusts itself.
- Internalisation through value correction or intervention. Reduction results from an external market adjustment to align market efficiency gain with an external calculation of economic gain with a wider sense of welfare.

The implication we conclude from long and complex impact pathways is that it is unlikely internalisation created by present dependencies will provide a major reduction in impact. Intervention to establish more direct dependencies or amplify existing dependencies would increase the contribution to food system transformation.

Internalising the external costs can have winners and losers[33]. Unable to compete, companies and industries that are not able to adapt when external costs are internalised are replaced by new ventures or industries that provide greater value in the adjusted market. Structural change occurs in the sector in order to manage dependencies or align with the value loss its externalities are creating.

The three categories of internalisation generally involve an increasing investment in change and different sets of actions. It is an open research question how much abatement of the present and future impacts caused by the food system can be achieved through market efficiency gains in the present market.

How much abatement of present and future impacts of the food system can be achieved through efficiencies in the present market is an open research question.

The issues identified by the scientific community that are creating impact (Table 1, p. 24) require actions from existing market efficiency gains, to better information on dependencies, to regulatory or fiscal interventions[34]. Policy options for *prima facie* market inefficiencies such as food loss and waste occupy their own reports[35]. Roughly knowing how much effort needs to go into value correction versus self-correction to achieve targets for food system transformation is important. It is natural for business to err on the side of self-correction and civil society on the side of value correction. It is also important for valuation. Abatement costing depend upon beliefs about actions and their efficacy.

Drivers of globalised impact, or of local or regional impact occurring concurrently globally, not being corrected by market efficiency gains in the present market are the ones of concern[36]. They are the issues identified by the scientific community that are believed to be creating most of the external cost, see Table 1[37]. The issues largely coincide with dependencies that are

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[33] For the discussion on the difference between a Pareto efficiency gain where no economic actor loses and optimality in the context of economic adjustment for carbon emissions, see Box 3.4, p. 227 C. Kolstad et al., "Social, Economic and Ethical Concepts and Methods," in *Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*, ed. O. Edenhofer et al. (New York, NY: Cambridge University Press, 2014).
[34] Chapter 7: IPCC, *IPCC Special Report on Climate Change, Desertification, Land Degradation, Sustainable Land Management, Food Security, and Greenhouse gas fluxes in Terrestrial Ecosystems*.
[35] S. Priestley, *Food waste Briefing Paper CPB07552*, House of Commons Library (London, 2016). M. Vittuari et al., *Recommendations and guidelines for a common European food waste policy framework*, FUSIONS (Bologna, 2016), http://dx.doi.org/10.18174/392296.
[36] E. Mendenhall and M. Singer, "The global syndemic of obesity, undernutrition, and climate change," *The Lancet* 393, no. 10173 (2019), https://doi.org/https://doi.org/10.1016/S0140-6736(19)30310-1.
[37] Sources for Table 1:

uncertain and indirect. This is likely why costs have accumulated without correction. The connection of the issues identified in Table 1 to day-to-day market transactions can be complex. Indicative features of the issues include:

- Systemic
    - Significant costs accumulate at the societal level with indirect dependencies or slow feedbacks to the spatial and temporal scale of private costs and benefits. For example, the cost of the carbon emissions or the nitrogen leached from one farm to produce a bushel of corn is not observed until combined with other farms and other food sector activities. Combined emissions and leaching result

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Sustainability: TEEB, *TEEB for Agriculture & Food: Scientific and Economic Foundations*. FAO, *Sustainability Asessment of Food and Agriculture Systems (SAFA) Guidelines*, Food and Agriculture Organization of the United Nations (Rome, 2014), http://www.fao.org/3/a-i3957e.pdf. A. Chaudhary, D. Gustafson, and A. Mathys, "Multi-indicator sustainability assessment of global food systems," *Nature Communications* 9, no. 1 (2018), https://doi.org/10.1038/s41467-018-03308-7; P. S. Nathaniel et al., "Sustainable Sourcing of Global Agricultural Raw Materials: Assessing Gaps in Key Impact and Vulnerability Issues and Indicators," *PLoS ONE* 10, no. 6 (2015), https://doi.org/10.1371/journal.pone.0128752. M. Zurek et al., "Assessing Sustainable Food and Nutrition Security of the EU Food System—An Integrated Approach," *Sustainability* 10, no. 11 (2018), https://doi.org/10.3390/su10114271; 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). S. van Berkum, J. Dengerink, and R. Ruben, *The food systems approach: sustainable solutions for a sufficient supply of healthy food.*, Wageningen Economic Research (Wageningen, 2018).
Environmental: B. M. Campbell et al., "Agriculture production as a major driver of the Earth system exceeding planetary boundaries," *Ecology and Society* 22, no. 4 (2017), https://doi.org/10.5751/ES-09595-220408.
Ecosystems and biodiversity: CISL, *Soil health: evidence review*, University of Cambridge Institute for Sustainability Leadership (Cambridge, 2017); IPBES et al., *The IPBES assessment report on land degradation and restoration*.
Water: OECD, *Climate Change, Water and Agriculture: Towards Resilient Systems* (Paris: OECD Publishing, 2014); OECD, *Sustainable Management of Water Resources in Agriculture* (Paris: OECD Publishing, 2010).
Climate: M. T. Niles et al., *Climate change and food systems: Assessing impacts and opportunities*, Meridian Institute (Washington DC, 2017); IPCC, *IPCC Special Report on Climate Change, Desertification, Land Degradation, Sustainable Land Management, Food Security, and Greenhouse gas fluxes in Terrestrial Ecosystems*. S. J. Vermeulen, B. M. Campbell, and J. S. I. Ingram, "Climate Change and Food Systems," *Annual Review of Environment and Resources* 37, no. 1 (2012), https://doi.org/10.1146/annurev-environ-020411-130608.; F. N. Tubiello et al., "The Contribution of Agriculture, Forestry and other Land Use activities to Global Warming, 1990–2012," *Global Change Biology* 21, no. 7 (2015), https://doi.org/10.1111/gcb.12865.
Health: IPES-Food, Unravelling the food-health nexus: addressing practices, political economy, and power relations to build healthier food systems. Willett et al., "Food in the Anthropocene: the EAT–Lancet Commission on healthy diets from sustainable food systems." HLPE, *Nutrition and food systems. A report by the High Level Panel of Experts on Food Security and Nutrition of the Committee on World Food Security*, Committee on World Food Security (Rome, 2017), http://www.fao.org/3/a-i7846e.pdf.
Social and Economic: National Research Council, *Framework for Assessing Effects of the Food System*, National Academies Press (Washington, 2015); E. Gladek et al., *The Global Food System: An Analysis*, Metabolic. WWF Netherlands. (Amsterdam, 2017), https://www.metabolic.nl/publications/global-food-system-an-analysis/. R. Townsend et al., *Future of food : shaping the food system to deliver jobs*, World Bank Group (Washington, DC, 2017). L. Unnevehr, *Economic Contribution of the Food and Beverage Industry*, Committee for Economic Development of The Conference Board (Arlington VA, 2017). FF&CC, *Our Future in the Land*, Food, Farming and Countryside Comission, RSA (London, 2019).
Food loss and waste: FAO, *Food loss and waste: issues and policy options*, Food and Agriculture Organization of the United Nations (Rome, 2017).

in ecosystem or atmospheric effects. The impact on public health costs accumulate from individuals consuming meals and combinations of food products (diets).

    - Impact is dispersed system wide by dynamic processes. This increases the distance, not only spatially but also conceptually, jurisdictionally, and fiscally between the original activity and the borne costs. Attribution of impact and comparison of benefits and costs across economies separated by the dimensions listed is difficult. Action or feedback across these boundaries is equally challenge. Often the only link is the chain of market transactions. For example, consumed food products are combinations of thousands of commodities sourced globally in long value chains. The ability of the consumer or food retailer to communicate with the original producer, to be able to identify impacts, to be able to obtain credible assessments of impacts, even to redress impacts, reduces as the value chain lengthens.
    - Impact is the result of the business or consumer activity combining with biophysical systems, the behaviour of other business and government actors, other socio-economic trends, e.g. urbanisation, and societal values and choices. Despite being dispersed system wide, significant correlations exist between the impacts. For example, even though carbon emissions and nitrogen leaching occur from many farms across the globe, largely the same biophysical process is responsible for impacts. If science has underestimated the effects of that biophysical process, then the fact that there are numerous point sources of emissions and leaching does not "average out" the error. Similar correlations exist in global human health effects due to the increasing concentration of agricultural commodities in diets.
- Intergenerational
    - Long timeframes, or delay, in the occurrence of impact from an activity today. Some food system impacts, e.g. climate change and obesity, have lock-in effects for future generations as well as present ones.

The difficulty in measurement and attribution along impact pathways reduces the visibility and feedbacks between impacts and business and consumer activity. It also compounds the uncertainty in measurement and attribution. Uncertainty in complex biophysical and socio-economic processes combines with ambiguity in the comparison of economies and costing impacts that have not occurred yet. Accumulation of impacts can either reduce or increase uncertainty depending on the correlation between the individual impacts being aggregated. The challenges uncertainty poses for impact valuation are discussed further from p. 115.

Dependencies being complex, a weak direct signal to revenue and cost, uncertain, and yet the external costs which accumulate are, or will be, evident and large, are features of the impact created by the food system.

The implications are that:

- Impact valuation for the food system's impact on society is challenging. Market prices and existing exchange markets are poor estimators.
- For major reduction in impact, impact valuation is more likely needed for external corrections to private benefit and cost calculations. This will require practical and comparable valuations rather than internally determined and incomparable valuations.

Issues associated to food system impact

Indicative list only. Issues are not generally footprints, capital changes or impacts themselves, and not independent; they represent a collection of drivers and impact pathways believed by the scientific community to be creating most of the impact from food systems. Issues labelled 'environmental' or 'social' do not cause only natural capital, resp. social & human captial, changes. Issues are often negative impact, and positive contributions from actors toward addressing issues can be viewed as abatement. Compiled from references in footnote 37.

Table 1: an indicative list of material issues for society for food systems

	Issue	*Pathway via*	*Capital changes*	*Reference*
environmental	Climate change	CO2-eq emissions, land-use	Global, affecting terrestrial systems, biosphere, and through this agricultural and marine production, all economic sectors, social stability, and human health.	IPCC, *2019*
environmental	Nutrient pollution	Run-off or processing water pollution, air pollution from erosion, soil processes and application	Health effect, ecosystem degradations. Economic losses and inefficiency in fertiliser overapplication.	Campbell, et al. *2017*
environmental	Ecosystem collapse	Biodiversity loss (pesticide and nutrient application), land-use and land degradation, atmospheric and terrestrial changes, pollution, water extraction.	Pollinator services, soil services, erosion, water and air services, feedback with climate change, other primary based economic sectors, pleasure in nature, cultural loss	IPBES, *2018*
environmental	Water scarcity	Water-use and quality changes of water.	Water services, health, ecosystem degradations, economic losses, conflict	OECD, *2012*
social	Safety and non-harm	Accidents Child labour Toxicity exposure in production or consumption Antibiotic use Exotic pathogens	Health, human development, communities, economic losses.	TEEB, *2018*
social	Exploitation and social equity	Child labour, accidents and exposure compared to other sectors, pay rates, price fluctuations, power imbalance, control of inputs	Human development, poverty, institutional loss through conflicts and migration, suicide, cultural loss, rural development.	TEEB, *2018* NRC, *2015*
health	Nutrition and Malnutrition	Consumption of food products in diets in subpopulation context (income, activity level, age, etc)	Food security (availability, access, utilisation). Human health and development. Obesity, diabetes, hunger, stunting, human health changes with corresponding social and economic losses.	IPES-FOOD, *2017* Willet et al., *2019*
economic	Economic value of food sector, livelihoods and employment	Value add, growth, investment, competitiveness, efficiency, employment, wages, taxes	Produced and financial capital, provision of livelihoods, welfare through consumption, contribution to society of taxes, sustenance, pleasure. Consumption of human education and time, infrastructure, natural resources, etc.	NRC, *2015* Townsend, *2017*
inefficiency	Food loss and waste	Inefficiency of production and consumption. Embedded emissions, water use, land-use, nutrient pollution, exposure. Pollution and exposure via waste.	As per embedded footprint. Economic losses, nutrition losses in the case of subsidence, and costs of treatment and disposal.	FAO, *2017*

Evidence of the theory of change

Impact valuation estimates social costs due to food system actors. That it will contribute to reduction of the impacts of food systems identified by the scientific community[38] through an economic theory of change is a series of hypotheses.

Economic theory of change:

- Food system impacts are due to market inefficiencies and external costs of food system actors [hypothesis]
- Internalising the external costs will reduce impacts through market dynamics [hypothesis]
- Enough externalities can be internalised to transform the food system to scientific targets [hypothesis]
- Internalising causes reflection and value change [hypothesis]

Food system impacts are due to market inefficiencies and external costs of food system actors

If food system impacts are not externalities or inefficiencies of the activities associated to market transactions of food system actors, then market efficiency gains and internalisation will not achieve any reduction of the impacts. The scientific studies mentioned in footnote 1 discuss attribution of environmental (IPCC, IPBES), social (TEEB), and health (GBD, Eat-Lancet, Food-Health Nexus) impacts to the production and consumption of food in addition to the scale of the impacts. This hypothesis is well evidenced by the literature.

Internalising the external costs will reduce impacts through market dynamics

If market efficiency gains are not enough to reach scientific targets for food system transformation (which seems unlikely), then internalising external costs could contribute further to reaching targets. That internalisation will result in impact reduction is an assumption. It assumes that the market adjustment will be accepted, and that consumption will respond to price changes that result from the adjustment. Even if accepted and not compensated for by circumventing regulation, shifting production, or absorbing price increases, there is no guarantee that the internalisation mechanism will not create external costs for society of similar magnitude to the reduction, i.e. unintended consequences. It is still not clear what internalisation, of the scale required to achieve significant reduction in food system impacts, will do to the price of food staples or livelihoods in some communities[39]. There are many impact and attribution studies now of the food system suggesting large fiscal or policy interventions, and other changes that amount to internalisations. Detailed dynamic economic modelling of

[38] The IPCC, the IPBES, the Global Burden of Disease, TEEB, the Eat-Lancet Commission on Food, Planet, Health, etc, see footnote 1. Impact reduction targets and footprint reduction targets are discussed further on p. 107.

[39] L. Scherer et al., "Trade-offs between social and environmental Sustainable Development Goals," *Environmental Science and Policy* 90 (2018), https://doi.org/10.1016/j.envsci.2018.10.002. P. Smith et al., "How much land-based greenhouse gas mitigation can be achieved without compromising food security and environmental goals?," *Glob Chang Biol* 19 (2013), https://doi.org/10.1111/gcb.12160. P. Smith, "Delivering food security without increasing pressure on land," *Global Food Security* 2, no. 1 (2013), https://doi.org/http://dx.doi.org/10.1016/j.gfs.2012.11.008; S. A. Wood et al., "Trade and the equitability of global food nutrient distribution," *Nature Sustainability* 1, no. 1 (2018), https://doi.org/10.1038/s41893-017-0008-6. Chapter 6 and Section 7.5.6 7-80 in IPCC, *IPCC Special Report on Climate Change, Desertification, Land Degradation, Sustainable Land Management, Food Security, and Greenhouse gas fluxes in Terrestrial Ecosystems*.

the follow-on consequences is less complete in the literature[40]. Internalisation may produce a higher price for inputs, for commodities, or for consumers, in the short to medium term. The implications of internalisations that reduce food system impact will be a stumbling block to dialogue with policymakers without detailed answers.

Enough externalities can be internalised to transform the food system to scientific targets

Assuming internalisation can reduce impacts, then internalisation mechanisms will be more, or less, effective for some issues and in some contexts. There are opportunity, political and reactionary costs to internalisation. Regulation will impact livelihoods, requiring time to transfer knowledge and labour between industries. To transform the food system requires that enough impact reducing mechanisms come online, become accepted and operational, in enough time, to avert environmental, social and human health impacts[41]. Whilst maintaining overall economic stability of the food sector and provision of food security and livelihoods. This hypothesis needs further applied research. Studies are required on mechanisms available and potential economic trajectories of internalisation to achieve scientific targets. While CO2-eq marginal abatement cost curves have critics[42], they have allowed climate science to engage in policy and economic dialogue. As clear an economic presentation does not exist for food system transformation[43].

Dynamic economic modelling of the follow-on consequences from large fiscal or policy interventions suggested by impact and attribution studies, and merit order curves and economic trajectories for food system transformation through internalising externalised costs, need further applied research.

Internalising causes reflection and value change

The hypotheses are not rigid in time but can be reassessed and updated. Feedback has the potential to accelerate the change. Internalisation, which is occurring with carbon taxes, carbon offset markets, and carbon disclosure, raises societal awareness, regulatory risk, prompting value changes whereby opportunity and political costs lessen. Awareness, regulatory and reputational risk act as additional internalisation measures whereby reduction of external costs become voluntary market efficiencies. Positive feedback 'lowers the bar'. It becomes more likely internalisation will reduce further impacts and the momentum bring new or more of the same mechanisms online.

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40 M. M. Rutten, "What economic theory tells us about the impacts of reducing food losses and/or waste: implications for research, policy and practice," *Agriculture & Food Security* 2, no. 1 (2013), https://doi.org/10.1186/2048-7010-2-13. FOLU, *Growing Better: Ten Critical Transitions to Transform Food and Land Use, The Global Consultation Report of the Food and Land Use Coalition.*

41 FABLE, *Pathways to Sustainable Land-Use and Food Systems. 2019 Report of the FABLE Consortium.* Box 9, p 7-79 in IPCC, *IPCC Special Report on Climate Change, Desertification, Land Degradation, Sustainable Land Management, Food Security, and Greenhouse gas fluxes in Terrestrial Ecosystems*. C. Béné et al., "When food systems meet sustainability – Current narratives and implications for actions," *World Development* 113 (2019), https://doi.org/https://doi.org/10.1016/j.worlddev.2018.08.011.

42 F. Kesicki and P. Ekins, "Marginal abatement cost curves: a call for caution," *Climate Policy* 12, no. 2 (2012), https://doi.org/10.1080/14693062.2011.582347.

43 M. T. Niles et al., "Climate change mitigation beyond agriculture: a review of food system opportunities and implications," 33, no. 3 (2018), https://doi.org/10.1017/S1742170518000029. L. Bockel et al., *Using Marginal Abatement Cost Curves to Realize the Economic Appraisal of Climate Smart Agriculture Policy Options*, Food and Agriculture Organization of the United Nations. (Rome, 2012).

Hypothesis two still needs to be checked: whether economic value overall is being increased by the reduction of food system impacts. Hypothesis three still needs to be checked: whether the value change is sufficient to achieve targets and occurring in communities of society that have the power to effect economic change. Climate change has become a cultural and ideological battleground with deep inertia in some business sectors, demographics, conservative governments and vested capital. The debate on climate change is instructive; those communities have subscribed against the hypotheses, especially one and two. Firstly, that impacts of climate change exist or will be net negative for economies, or that they can be attributed to human economic activity. Secondly, even if the impacts were net negative and due to externalities, that internalisation would create more economic costs than are reduced. Hence there is no optimal economic trajectory into the future other than absorbing the impacts. Despite scientific consensus for the first two hypotheses in the case of climate change and all economic sectors, summarised and updated in IPCC assessments, the inertia remains.

Triad of food system science, valuation and users

The theory of change is being acted upon. We indicate current activity around a triad of food system science, valuation, and users (Figure 4). We refer more detail on food systems[44] and economic valuation[45] to other reports and literature.

We summarise the role of impact valuation in an economic theory of change of food system impacts (Figure 4): food system science says indicates a loss of economic value and sets scientific targets like climate science sets targets such as 2 or 1.5 degrees. Valuation provides an account of the value loss that is presently not costed into the economic system. Valuations inform internalisation leading to movement to targets for impacts. By having agreed and credible changes in value the economic system re-forms or is reformed around the value change. The process is iterative until optimal, i.e. the economic trajectory of most value becomes the impact neutral (or sustainable) trajectory.

> The process is iterative until the economic trajectory of most value becomes the impact neutral (or sustainable) trajectory.

Impact neutral is defined by valuations of externalities and economic optimality. A food system on an impact neutral or sustainable trajectory is distinguished from a food system with no impacts on natural, social and human capital. As an example, an optimal amount of food loss and waste in an economic system is unlikely to be none[46]. How impact neutral accords with other theories of change and

[44] Vermeulen, Campbell, and Ingram, "Climate Change and Food Systems."; P. J. Ericksen, J. S. I. Ingram, and D. M. Liverman, "Food security and global environmental change: emerging challenges," *Environmental Science & Policy* 12, no. 4 (2009), https://doi.org/http://dx.doi.org/10.1016/j.envsci.2009.04.007. P. J. Ericksen, "Conceptualizing food systems for global environmental change research," *Global Environmental Change* 18, no. 1 (2008), https://doi.org/http://dx.doi.org/10.1016/j.gloenvcha.2007.09.002.

[45] Dasgupta, *Human Well-Being and the Natural Environment*. K. J. Arrow et al., "Sustainability and the measurement of wealth," *Environment and Development Economics* 17, no. 3 (2012), https://doi.org/10.1017/S1355770X12000137; National Research Council, "5: Economic methods of valuation." S. Faucheux and M. O'Connor, eds., *Valuation for Sustainable Development* (Cheltenham, UK: Edward Elgar Publishing, 1998). E. Gómez-Baggethun et al., "The history of ecosystem services in economic theory and practice: From early notions to markets and payment schemes," *Ecological Economics* 69, no. 6 (2010), https://doi.org/https://doi.org/10.1016/j.ecolecon.2009.11.007. R. B. Howarth and R. B. Norgaard, "Environmental Valuation under Sustainable Development," *The American Economic Review* 82, no. 2 (1992). Y. E. Chee, "An ecological perspective on the valuation of ecosystem services," *Biological Conservation* 120, no. 4 (2004), https://doi.org/https://doi.org/10.1016/j.biocon.2004.03.028.

[46] E.g. p. 12 FAO, *Food wastage footprint: full-cost accounting*, Food and Agriculture Organization of the United Nations (Rome, 2014).

measures of food system impact, e.g. ethical and moral, depends on the definition of economies and what values they represent. Monetary valuation informs internalisation, but it is not internalisation *per se*. Value changes in society can internalise externalities directly through demand changes. Through iteration and the fourth step of the theory of change valuations and value changes work to the same end. Value changes become valuations and valuations can result in value changes. There is conceptual flexibility in what is economic value, exploited in the foundation of environmental, ecological and welfare economics. Defining economic value is part of the process of doing impact valuation, as discussed from p. 61.

Starting with food systems and moving clockwise we provide examples of current activity around the triad (Figure 4):

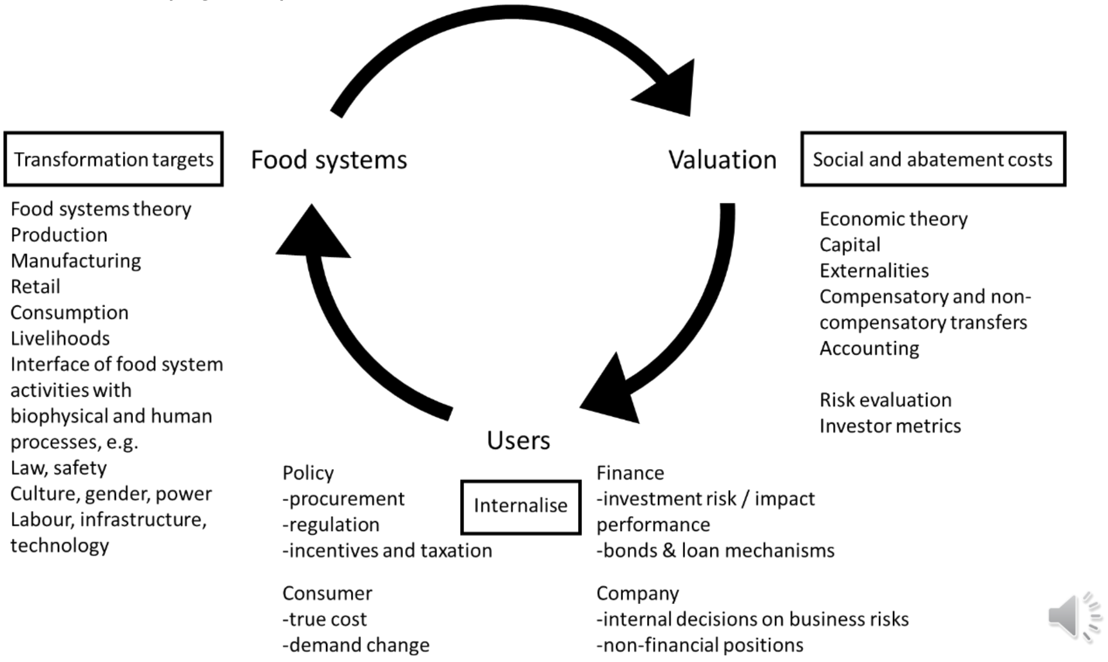

Figure 4: A triad of food system science, valuation, and users. *Food system science* indicates a loss of economic value and sets scientific targets like climate science sets targets such as 2 or 1.5 degrees. *Valuation* provides an account of the value loss that is presently not costed into the economic system. Valuations inform *internalisation* leading to movement to targets. By having agreed and credible changes in value the economic system re-forms or is reformed around the value change. The process is iterative until optimal, i.e. the economic trajectory of most value becomes the impact neutral (or sustainable) trajectory.

For food system science that links food system impacts to value loss on capitals we mention the TEEB AgriFood Framework and the Natural Capital Food & Beverage Sector guide, noting other frameworks[47]. For transformation targets we mention the UN Sustainable Development

[47] TEEB, *Measuring what matters in agriculture and food systems*, UN Environment (Geneva, 2018). NCC, *Natural Capital Protocol: Food & Beverage Sector Guide*. FAO, *Sustainability Assessment of Food and Agriculture Systems (SAFA) Guidelines*., National Research Council, *Framework for Assessing Effects of the Food System*. Zurek et al., "Assessing Sustainable Food and Nutrition Security of the EU Food System—An Integrated Approach." S. Vionnet and J.-M. Couture, *Measuring Value - Towards New Metrics and Methods*, Quantis and Ageco (Switzerland, 2015). IVR, *Operationalizing Impact Valuation: Experiences and Recommendations by Participants of the Impact Valuation Roundtable*, Impact Valuation Rountable (2017), https://docs.wbcsd.org/2017/04/IVR_Impact%20Valuation_White_Paper.pdf.

Goals (SDGs), the EAT-Lancet Commission on healthy diets from sustainable food systems footprint targets, and the FABLE Consortium targets and pathways[48].

Accounting gets used in two senses for non-financial capital. It can mean just to account, to bring to consideration, to record[49]; true-cost accounting in this sense highlights what is happening with non-financial capitals for food system activities. And accounting[50] – a formal reporting system of financial and, in this case, non-financial transactions, expenditures and revenues (changes to value flows) and current and non-current assets and liabilities (present and locked-in future changes to what contributes to value flows). An example of the latter type of accounting is natural capital accounting, which refers to quality and quantity of natural capital stocks. Monetary amounts pair readily with quantities and qualities for produced and financial capital. It is an additional step for non-financial capital. There is merit in distinguishing non-financial capital accounting for an inventory of capital assets and valuing that inventory. Valuing non-financial capital absolute quantities is contentious, e.g. the total value of all ecosystems on earth[51]. The value of produced and financial capital should be products of relative changes in non-financial capital. Value of non-financial capital to human activity should also be treated in relative terms[52]. Aggregation of non-financial capital to obtain 'totals' is different than financial capital.

For accounting standards we note the UN System of national accounts Environmental Economic Accounting – Experimental Ecosystem Accounting (SEEA-EEA)[53]. The SEEA-EEA is discussed further on p. 41. The SEEA-EEA's scope includes both accounting of quantities and qualities of capital and valuation. The current revision of the SEEA-EEA likely offers the best conceptual discussion for accounting for non-financial capital that can underpin or be adapted for a food system non-financial accounting standard[54]. This is discussed further on p. 41.

For economic valuation theory we mention direct valuation and valuation proxies. Case studies starting p. 128 indicate the current activity for impact valuation. Details on existing methods for impact valuation mentioned through this report are summarised on p. 170. Valuation proxies imply a loss of value in the eventual internalisation of food system externalities and a proxy estimate using financial indicators like investment and credit risk[55].

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48 FAO, *Transforming food and agriculture to achieve the SDGs*, Food and Agriculture Organization of the United Nations (Rome, 2018), http://www.fao.org/3/I9900EN/i9900en.pdf. Willett et al., "Food in the Anthropocene: the EAT–Lancet Commission on healthy diets from sustainable food systems." FABLE, *Pathways to Sustainable Land-Use and Food Systems. 2019 Report of the FABLE Consortium.* M. Obersteiner et al., "Assessing the land resource–food price nexus of the Sustainable Development Goals," *Science Advances* 2, no. 9 (2016), https://doi.org/10.1126/sciadv.1501499. C. Hawkes and B. M. Popkin, "Can the sustainable development goals reduce the burden of nutrition-related non-communicable diseases without truly addressing major food system reforms?," *BMC Medicine* 13, no. 1 (2015/06/16 2015), https://doi.org/10.1186/s12916-015-0383-7.

49 https://www.lexico.com/en/definition/account

50 https://www.lexico.com/en/definition/accounting

51 M. Toman, " Why not to calculate the value of the world's ecosystem services and natural capital," *Ecological Economics* 25, no. 1 (1998), https://doi.org/10.1016/S0921-8009(98)00017-2.

52 UNEP, *Inclusive wealth report 2018 : measuring progress towards sustainability*.

53 A4S CFO Leadership Network, *Natural and Social Capital Accounting*, Accounting for Sustainability (2014); OECD et al., "System of Environmental Economic Accounting 2012 : Experimental Ecosystems Accounting," (2014), https://doi.org/10.1787/9789210562850-en.

54 https://seea.un.org/content/seea-experimental-ecosystem-accounting-revision

55 Francisco Ascui and Theodor F. Cojoianu, "Implementing natural capital credit risk assessment in agricultural lending," *Business Strategy and the Environment* 28, no. 6 (2019), https://doi.org/10.1002/bse.231 FAIRR, *Factory farming: asessing investment risks*, Farm Animal Investment Risk & Return (London, 2016). FAIRR, *Plant-based profits: investment risks & opportunities in sustainable food systems*, Farm Animal Investment Risk & Return (London, 2018).

For users and uses we mention corporate reporting and impact frameworks[56], business risk and opportunity[57], and finance initiatives and directives such as the Natural Capital Declaration[58]. Civil society reports on the true cost of food and taxation act as internalisations by stimulating demand change and regulatory risk[59]. There are already private and public fiscal incentives to reduce food system impacts[60]. For the issue of climate change, policy and market interventions are detailed in Chapter 7 starting p. 7-33 of the 2019 IPCC report[61].

The next section describes the impact valuation process in the TEEB AgriFood Framework and the Natural Social & Human Capital Protocols. The section after concentrates on doing food system impact valuation.

Needed are the vision, the inspiration, the credible pathway of systemic change through internalising the external costs as much as the methods and the data are needed.

As well as practical impact valuation and accounting, realising transformation in the food system through internalisation requires consideration of the full range of regulatory, market and financial options and examples of them[62]. Needed are the vision, the inspiration, the credible pathway of systemic change through internalising the external costs as much as the methods and the data are needed. Uses drive development, and drive credibility, agreement and comparability. In turn, development and alignment of methods and tools reduce barriers and opens the territory to more, or more effective, uses. The process accelerates the closer the triad comes together. Synergy between the triad of food system science, economics and users requires a network and investment that enables the community to develop and promote measures for economic correction of food system impact at scale.

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[56] T. Singer, *Total Impact Valuation. Overview of Current Practices. Research Report R-1661-18*, The Conference Board (2018). J. Unerman, J. Bebbington, and B. O'Dwyer, "Corporate reporting and accounting for externalities," *Accounting and Business Research* 48, no. 5 (2018), https://doi.org/10.1080/00014788.2018.1470155. P. Conradie and D. de Jongh, "Realising the vision of Integrated Reporting: A critical viewpoint," *Journal of Economic and Financial Sciences* 10, no. 2 (2017), https://doi.org/10.4102/jef.v10i2.18.

[57] B. Caldecott, N. Howarth, and P. McSharry, *Stranded assets in agriculture: protecting value from environment related risks*, Oxford University - Smith School for Enterprise and the Environment (Oxford, 2013). J. Poore and T. Nemecek, "Reducing food's environmental impacts through producers and consumers," *Science* 360, no. 6392 (2018), https://doi.org/10.1126/science.aaq0216. WBCSD, *True Cost of Food: Unpacking the value of the food system*, World Business Council for Sustainable Development (Geneva, 2018). CISL, *How businesses measure their impact on nature: a gap analysis*, University of Cambridge Institute for Sustainability Leadership (Cambridge, 2017).

[58] Natural Capital Declaration, *Towards Including Natural Resource Risks in Cost of Capital, State of play and the way forward*, World Bank, Global Canopy Programme, UNEP FI (Geneva, 2015). Millan, Limketkai, and Guarnaschelli, *Financing the Transformation of Food Systems Under a Changing Climate.* B. Scholtens, "Why Finance Should Care about Ecology," *Trends in Ecology & Evolution* 32, no. 7 (2017), https://doi.org/10.1016/j.tree.2017.03.013.

[59] I. Fitzpatrick and R. Young, *The Hidden Cost of UK Food*, Sustainable Food Trust (Bristol, 2017). S. Henderson et al., *The real cost of food: examining the social, environmental and health impacts of producing food*, Food Tank (Chicago, 2015). GAFF, *On true cost accounting & the future of food*, Global Alliance for the Future of Food (Toronto, 2018).

[60] Helm, "Agriculture after Brexit." CISL, *Modelling better business: Nestle trials natural capital premium with UK dairy farmers*, Natural Capital Impact Group (Cambridge, 2018). https://www.fairr.org/

[61] IPCC, *IPCC Special Report on Climate Change, Desertification, Land Degradation, Sustainable Land Management, Food Security, and Greenhouse gas fluxes in Terrestrial Ecosystems*.

[62] Chapters 9 and 10 of TEEB, *TEEB for Agriculture & Food: Scientific and Economic Foundations*. discuss building networks and uses to affect change.

ALIGNMENT WITH IMPACT FRAMEWORKS SUMMARY

Impact frameworks outline the basic process for impact valuation. This section examines two leading food system impact frameworks: the TEEB AgriFood Evaluation Framework and the Natural, and Social and Human, Capital Protocols. The Natural Capital Protocol has a Food and Beverage Guide.

This section finds that the impact frameworks are aligned. They identify a process where food system activities, with their upstream inputs and downstream outputs, are identified and measured for factors which drive changes in natural, social and human capital. Determining the amount of capital change caused by the factors is called attribution. What effect the capital change has on social and human well-being is estimated by a valuation of the capital changes. The three steps linked together: activities, attribution to capital changes, valuation of capital changes, are a valuation of the changes in social and human well-being due to activities of a food system actor. That is, an impact valuation. Quantification of the factors which link activities of the food system actor to capital changes and impact is introduced in the next section under the term footprint. Greater detail within the three steps is considered in the next section.

The previous section argued that comparable and agreed valuations of the major external costs introduced by the food system are likely to have the most effect on reducing impact. Comparable valuation is needed for external correction such as impact investing and government policy. This implies a shared decision process, whereas the Protocols concentrate on a company's internal decision process. The scoping steps in the impact frameworks are considered with this view. The scoping steps that lead to the three steps of impact valuation include system boundaries and value perspectives.

This section finds that comparable valuation will likely involve a limited number of frequent uses. External corrections are resource intensive, limiting their number, and likely to be applied at scale, increasing their frequency of use. The limited number of use cases provides an opportunity to standardise scope for impact calculations. External use cases could base their requirements on the fixed scope. It is recommended to push variation of scope such as non-disclosure of a footprint into the impact calculation. Impact calculations already have variation and uncertainty which needs addressing. Sources of variation and uncertainty are discussed in detail in the next section.

Uncertainty in valuation of impacts from externalities represent risk or opportunity transacted from business to society. Information on, and comparability of, the uncertainty in the monetary value is as important as the monetary value itself. Non-disclosure, through uncertainty in the actor's footprint and the total societal footprint, has a double contribution to uncertainty in impactsand hence risk borne by society.

The section recommends a non-financial capital accounting framework for the food system as an eventual basis for comparable impact valuation. It would specify:

- Issues associated to the major external costs introduced by the food system – which guide what to measure.
- Footprint: what to measure, i.e. what aspects of a business or food system actor's operation; what units; what to disclose (a footprint protocol).
- Capitals: what to measure, i.e. the capital change most relevant to societal impact, intersected with the capital change attributable to food system actors.
- Formalisation of the exchanges and contributions between footprints, capitals, footprint to capital and capital to human well-being relevant to impact (impact pathways).

A first step toward the accounting framework would be a footprint protocol. It is found that the SEEA-EEA, the ecosystem component of the UN System of Environmental Experimental Accounting, and the Sustainability Assessment of Food and Agriculture systems (SAFA) terminology from the UN Food and Agriculture Organization (FAO) offer a blueprint and basis for the accounting framework. A second step would be collating impact pathways presently distributed in literature across different disciplines.

ALIGNMENT WITH IMPACT FRAMEWORKS

Valuation is part of the Measure and Value stages of the Natural and Social & Human Capital Protocols. It also part of the TEEB AgriFood Evaluation Framework under the term evaluation.

Steps to measure and value

The Protocols outline nine steps to understand, measure, value and improve the natural, social and human capital performance of a company (Figure 5).

Examples of uses for food system impact valuation are listed on p. 5 and p. 30. This report concerns impact valuation of the societal impacts of the food system. The previous section argued that this will fix a list of material issues and the need for comparable valuations. In this section we discuss how this fixes consideration in the Protocols for the scope of the impact calculation.

Under “Measure and Value” are three steps (Figure 6), indicating footprint (Step 05), attribution of changes in the quantity and quality of capital stocks to the incurred footprint (Step 05 to Step 06), and the valuation of the capital changes (Step 06 to Step 07). From p. 45 we define

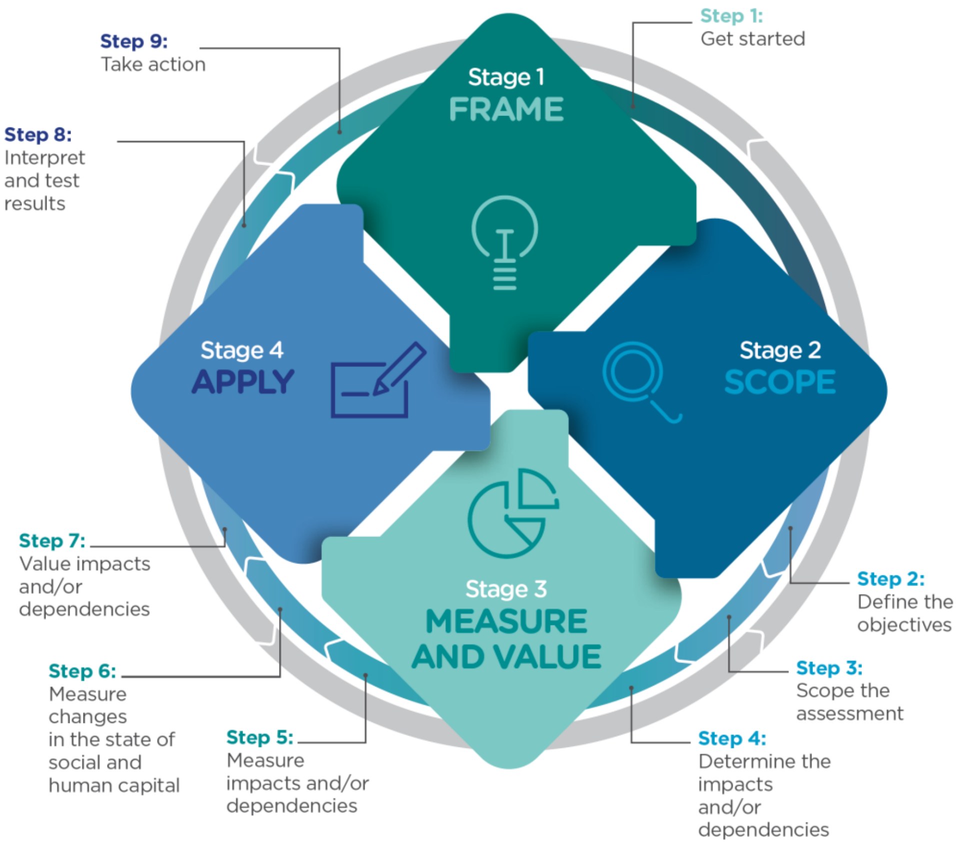

Figure 5:Steps in the Natural and Social & Human Capital Protocols (Source: S&HCC, Social & Human Capital Protocol).

impact valuation according to footprint, attribution and valuation, corresponding to the Steps 05-07 (see also Figure 17 on p. 64).

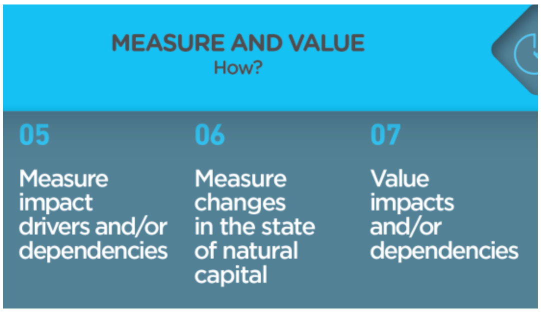

Figure 6: Steps 05-07 in Measure and Value (Source: NCC, Natural Capital Protocol).

The TEEB AgriFood initiative and the Natural, and Social & Human, Capital Coalitions emerged from an earlier TEEB initiative. The common conceptual basis between flows-outcomes-impacts in the TEEB AgriFood Evaluation Framework and driver-capital changes-values in the Protocols should therefore be expected (Figure 7 and Table 2).

Impact in both the TEEB Framework and the Protocols is defined as impact on human well-being[63]. This report uses the terms economic value synonymously with human well-being and a broad measure of welfare. The term impact is also used in some environmental studies to mean impact on capital, which are outcomes in

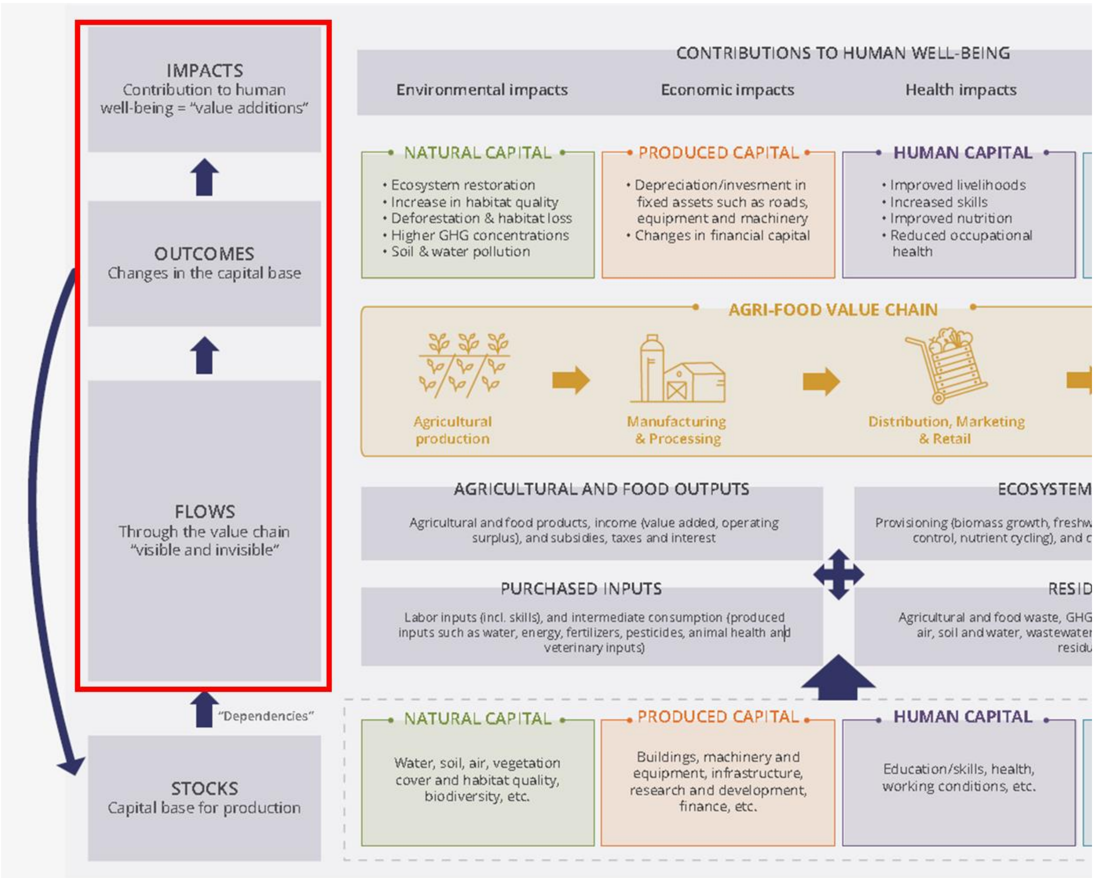

Figure 7: The same concepts in the TEEB AgriFood Evaluation Framework, where flows include drivers in the terminology of the Protocols, outcomes include changes in capitals attributable to food system actors, and impact includes value changes due to changes in capital. (Source: TEEB, *TEEB for Agriculture & Food: Scientific and Economic Foundations* p. 238)

[63] A. McGregor, S. Coulthard, and L. Camfield, *Mesauring what matters: the role of well-being methods in development policy and practice*, Overseas Development Institute (ODI) (London, 2015); OECD, *OECD Guidelines on Measuring Subjective Well-being* (2013). Dasgupta, *Human Well-Being and the Natural Environment*; P. Dasgupta and A. Duraiappah, "Well-being and wealth," in *Inclusive Wealth Report 2012: measuring progress toward sustainability*, ed. IHDP-UNU and UNEP (Cambridge: Cambridge University Press, 2012).

the TEEB terminology. The trend in environmental impact assessment is converging toward sustainability assessment including socio-economic and well-being indicators[64].

Other frameworks for impact valuation include the Impact Valuation Roundtable (IVR) white paper. It is based on the terms input-activity-output-outcome-impact[65]. Here input-activity-output falls within the scope of drivers (Protocols) and flows (TEEB Framework). Outcome and impact have the same meaning as for the TEEB Framework and the Protocols. Impact valuation defined in terms of a measurement of activity which us attributed to capital change (Step 05), attribution (Step 05 to Step 06) and valuation (Step 06 to Step 07) is common to all frameworks (Table 2). Social return on investment (SROI) is another philosophically aligned framework. It is based on input-activity-output-outcome-impact and seeks to value welfare beyond aggregated individual utility of consumption. SROI is a more abstract framework. It does not factor welfare impacts through a stock and flow construction like natural, and social and human capitals. SROI is not a direct foundation on which to build an non-financial capital accounting structure, unlike the TEEB AgriFood Evaluation Framework. Monetary valuation attached to life-cycle impact assessment (LCIA) has essentially the same presentation as the impact frameworks that have been mentioned[66].

Table 2: Alignment of impact frameworks. The terms are not directly interchangeable, e.g. Flows in the TEEB AgriFood Evaluation Framework is a more general concept than Impact Drivers in the Protocols, but there are either inclusions or basic mappings between them

	Drivers of capital change	***Capital change***	***Value of capital change***
	Step 05	**Step 06**	**Step 07**
Protocols	Impact Drivers (of the business)	Changes in the state of capitals	Value impacts
TEEB	Flows	Outcome	Impact
IVR & SROI	Input-Activity-Output (of the business or project)	Outcome	Impact
E.Valu.A.TE	Within specification of “Scenarios” and “Activities and Impacts”	Models and Data to quantify changes	Human Welfare Impact and Valuation

[64] J. Glasson, R. Therivel, and A. Chadwick, *Introduction to environmental impact assessment*, 4th Edition ed. (London: Routledge, 2013).

[65] Also the model in Social Return on Investment (SROI): A. E. Roest, A. v. Schie, and G. S. Venema, "Using SROI and SCBA for measuring social return of Green Care in Agriculture" (paper presented at the COST Action 866-meeting, Green Care in Agriculture, Witzenhausen, Germany, 24 - 28 August, 2010, Loughborough, 2010). Originating as the Logic Model in planning and evaluation, J. A. McLaughlin and G. B. Jordan, "Logic models: a tool for telling your programs performance story," *Evaluation and Program Planning* 22, no. 1 (1999), https://doi.org/https://doi.org/10.1016/S0149-7189(98)00042-1; D. A. Julian, A. Jones, and D. Deyo, "Open systems evaluation and the logic model: Program planning and evaluation tools," *Evaluation and Program Planning* 18, no. 4 (1995), https://doi.org/10.1016/0149-7189(95)00034-8.; Vionnet and Couture, *Measuring Value - Towards New Metrics and Methods*; IVR, *Operationalizing Impact Valuation: Experiences and Recommendations by Participants of the Impact Valuation Roundtable*.

[66] See for example Figure 9, p. 37: 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.

Both the Protocols and the IVR white paper make explicit the actors' drivers of capital change. They are less explicit on the other drivers required to calculate how much capital change is attributable to the actor's drivers. For example, the impact from a business's own emissions depends on the total emissions of businesses and society and socio-economic trends into the future. Obesity social costs depend on the nutrient profile and quantity of a produced food (a business output) and on the combination of quantities consumed in diets by subpopulations of society that have different levels of exercise, personal physiology and biochemistry. Other drivers are a major source of variability in valuations. All the drivers mentioned sit conceptually under flows in the TEEB AgriFood Evaluation Framework.

The Protocols provide examples for performing Steps 05-07 for a food system actor. No emphasis is placed on comparability. The TEEB AgriFood Evaluation Framework describes a stepwise process in Chapter 6 (Figure 8) that does not line up directly with Steps 05-07 in the Protocols. They can be mapped to each other. Chapter 7 of the TEEB AgriFood Evaluation Framework has a common list of valuation methodologies[67]. The Cambridge Institute for Sustainability Leadership (CISL) developed the E.Valu.A.TE process for valuation of environmental externalities. The CISL process is similar to the TEEB AgriFood Evaluation Framework steps in Figure 8.

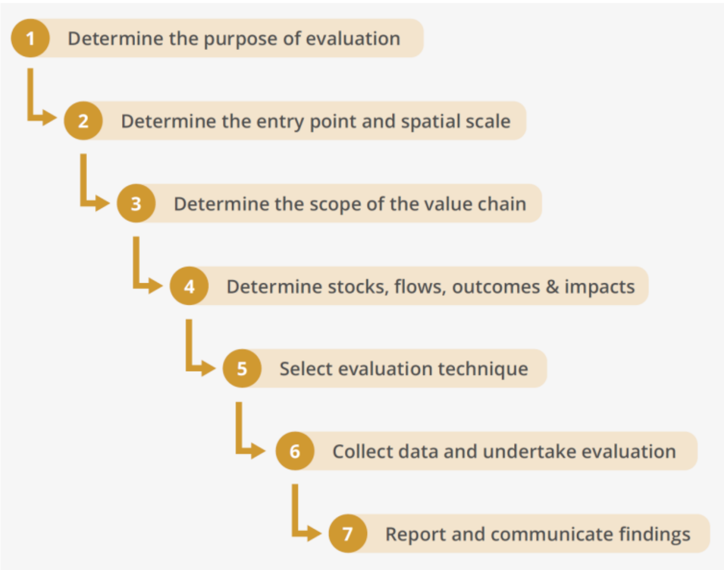

Figure 8: Steps for applying the TEEBAgriFood Evaluation Framework (Source: TEEB, *TEEB for Agriculture & Food: Scientific and Economic Foundations* p. 232). Steps 1-3 are primarily scoping and have the same effect as Steps 02-04 of the Protocols. Steps 4-6 are different to Steps 05-06 in the Protocols.

The TEEB AgriFood Evaluation Framework focusses on all capitals and food system actors. TEEB case studies have focussed on community, regional or national true-cost accounting and valuation[68]. The TEEB Framework comprehensively covers upstream (supply chain) and downstream (population health effects of consumption). The combination of the Protocols covers all capitals and is aimed at business, with case studies of food companies in the Food & Beverage guide. The case studies concentrate on changes due to upstream activities. E.Valu.A.TE considers upstream natural capital changes. Within this scope the E.Valu.A.TE process is clearer than the TEEB AgriFood Evaluation Framework steps in Figure 8

Comparable and non-comparable valuations have different implications for capturing and transacting the uncertainty in the valuation. Sensitivity analysis for an end decision or application (Step 8 of the Protocol process in Figure 5) is different than the uncertainty in the

[67] Section 7.3, p. 255, TEEB, *TEEB for Agriculture & Food: Scientific and Economic Foundations*.; p. 114, UNEP, *Inclusive wealth report 2018 : measuring progress towards sustainability*.; p. 22, FAO, *Food loss and waste: issues and policy options*.; p. 66, M. Schaafsma and G. Cranston, *E.Valu.A.TE: The Practical Guide*, The Cambridge Natural Capital Leaders Platform (Cambridge, UK, 2013).
[68] http://www.teebweb.org/resources/case-studies/

valuation[69]. A business decision about whether to proceed with produced capital investment is generally less sensitive to different values of, say, the social cost of carbon, than an impact valuation. If different estimates of the social cost of carbon are used the decision may well be the same. If different estimates of the social cost of carbon are used the impact valuation is not going to be the same.

The previous section argued that comparable and agreed valuations of the major external costs introduced by the food system are likely to have the most effect on reducing impact. Comparable valuation is needed for external correction such as impact investing and government policy. In a shared decision process the impact valuation itself is shared information for a determination of penalties or incentives received by the business (Figure 9).

The uncertainty and choices behind the impact valuation become relevant to the other party. Ultimately, uncertainty in valuation of impacts on society due to externalities represent risk or opportunity transacted from business to society. Information and comparability of the uncertainty in the monetary value is as important as the monetary value itself in this case.

Uncertainty in valuation of impacts on society due to externalities represent risk or opportunity transacted from business to society. Information and comparability of the uncertainty in the monetary value is as important as the monetary value itself.

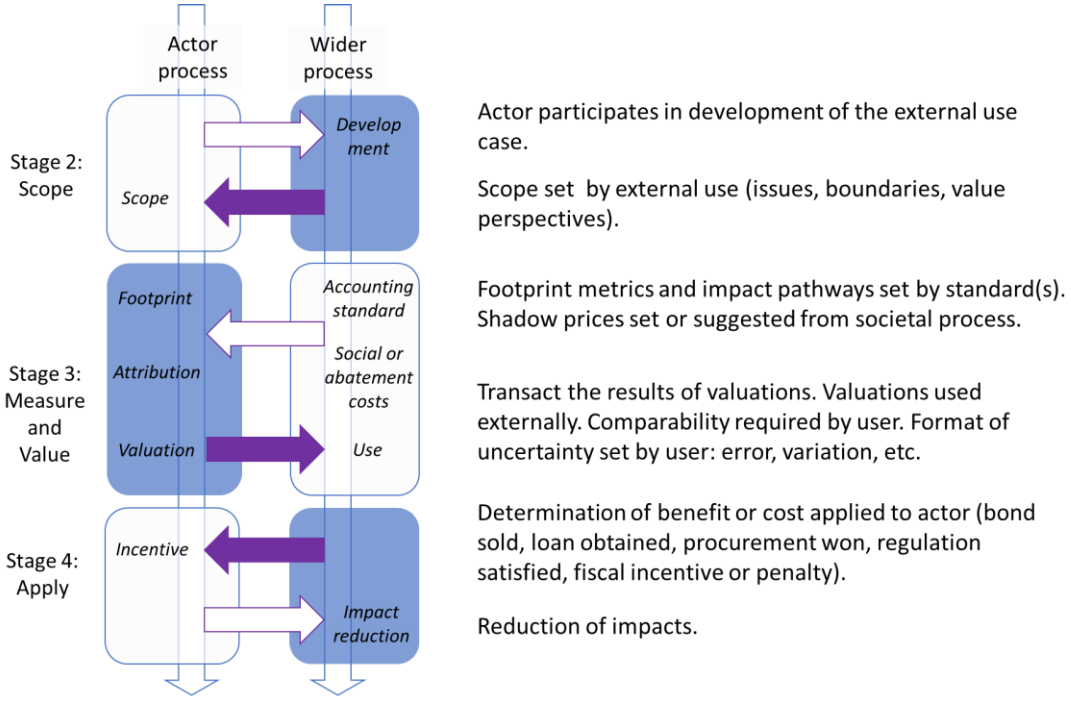

Figure 9: Stages for a shared decision process

Boundary conditions

The business sets the scope of impact valuation in the Protocols. The Protocols discuss material issues to stakeholders relevant to the business decision. An external use case where society is the stakeholder with the purpose of reducing the major external costs introduced by the food system sets the issues of concern. The issues of concern are those associated to the major external costs introduced by the food system (Table 1). They and the use case set what to measure, what to include in scope, what are the impact pathways, what to report, what will

[69] Step 8.3 on p. 65 of S&HCC, *Social & Human Capital Protocol*.; See also Step 5.5 p. 80 in Schaafsma and Cranston, *E.Valu.A.TE: The Practical Guide*.

be the result (Figure 9). We explain that this does not limit the boundaries discussed in the Protocols. It does set the scope of the impact calculation and the value perspective.

The organisational scope is not limited (Figure 10). The social costs from changes in natural, social and human health capital can be factored into a corporate impact statement or added to the price of individual products as an indicator of their sustainability.

The geographic extent of activities is not limited (Figure 10), the criteria of a material issue for society is the concurrent global impact of local activities. For example, a pollutant in a local waterway not presently threatening planetary boundaries due to its global use, and not especially amplifying the impact of pollutants that are, is a local material issue. Valuation of the impact of nitrogen leaching from a specific locality is still within the scope of a material issue for society because of the concurrent impacts from nitrogen. A local issue with concurrent global impacts will be more costly than if it were localised material issue. This is evident from the difference between carbon emissions from energy production when the rest of the world is emitting carbon for energy production, versus carbon emission in one locality if the rest of the world were emitting no carbon for energy production at all.

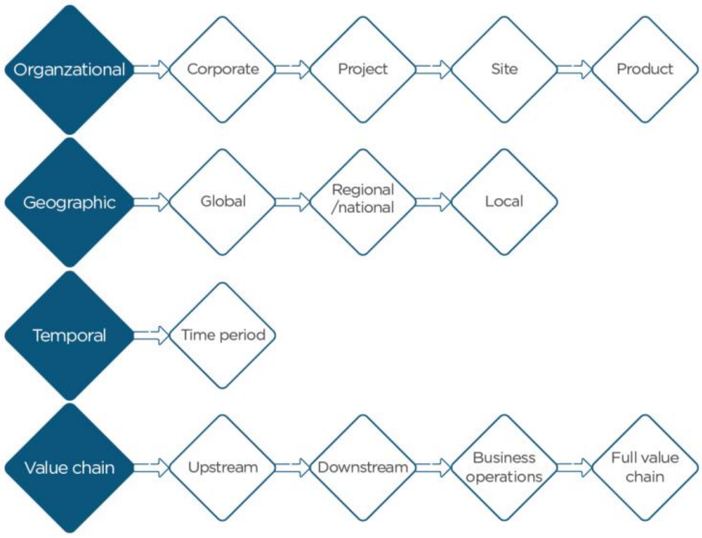

Figure 10: Representation of basic boundaries in the Protocols (Source: S&HCC, *Social & Human Capital Protocol, p. 25)*

Value chain scope of activities can be upstream, downstream, business operations or full value chain (Figure 10). Activities in any of these scopes can contribute to the major external costs introduced by the food system. The use case will fix the scope. Extended producer responsibility is unresolved for food products. It is unclear what proportion of downstream impacts should be attributed to the agricultural producer, the food product manufacturer, or the retailer. Most uses will need a way to account, or transact, impact between actors in the value chain to avoid double counting of impact in the food system. Conceptually this is no different from value adding to determine total market value. Impact is, generally, not linear in footprint. Assumptions are required to use footprint accounting, e.g. lifecycle inventory, to apportion impact.

In summary, comparable impact valuations

- will involve objectives, scope of activities, and boundaries, set by the external use of the impact valuation, not chosen by the food system actor.

This

- specifies scope of impact calculation not scope of activities.

Temporal scope of activities is mostly fixed by the use. An impact statement looks at annual period of activity. A procurement might look at the total lifetime of activity of the full value chain (inputs, production, consumption, disposal). The temporal scope of impacts is total lifetime of impacts. We diverge in the next few paragraphs to discuss this.

Irreversible losses in capital changes caused by present activities are often raised as a problem with calculating total impacts. The impacts may continue to compound into the future making the aggregate impact over the full lifetime 'infinite'. Three factors mediate this in practice.

First, monetary valuation of impact on welfare involves an extended representation of economic value loss or gain against a baseline. Discounting (the creation of value in the future from the capital base outside of the irreversible capital loss or due to consumption of that capital) can make the opportunity loss to future economies of irreversible capital changes from present activities finite when aggregated over the future. A second component of discounting does not assume an increase of value in the future, but that there is an opportunity loss to present economies compared to future ones from not utilising a non-renewable resource. Assumptions about intergenerational welfare create variability in the application of the two components[70]. The ethical choices implicit in impact valuation are summarised from p. 86. Discounting is discussed further from p. 73.

Second, future irreversible capital losses are uncertain. If we assume that economies of the future will compensate for the value loss at some stage then the issue is not an 'infinite' valuation, but what is the behaviour of the tail in a distribution of valuation estimates toward infinity. A distribution of valuation estimates is illustrated in the discussion of the social cost of carbon (Figure 14 on p. 53). Assuming that economies of the future will compensate for the value loss is routinely done. It is implicit in the climate change debate that there is a zero chance that future economies will not overtake in value the loss of non-renewable fossil fuels utilised for present welfare. Understanding a distribution of valuation estimates is one of the reasons why communication and comparability of not only the valuation, but the uncertainty in the valuation, is needed. Society, as the ultimate stakeholder and bearer of externalities, including catastrophic irreversible losses, needs to attribute those possibilities to the activities of the externality producer. 'Fatter' tails in distributions of valuations involving long-term impacts will mostly be due to catastrophic irreversible losses as discount rates kills more certain, time-limited and smaller scale economic impacts[71].

Third, unless the irreversible capital loss, of the kind where economies of the future will not compensate for the value loss (e.g. planetary loss of human life-support services), is certain to occur from activities within the temporal scope of activities (e.g. annual emission), then an infinite social cost calculation is not necessarily required to sponsor a finite abatement cost. The social cost need only be, in practice, finite but sufficiently large. Equivalently, the assumption is future economies will abate such losses, i.e. social optimism[72]. For example, the loss of territorial lands of an indigenous people through environmental degradation may

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[70] P. Dasgupta, "The Stern Review's economics of climate change," *National Institute Economic Review* 199, no. 1 (2007), https://doi.org/10.1177/0027950107077111.

[71] M. Weitzman, "Fat-tailed uncertainty in the economics of catastrophic climate change," *Rev. Environ. Econ. Policy.* 5 (2011). 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.

[72] K. Schweizer and R. Schneider, "Social optimism as generalized expectancy of a positive outcome," *Personality and Individual Differences* 22, no. 3 (1997), https://doi.org/https://doi.org/10.1016/S0191-8869(96)00219-X. T. Sharot, "The optimism bias," *Current Biology* 21, no. 23 (2011), https://doi.org/https://doi.org/10.1016/j.cub.2011.10.030. E. M. Markowitz and A. F. Shariff, "Climate change and moral judgement," *Nature Climate Change* 2, no. 4 (2012), https://doi.org/10.1038/nclimate1378.

be associated to irreversible welfare loss in their economy. The staggering costs of a utilitarian parity calculation of, say, compensation (the cost per capita of moving the UK or Switzerland's population if the equivalent capital loss occurred in those economies), would likely be a sufficient lower bound on social cost to sponsor abatement. This example is illustrative. The value perspectives inherent in choices of spatial and temporal parity to compare economies and in the calculation of the value require, in the end, an agreed process.

A belief amongst all parties involved that activities within the temporal scope of activities (e.g. this year's emissions) will result in certain destruction of non-renewable capital with a non-zero chance of irreversible intergenerational welfare loss invalidates the three mediations described. Moral and ethical discussion of, and action on, irreversible welfare losses under such assumptions is outside the scope of valuation theory and the economic theory of change[73].

The three factors discussed can produce finite impact estimates from the full lifetime of impacts. Uncertainty in the impact valuation is increased by including full lifetime of impacts. The uncertainty introduced is less than the error that would be introduced by omitting future impacts. Variation and uncertainty in impact valuation is discussed from p. 115.

The recommendation in this report is that scope and boundaries for comparable monetary impact valuations be fixed by uses, and that variations, including non-disclosure of information within that scope, be pushed into the uncertainty in the impact calculation. For example, for a protocol from an investment community aiming to incentivise reduction of the global food system's major impacts might include calculating the annual company impact from non-renewable water extraction. A company might not have data on non-renewable water extraction. If the company omits the contribution of non-renewable water extraction to the impact valuation, the investor community cannot compare the impact valuation with other companies that have the data and have included it in their impact valuations. The investor community has set the scope. They can compare all companies at the same scope and the same boundaries by putting a non-renewable water extraction figure in for the company that omitted it. What to put in is discussed further from p. 115. The maximum figure amongst all the other companies is one way to penalise non-disclosure. This makes the impact valuation of the company that did not disclose uncertain but comparable.

Scope of impact valuation for reducing the major external costs of the food system

Comparable valuation of impacts with the purpose of reducing the major external costs introduced by the food system narrows the scope of the impact frameworks, which are more general.

We phrase limitation of scope in the terminology of the Protocols' Stage 2: Scope.

Step 02: Define the objective will be fixed by the use case of the valuation where comparison is required, for example an impact statement. Step 03: Scope the assessment sets boundary conditions and whose value perspectives[74].

[73] S. Rose-Ackerman, "The Limits of Cost/Benefit Analysis When Disasters Loom," *Global Policy* 7, no. S1 (2016), https://doi.org/10.1111/1758-5899.12279.
[74] D. W. Cash et al., "Scale and cross-scale dynamics: governance and information in a multilevel world," *Ecology and Society* 11, no. 2 (2006), http://www.ecologyandsociety.org/vol11/iss2/art8/; G. Midgley, "The sacred and profane in critical systems thinking," *Systems practice* 5, no. 1 (1992), https://doi.org/10.1007/BF01060044.

Value perspective

For comparable impact valuations with the purpose of reducing the major external costs introduced by the food system the value perspective is “impact on society”. What impact on society means in practice is specification of impact pathways according to the issues of concern in Table 1, specification of economic value or welfare, the ability to forecast economic trajectories with and without impact, and the choice of parity and discounting. We discuss these factors further in the next section from p. 48 and p. 71.

Comparable valuation that contributes to food system transformation will likely involve a limited number of frequent uses. Internalisations that involve external corrections are generally resource intensive, limiting their number, and likely to be applied at scale, increasing their frequency of use. The limited number of use cases provides an opportunity to standardise scope. We recommend pushing variation of scope into the impact calculation based on the case studies and the breakdown of valuation from p. 63:

- Placing the value perspective, or the definition of welfare, into the model of the economies, is in-line with social and abatement costs in welfare economics. Many other boundary conditions, including value judgements (e.g. choice and quality of model and data, choice of discount rate), are already inside the valuation calculation[75].
- These considerations require an agreed and credible process. They should not validate by economics the destruction of an ecosystem in one part of an ‘economically’ unimportant part of the world (substitution of economic value). Present approaches for business impact valuation still permit this, especially in adding up ‘total value’. For the issues of concern to society, society, as risk bearer of the externalised costs, needs to set the value perspective. Valuation components such as shadow prices and their uncertainty, and the choices of spatial and temporal parity should be, in the end, the result of a societal scientific process.
- Even if a business uses software to perform a valuation that, in its simplest form, requires as input a standard list of quantities from the business’s own operations (for example a lifecycle inventory) and provides as output a valuation, for comparability the business or software will need to report on the assumptions underlying the calculation. This does not appear onerous. If society, through internalisation, requires of business comparable valuations, business demands of the software vendor a button to export appropriate metadata on the calculation. The metadata should allow a recalculate the valuation. The discussion in later sections of this report indicates the kind of metadata needed.
- Business should be users of marginal valuations such as the social cost of carbon, not developers. The potential frequency of use of comparable impact valuations needs to sponsor the societal development (by a consortium of intergovernmental and institutional actors and experts, in collaboration with the food sector) of the valuation factors.
- Putting uncertainty from scope into the impact calculation introduces uncertainty into the impact valuation. Impact valuations will already have considerable uncertainty from other factors, described from p. 115. Some of those uncertainties are irreducible. There

[75] M. Fleurbaey et al., "The Social Cost of Carbon: Valuing Inequality, Risk, and Population for Climate Policy," *The Monist* 102, no. 1 (2018), https://doi.org/10.1093/monist/ony023.

does not seem a credible way of avoiding measurement and valuation of the uncertainty[76]. Uncertainty exists in both marginal social and abatement costs[77].

- The complication of dealing with distributions of variation estimates is placed on the societal development. Business do not need to deal with the distributions, only numbers – but that number could include the cost of a risk premium to society from the uncertainty in the valuation.
- Valuations already deal with uncertainty of impacts on the value of produced and financial capital where there are limited markets for exchange and infrequent transactions, e.g. catastrophe bonds, and terrorism and cyberattack insurance. The uncertainty in valuation of non-financial capital changes is large and more complicated, indicating higher premium, as befits the risk society bears when business and society alike cannot estimate with accuracy the impacts of externalities.

We have not been very specific on uncertainty. The division of risk and uncertainty attributed to Knight is common in financial and economic disciplines. Risk is a measure of observed variation in the Knight view. Risk in the ISO31000 view is uncertainty in the distribution of impact, which may include representation of epistemological uncertainty (lack of knowledge) as well as aleatory uncertainty (randomness)[78].

How adding a risk premium to an impact valuation might work practically is discussed on p. 121.

Non-financial capital accounting frameworks for food systems

A non-financial capital accounting framework for food systems at a resolution that aligns with internalisations that have the potential to create the most change does not yet exist.

A non-financial capital accounting framework for food systems based on the issues associated to the major external costs would consolidate the scope further and provide a standard basis for uses. The System of Environmental-Economic Accounting (SEEA) is an example of an accounting framework that includes non-financial capital accounting. It is designed for national accounts. The resolution is too coarse to act as an accounting basis for most internalisation mechanisms and it is not specific to food systems. A non-financial capital accounting framework for food systems at a resolution that aligns with the internalisations that have the potential to create the most change does not yet exist.

In the Protocols, Step 04: Define the impacts lists material issues, a consideration of how they result in impact, called an impact pathway, and prioritization of issues according to impact. This step for comparable valuations is fixed by the issues associated to the major external costs introduced by the food system. A standard list of issues can be extracted from the large amount of scientific literature on food system impact and consolidated through a societal

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[76] Dasgupta and Duraiappah, "Well-being and wealth." argue that the shadow prices will never be "right", they are fundamentally uncertain.

[77] D. Helm, *Carbon valuation in UK policy appraisal: a revised approach and peer reviews. Peer review Dieter Helm.*, Natural Capital Comittee. UK Department of Energy & Climate Change. (London, 2009), https://www.gov.uk/government/publications/carbon-valuation-in-uk-policy-appraisal-a-revised-approach.

[78] S. F. LeRoy and L. D. Singell, "Knight on Risk and Uncertainty," *Journal of Political Economy* 95, no. 2 (1987), https://doi.org/10.1086/261461; M. E. Pate-Cornell, "The Engineering Risk Analysis Method and Some Applications," in *Advances in Decision Analysis*, ed. W. Edwards, R. F. Miles, Jr., and D. Von Winterfeldt (Cambridge, UK: Cambridge University Press, 2007); Standards Australia and Standards New Zealand, *AS/NZS ISO31000:2009 Risk management - Principles and guidelines*, IEC (Geneva, Switzerland, 2009).

process (Table 1). The FAO Sustainability Assessment of Food and Agriculture systems (SAFA) Guidelines and the EU SUSFANS project are examples of consolidation of literature on which a food system specific accounting framework could be based[79]. The list of issues would already be prioritised according to societal impact. Trade-offs across the activities of the food system that contribute to these issues means that impact valuation should include the full range of capitals, rather than concentrate on natural or on social and human. For example, climate change, human health and agricultural livelihoods involve intertwined impact pathways.

A non-financial capital accounting framework for the food system would specify

- Issues associated to the major external costs introduced by the food system – which guide what to measure. Measuring all the difference from capital changes caused by activities of the food system would be difficult and unnecessary. The issues identified represent scientific consensus about what components of activities are believed to produce the most difference in welfare in economies of concern. Working with these issues restricts measurement and specifications to what is believed to be most of the impact.
- Footprint
    - What to measure, i.e. what aspects of a business or food system actor's operation
    - What units
    - What to disclose
- Capitals
    - What to measure, i.e. the change in value flow from which capitals is most relevant to societal impact, intersected with the value flow from which capitals is attributable to food system actors.
    - Stocks
    - Quantity and qualities
- Formalisation of the exchanges and contributions between footprints, capitals, footprint to capital and capital to human well-being relevant to impact (impact pathways).

Capital changes are relevant to national accounting of assets, e.g. natural capital accounting in the UK, and processes to determine and update social and abatement costs.

Reconstructing what footprints and impact pathways are relevant proceeds in reverse. The scientific literature starts with value loss and deconstructs what changes in the capital base produce it, what changes in the capital base are due to the food system, and then what aspects of business or food system actor operation need to be measured in a prioritised sense of a feasible set covering most of the value loss.

The TEEB AgriFood Evaluation Framework lists material issues and what conceptually to measure. It is not prescriptive on metrics and units, and, in order to retain universality across a range of evaluation approaches, does not formalise impact pathways. It is not an accounting framework in the above sense. In the edge of the triad representing interaction between food system science and economic valuation (Figure 4), food system science informs the structure and quantification for changes in capital stocks, and their quantity and quality. In Figure 4 we place accounting frameworks on the arrow from food system science to economic valuation closer to economic valuation in recognition of their more formal and prescriptive scope.

[79] FAO, *Sustainability Asessment of Food and Agriculture Systems (SAFA) Guidelines*; Zurek et al., "Assessing Sustainable Food and Nutrition Security of the EU Food System—An Integrated Approach.". The SUSFANS project is more specific on metrics.

The SEEA has a component for Agriculture, Forestry and Fisheries, SEEA-AFF. It concerns national aggregates and is environmentally focussed, but it provides a baseline for accounting.

A capital accounting framework fixing the measurement and disclosure scope, which use cases could base their own requirements on a subset of if necessary, is the eventual requirement for comparable valuations. Arguments why a footprint has not been included in the scope become part of disclosure. Non-disclosure should be pushed into the uncertainty in the valuation. The rationale is the same as before: society bears the risk of business externalities and risk has increased through lack of information. Note that disclosure does not just affect a business' own determination of attribution for the valuation, but the calculation of shadow prices depend on information from the sector, and other economic sectors, as a whole. Non-disclosure has a double contribution to uncertainty in the impact valuation, and hence risk to society.

In suggesting what a non-financial capital accounting framework for food systems should include above, we have covered inventory accounting. In the System of Environmental Economic Accounting – Experimental Ecosystem Accounting (SEEA-EEA), this corresponds to Chapters II, III, IV. Even though SEEA-EEA is designed for national accounts it needs geospatial context to do so. The SEEA-EEA recognises that the spatial resolution of capitals, capital changes and impacts does not accord with national boundaries. This is also essential for accounting for food system impacts. The spatial resolution at which to measure footprint for food system impact valuation will be a major consideration through the next section. A concentrated discussion can be found from p. 78. The SEEA-EEA includes both accounting of quantities and qualities of capital, and valuation (Chapters V,VI) in its scope. The current revision of the SEEA-EEA offers a conceptual discussion on non-financial capital accounting that could underpin a version for food systems[80].

Impact pathways are illustrated in the next section and in the case studies from p. 128. Impact pathways for food systems for the issues associated to the major external costs have yet to be collated. Collating impact pathways that are presently distributed in literature across different disciplines and matching the beginning of the pathways to the footprint protocol is a step toward an accounting standard.

An accounting framework should also consider

- Standardised scenarios for the assessment of non-current non-financial assets and liabilities, and value changes over time.

Valuations of food system impacts will vary greatly depending upon assumptions about the future; the social cost of carbon is evidence of this. Social and human capital also have intergenerational effects[81]. Using the example of the social cost of carbon, the impact of an actor's carbon equivalent footprint now depends on the rest of the economy's footprint now and into the future (called RCPs in climate science[82]), and the socio-economic drivers into the

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[80] OECD et al., "System of Environmental Economic Accounting 2012 : Experimental Ecosystems Accounting." Discussion papers for the SEEA-EEA revision include crop cultivation and fisheries https://seea.un.org/content/seea-experimental-ecosystem-accounting-revision

[81] C. G. Victora et al., "Maternal and child undernutrition: consequences for adult health and human capital," *The Lancet* 371, no. 9609 (2008), https://doi.org/https://doi.org/10.1016/S0140-6736(07)61692-4; K. L. Whitaker et al., "Comparing maternal and paternal intergenerational transmission of obesity risk in a large population-based sample," *The American Journal of Clinical Nutrition* 91, no. 6 (2010), https://doi.org/10.3945/ajcn.2009.28838.

[82] B. C. O'Neill et al., "A new scenario framework for climate change research: the concept of shared socioeconomic pathways," *Climatic Change* 122, no. 3 (2014), https://doi.org/10.1007/s10584-013-0905-2.

future which might coincide with those radiative concentration pathways (called SSPs[83]). The combination of an RCP and SSP provides exogenous specification to calculating the social cost of carbon[84]. Calculating the social cost of carbon is discussed further on p. 51. Scenarios are discussed further on p. 84.

Initiatives to assess where business accounting associated to food system impacts, currently unscripted and unharmonized, can leverage on the accounting structure of the SEEA-EEA and conceptual consolidation such as the FAO SAFA guidelines, are useful for comparable and credible food system impact valuation.

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[83] D. P. van Vuuren et al., "A new scenario framework for Climate Change Research: scenario matrix architecture," *Climatic Change* 122, no. 3 (2014), https://doi.org/10.1007/s10584-013-0906-1.

[84] Despite the RCP and SSP specification, which has been used by thousands of studies, and the hundreds of calculations of the social cost of carbon, there does not appear to be a standard association between discount parameters and RCP and SSP combinations. Implicit in SSPs are rates of economic growth and marginal utility, and by the action or inaction on climate change are implicit preferences for intergenerational welfare.

VALUATION IN PRACTICE SUMMARY

Based on the impact frameworks described in the previous section we phrase impact valuation in terms of footprint created by activities (quantities associated to impact such as tonnes CO2-eq emitted or kg reactive nitrogen leached), the capital change attributable to the footprint, and the value change from the capital change. The activity might be the annual operations of a food company, the lifecycle of a food product, the production of a tonne of an agricultural commodity, or a change in farming practice. Footprints become the quantities associated to increase or decrease in economic value. In economic theory quantities should either be produced or reduced to maximise economic value overall.

A review of marginal social and abatement costs of carbon associated to the footprint of CO2-eq emissions indicate the variation in estimates due to modelling and data choices, scenarios, parity, and discounting. Parity is the choice of how to compare economic value between economies; usually national economies. Discounting is the choice of how to compare economic value between an economy now and an economy in the future.

Marginal social and abatement costing are examined in detail with comment on adjustments for food system impact valuation. It is found that the variety of data, models, tools, scenarios, and valuation methods already used, and fundamental uncertainties in ethical choices as well as scientific estimates, will result in potential order of magnitude differences in food system impact valuations. It is unclear at present where the major sensitivities lie for practical estimation of error bars. Research is required on the sensitivity of valuation to intergenerational effects in other dimensions of food impact such as obesity and rural poverty, and international effects embedded in food's global value chains.

The foremost difference from carbon costing found is that impact from food system activities is associated to footprints in plural, some of which need to be broken down further due to spatial and contextual differences in impact due to those footprints.

A level of resolution in spatial and contextual divisions is recommended. If the resolution is too coarse the error bars in valuation estimates will be too large and not trusted. Also, users will not be able to highlight the differences in impact from distinct production practices. Too fine a resolution then energy and time are wasted on perturbations to valuation numbers that will not make much difference to global scale transformation.

An important argument for agreed monetary food impact costing is exposing and pricing longer-term value losses in the economy as a counter to short-term political dynamics. Enabling economic mechanisms to invest in offsetting or creating longer-term value. This was an important outcome of carbon costing. The same applies if a tandem food system and economic community were able to promote and calculate social and abatement costs for nitrogen, land-use, obesity and diabetes, rural welfare, and the other major external costs of the food system.

Social and abatement costing

Marginal social and abatement costs are two different marginal valuations. They lead to different impact valuations when applied to the same footprint.

A marginal social cost is the change in economic value from producing footprint. A marginal abatement cost is the cost incurred in reducing footprint. Reducing the footprint avoids incurring the social costs. Marginal abatement costs are derived from portfolios of abatement measures designed to achieve a footprint reduction target for the least cost.

Sustainable food and agricultural products, and companies incorporating sustainable practices or sustainable sourcing, are found to offer abatement of footprint compared to their unsustainable counterparts. The additional cost of the sustainable products and practices is their abatement cost. The reduction in footprint from substituting the unsustainable product or practice is the abatement. The social benefit associated to the abatement is the abatement value.

An impact valuation using marginal social costs and abatement as footprint calculates the abatement value of the sustainable product or practices.

An impact valuation using marginal abatement costs and abatement as footprint indicates the cost-effectiveness of the sustainable product or practice as an abatement measure contributing to a footprint reduction target.

It is found that the two are complementary views of the value of sustainable food and agricultural products. Both can be used to set incentives. It is presently unclear what will be the major viewpoint of those offering incentives – meeting footprint targets at least cost or achieving the most social benefit.

The 2019 EAT-Lancet Commission on healthy diets from sustainable food systems, the 2019 IPCC Special Report on Climate and Land, and the 2019 FABLE consortium report, have laid the foundation for 2050 global food system footprint reduction targets in CO2-eq emissions, biodiversity loss, freshwater use, reactive nitrogen and soluble phosphorus leakage, and land-use change. Also provided are global malnutrition footprint reduction target for food consumption categories. It is found that one of the major uncertainties in abatement costing is whether dietary changes will be realised. While international agreements can cap physical emissions and extractions, there is large uncertainty in the achievement of dietary targets. Dietary changes are necessary to reach global footprint targets.

There are no global targets as yet for social capital impacts. It is found that targets can be set with reference to the SDGs, but it is not clear that the food system can achieve them. While pushing down one target, another may rise. Assuming the global diet targets are achieved, the EAT-Lancet Commission report shows that environmental footprint reduction targets and preventable human death and disease targets can be achieved together. It is found in this section that maximising economic value is a rationale for disaggregating global footprint targets into spatial and contextual footprint targets. At least as a start point for political agreement. There is enough scientific work to inform food system impact or footprint targets. The gap is in the political and societal process.

Overall, because of the complexity in abatement costing, it is recommended to use social costs until abatement costings for food impacts are further developed. Abatement costing should be further developed for two reasons: one, to inform costs of tangible action and economic trajectories for food system transformation; two, to improve cost-effectiveness measures of the value provided by sustainable food products and practices. This section finds that the most useful measure for society and governments is the total abatement provided by products and practices. Calculating total abatement depends on projecting demand for the sustainable product and practice. More research on demand projections is recommended. Demand projections are discussed further next section.

Ethical choices and uncertainty

This section finds that the fundamental uncertainties in ethical choices as well as scientific estimates make it unlikely that agreement can occur on single values or single methods for marginal valuations. Food impact costing does not need to get the 'correct' answer. Agreement, credibility, and the opportunity to intervene in market failure in the direction of food system transformation, are the guiding principles for costings. A mechanism for retaining variation but pricing risk into impact valuations is suggested in this section. Costing is a mechanism designed to match quantity of production (for a quantity controlled by humans) with human and social well-being. It is recommended that practical and comparable valuation for users be based on shadow prices of footprint changes and not capital changes for this reason.

It is found that all impact valuations observed in practice use a linear approximation to estimate economic value change from footprint changes. Non-linear corrections to impact costing for scarcity and interactions created by food's multiple footprints are examined. Whether non-linear corrections make a significant difference for economic food policy designed to reduce food system impacts is unknown because they have not been quantified. It is recommended that research develop quantitative estimates of second order corrections due to the synergies and trade-offs described in the 2019 IPCC Special Report on Climate and Land.

Variation in valuations from different choices have real or perceived ethical implications. Businesses make implicit ethical choices in valuations themselves, or by using choosing calculations of shadow prices in literature that have. This section recommends that, given unavoidable ethical choices and order of magnitude uncertainties inherent in both social and abatement costing, a societal process building on private starts and national handbooks should compile, set and update marginal valuations with their uncertainty associated to food footprints.

A practical model for risk pricing is suggested in this section. It replaces terms in the linear model with random variable equivalents (uncertain shadow prices, uncertain footprints, etc) and calculates a risk premium that can be priced into the impact valuation. The following points are found:

- The risk premium describes how much society should "charge" to take on the uncertainty in external costs associated to the footprint produced by a product, practice, or company.
- Businesses have the same playing field if shadow prices and their uncertainty were agreed. The premium is a further chance for credibility and agreement in impact valuation – if set in collaboration with civil society and government who represent the bearers of risk. The food sector investing in a societal process for better information about impacts and valuation would reduce the risk premium on shadow prices, creating an incentive.
- Businesses can compete on footprint reduction and on disclosure. Calculating footprint is closer to the activity of the business itself. Methods for footprint calculation such as lifecycle analysis (LCA) are already well developed. Disclosure would reduce the risk premium, creating an incentive.
- Risk premiums are likely to be dominated by uncertainty and correlations between the greatest impacts, e.g. carbon and health. Major non-market costs that pose significant joint risk to global welfare. Research is required to understand and quantify correlations.

Nine case studies in the next section show the variation in practice in footprint, models and data, and valuation methodology, and a precedent for pricing uncertainty.

VALUATION IN PRACTICE

Impact valuation estimates external costs in order to inform internalisation. Impact valuation should also indicate who incurred the costs and what food system activities they originate from. The purpose of food system impact valuation is to align the market dynamics of food and agricultural toward the social and human well-being targets of food system transformation.

The process of impact valuation identified in impact frameworks (Table 2). What society and individuals value is some function of produced, natural, social and human capital. Impact is value gained or lost due to capital change. Capital change is some function of activities in the food sector and additional drivers. A practical connection between activities in the food sector and capital change is footprint. Footprint is the quantities relevant to impact of a food system actor, see Figure 11. Footprint is some function of upstream inputs, an actor's own operations, and downstream outputs, depending on the extended responsibility implicit in the scope of the use case.

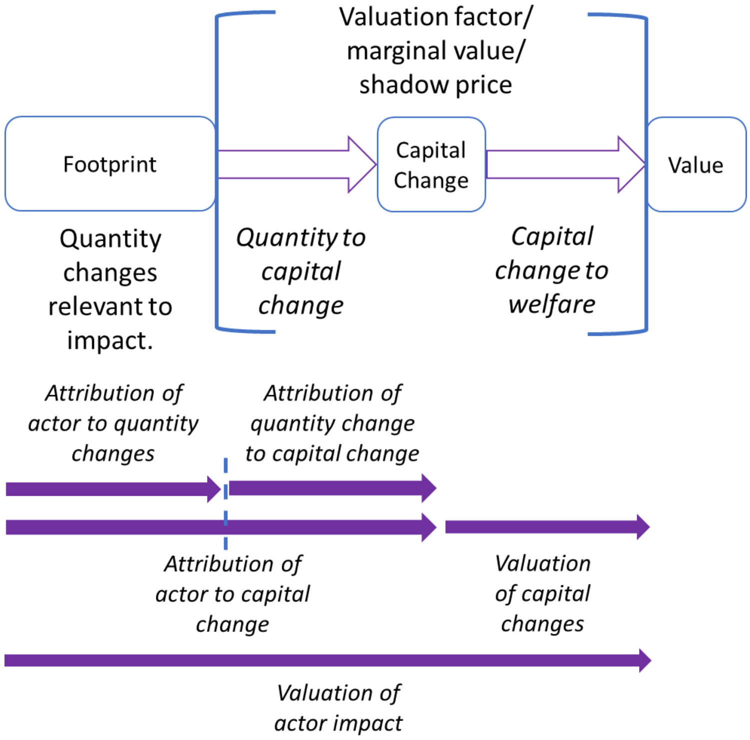

Figure 11: Impact valuation in terms of footprint change (quantities associated to impact such as tonnes CO2eq emitted or N leached), the capital change attributable to the footprint change, and the value change from the capital change.

Footprints should be identified by working backwards from impact. Where food systems are creating the most concern for social and human value change (Table 1), traced through capital changes, identifies quantities relevant to impact such as tonnes CO2-eq emitted or kg reaction nitrogen leached[85]. Tracing from impact back to footprint identifies an impact pathway.

[85] Carbon footprint: B. P. Weidema et al., "Carbon Footprint," *Journal of Industrial Ecology* 12, no. 1 (2008), https://doi.org/10.1111/j.1530-9290.2008.00005.x.. T. Wiedmann and J. Minx, "A Definition of 'Carbon Footprint'," in *Ecological Economics Research Trends*, ed. C. C. Pertsova (Hauppauge NY: Nova Science Publishers, 2008).Water footprint: A. Y. Hoekstra et al., *The Water Footprint Assessment Manual: Setting the Global Standard* (London: Earthscan, 2011).. Nitrogen footprint: J. N. Galloway et al., "Nitrogen footprints: past, present and future," *Environmental Research Letters* 9, no. 11 (2014),

Examples of impact pathways:

Preventable respiratory diseases and death associated to air pollutants (NH3, So2, NOx, VOCs, PM10) which are increased in concentration or due to natural capital changes (soil erosion, ecosystem changes) resulting from agricultural activities including direct nitrogen fertiliser application. Loss of productivity from individuals and households of individuals affected by preventable respiratory disease is one monetary reflection of the loss of value.

Tonnes of air pollutant is the footprint. Loss of social and human well-being is the impact.

The agriculture and food production sectors are associated generally to low wages and high accident rates for small-holder farmers and production workers. Market concentration, power imbalances and contractual value chains coupled with bearing the direct burden of risk from extreme weather and plant and animal diseases further increase stress on households and communities of workers and farmers in the food sector (produced, social and human capital changes). The increased incidence of economic destitution of households and breakdown of community support leads to increased social costs from lost productivity, increased crime and obesity (high intake of calorie-dense nutrient-poor cheap food)[86].

Incomes and accident rates in spatial, socio-economic and value chain context are the footprints. Loss of social and human well-being is the impact.

Preventable diseases and death related to obesity which have increased in prevalence and severity in part by diets high in sugar, fat and processed foods consumed by individuals and produced by the mostly private food sector. Increased social costs of healthcare are one monetary reflection of the loss of value associated to preventable diseases and death related to obesity.

Contribution to food products consumed in present diets with socio-economic and demographic context are the footprints. Distance of the present diets from reference diets for optimal health diets in context link the food products to preventable disease and death. Loss of social and human well-being is the impact.

Capital changes and the pathways leading to them are complex. The same activity can lead to changes in multiple footprint quantities. Change in the same footprint quantity can lead to changes in multiple capitals. The change in one capital, e.g. natural capital, can lead to changes in other capitals and multiple impacts (Figure 1 and Figure 18 on p. 81). Scientific detail of impact pathways associated to food systems – environmental, social, health – can be found in the references for Table 1. Impact pathways for food systems have yet to be collated. This was a potential function of an accounting standard mentioned last section. Collating impact pathways are steps toward the accounting standard.

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https://doi.org/10.1088/1748-9326/9/11/115003.. A. M. Leach et al., "Environmental impact food labels combining carbon, nitrogen, and water footprints," *Food Policy* 61 (2016), https://doi.org/https://doi.org/10.1016/j.foodpol.2016.03.006.. L. Čuček, J. J. Klemeš, and Z. Kravanja, "A Review of Footprint analysis tools for monitoring impacts on sustainability," *Journal of Cleaner Production* 34 (2012), https://doi.org/https://doi.org/10.1016/j.jclepro.2012.02.036.

[86] National Research Council, *Framework for Assessing Effects of the Food System*; H. J. Holzer et al., *The economic costs of poverty in the United States : subsequent effects of children growing up poor. Institute for Research on Poverty Discussion Paper no. 1327-07*, Center for American Progress (Washington DC, 2007), https://irp.wisc.edu/publications/dps/pdfs/dp132707.pdf; A. Drewnowski, "Obesity, diets, and social inequalities," *Nutrition Reviews* 67, no. suppl_1 (2009), https://doi.org/10.1111/j.1753-4887.2009.00157.x. C. B. Barrett et al., "Smallholder Participation in Contract Farming: Comparative Evidence from Five Countries," *World Development* 40, no. 4 (2012), https://doi.org/10.1016/j.worlddev.2011.09.006.

More examples of impact pathways (involving natural capital changes) are described in the Natural Capital Protocol Food & Beverage Guide. From pages 38-50 the Guide provides a list of worked examples illustrating footprint, considering capital changes, and then a basic formula for multiplying total footprints by a marginal value (a monetary amount per unit of the footprint). This section, the longest in the report, is concerned with the details that go into marginal valuations: what causes variation and uncertainty in the amounts, what might reduce reliability in the figures produced and so limit the use of the valuation, and what are the considerations for enhancing the comparability of valuations while still retaining practicality.

Figure 11 is an abstraction of detail relevant to practice. Detail which makes comparison difficult and causes variation in valuations. The variation is illustrated in the nine case studies from p. 128. The case studies also provide additional examples of impact pathways. Ambiguity in monetary estimates resulting from the complexity of capital changes is discussed on p. 98.

Despite being conceptual, Figure 11 provides a basis from which to understand the process of valuation, to distinguish quantity (footprint) and marginal value (shadow price), and to break down what components and assumptions are involved in valuation. The components, overlayed onto Figure 11 in Figure 17 and discussed from p. 63, are actor footprint, societal footprint, assumptions about socio-economic drivers, models and data for attribution of capital change, choice of welfare measure, parity and discounting.

The breakdown into components and assumptions provides a template in which to examine the variation in each case study from p. 128 and to distinguish available models and data, e.g. the inventory from p. 170. The conceptual view of Figure 11 is used to separate what parts of the valuation process are best developed through shared development (shadow prices) and which are competitive (footprint), which will feature again in implications from p. **Error! Bookmark not defined.**. The view of Figure 11 also provides a conditional sequence of random variables on which to build a simple approach to risk pricing from p. 115.

Carbon costing

Food systems are associated to 21-37% of global CO2-eq emissions[87]. Tonnes of CO2-eq emitted is a footprint associated to external impacts from the production and consumption of food products (Figure 12). Carbon costings, estimating both the social costs of the projected impact of capital changes due to a tonne of CO2-eq emission today and the abatement cost to avoid or sequester that tonne of emitted CO2-eq, are examples of marginal valuations. Reviewing carbon costing illustrates many features of valuations relevant to food system impact: social costs, abatement costs, discount rate, scenarios, actor footprint versus societal footprint, the complications of a chain of capital changes, and risk pricing due to variation in the calculation due to choices and settings[88].

[87] Niles et al., *Climate change and food systems: Assessing impacts and opportunities*; IPCC, *IPCC Special Report on Climate Change, Desertification, Land Degradation, Sustainable Land Management, Food Security, and Greenhouse gas fluxes in Terrestrial Ecosystems*. Vermeulen, Campbell, and Ingram, "Climate Change and Food Systems."; Tubiello et al., "The Contribution of Agriculture, Forestry and other Land Use activities to Global Warming, 1990–2012."

[88] Most reports on valuing food system impacts discuss the social cost of carbon, see e.g. p. 90 de Bruyn et al., *Environmental Prices Handbook EU28 Version*.; p. 10 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., p. 15 TruCost, *TruCost's Valuation Methodology*, TruCost (2015), https://www.gabi-software.com/fileadmin/GaBi_Databases/Thinkstep_Trucost_NCA_factors_methodology_report.pdf., p. 34 FAO, *Food wastage footprint: full-cost accounting*. p. 7-30 IPCC, *IPCC Special Report on Climate*

Figure 12 illustrates how the calculation of the social cost of carbon attributed to an actor factors through capital changes and the actor's carbon footprint. Sea level rise is indicated as an example; for explicit scientific detail of climate change impact pathways see the IPCC Special Report on Climate Change and Land[89]. In practice the actor's carbon footprint in tonnes is multiplied by a monetary value for the impact from one additional tonne of carbon emitted. The monetary value is the marginal social cost of carbon, marginal meaning the cost if one more tonne of CO2-eq was emitted in addition to existing CO2-eq levels in the atmosphere. The word marginal is routinely omitted.

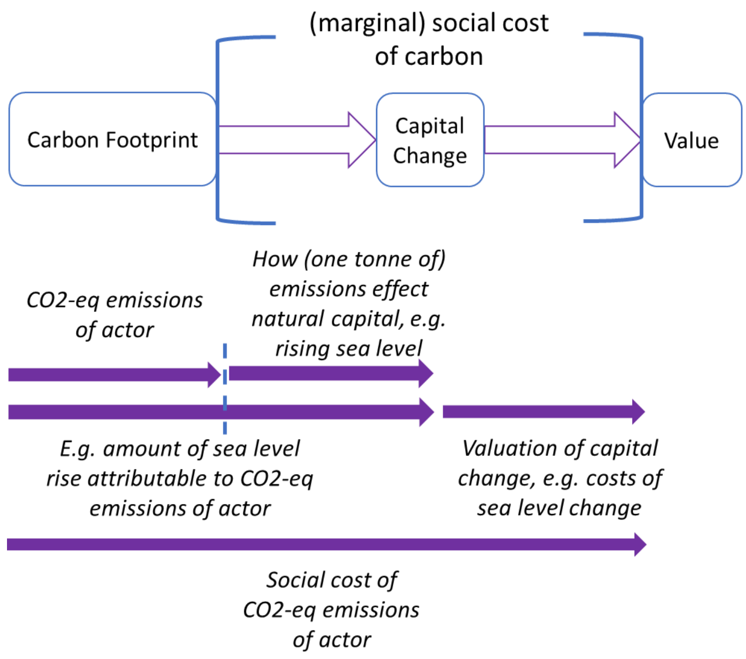

Figure 12: Example of Figure 11 for one capital change (sea level rise) included in the calculation of the social cost of carbon.

Social cost of carbon

The social cost of carbon (SCC) is a calculation of the difference in global economic value between a baseline economy with a specific quantity of CO2-eq emissions added to a continued trajectory of CO2-eq emissions and an alternative economy without that added quantity of CO2-eq emissions (for the SCC this quantity is usually one tonne). The difference in economic value between the economies is projected over time. The baseline economy gains the private and external benefits of the production and consumption of good and services that results in the additional CO2-eq emission but incurs the private and external costs of additional effects of climate change. The alternative economy avoids the private and external costs of additional climate change but loses the potential benefits of production and consumption from the CO2-eq emission. The difference is monetised by calculating PPP GDP changes. Welfare losses including greater morbidity and mortality, the extinction of species, and social disruptions are assumed to be reflected in GDP changes. Different weightings between national GDP for regions more, or less able, to absorb the effects of climate change have been

Change, Desertification, Land Degradation, Sustainable Land Management, Food Security, and Greenhouse gas fluxes in Terrestrial Ecosystems.

[89] IPCC, *IPCC Special Report on Climate Change, Desertification, Land Degradation, Sustainable Land Management, Food Security, and Greenhouse gas fluxes in Terrestrial Ecosystems*.

used to calculate the SCC (parity choices)[90]. More general monetisation of social and human welfare than GDP has been used (welfare choices)[91]. The difference between the two trajectories is discounted to present value and then integrated over time to obtain an estimate for the total amount of social costs due to the quantity of CO2-eq emission (Figure 13).

The SCC depends how the difference in economic value between the economies is computed.

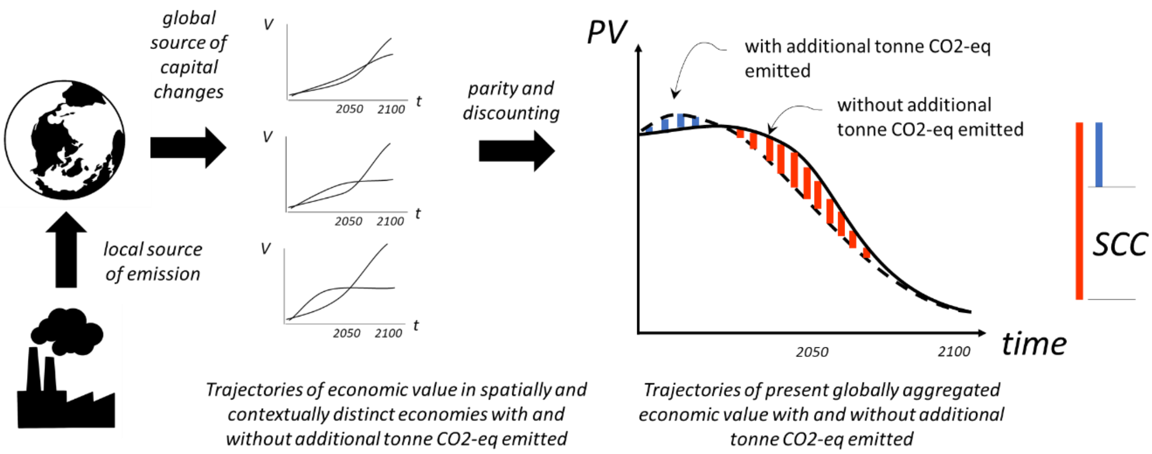

Figure 13: Calculating the social cost of carbon: one tonne of additional CO2-eq emission now changes global climate now and into the future, which is a source of capital changes; which causes change in economic value (V) globally over time (t); parity and discounting are used to equate and aggregate value in economies separated over time and space (present value PV). Integrating over the difference between the PV economic trajectories over time with and without the additional tonne of CO2-eq emitted (adding red comparative costs and subtracting blue comparative benefits of the additional tonne) leads to the estimate of the social cost of carbon (SCC).

We describe the modelling-based integrated modelling approach and the expert-based catastrophic risk approach[92]. Both methods are sensitive to assumptions about equivalence of value between the economies affected by global climate change and its monetisation (parity)[93], what is included in terms of the scope of capital changes for both the damage estimates and the benefits of using carbon for production, and by the economic value of the long-term effects of carbon emitted now (discounting)[94]. The value of the SCC can also change depending whether the economies have non-optimal policy and structures in place, versus assuming the economies are optimising economic value. Discounting has been shown to be

[90] M. Adler et al., "Priority for the worse-off and the social cost of carbon," *Nature Climate Change* 7, no. 6 (2017), https://doi.org/10.1038/nclimate3298; Kolstad et al., "Social, Economic and Ethical Concepts and Methods."

[91] Fleurbaey et al., "The Social Cost of Carbon: Valuing Inequality, Risk, and Population for Climate Policy."; Kolstad et al., "Social, Economic and Ethical Concepts and Methods."

[92] W. D. Nordhaus, "Revisiting the social cost of carbon," *Proceedings of the National Academy of Sciences of the United States of America* 114, no. 7 (2017), https://doi.org/10.1073/pnas.1609244114; Tol, "On the Uncertainty About the Total Economic Impact of Climate Change." Pindyck, "The social cost of carbon revisited." Weitzman, "Fat-tailed uncertainty in the economics of catastrophic climate change."

[93] Fleurbaey et al., "The Social Cost of Carbon: Valuing Inequality, Risk, and Population for Climate Policy."; Adler et al., "Priority for the worse-off and the social cost of carbon."; Kolstad et al., "Social, Economic and Ethical Concepts and Methods." There are country level as well as global estimates of SCC: K. Ricke et al., "Country-level social cost of carbon," *Nature Climate Change* 8, no. 10 (2018), https://doi.org/10.1038/s41558-018-0282-y. M. J. Kotchen, "Which Social Cost of Carbon? A Theoretical Perspective," *Journal of the Association of Environmental and Resource Economists* 5, no. 3 (2018), https://doi.org/10.1086/697241.

[94] Dasgupta, "The Stern Review's economics of climate change." Nordhaus, "Revisiting the social cost of carbon."

the most sensitive parameter resulting in ranges for the SCC in 2015 of 2010US$ 10 with a 5% discount rate and 2010US$ 200 for the discounting approach of the Stern review (effectively 1.4%)[95]. Discount rates greatly change the shape of the PV curves in Figure 13 and so the areas between them (the total amount of red and blue). The discount rate introduces decay in the difference of present value (even though the difference in non-discounted value may diverge) so that the signed area between the PV curves is finite. Otherwise the social cost of a certain amount of CO2-eq emitted becomes "infinite". Catastrophic effects of climate change that create an increasing divergence in non-discounted value over time result in the possibility of greater area between the PV curves, resulting in higher estimates of the SCC. A non-finite area between the PV curves (that is the value loss diverges at a sufficiently fast rate compared to discounting) was discussed on p. 40.

The SCC is normally computed with an Integrated Assessment Model (IAM), which describes the coupling of the economy and the climate system. Three prominent IAMs which calculate the trajectories of GDP change: the PAGE model, the FUND model, and the DICE model, were used by the US Intergovernmental Working Group on the Social Cost of Carbon (IWGSCC) to examine variation in the models combined with variation in discount (Figure 14)[96].

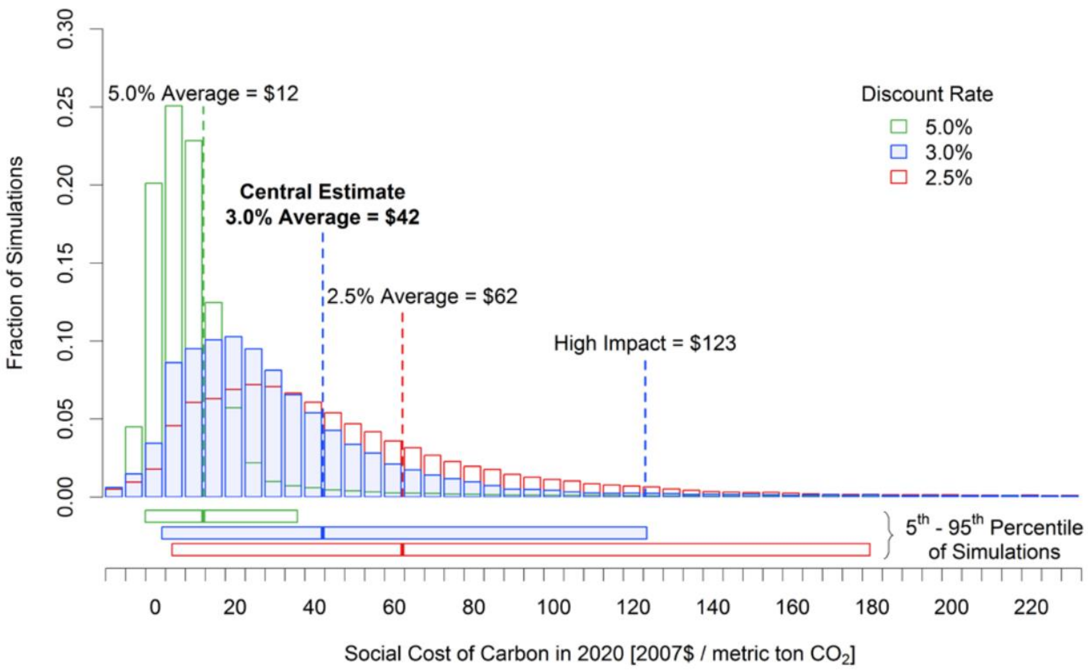

Figure 14: Distribution of SCC estimates using the DICE, FUND and PAGE models with variation in discount rate (Source: Figure 1 IWGSCGG, *Technical Support Document: Technical Update of the Social Cost of Carbon for Regulatory Impact Analysis*).

The IAMs, in the terminology of food system impact frameworks, embody different representations of the impact pathway from the footprint of CO2-eq emissions to change in economic value. The literature cited on the social cost of carbon, noting a description relevant

[95] Table 1. Nordhaus, "Revisiting the social cost of carbon." N. Stern, *The economics of climate change: the Stern review* (Cambridge, UK: Cambridge University Press, 2007).
[96] IWGSCGG, *Technical Support Document: Technical Update of the Social Cost of Carbon for Regulatory Impact Analysis*, Interagency Working Group on Social Cost of Greenhouse Gases, United States Government (Washington DC, 2016), https://www.epa.gov/sites/production/files/2016-12/documents/sc_co2_tsd_august_2016.pdf. G. E. Metcalf and J. H. Stock, "Integrated Assessment Models and the Social Cost of Carbon: A Review and Assessment of U.S. Experience," *Review of Environmental Economics and Policy* 11, no. 1 (2017), https://doi.org/10.1093/reep/rew014.

to food systems in an FAO study on food loss and waste in 2014[97], describe what is, and what is not, included in terms of benefits and costs in the IAM models. Generally included are damage effects on agriculture, forestry, sea-level rise, cardiovascular and respiratory disorders related to cold and heat stress, malaria, dengue fever, diarrhoea, energy consumption, water resources, unmanaged ecosystems, and tropical and extra tropical storms. Three GHGs important to food production emissions[98], CO2, CH4 (methane) and N2O (nitrous oxide), are differentiated in their warming effects.

The spread of SCC estimates represent uncertainty in what the social cost of carbon will be (Figure 14). The nature of CO2-eq emissions as an externality of production and consumption means that uncertainty in the social cost amounts to risk transferred from those that benefited from the CO2-eq emissions to society.

The uncertainty and arguments for pricing the risk into the SCC is discussed in the social cost of carbon literature[99]. Risk pricing is basically taking a higher value in the distribution such as the 95-th percentile ("high impact" at 3% discount rate in Figure 14) instead of the mean ("central estimate" in Figure 14). Choosing in the tail (right-end) of the distribution has many precedents in precautionary approaches and industry standard practice in finance (VaR and CVaR)[100]. There are arguments that the SCC should be lower than the mean, that is, the SCC value should include the risk to economic growth and development from reducing CO2-eq emissions[101]. There are arguments that the IWGSCC SCC distribution (Figure 14) is severely underestimating the tail uncertainty[102]. Despite social and human well-being beyond that derived from consumption of goods having limited representation in PPP GDP changes[103], pricing risk into uncertain social costs would drive significant change with a SCC at over US$2010 100 if internalisation mechanisms based on the SCC were fully implemented. There are arguments that risk pricing could, or already does, include perturbation in welfare measurement.

For many economists the social cost of carbon will never be resolved as a single number; the discounting rate for example is an ethical choice rather than a scientific fact, and so the uncertainty in the social cost is irreducible[104].

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[97] Box 1, p. 37: FAO, *Food wastage footprint: full-cost accounting*.
[98] IPCC, *IPCC Special Report on Climate Change, Desertification, Land Degradation, Sustainable Land Management, Food Security, and Greenhouse gas fluxes in Terrestrial Ecosystems*.
[99] S. Dietz, "The Treatment of Risk and Uncertainty in the US Social Cost of Carbon for Regulatory Impact Analysis," *Economics* 6, no. 18 (2012). van den Bergh and Botzen, "A lower bound to the social cost of CO2 emissions." R. S. Pindyck, "The Use and Misuse of Models for Climate Policy," *Review of Environmental Economics and Policy* 11, no. 1 (2017), https://doi.org/10.1093/reep/rew012, https://doi.org/10.1093/reep/rew012.
[100] M. Choudhry, *An Introduction to Value-at-Risk* (Wiley, 2012).
[101] D. Pearce, "The Social Cost of Carbon and its Policy Implications," *Oxford Review of Economic Policy* 19, no. 3 (2003), https://doi.org/10.1093/oxrep/19.3.362.
[102] N. Stern, "The Structure of Economic Modeling of the Potential Impacts of Climate Change: Grafting Gross Underestimation of Risk onto Already Narrow Science Models," *Journal of Economic Literature* 51, no. 3 (2013), https://doi.org/10.1257/jel.51.3.838. F. Ackerman and E. Stanton, "Climate Risks and Carbon Prices: Revising the Social Cost of Carbon," *Economics* 6, no. 10 (2012).
[103] Fleurbaey et al., "The Social Cost of Carbon: Valuing Inequality, Risk, and Population for Climate Policy."
[104] J. C. V. Pezzey, "Why the social cost of carbon will always be disputed," *Wiley Interdisciplinary Reviews: Climate Change* 10, no. 1 (2019), https://doi.org/10.1002/wcc.558. Pindyck, "The social cost of carbon revisited." Pindyck, "The Use and Misuse of Models for Climate Policy." C. Hepburn, "Climate change economics: Make carbon pricing a priority," *Nature Climate Change* 7, no. 6 (2017), https://doi.org/10.1038/nclimate3302.

Following arguments of Weitzman (2009) and Pindyck (2019), probabilities of large changes in welfare (catastrophic changes, e.g. > 20% GDP reduction) from climate change constitute most of the SCC figure[105]. Because of the discount rate and long timeframes, the contribution of smaller or even medium economic changes becomes minimal when converted to present value. Asking experts to judge the chances of such large GDP reductions over a certain timeframe and what reduction in CO2-eq emissions are needed to reduce those chances constitutes a way to derive a SCC figure which does not involve IAMs. It is not clear that models and impact pathways are avoided by this method, only the appearance of precision: an explicit but epistemologically uncertain quantitative model of the mechanisms by which economic value is lost is replaced by the implicit subjective qualitative model in the mind of the expert used to estimate chances of certain levels of GDP reduction.

To summarise the components to calculate the social cost of carbon and major sources of variance:

- Scenarios: assumption on socio-economic drivers and especially the societal carbon footprint now and into the future, i.e. emission scenarios. The SCC is routinely calculated by adding one additional tonne of carbon (from an actor) now onto an existing (societal) trajectory of emissions into the future. Change the trajectory of emissions into the future, or change population and GDP growth, and the SCC will change by an order of magnitude.
- Parity and discounting: choices in equating value in time and space will change the SCC by an order of magnitude as discussed. Prioritising poorer nations will not always increase the global social cost of carbon; poorer nations are likely to experience greater impact from climate change (though in PPP GDP this impact is deflated in monetary terms compared to a similar scale of capital change in a richer country) but also have more to lose in terms of not utilising carbon for development.
- Models and data: each IAM is structurally different and can use different data sources. Large changes (catastrophic events, tipping points[106], etc.) are fundamentally uncertain and struggle to be captured in modelling. One of the models analysed by the IWGSCC computes small chances of a negative social cost for carbon (climate change is beneficial).

[105] Pindyck, "The social cost of carbon revisited." M. Weitzman, "On Modeling and Interpreting the Economics of Catastrophic Climate Change," *The Review of Economics and Statistics* 91, no. 1 (2009), https://doi.org/10.1162/rest.91.1.1.

[106] E. Kriegler et al., "Imprecise probability assessment of tipping points in the climate system," *Proceedings of the National Academy of Sciences* 106, no. 13 (2009). T. M. Lenton, "Arctic Climate Tipping Points," *Ambio* 41, no. 1 (2012), https://doi.org/10.1007/s13280-011-0221-x; S. E. Werners et al., "Thresholds, tipping and turning points for sustainability under climate change," *Current Opinion in Environmental Sutainability* 5 (2013).

Applying the SCC to economic climate policy is as intricate and debated as calculating it[107]. The SCC literature is a good study for similar considerations needed for applying social costs from other footprints related to food system externalities to economic food policy[108].

The fundamental uncertainty in SCC estimates and perceived difficulties in applying it to national policies on emissions targets led to the abatement approach to costing carbon[109].

Abatement cost of carbon

The marginal abatement cost of carbon (MAC) is the cost to avoid or sequester the emission of an additional tonne of CO2eq over a specified emissions target. The social costs that would have been incurred from that additional tonne over the specified emissions target are abated. The abatement cost is not the mirror of Figure 13 (i.e. changing the labels of the present value trajectories so that they read "without and with one tonne removed" instead of "with and without additional tonne" respectively and with an emission trajectory starting at the emission target). The abatement cost is generally different than paying the social cost of an additional tonne of CO2eq over a specified emissions target. In the social cost, part of the benefit to the economy is the profit in the goods and service that the additional tonne of carbon enables. There are potentially lower costs utilising or associated to different goods and services to avoid or sequester a tonne of carbon; lower than the missed profit and different to the goods and service that the missed additional tonne would have enabled[110].

Calculating a marginal abatement cost requires substituting a baseline portfolio of activities in the economy with an abatement portfolio of actual or potential activities, that meets the specific emission target by avoiding or sequestering carbon, without change in economic value[111]. The

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107 For example, Fleurbaey et al., "The Social Cost of Carbon: Valuing Inequality, Risk, and Population for Climate Policy." p. 86 "Another concern with the standard approach is that it suggests that a unique tax, corresponding to the magnitude of the SCC, should be imposed on all private agents in order to maximize overall welfare. But this recommendation is not always correct. A unique tax equal to the SCC is optimal if the distribution of resources among individuals is socially optimal. If inequalities are excessive and will not be corrected by inequality-reducing transfers implemented in addition to climate policy, then a single carbon tax is actually socially worse than differentiated taxes that favor disadvantaged populations…It is often objected that differentiated taxes would generate an inefficient distribution of abatement, because the marginal cost of abatement would be greater where the tax is greater, thereby failing to minimize the total abatement cost. But this objection assumes that minimizing the total abatement cost is a good objective, which is not the case if the cost is distributed among individuals with unequal social priority (because some are poorer)."

108 Chapter 7: IPCC, *IPCC Special Report on Climate Change, Desertification, Land Degradation, Sustainable Land Management, Food Security, and Greenhouse gas fluxes in Terrestrial Ecosystems*.

109 Hepburn, "Climate change economics: Make carbon pricing a priority." CCE, *Carbon valuation in UK policy appraisal: a revised approach*, UK Department of Energy and Climate Change. (London, 2009), https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/245334/1_20090715105804_e____carbonvaluationinukpolicyappraisal.pdf. 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.

110 K. Gillingham and J. H. Stock, "The Cost of Reducing Greenhouse Gas Emissions," *Journal of Economic Perspectives* 32, no. 4 (2018), https://doi.org/10.1257/jep.32.4.53. McKinsey & Company, *Pathways to a Low-Carbon Economy: Version 2 of the Global Greenhouse Gas Abatement Cost Curve*, McKinsey & Company,, (New York NY, 2019), https://www.mckinsey.com/~/media/McKinsey/Business%20Functions/Sustainability/Our%20Insights/Pathways%20to%20a%20low%20carbon%20economy/Pathways%20to%20a%20low%20carbon%20economy.ashx.

111 The original McKinsey & Co. report p. 9 states that substitution of the abatement portfolio for the baseline is "not having a material effect on the lifestyle of consumers and our results are therefore consistent with continuing increases in global prosperity". We take this to mean equivalent welfare. The total abatement cost is how much more it would cost to substitute the baseline portfolio for a portfolio

marginal abatement cost of the portfolio meeting the emissions target is the maximum cost of an abatement measure in the portfolio. Smaller abatement and baseline portfolios, starting with those that have the lowest marginal abatement costs, can be aggregated into larger portfolios if their provision of goods, services, and CO2-eq avoidance or sequestration do not intersect.

The McKinsey & Co. global marginal abatement cost curve (MACC) is an aggregate of individual measures such that the global abatement portfolio meets 2030 emission targets (as assessed in 2009) to stay within 2 deg C of global warming (Figure 15). The baseline portfolio is associated to business-as-usual. In Figure 15 the vertical axis is the marginal abatement cost for that measure, the area of each box is the total cost (or benefit if the marginal

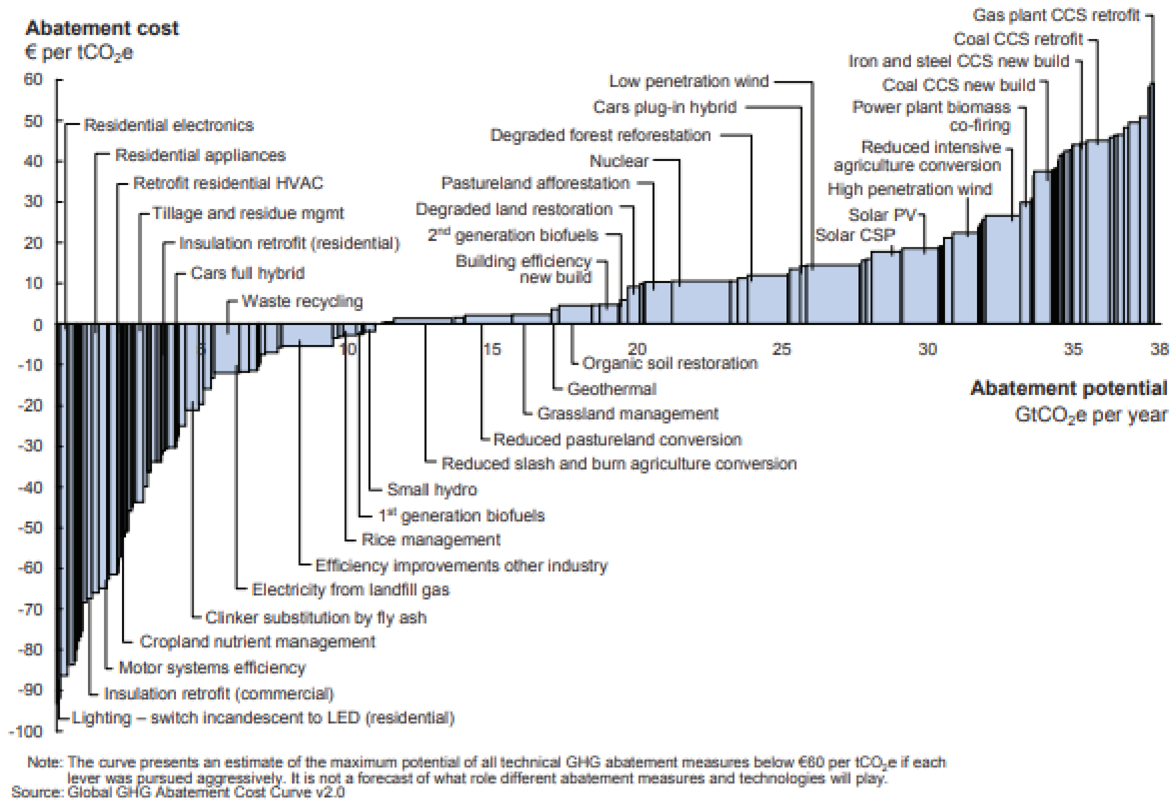

Figure 15: Global GHG abatement cost curve with CO2-eq emissions reduction target of 38Gt by 2030 to stay within 2 deg C of global warming. The portfolio of carbon abatement measures is listed from lowest abatement cost to highest, with the width of the box on the horizontal axis the total reduction in CO2-eq emissions the abatement measure offers. The total abatement cost of the portfolio of measures is the area between the curve above the horizontal axis minus the area of the curve below the horizontal axis. The MAC or global marginal abatement cost of carbon is 2009€ 60 /tCO2eq, the cost of the highest abatement cost in the abatement portfolio (Source: McKinsey & Co. *Pathways to a Low-Carbon Economy: Version 2 of the Global Greenhouse Gas Abatement Cost Curve*)

abatement cost is negative) for that measure above the baseline equivalent, and the horizontal axis is the change in footprint compared to the baseline (CO2-eq emissions). The target for 2030 emission targets to stay within 2 deg C of global warming is to reduce CO2-eq emissions by 38Gt. The total abatement cost of the entire portfolio is the area between the curve above

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of abatement measures that achieve the same welfare. It is implicit that the effect of the additional cost of abatement portfolios on welfare is greater than or equal to the welfare gains in meeting the abatement target. Optimising to find the lowest cost abatement portfolio results in theoretically matching the lowest cost abatement portfolio with the welfare gain from meeting the abatement target. This is the rational for the abatement cost as a valuation: it assigns a monetary value (the lowest cost amongst abatement portfolios) to the welfare gain of meeting the abatement target.

the horizontal axis minus the area of the curve below the horizontal axis. The marginal abatement cost for carbon with a certain emission target is the cost of the most expensive abatement measure in the abatement portfolio with the lowest total cost. This is what it would cost to avoid or sequester an additional tonne of carbon above the emissions target assuming all other lower cost options have been utilised to meet the emissions target already. In the case of Figure 15, the 2009 estimate of the marginal abatement cost of carbon for the 38Gt emission reduction target by 2030 is €60 /tCO2-eq.

The calculation of the MAC in practice depends on existing baselines, designing abatement portfolios of substitutions which, essentially, provide the same utility to consumers except for the abatement and additional cost, and estimating the costs of CO2-eq avoidance or sequestration to achieve that same level of utility.

MAC, like the SCC, has supporters and detractors. MACs are viewed as lower estimates of carbon costing to achieve international obligations on emissions (and therefore more advantageous from the viewpoint of minimal intervention to many governments). They are argued to be less uncertain than the SCC as they involved tangible portfolios of measures costed now versus manifest uncertainty in modelling or forecast economic trajectories over one hundred years[112]. The UK shifted from a social cost of carbon approach to an abatement cost approach for policy appraisals in 2011[113]. MACCs enable concrete discussions of transition and transformation grounded in the economic activities of the private and public sectors[114].

That marginal abatement costs are more certain than social costs is contestable[115]. Marginal abatement cost curves are static. They cannot reflect changes in costs, including fossil fuel prices, and actions and technology over time[116]. Interdependencies between the measures in in the portfolio are often not considered and can be consequential[117]. Abatement costing has clear variation and is highly specific to the assumptions about the abatement portfolios, substitution of the baseline, the emissions target, and policy support for implementation including carbon prices and other policy measures[118].

One disadvantage of the MAC is that the presentation of uncertainty is relatively unexplored and not as developed as the SCC. High and low abatement cost figures based on emissions targets and Dutch WLO socio-economic scenarios are used in the EU-28 CE-Delft pricing

[112] S. Dietz and S. Fankhauser, "Environmental prices, uncertainty, and learning," *Oxford Review of Economic Policy* 26, no. 2 (2010), https://doi.org/10.1093/oxrep/grq005; Dietz, "The Treatment of Risk and Uncertainty in the US Social Cost of Carbon for Regulatory Impact Analysis."

[113] CCE, *Carbon valuation in UK policy appraisal: a revised approach*.

[114] S. K. Huang, L. Kuo, and K.-L. Chou, "The applicability of marginal abatement cost approach: A comprehensive review," *Journal of Cleaner Production* 127 (2016), https://doi.org/10.1016/j.jclepro.2016.04.013.

[115] Helm, *Carbon valuation in UK policy appraisal: a revised approach and peer reviews. Peer review Dieter Helm*; Kesicki and Ekins, "Marginal abatement cost curves: a call for caution." Ackerman and Stanton, "Climate Risks and Carbon Prices: Revising the Social Cost of Carbon."

[116] A. Vogt-Schilb and S. Hallegatte, "Marginal abatement cost curves and the optimal timing of mitigation measures," *Energy Policy* 66, no. C (2014), https://doi.org/10.1016/j.enpol.2013.11.045; Kesicki and Ekins, "Marginal abatement cost curves: a call for caution." Gillingham and Stock, "The Cost of Reducing Greenhouse Gas Emissions."

[117] F. Levihn, "On the problem of optimizing through least cost per unit, when costs are negative: Implications for cost curves and the definition of economic efficiency," *Energy* 114 (2016), https://doi.org/https://doi.org/10.1016/j.energy.2016.08.089.

[118] L. Bernard and W. Semmler, *The Oxford handbook of the macroeconomics of global warming*, Handbook of the macroeconomics of global warming, (New York: Oxford University Press, 2015).

handbook[119]. An upper and lower range of marginal abatement costs is also expressed in the 2017 report of the High-Level Commission on Carbon Prices[120]

Technically, from footnote 111, the marginal abatement cost as a valuation comes from the lowest cost abatement portfolio with no other change in economic value except for abatement of the social cost of carbon above a certain level of emissions. Amongst valuation methods it might be described as potential-to-pay (it assumes exact trade-off between the abatement cost and the abatement). With this assumption on abatement portfolios the minimal abatement cost provides the maximal increase in economic value for that cost.

Inclusions or omissions in the consideration of economic value can change which is the lowest cost abatement portfolio[121]. Another abatement portfolio might provide an increase or decrease in economic value in other areas besides abatement which more than offsets a higher or lower cost, respectively, than the minimal abatement cost. This is relevant for the consideration of abatement costing of food system impacts and discussed from p. 105.

Abatement costs generally feature economic costs, so costs of investment and costs of implementation. Changing to LED bulbs is a market efficiency for those making the LED bulb and the consumer of LED bulbs (the higher purchase price is paid back by lower electricity costs over the lifetime of the bulb), but a manufacturer of lighting that is unable to shift to LEDs is likely to lose out. It is not necessarily a Pareto gain in financial value for the entire market. The secondary consequences for the economy with such changes are not generally accounted for.

The cost to make plant protein as attractive as animal protein for a certain number of consumers has potential health benefits above the carbon abatement[122]. Based on a comparison with an abatement measure with the same cost in a MACC, the replacement plant protein product appears an inefficient way to abate carbon, but it may be a greater economic efficiency gain (costs less overall when external health benefits are subtracted from the development cost).

Note that marginal abatement cost curves list all potential market efficiency gains with negative marginal abatement cost first. According to the MACC in Figure 15, nearly 30%, or 11 Gt, of emissions reduction are achievable by financial efficiency where the private savings outweighs the private costs and abatement of carbon is available for free. The representation of negative costs and inefficiencies has been criticized on the account of whether all economic costs have been accounted for and whether an imperfect but still competitive economy has neglected such large potential efficiencies[123].

The MAC should be less than the SCC adjusted for the emissions target. If no abatement portfolio costs less than the damage costs from doing nothing, then paying the damage cost is optimal for welfare (Figure 16). In this sense the social benefit (the social cost abated by an abatement portfolio) is the abatement value that can be obtained by the abatement cost of that portfolio. Owners of measures that have greater costs to avoid or sequester a tonne of

[119] Described on p. 94 de Bruyn et al., *Environmental Prices Handbook EU28 Version*.: Using the EU ETS to reflect abatement potential is described in: 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).
[120] CPLC, *Report of the High-Level Commission on Carbon Prices*.
[121] Kesicki and Ekins, "Marginal abatement cost curves: a call for caution."
[122] M. A. Clark et al., "Multiple health and environmental impacts of foods," *Proceedings of the National Academy of Sciences* (2019), https://doi.org/10.1073/pnas.1906908116.
[123] Gillingham and Stock, "The Cost of Reducing Greenhouse Gas Emissions." Levihn, "On the problem of optimizing through least cost per unit, when costs are negative: Implications for cost curves and the definition of economic efficiency."

carbon than un-utilised measures with lower costs would theoretically gain in exchanging carbon emission rights, as the lowest cost available measure is more efficient at abating carbon. This is the theory by which an emission rights trading scheme, with caps designed to limit emissions to the emissions target, will realise the potential in the abatement curve, filling up the low cost opportunities until the point where the emission target is reached and the market price for emissions rights approaches the marginal abatement cost of the realised abatement portfolio[124].

The MAC theoretically equals the SCC adjusted for the emissions target only under assumptions of optimal economic policy (Figure 16). That policy is assumed to resolve future economic trajectories into the abated trajectory. Optimising the social cost involves paying abatement costs where the cost is lower than damages. Those forecasted economies where the capital changes occur and cause damage costs more expensive than the economy with abatement are not realised. The uncertainties mentioned in calculating damage costs and calculating abatement costs, and the ability of an economic policy to perfectly realise the exchange value between the profit loss and external costs of certain goods and services and the abatement cost for other goods and services, means that equating the marginal abatement cost to a marginal social cost adjusted for the emissions target involves strong assumptions and is likely incorrect for non-optimal economies.

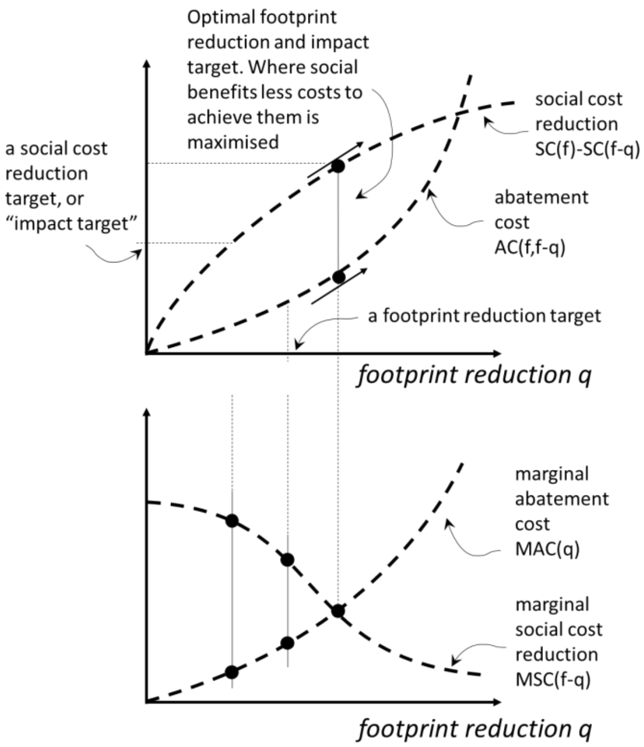

Figure 16: Conceptual relationship between marginal abatement cost and marginal social cost as the marginal value of abatement. Marginal social cost depends upon an emission trajectory with current carbon emissions f and the emissions reduction target q as an adjustment to that trajectory. As the emissions reduction q increases, the marginal social cost of an additional unit of emission in the reduced emission trajectory should decrease. The marginal abatement cost increases. An optimal economy able to exchange social costs with the cost of increased abatement will tend to the equilibrium point and the amount of emissions reduction where MSC(f-q) and MAC(q) are equal.

The components to calculate, and major sources of variance in, the marginal abatement cost of carbon are categorically similar to the social cost of carbon:

- Scenarios: assumptions about socio-economic drivers are embedded in the costs, availability and realisation of abatement measures over time, and what is an acceptable substitution of baselines for present and future welfare. Emission scenarios are still relevant, because they determine emission targets.
- Parity and discounting: PPP is used to aggregate costs of abatement measures across multiple nations into a global cost. Parity becomes more directly relevant than in SCC in terms of the different costs, availability and realisation of abatement measures

[124] E. Narassimhan et al., "Carbon pricing in practice: a review of existing emissions trading systems," *Climate Policy* 18, no. 8 (2018), https://doi.org/10.1080/14693062.2018.1467827.

across countries. Discounting as a balance between present and future generations is relevant in terms of future societal wealth or increased resources available now to influence costs and availability of abatement measures. Setting different national targets to achieve a global total involves parity considerations.

- Models and data: models and data are still required to calculate costs and the reduction of CO2-eq emissions. Uncertainty about the long future in the SCC is traded against lack of knowledge of the present in the MAC. Realisation of abatement though political and economic processes may be more uncertain than damage costs that depend on mechanistic physical processes like sea level rise. The McKinsey & Co. 2009 report identified a 10-year window of action. Many of the efficiency measures, and abatement potentials, are not realised now in 2019[125]. The uncertainty in whether the potential in an abatement portfolio is realised would suggest a similar risk pricing approach to the SCC in terms of using estimates above the central values to incorporate a risk premium. Uncertainty in the realisation of abatement measures is discussed again under the heading of abatement demand of products and practices in the food system on p. 157.

Food impact costing

Carbon costing illustrated features of valuations relevant to food system impact: social costs, abatement costs, discount rate, scenarios, actor footprint versus societal footprint, the complications of calculating monetary amounts from models of complex chains of capital changes across space and time, parity and discounting, and risk pricing due to variation in the calculation.

These features are relevant for calculating other social and abatement costs for the food system. We discuss them generally and comment on adjustments for food system impact valuation[126]. Case studies from p. 128 use a template that illustrates the social and abatement costs, discount rate and parity chosen, how footprints were calculated and models applied.

The foremost difference for the food system from carbon costing is that impact from food system activities is associated to footprints in plural, some of which need to be broken down further due to spatial and contextual differences in impact due to those footprints.

Valuation as a function of footprint

Issues where food systems are creating the most concern for social and human value change (Table 1), traced through capital changes, identifies quantities relevant to impact such as tonnes CO2-eq emitted (CO2, CH4, NOx), tonnes reactive nitrogen (N) and soluble phosphorous (P) leached, water consumption m^3, ha land-use change, number of injuries in a workforce, etc. Amongst all quantities that could be associated to activities in the food system, impact valuation requires a balance between a tractable list of quantities and capturing believed to cause the greatest value change.

Footprint is a vector of individual footprint quantities. The nine case studies from p. 128 indicate a range of footprint quantities considered for food system impacts. Footprint for an impact valuation should to be delineated to account for spatial and contextual variation. These details will be considered subsequently from p. 78 and p. 98. In the case of valuing social and human capital change the footprint quantity also needs to be considered alongside the models

[125] https://www.nytimes.com/interactive/2018/12/07/climate/world-emissions-paris-goals-not-on-track.html

[126] Commonly listed valuation methods such as willingness-to-pay, damage costs, market values, averting expenditure, are used as appropriate within the models of social or abatement costs. Examples of their use can be found in the case studies from p. 127.

(of marginal valuation) that will be used to perform the valuation. Quantities associated to environmental marginal valuations are well established.

We denote a vector, or list, of footprint quantities

$$f = [f_1, \cdots, f_n].$$

For instance, the first quantity in the footprint f_1 could be t CO2-eq emitted into the atmosphere by society after a certain date.

Denote by V a function that takes a list of present footprint quantities f as input and assigns to them a monetary amount relating to economic value $V(f)$ as output (Figure 11). If a food system actor is responsible for a change in societal footprint from f to $\hat{f}$ (the amount of generated CO2-eq emissions, leached nitrogen, improvement of community access to drinking water, food products sold that caused preventable death and disease compared to reference diets, etc.) then the change in economic value, or impact, is

$$V(\hat{f}) - V(f).$$

The change in economic value due to the change in footprint depends on the societal footprint. This dependency is what is reflected in the variation in the social cost of carbon due to emissions trajectories and other socio-economic factors. Similarly, the health costs of food products depend not just on health and lifestyle factors but economic and environmental factors, etc. To include these other factors s, and if these other determinants of value are kept constant from the actor's contribution to footprint increase,

$$V(s, \hat{f}) - V(s, f)$$

is the change in economic value. This notation simply means that the calculation is dependent on the other factors denoted by s. That economic value is even changing significantly due to variation in the footprint quantities is not included in conventional economic measurement. Ignoring the total value loss and gain through non-financial capital changes is equivalent to setting the difference to be zero and saying that economic value is independent of the variation in footprint.

The scientific evidence, and evidence from initial valuations such as the social cost case studies from p. 128, is that economic value is not invariant to changes in footprint quantities. The implication is that footprints are economic quantities, hence are factors to welfare like other quantities measured and tracked by the economic system.

For large changes in footprint, other socio-economic quantities embodied in s are unlikely to remain constant. Footprint quantities are the result of production and consumption. Inverting that relationship, reducing footprint results in changes in production and consumption with flow-on effects through the economy. For large changes in footprint the flow-on effects are extremely important to understand in order to estimate the change in economic value:

$$V(s(\hat{f}), \hat{f}) - V(s(f), f)$$

where $s(f) \mapsto s(\hat{f})$ is the simultaneous change in other socio-economic quantities associated to the change in footprint $f \mapsto \hat{f}$. For example, large scale changes in food loss and waste will either result in a drop in agricultural production (if the same amount of food is consumed less production required) with flow on effects for agriculture and input industries, or flow on effects for human health and society (if the same amount of food is produced with no loss then much more food is consumed)[127]. As another example, large scale dietary changes for plant-based

[127] Rutten, "What economic theory tells us about the impacts of reducing food losses and/or waste: implications for research, policy and practice."

meat and dairy results in large structural changes in all industries attached to animal meat and dairy production, and frees enormous land resources with flow-on effects for biofuels, bioplastics, and/or ecosystem benefits. If the dietary changes are not voluntary but are achieved through fiscal pressure that also raises large amounts of revenue, then what is done with the revenue is also a factor. Canada recently legislated a carbon tax where revenue raised from CO2-eq emission is transferred to households[128]. What consumers might do with the extra revenue in terms of increased consumption of emissions embedded in goods from outside Canada is uncertain. The redistribution of revenue is not likely to cancel out the benefit from reducing production from the most intensive sources of emission and increasing production of likely less intensive sources, but it is a second order correction to the size of the benefit.

Estimating $V\left(s(\hat{f}),\hat{f}\right) - V(s(f),f)$ for changes in footprint f to $\hat{f}$ associated to food system actor(s) is an impact valuation.

We do not have the models, data, or knowledge to be definitive about the estimates. There are presently no global or national general equilibrium models that include footprint quantities as variables and measure economic value in terms of wider aspects of social and human well-being. For CO2-eq emissions the closest are the IAMs used in the calculation of the social cost of carbon. They are not general equilibrium models; they describe basic feedback between the climate and the economy and use a variety of proxy valuations to estimate monetary damage to PPP GDP. Theoretically, with general equilibrium models that could include footprints associated to major external costs, the natural dynamics moving the economic system to equilibrium and economic efficiency are depicted in Figure 16. The model would depict optimal shadow prices (also called efficient prices) and the sustainable level of footprint[129].

In the absence of such models impact valuation involves an approximation of the difference $V\left(s(\hat{f}),\hat{f}\right) - V(s(f),f)$ and making the arguments why certain aspects of the calculation can be simplified and what the degree of error might be.

Filling in the steps

The general components that feature in present approximations of economic value change from a footprint change are actor footprint, societal footprint, assumptions about socio-economic drivers, models and data for attribution of capital changes across space and time, choice of welfare measure, parity and discounting. The overlay of the components on Figure 11 (Figure 17) demonstrate what is required to fill in the “Measure and Value” steps (Steps 05-07) of the Natural Capital, and Human and Social Capital, Protocols (Figure 6) for monetary valuation. The Natural Capital Protocol Food & Beverage Guide from pages 38-50 provides a list of worked examples on the basic steps in Figure 17 of determining footprint, considering capital changes, and then multiplying total footprints by a marginal value. This section concerns the detail behind the numbers.

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[128] https://www.theguardian.com/environment/climate-consensus-97-per-cent/2018/oct/26/canada-passed-a-carbon-tax-that-will-give-most-canadians-more-money

[129] Understanding valuation as an approximation to the welfare difference using an equilibrium model that can incorporate externalities is the fundamental link between welfare economics and impact valuation, noted in: Bachmann, "Optimal pollution: the welfare economic approach to correct market failures."; Arrow et al., "Sustainability and the measurement of wealth."; Dasgupta and Duraiappah, "Well-being and wealth."; FAO, *Food wastage footprint: full-cost accounting*; de Bruyn et al., *Environmental Prices Handbook EU28 Version*. E. P. Fenichel and Y. Hashida, "Choices and the value of natural capital," *Oxford Review of Economic Policy* 35, no. 1 (2019), https://doi.org/10.1093/oxrep/gry021.

We break down the steps into the simplest logic. We have a food system actor. This might be a government, a sector, a company, a farmer. The final task is to estimate the eventual difference in a monetary representation of economic value, be it positive or negative, from changes to natural, social and human capital due to the actor. Thought needs to be given in the measure of economic value and which economies are affected by the capital changes. Those details are discussed further on.

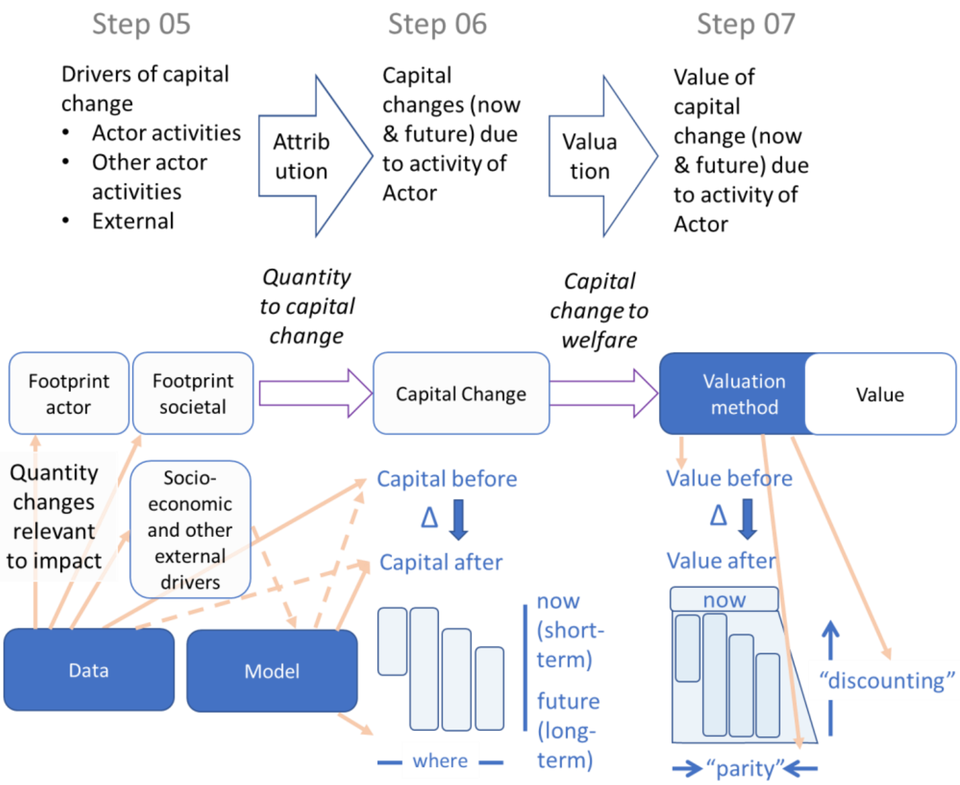

Figure 17: Measure and value steps in impact frameworks as the process of attribution and valuation of capital changes. Data and models are needed to estimate footprints of actor, footprints of society and other socioeconomic drivers. Further data and models are needed to attribute the footprint of the actor to capital changes. Valuation methods estimate the value change from the capital change. They involve a new set of data and models, as well as ethical choices on how to compare value changes between economies (parity) and across time (discounting to present value).

Impact of activities factor through capital changes. In impact frameworks like the TEEB AgriFood Evaluation Framework, without capital changes there are no impacts. To estimate the difference in a monetary representation of economic value requires determining the capital changes due to the actor. To do that requires determining the drivers of change in quantity and quality of produced, natural, social and human capital. Going from Step 06 to 07 is valuation of a capital changes. Going from Step 05 to 06 is attribution of a capital change, i.e. how much of the capital changes valued are due to actor activities. Capital changes due to the actor factors through footprint. The same footprint can be associated to different capital changes, and the same capital change can be associated to different impacts.

Actor footprint, societal footprint and socio-economic drivers

The drivers of capital change are the present activity of that actor and other actors who are using or changing that capital which might be from other sectors. For example, the actor in question might not be the only one drawing water from a non-renewable water source. If other users are extracting more water, and on a trajectory to accelerate the extraction in the future, a unit of additional extraction by the actor has potentially worse impacts. Another example from the social costs of carbon are the impacts of one emitter depends on total societal emissions. Most impact pathways associated to the food system have the same consideration. What food the rest of the food system is producing, and what people are eating beside the produce or products of the actor, is a central determinant of the health impacts. The determination of the impact from a can of soft drink without context is impossible. The nutrient profile of the product itself is insufficient.

Therefore, given the footprint of a food system actor, the footprint of other actors and other external factors are required to calculate, from the actor's footprint, the capital changes attributable to the actor.

In climate science, emission scenarios are used to indicate different possible trajectories of total emissions. However, the same emissions trajectory can have worse impacts depending on a range of socio-economic factors from population, attitudes to natural renewable and non-renewable resources, and general ability to absorb economic and social shocks reflected in GDP and community resilience. Nutrient pollution into an already degraded ecosystem will generally accelerate degradation and loss of services more than the same pollution into a healthy ecosystem. Public health outcomes depend on levels of physical exercise in the population and general metabolic factors not only on dietary intake. External factors to the actor footprint and the total footprint may have a major effect on the total capital change such as ecosystem dynamics and social trends. The capital changes occur in the general context of socio-economic trends such as demographics, social dynamics, technology, ecosystem dynamics, etc. that effect the exiting quantities and qualities of capital stocks.

Factoring impact of food system actors' activities through footprint has implications. There are other activities, e.g. advertising, lobbying, of food system actors that influence socio-economic trends and estimation of future footprints and impacts. They are not captured by the kind of footprints currently suggested by scientific studies for food system impact (Table 1). If not captured in footprint they are not observable as economic quantities whose variation is explicit in change of economic value except through the specification of external factors. They can be captured in a static way in scenarios and in models for the calculation of capital change. Changes in the static picture can be reflected by an update mechanism of scenarios and shadow prices suggested further below on p. **Error! Bookmark not defined.**.

The exogenous information required to determine capital changes not calculated endogenously within the models for capital change described next section is either provided by data or by scenarios. Scenarios do not relate only to long-term events. Scenarios are alternative specifications when there is uncertainty. For example, specifying alternatives for consumers spending of revenue from carbon taxation, or how consumers and producers respond to food price increases from Pigouvian taxation, are scenarios. Scenarios are implicit in a valuation calculation where there are assumption about what happens when footprints change in the short-term, e.g. economic flow-on effects, or what may be happening now but we do not have the monitoring ability to obtain data, e.g. community damage, health effects in subpopulations.

Models and data to determine capital changes

Given the footprint of a food system actor and the context of the footprint of other actors and external factors the next step of the process is to calculate the capital changes attributable to the actor's footprint.

For capital change we need to calculate the capital quantity and quality before and the capital quantity and quality after. The capital quantity and quality after is not at some fixed time after. It needs to be the total change due to the footprint change (emission, pollution, nutrition embedded in product, etc.). It is the total change which relates to damage to present and future economies from activities today. An example is that carbon emitted today will be contributing to temperature change and so damages from those temperature changes until climate equilibrium is reached. Another example is health where nutrition or injuries today contributes to long-term health and social effects, some for generations[130]. Nitrogen leakage (NO3) to groundwater from nitrogen fertiliser applied to soils is highly variable but can continue for decades[131]. It is both the level and change of quantity and quality that are relevant to damages. Species lost in an abundant and diverse ecosystem are different from the last few species lost in an endangered ecosystem.

Monitoring of the present level and quantity of capital stocks would provide direct data on capital change. It might also be able to observe direct attribution to actors by correlating footprints with capital changes. Most likely the capital changes have to be modelled and this is the norm. IAMs were discussed in the last section on costing carbon. Well-developed models exist for air and water pollution for developed countries – the NEEDS model that underpins the CE-Delft EU28 Environmental Prices Handbook is discussed in case study 7 from p. 137. A model of life stages impacted by stunting, to calculate income difference is adulthood is discussed in case study 6. A linear regression model associating income changes to social repercussions of climate change, soil degradation, pesticide use from growing food that was lost and wasted is in case study 1. Large amounts of data are, or would be, required to populate the models, train them, and estimate their error.

In many cases not only the change, but the existing level of capital needs estimating through a model[132]. Even for natural capital there is an increasing but limited monitoring capability. Many of the present stocks are likely not directly observed but are extrapolated or calculated.

For footprints incurred today, that have the potential to lock-in impact over longer time periods including generations, complicated models that require exogeneous projections of socio-economic drivers and trajectories for societal footprint introduce significant uncertainty, e.g. IAMs in carbon costing. Modelling is associated to a catch-22 situation; using a model introduces uncertainty but not costing the impact introduces potentially greater error.

Parsimony was observed in climate costing. Resolution of modelling impacts over time can become coarser. Large generational impacts are potentially the only ones that survive not being reduced to very small differences in present value by discounting. However, uncertainty can introduce caveats to this principle. Uncertainty in compounding or cascading effects from locked-in capital changes allow a potential inflation in impact that outstrips the deflation represented by discounting[133]. Especially when continued trajectories of use which create scarcity. Not many social costs from the case studies consider lock-in impacts outside of carbon costing.

The prices in the CE-Delft EU28 Handbook of Environmental Prices are an exception due to the development embodied in the NEEDS model of impact and environmental pollution. The EU funded a progression of research projects that provided continuity of development leading

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130 Victora et al., "Maternal and child undernutrition: consequences for adult health and human capital."; Whitaker et al., "Comparing maternal and paternal intergenerational transmission of obesity risk in a large population-based sample." D. Hulme, K. Moore, and A. Shepherd, "Chronic Poverty: Meanings and Analytical Frameworks," *SSRN Electronic Journal* (2001), https://doi.org/10.2139/ssrn.1754546; D. Conley and J. Thompson, *Health Shocks, Insurance Status and Net Worth: Intra- and Inter-Generational Effects*, National Bureau of Economic Research (Cambridge, MA, 2011).

131 S. Mathieu et al., "Long-term fate of nitrate fertilizer in agricultural soils," *Proceedings of the National Academy of Sciences* 110, no. 45 (2013), https://doi.org/10.1073/pnas.1305372110.

132 UNEP, *Inclusive wealth report 2018 : measuring progress towards sustainability*.

133 C. Gollier, "Valuation of natural capital under uncertain substitutability," *Journal of Environmental Economics and Management* 94 (2019), https://doi.org/10.1016/j.jeem.2019.01.003.

to the NEEDS model[134]. Environmental pricing handbooks are concentrated on environmental pollution and similar well-developed studies on noise pollution. There are few other prices in the handbooks suitable for non-environmental aspects of food system impact valuation.

The division of the impact attributable to an actor into the three-step conditional sequence of change in economic value given capital changes, capital changes given societal footprint, other drivers, and actor footprint, and the calculation of footprints (Figure 17) is useful conceptually. Often the terms data and model are used in discussions about impact valuation without qualification, which is discussed further from p. 163.

The case studies and examples such as carbon costing evidence that models and data are used at each step of the process. It is more helpful in discussions to categorise the models and data whether they are for calculation of footprints, or used in valuation and attribution for either calculation of capital changes, or estimation of welfare changes from those capital changes.

<u>Models and data for footprints:</u> models to calculate footprints are the most developed, particularly for environmental footprints. Models are used to calculate the footprint of actors (usually by companies, e.g. life-cycle inventories (LCI) calculated from lifecycle models and databases), Models estimate total footprints (usually in scientific literature, e.g. a combination of monitoring data and models are used to determine non-renewable water use by region or globally, soil degradation regionally or globally, etc.[135]). LCI was developed to calculate environmental footprints. The data used for LCI is mostly a compilation of open source databases generated initially by European government funded initiatives. The data is rarely specific to a product or a production process, but instead uses averages for that type of product with varying levels of spatial and contextual specification (e.g. organic apple grown in Spain)[136]. Life cycle analysis (LCA) is a widely used and standardised tool, which is increasing coverage applicable to food systems including better treatment of complicated environmental aspects such as land-use, pesticide exposure, and footprints relating to other capital changes such as social capital[137]. LCA also uses societal footprints as part of normalisation[138]. LCA footprint calculation for activities associated to a food product is used in case study 7 and 8 and some part in most of the other case studies.

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[134] p. 139: de Bruyn et al., *Environmental Prices Handbook EU28 Version*.

[135] For example: D. Carole et al., "Groundwater depletion embedded in international food trade," *Nature* 543, no. 7647 (2017), https://doi.org/10.1038/nature21403.

[136] L. Peano et al., "The World Food LCA Database project: towards more accurate food datasets" (paper presented at the Proceedings of the 9th International Conference on Life Cycle Assessment in the Agri-Food Sector (LCA Food 2014), San Francisco, CA, 8-10 October, 2014. 2014).

[137] 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.. Pesticide: P. Fantke and O. Jolliet, "Life cycle human health impacts of 875 pesticides," *The International Journal of Life Cycle Assessment* 21, no. 5 (2016), https://doi.org/10.1007/s11367-015-0910-y.. Social: A. Jørgensen et al., "Methodologies for social life cycle assessment," *The international journal of life cycle assessment* 13, no. 2 (2008). UNEP, *Guidelines for social life cycle assessment of products: social and socio-economic LCA guidelines complementing environmental LCA and Life Cycle Costing, contributing to the full assessment of goods and services within the context of sustainable development*, UNEP DTIE Sustainable Consumption and Production Branch (Paris, 2009), http://hdl.handle.net/20.500.11822/7912.

[138] S. Sala et al., *Global normalisation factors for the Environmental Footprint and Life Cycle Assessment*, Publications Office of the European Union (Luxembourg, 2017). E. Crenna et al., "Global environmental impacts: data sources and methodological choices for calculating normalization factors for LCA," *The International Journal of Life Cycle Assessment* 24, no. 10 (2019), https://doi.org/10.1007/s11367-019-01604-y.

The list of estimates from scientific literature of CO2-eq emissions, water use in agriculture, pesticide use, etc., social and nutritional footprints related to food systems using a range of different models, modelling methods, and data sources, is tremendous. The challenge is processing them so that they can be made available for footprint and capital change calculations. Tools have emerged to consolidate scientific knowledge about agricultural footprints specifically such as the CoolFarmTool[139] as part of a shift by the food sector towards metrics of improvement rather than compliance with standards[140].

An input-output model used by the consulting company TruCost offers a different way to associate environmental footprints[141]. It associates revenue of sectors of the economy to environmental footprint. It then uses the input-output structure of the economy to determine the dependence of a company or one sector on other sectors to calculate their "upstream" environmental impacts. This method is justifiably described as a top-down approach. The bottom-up approach would be to use LCA to calculate the production of all products of the company and ancillary footprints associated to that production.

At a global level global agricultural and trade production models such as GLOBIOM, IMPACT and MAGPIE[142] can be used to back-calculate some footprints. This is the perspective of case studies 1-3 on impact of activities of the global food system. Given exogenous settings of GDP, population, technological advance and consumption demand (which is translated back to commodities from exogenously set global diets), the models can determine agricultural land use associated to crops and livestock, water use, estimates of fertiliser use, commodity prices and yields. The resolution is at sub-regional level, accounting for spatial distinction of suitable or existing primary growing regions for commodities. For example, the IMPACT model divides the land surface of the globe into 320 units of food production which overlap a similar division of associated water basins with 36 crop and 6 livestock production categories[143].

Valuation method

Following the approach of impact frameworks we use economic value synonymously with welfare and human well-being in a broad sense. A valuation method specifies whose values for which loss or gain is being considered, and the representation of economic value in monetary terms. We discuss the measure of welfare and parity and discounting below.

Economic valuation theory has a list of valuation methods applicable to valuation of capital changes including willingness-to-pay using revealed preferences or contingent valuation, damage costs, market values, averting expenditure, etc. Summaries of these methods and their application to valuing non-financial capital changes can be found in Chapter 5 of the Inclusive Wealth Report, Chapter 7 of the TEEB AgriFood Evaluation Foundations report, and

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[139] B. Kayatz et al., "Cool Farm Tool Water: A global on-line tool to assess water use in crop production," *Journal of Cleaner Production* 207 (2019), https://doi.org/https://doi.org/10.1016/j.jclepro.2018.09.160; J. Hillier et al., "A farm-focused calculator for emissions from crop and livestock production," *Environmental Modelling & Software* 26, no. 9 (2011), https://doi.org/http://dx.doi.org/10.1016/j.envsoft.2011.03.014.
[140] S. Freidberg, "Big Food and Little Data: The Slow Harvest of Corporate Food Supply Chain Sustainability Initiatives," *Annals of the American Association of Geographers* 107, no. 6 (2017), https://doi.org/10.1080/24694452.2017.1309967.
[141] TruCost, *Top-down methodology TEEB Animal Husbandry*.
[142] K. Wiebe et al., "Comparing impacts of climate change and mitigation on global agriculture by 2050," *Environmental Research Letters* 13 (2018).
[143] S. Robinson et al., *The International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT): Model description for version 3*, International Food Policy Research Institute (IFPRI) (Washington, DC, 2015), http://ebrary.ifpri.org/cdm/ref/collection/p15738coll2/id/129825.

the 2014 FAO report on valuing food loss and waste[144]. Applications of different methods can be found in the case studies, and meta-studies of monetary values have aggregated monetary amounts across different valuation methods[145]. As indicated in footnote 126, our concern is less on the distinction between valuation methods, though they are important, than on the distinction between social and abatement costs. From the rationale in Figure 16 social costs represent the economic value loss from food systems and abatement is the economic means, the mechanisms, the least cost pathways and merit orders of action, to avert or recover that value loss.

Models and data for valuation: In case study 3 data and models within the Global Burden of Disease Study perform the attribution of preventable global disease and death in DALYs to the dietary intake of individuals that differ from a defined diet for ideal health[146]. Footprint is canonical in the case study because the global food system is the focus and it provides all global dietary intake. Therefore, with DALYs as a measure of human health change, the Global Burden of Disease Study has in this case performed the step of attribution.

Turning DALYS into a monetary amount reflecting welfare loss is an example of a valuation of a capital change. Models and data, with assumptions resulting in significant variation, are used to determine the value of a DALY[147].

Other examples of modelling used in valuation relate to established valuation methods such as revealed preference valuation studies and benefit transfer[148]. Parametrised benefit transfer tries to associate, often through linear regression, the variation in monetary amounts from valuations at study sites to broad parameters such as population, population density, average income per capita, etc. By linking the monetary value to these parameters, the valuation can be transferred to new sites by substituting the appropriate parameters, e.g. population, income per capita, of the new site. For example, damage costs from studies across multiple EU countries might reveal relationships between the monetary amount and other variables which enable the damage cost estimate to be transferred to another country. The regression usually has very few study sites to inform it and missing variables can lead to large errors[149].

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144 UNEP, *Inclusive wealth report 2018 : measuring progress towards sustainability*. TEEB, *TEEB for Agriculture & Food: Scientific and Economic Foundations*. FAO, *Food wastage footprint: full-cost accounting*.

145 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.

146 Afshin et al., "Health effects of dietary risks in 195 countries, 1990–2017: a systematic analysis for the Global Burden of Disease Study 2017."

147 P. J. Neumann et al., "A Systematic Review of Cost-Effectiveness Studies Reporting Cost-per-DALY Averted," *PLOS ONE* 11, no. 12 (2016), https://doi.org/10.1371/journal.pone.0168512. T. Arnesen and E. Nord, "The value of DALY life: problems with ethics and validity of disability adjusted life years," *BMJ (Clinical research ed.)* 319, no. 7222 (1999), https://doi.org/10.1136/bmj.319.7222.1423.

148 I. Crawford and B. De Rock, "Empirical Revealed Preference," *Annual Review of Economics* 6, no. 1 (2014), https://doi.org/10.1146/annurev-economics-080213-041238; M. L. Plummer, "Assessing benefit transfer for the valuation of ecosystem services," *Frontiers in Ecology and the Environment* 7, no. 1 (2009), https://doi.org/10.1890/080091. K. J. Boyle et al., "The Benefit-Transfer Challenges," *Annual Review of Resource Economics* 2, no. 1 (2010), https://doi.org/10.1146/annurev.resource.012809.103933.

149 S. Kaul et al., "What can we learn from benefit transfer errors? Evidence from 20 years of research on convergent validity," *Journal of Environmental Economics and Management* 66, no. 1 (2013), https://doi.org/10.1016/j.jeem.2013.03.001. R. Ready et al., "Benefit Transfer in Europe: How Reliable Are Transfers between Countries?," *The Official Journal of the European Association of Environmental and Resource Economists* 29, no. 1 (2004), https://doi.org/10.1023/B:EARE.0000035441.37039.8a. Kaul et al. (2013) indicates that parameterisation in terms of environmental quantity variables reduces errors compared to quality variables and that similarity of sites reduces errors.

Relevant consolidations of estimations in the scientific literature into databases or registers exist, for example the Global Health Cost-Effectiveness Analysis (GHCEA) Registry, a repository of Cost-per-DALY Studies (http://healtheconomics. tuftsmedicalcenter.org/ghcearegistry/) and the Ecosystem Services Valuation Database (ESVD) (https://www.es-partnership.org/services/data-knowledge-sharing/ecosystem-service-valuation-database/) [150].

Data and models are needed to calculate footprint (e.g. lifecycle inventory), other models and data calculate attribution (e.g. biophysical models that calculate dispersion of air pollution sources and their concentration in human habitats to determine dose, coupled with dose response models to determine disease) and then data and models for valuation (e.g. data on healthcare costs of respiratory diseases and estimates of reduced productivity) are required. Different data and models are used at each step. Placing them together into an integrated model is an instantiation of one or many impact pathways and represents the valuation of the food system actor's activities represented by the footprint change $\hat{f} - f$. That is, the integrated model is an instantiation of the function $\hat{f} - f \mapsto V(\hat{f}) - V(f)$ from p. 61. All the case studies from p. 128 represent integrated models by assembling existing modelled estimates of footprints, capital changes and valuations. The assembling is mostly multiplying a footprint quantity by a valuation factor or shadow price, see p. 91 below on linear approximation.

Using different models and data can result in variation in valuations even though the valuation is conceptually of the same actor, with the same socio-economic drivers, the same activities and the same impact pathway(s)[151]. The variation is observed in the case studies.

A first step toward consistency and comparability in valuations is not making all the models and the data the same. The first step is structural consistency. That the, in practice, integrated models assembled by practitioners doing valuations for the same uses (e.g. integrated impact statement of food companies and abatement value of products) are:

i) working with the same footprints

ii) including the same components in the impact pathway (what aspects of capital changes should be considered, and what economic costs, so that one study does not include scarcity effects while another does, or one study does not include the cost of securing investment capital while another does not, or one study does not include health changes from increased consumption while another does not)

iii) specifying the welfare measure and recording the discount rate and parity used (next section)

Structural consistency promotes the ability for comparison valuations and comparative testing by substitution of different parity and discount settings.

In the environmental dimensions, LCI and LCIA represent a host of standardised footprint and impact pathway structures. The structural consistency enables handbooks of environmental prices such as CE Delft EU28 Environmental Prices to be attached on top. In turn enabling valuation to be added efficiently into LCA software such as SimaPro and GaBI (case studies 7 and 8). Uncertainty from using different data and models for footprint, capital changes and valuation of capital changes decreases if they are associated to the same structural basis. As

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[150] Neumann et al., "A Systematic Review of Cost-Effectiveness Studies Reporting Cost-per-DALY Averted." de Groot et al., "Global estimates of the value of ecosystems and their services in monetary units."

[151] Tremmel et al., "Economic Burden of Obesity: A Systematic Literature Review." H. J. M. van Grinsven et al., "Costs and Benefits of Nitrogen for Europe and Implications for Mitigation," *Environmental Science & Technology* 47, no. 8 (2013), https://doi.org/10.1021/es303804g.

mentioned earlier, the SEEA-EEA offers a blueprint of a practical resolution for standardising structure of food system footprints and impact pathways.

There are databases and registers that are promoting ontological integration of attribution and valuation. They act to increases structural consistency. SROI is an impact framework (Table 2) based on indicators of outcomes (measures of capital changes) and impacts (valuations of value loss or gain). The Global Value Exchange (GVE) online database supported by Social Value UK is an example of an integrated repository where indicators of outcomes and valuations are ontologically connected and can be assembled for the purposes of impact valuation attributable to actors[152].

Welfare measure

In welfare economics the purpose of an economy is to maximise economic value from the utilisation of capital. Economic value has a long philosophical history[153] which identifies distinctions between

Exchange value: the price of a good or service which can be sold and bought in markets

Use Value: the satisfaction or utility which obtained from the using goods or receiving services

Non-use value: value independent of use value.

Following the approach of the TEEBAgriFood Framework and the Natural and Human Capital Protocols we treat economic value as synonymous with social and human well-being and synonymous with welfare in a broad sense. Activities in the food system are mostly intended to produce goods and services for exchange, e.g. private food products for consumption. The activities also create natural, social or human capital changes in addition to produced capital changes. It is exchange, use and non-use value in the associated capital changes that aggregate to the additional and mostly external economic value loss or gain from the activities outside of market (exchange) values of the produced goods and services.

Despite its flaws as a measure of well-being[154], GDP as a measure of the conventional sense of welfare (the satisfaction of aggregated individual utilities by produced goods) can be sufficient to understand that market failures created by the food system can lead to a lower economic value than might otherwise be possible. That is, that internalisation can lead to

[152] http://www.globalvaluexchange.org/news/b07bcb501c. A search in GVE on food lists 6 outcomes, 27 indicators of those outcomes and 127 valuations that have been ingested from literature or reports. As such the valuations are very specific to the study sites and participants. Links to the sources of the valuations enable a user to examine the structural considerations and assumptions behind a valuation, say of the cost of food loss and waste per kg. The consistency between food loss and waste valuations in the GVE can only be checked by reverting to the sources.

[153] p. 6: Sandelin, Trautwein, and Wundrak, *A short history of economic thought*; McGregor and Pouw, "Towards an economics of well-being."; Turner, Bateman, and Pearce, *Environmental economics : an elementary introduction*. Parks and Gowdy, "What have economists learned about valuing nature? A review essay." Dasgupta, *Human Well-Being and the Natural Environment*.

[154] P. Dasgupta, "Nature's role in sustaining economic development," *Philosophical Transactions of the Royal Society B* 365, no. 1537 (2010), https://doi.org/10.1098/rstb.2009.0231. J. E. Stiglitz, A. Sen, and J. P. Fitoussi, *The measurement of economic performance and social progress revisited. Reflections overview.*, Commission on the measurement of Economic Performance and Social Progress (Paris, 2009), https://wedocs.unep.org/bitstream/handle/20.500.11822/19041/Report_by_the_Commission_on_the_Measurement_of.pdf?sequence=1.

higher economic value from reducing impacts of food systems[155]. Monetary estimates are never “exactly” economic value. The purpose of valuations is to inform and enable choices believed to increase economic value[156]. The social cost of carbon projects loss of GDP. The social cost of carbon could be higher if a greater range of use and non-use values were incorporated into IAMs. However, pricing risk in the current social cost of carbon (Figure 14) could lead to an implemented carbon price at over US$2010 100, driving significant change.

A similar argument applies for health costs. Based on existing productivity monetary estimates or direct costs of public healthcare or health insurance without incorporating non-use values[157], an appropriate risk adjusted price would likely drive significant change. The changes driven by internalised costings of the overt material issues of the food system are likely to constitute the majority, or, at the lowest expectation provide a kickstart to, food system transformation. The more overt the magnitude of the externality due to food systems, the more likely they reflect in changes in conventional economic measures once factored.

Exercises that measure the utility of the outcomes of an economy (quality of life, life expectancy, equality, as well as consumption) as a measure of economic value show that GDP is only one factor. GDP is a primary factor; it is strongly correlated with outcomes-based measures of economic value[158]. However, among nations there are outliers. In practice this would mean that economic value loss or gain is being incurred and GDP is not sensitive enough to this gain or loss to inform optimal policy responses. One way to introduce a monetary indicator of economic value which is more sensitive to added factors of well-being is to derive shadow prices of capital quantities based on production of income or GDP, then multiply those shadow prices directly by capital stocks. This is the approach to human capital used in the 2012, 2014 and 2018 UN Inclusive Wealth Report. Another way to inflate the sensitivity of GDP is to determine how much substitution of consumption is required to match the increased utility of leisure, life expectancy, and equality[159]. Using GDP increased by the equivalent consumption amount for non-financial production factors creates a more sensitive measure of economic value.

It is not entirely clear that the valuation methods commonly used, and the valuations of social costs from the case studies from p. 128 are measures of change in societal economic value. Healthcare costs are monetary losses for society and individuals but in paying healthcare professionals there are benefits to society and other individuals. Some of the costs imposed by the food system are benefits to the health sector. The net change in economic value from reducing food system impacts is the social benefits of better health minus the social costs of less healthcare spending. This is less than just the benefits of better health alone. While well-being approaches should emphasise the greater value in having health over the spending healthcare sector, it will still generally be an overestimate of the social cost to omit benefits of healthcare employment altogether. Over- and under-estimates from not accounting for subsequent economic changes are part of the additional uncertainty (error) in valuations. If subsequent economic changes are not included the social or abatement costs statement should have a clear statement on the inclusions or omissions, or the indication that other economic changes are assumed to balance out *ceteris paribus*.

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[155] R. Tinch, "Debating Nature’s Value: The Role of Monetary Valuation," in *Debating Nature's Value: The Concept of 'Natural Capital'*, ed. V. Anderson (Cham: Springer International Publishing, 2018).
[156] Fenichel and Hashida, "Choices and the value of natural capital."
[157] Tremmel et al., "Economic Burden of Obesity: A Systematic Literature Review."
[158] C. Jones and P. Klenow, *Beyond GDP? Welfare across Countries and Time*, National Bureau of Economic Research (Cambridge, MA, 2010).
[159] Jones and Klenow, *Beyond GDP? Welfare across Countries and Time*.

Projecting potential GDP losses for large capital changes and scaling those monetary estimates back to smaller capital changes is another way to obtain monetary estimates more reflective of well-being. By projecting forward either in time, or hypothetically, to a situation here the well-being loss is creating manifest distortion in the economy the well-being factors are overt. Using this situation as the basis for a valuation, and then scaling back to a smaller amount of change likely results in different answers than basing the valuation on the current or historical situation where well-being factors are absent from exchange values due to relative abundance or being public goods. As an example, it is likely revealed individual preferences will give a low value to the planetary life-support services provided by local ecosystems when, presently and historically within the observed bubble of activity of those individuals, enough eco-system services exist to provide those services. If all individuals value the services independently as low, and concurrently destroy local ecosystems with the loss of the life-support services, the total loss of ecosystem services and consequential effects invalidate the original assumption of abundance and stationarity (the future being like the past). This “tragedy of the commons” argument reveals the initial undervaluation that comes from an individual considered only their own local actions and assuming all else being constant or equal. It is an unrealistic ask on individual preferences to project forward the value loss of capital changes with covariant global changes, or to know with certainty the market price in a market that does not yet exist but may in a future economy due to scarcity resultant from their actions[160].

More on values is relevant. Alignment of economic systems with value systems is outside the scope of the report though. To summarise, there are conceptual welfare measures beyond GDP, including projecting GDP under large capital changes, that have an extensive background of development and discussion in economics. The main practical criteria for monetary estimates are that they are indicative of changes to social and human well-being, and that they are sufficient to realise the positive change or abate the negative change if those estimates were embodied in internalisation mechanisms. In practice, for nearly all the valuations in the food system (and all case studies from p. 128) the welfare measure itself is unspecified and unclear. The use of first order approximation, described from p. 91 below, means all that is seen of the welfare measure is its part specification in partial derivatives with respect to various footprint quantities. Those partial derivatives are specified in shadow price estimates or valuation factors.

The ambiguity in what is welfare is pushed into the uncertainty in the marginal social costs or marginal abatement costs. As are the values represented by a welfare measure. This may appear to be passing the buck and trading one uncertainty for another. However, structural uncertainty in social or abatement cost, and measuring it, has precedents in the social cost and marginal abatement cost of carbon. Incorporating a risk price can conceptually also reflect the risk that monetary measures are underestimating social and human well-being losses.

Parity and discounting

Value and supply chains of the food sector are global[161]. Agricultural inputs such as phosphorous can be mined in first countries, fertiliser can be used in agricultural production in second countries, agricultural commodities can be processed into food products in third countries, to be sold and consumed in fourth countries, with financial, managerial and

[160] T. Prugh et al., *Natural capital and human economic survival* (Boca Raton: Lewis Publishers, 1999). See also, for example, 3.10.1.5 in Kolstad et al., "Social, Economic and Ethical Concepts and Methods."
[161] P. Montalbano, S. Nenci, and L. Salvatici, *Trade, value chains and food security. Background paper prepared for The State of Agricultural Commodity Markets 2015–16*, Food and Agriculture Organization of the United Nations (Rome, 2015), http://www.fao.org/3/a-i5220e.pdf.

marketing services and financial flows accumulating in a fifth set of countries[162]. Footprints are created in this chain of production and consumption at each spatial location at each stage and with contextual distinction. The same volume of water extracted from a renewing catchment for phosphorus mining in North Carolina has different impacts than extraction from a non-renewing aquifer for wheat farming in Pakistan[163]. It would be an error to treat the total water footprint for the activity of food system actors aggregated across different countries and contexts as an economic quantity. The economic effects occur in what should be viewed as different economies. For example, the health effects of consumption and the economic consequences of improved human capital and shifting health expenditure occur in the consumption country. The health effects of production and the economic consequences of pesticide application or fertiliser leakage occur in the production country or other countries down-wind or downstream[164]. There are economies within national economies[165]. While cognisant of the importance in recognising subnational economic distinctions, our interest in this report is a practical disaggregation of footprint and impact that features major variances.

Parity is a method for comparing economic value across economies at the same point in time. Parity is used when aggregating the changes in economic value across the various economies so that the net impact of the activities associated to a food product, or a food company, or a food industry, can be valued.

There are exchanges of economic value attached to the market transactions and physical exchanges in the global value chains of the food sector. When accounting for non-financial capital changes the term “value-add” gains a wider meaning. There are implicit substitutions of economic value from capital changes associated to the chain of exchanges, some of which will be inequitable under standard measures such as exchange rates.

For financial capital flows along these chains currency exchange rates are used. If a monetary amount is not used for anything except a straight exchange of financial capital in one county for another (e.g. one stock holding for another), then currency exchange rates are appropriate. Arguments for using currency exchange rates rely on the “the law of one price”. The law of one price is an economic maxim that arbitrage results in very small deviation of most produced capital goods because of low transaction and transportation costs. It is debated whether the law of one price applies to food and agricultural products[166].

Most valuations in case studies 1-9 use purchasing power parity (PPP), which is the rate at which the currency of one country would have to be converted into that of another country to buy the goods and services in each country offering the same amount of satisfaction of basic needs. PPP acknowledges the value in use represented in value of exchange produced goods. It is based on bundles of good and services set and tracked by the World Bank

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[162] A reconstruction of the Nutella® value chain is an example p. 17: K. De Backer and S. Miroudot, *Mapping Global Value Chains, OECD Trade Policy Papers, No. 159*, OECD Publishing (Paris, 2013)..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).

[163] A. Rehman et al., "Economic perspectives of major field crops of Pakistan: An empirical study," *Pacific Science Review B: Humanities and Social Sciences* 1, no. 3 (2015), https://doi.org/https://doi.org/10.1016/j.psrb.2016.09.002.

[164] Fantke and Jolliet, "Life cycle human health impacts of 875 pesticides." J. Liu et al., "Reducing human nitrogen use for food production," *Scientific Reports* 6, no. 1 (2016), https://doi.org/10.1038/srep30104.

[165] D. Acemoglu and M. Dell, "Productivity Differences between and within Countries," *American Economic Journal: Macroeconomics* 2, no. 1 (2010), https://doi.org/10.1257/mac.2.1.169.

[166] D. Miljkovic, "The Law of One Price in International Trade: A Critical Review," *Review of Agricultural Economics* 21, no. 1 (1999), https://doi.org/10.2307/1349976.

International Comparison Program[167]. PPP is used to rescale GDP as a welfare measure based on consumption of produced goods.

The consumptive indices that underpin PPP are based on market price. The value of these exchanges of produced capital are centralised to market prices through frequent transactions. Imperfect information and the production of externalities create the situation where market prices do not reflect the economic value in non-financial capital changes being implicitly exchanged in produced and financial capital exchanges. Whether the economic value of natural and produced capital changes are substitutable has been a debate between 'weak' and 'strong' sustainability in sustainable development and ecological economics[168].

Exchange of value in human health is one impact for which it is contentious to use PPP. Declarations such as the Sustainable Development Goals (SDGs) indicate universal values for certain aspects of human and social capital irrespective of the economy in which the individuals are based[169]. Global parity for human capital impacts converts monetary values of economic loss to individuals to global PPP GDP per capita; that is, utilitarianism[170]. Global parity is used in Stern's valuation of the social cost of carbon[171] and in case study 3 below.

Prioritarianism, meaning benefits to individuals are higher in value the worse off in human development individuals are, is another philosophy of equality than can be applied to parity and discounting of economic value[172]. The IPCC indicates using alternative scaling factors for different countries to consider disproportionate economic costs from climate change, as have other studies on the social cost of carbon[173].

Benefit transfer discussed above is a parity calculation; it estimates the economic value change in a different economy based upon economic value change in another.

The case studies from p. 128 demonstrate a range of parity choices within first- and third-party valuation factors.

Parity choice is a mixture of technical and ethical considerations. Technical, in terms of tracking the implicit exchange of capital changes occurring in exchanges of produced capital (financial capital to financial capital, natural capital to financial capital) and calculation, e.g. the consumptive indices needed for PPP. Ethical choices concern equality and ambiguity on substitution of economic value in exchange value, e.g. weak and strong sustainability.

Discounting is a means to compare economies separated in time. Economic values from the past and present are usually converted into present value for comparison with economic value

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167 https://www.worldbank.org/en/programs/icp M. Silver, *IMF Applications of Purchasing Power Parity Estimates*, International Monetary Fund (Washington DC, 2010).

168 S. Dietz and E. Neumayer, "Weak and strong sustainability in the SEEA: Concepts and measurement," *Ecological Economics* 61, no. 4 (2007), https://doi.org/https://doi.org/10.1016/j.ecolecon.2006.09.007; J. Pelenc and J. Ballet, "Strong sustainability, critical natural capital and the capability approach," *Ecological Economics* 112 (2015), https://doi.org/10.1016/j.ecolecon.2015.02.006.

169 https://unstats.un.org/sdgs/report/2018/overview/

170 https://plato.stanford.edu/entries/equality/#Uti

171 C. Kenny, "A Note on the Ethical Implications of the Stern Review on the Economics of Climate Change," *The Journal of Environment & Development* 16, no. 4 (2007), https://doi.org/10.1177/1070496507308576.

172 D. Parfit, *Equality or priority?*, Lindley lecture, (Lawrence, Kan.: Dept. of Philosophy, University of Kansas, 1995).

173 Adler et al., "Priority for the worse-off and the social cost of carbon." Kolstad et al., "Social, Economic and Ethical Concepts and Methods."

now[174]. Discounting has two components. The first reflects that economies in the future are richer in the sense that one dollar of money spent on consumption at a future time provides more satisfaction. This first factor combines several aspects: efficiency, consumption as a measure of welfare, and an assumption of what society and individuals in the future value[175]. Forward projections of how much can be consumed at a future time for the same cost are based on GDP. GDP has an observed real growth rate (projecting forward historical trends that allocative and production efficiencies such as technical advances, etc. result in the same amount of goods and services in real terms costs less in the future) between 1-2%. This is generally uncontested in estimates of social carbon[176]. The assumption about what future generations value is generally phrased as marginal utility, which relates to the fact that, say a 2% decrease in the cost of the same goods and services results in more than a 2% increase in satisfaction. The increase in marginal utility usually multiplies the GDP growth projection by a factor of 1-3, resulting in an estimate that economies of the future have an overall increase in welfare (based on utility of consumption) of 1-6% per year – a mean of 3.5%. In the United Kingdom, HM Treasury fixes the social discount rate for the public sector at 3.5% with recommended adjustments for intergenerational effects[177]. Interest rate returns on private investments average 7-10% per year (so the present person would be more than 1-6% per year richer by investing without considering tax); the higher figure has been ascribed to risk bearing[178].

The second component of discounting is called time preference. This is not an assumed increase of value in the future. It reflects that there is a utility loss to present economies compared to future ones from not utilising a present resource. The time preference rate has various interpretations and ethical interpretations[179]. They range from setting time preference to zero so that no generation is given preference to the others to using mortality rates and consumer preference studies to quantify impatience for satisfaction. Assumptions about intergenerational welfare create variability in the application of the two components[180]. Stern's valuation of the social cost of carbon assumes a very small time preference compared to earlier studies, resulting in a higher amount for the SCC[181].

As noted from p. 40, discounting can provide finite value of changes in economic value for comparison of full impact from footprints incurred now. Discount rates kills more certain, time-

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[174] J. Roche, "Intergenerational equity and social discount rates: what have we learned over recent decades?," *International Journal of Social Economics* 43, no. 12 (2016), https://doi.org/10.1108/IJSE-07-2015-0193. K. J. Arrow et al., "Should Governments Use a Declining Discount Rate in Project Analysis?," *Review of Environmental Economics and Policy* 8, no. 2 (2014), https://doi.org/10.1093/reep/reu008.
[175] Dasgupta, "The Stern Review's economics of climate change."
[176] Table 3.2: Kolstad et al., "Social, Economic and Ethical Concepts and Methods."
[177] M. A. Moore et al., ""Just Give Me a Number!" Practical Values for the Social Discount Rate," *Journal of Policy Analysis and Management* 23, no. 4 (2004), https://doi.org/10.1002/pam.20047; J. Lowe, *Intergenerational wealth transfers and social discounting: Supplementary Green Book guidance*, HM Treasury (London, 2008).
[178] Moore et al., ""Just Give Me a Number!" Practical Values for the Social Discount Rate."; P. A. Grout, "Public and private sector discount rates in public–private partnerships," *Economic Journal* 113, no. 486 (2003), https://doi.org/10.1111/1468-0297.00109. Part IV: C. Gollier, *Pricing the planet's future : the economics of discounting in an uncertain world*, University Press Scholarship Online, (Princeton: Princeton University Press, 2017).
[179] Roche, "Intergenerational equity and social discount rates: what have we learned over recent decades?."
[180] Dasgupta, "The Stern Review's economics of climate change." Kolstad et al., "Social, Economic and Ethical Concepts and Methods."
[181] Stern, *The economics of climate change: the Stern review*.

limited and smaller scale economic impacts in the future[182]. Relating to intergenerational wealth, discount rates are a key aspect of sustainable development[183].

Like the effects of carbon, the scale and nature of impacts from food systems have the potential to dampen the growth of economic value. While produced capital may grow and be reflected in GDP growth as a welfare measure in forward projections, this does not imply an optimal path for economic value[184]. Social costs of obesity and poverty attributable to the food system have not yet been calculated to the same degree as the social cost of carbon to examine these dampening and non-optimal effects over time (footnote 130). Like the last section, economic value needs to be measured over time with benefits and costs flowing between sectors. An economy with the social costs incurred, and the economy with potential costs from shifting production to reduce footprint but with social costs averted.

There are methods for converging full impacts not based on discounting or variants. Priority parity over time converged the comparative difference in full impact between economies in a social cost of carbon study[185]. Lifecycle impact assessment (LCIA) is used as a basis for the CE Delft EU28 environmental prices handbook. Based on the ReCiPe model, it applies one of three perspectives to environmental damage in order to determine certain inclusions for damage costs and the time span to account for undiscounted impacts[186]. The individualist perspective uses only established cause-effect relationships for damage calculations and a time span for impacts of 20 years. The hierarchist perspective uses facts backed up by scientific and political bodies and a time span of 100 years. The egalitarian perspective is based on the precautionary principle and a very long-term perspective. In the CE Delft EU28 environmental prices handbook the individualistic perspective is mostly used. For some prices a lower value is based on the individualistic perspective and a higher value on the hierarchist perspective. The perspectives from the ReCiPe model relate not only to time factors, but to variation in social costs according to inclusion of damages in impact pathways.

For social discount rates, mostly the specification is exogeneous in assumptions about GDP growth. It has been noted that integrated models of climate change should update GDP growth endogenously in an evolving economic model with climate effects[187].

Part of the ambiguity in discount rates relates to ethical choices[188]. An ambiguity which is not easy to resolve. However, there are key implications for uncertainty in the discount rate coming just from uncertainty in the GDP growth rate due to probabilities of catastrophic damage to GDP. Weitzman argues that a low overall discount rate in the order of 1-2%, such as that taken by Stern in the Stern review, can be justified by risk aversion in stochastic GDP growth

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182 Pindyck, "The social cost of carbon revisited."
183 Arrow et al., "Sustainability and the measurement of wealth."
184 Dasgupta, "Nature's role in sustaining economic development."
185 Adler et al., "Priority for the worse-off and the social cost of carbon."
186 p. 136: de Bruyn et al., *Environmental Prices Handbook EU28 Version*.
187 S. Dietz and N. Stern, "Endogenous Growth, Convexity of Damage and Climate Risk: How Nordhaus' Framework Supports Deep Cuts in Carbon Emissions," *The Economic Journal* 125, no. 583 (2015), https://doi.org/10.1111/ecoj.12188.
188 Dasgupta, "The Stern Review's economics of climate change."

rates[189]. Weitzman and Gollier also showed that discount rates should decline in the presence of uncertainty for longer time frames of lock-in impact[190].

Parity and discounting are not generally separable. Simple forms are, e.g. a global discount rate to convert to present value combined with an application of PPP GDP to convert to international dollars. The implication of this simple treatment is that the PPP GDP structure of the present is projected forward statically into the future. Applying different discount rates to countries with the assumption of static parity is difficult to distinguish from applying a global discount rate with dynamic changes in parity. They are not equivalent in practice[191]. Substitution of capital is not a static consideration either. Weak sustainability has temporal aspects. It assumes that the substitution of natural for produced capital is temporary and development leads to efficient economies decoupled from resources. Uncertainty in actions over time and which natural capital changes are irreversible or recover are part of the uncertainty associated to a substitution[192].

We know discounting is one of the most sensitive parameters for the social cost of carbon. Discounting introduces order of magnitude changes. Parity also introduces order of magnitude changes[193]. Parity choices make a significant difference to climate costing. How sensitive food impact costing is to assumptions of parity and discounting, and uncertainty, depends on further studies. Obesity has potential generational effects and spatially heterogenous contextual factors for impact, though the potential for catastrophic tipping points like that of the climate system is less clear. Like the RCP and SSP specifications in climate science, suitable reference scenarios with explicit reference to parity and discounting could guide quantification for food impact costing.

Footprint and impact

A short survey of existing calculation methods including those described last section is tabulated from p. 170. The components in Figure 17 in practice are illustrated in nine case studies from p. 128.

In the next few sections we reinforce some of the distinctions and choices in valuation.

At the risk of being obvious, footprints and impact are not direct proxies to each other. The stark difference is highlighted in the steps and examples of calculations required to relate footprint and impact discussed last section.

Carbon creates a ruse where footprint and impact seem to be interchangeable by multiplying by the marginal valuation - a single number. Marginal valuation, or shadow price, is the estimate of the full lifetime economic value loss or gain attributable to an additional unit of footprint. The social cost and marginal abatement costs of carbon are marginal valuations. By

[189] M. Weitzman, "Risk-adjusted gamma discounting," *Journal of Environmental Economics and Management* 60, no. 1 (2010), https://doi.org/10.1016/j.jeem.2010.03.002. p. 192 Gollier, *Pricing the planet's future : the economics of discounting in an uncertain world*. C. Gollier, "On the Underestimation of the Precautionary Effect in Discounting," *The Geneva Risk and Insurance Review* 36, no. 2 (2011), https://doi.org/10.1057/grir.2011.6.

[190] C. Gollier and M. L. Weitzman, "How should the distant future be discounted when discount rates are uncertain?," *Economics Letters* 107, no. 3 (2010), https://doi.org/10.1016/j.econlet.2010.03.001.. A recommendation also in Moore et al., ""Just Give Me a Number!" Practical Values for the Social Discount Rate."

[191] Figure 4: Adler et al., "Priority for the worse-off and the social cost of carbon."

[192] F. Figge, "Capital Substitutability and Weak Sustainability Revisited: The Conditions for Capital Substitution in the Presence of Risk," *Environmental Values* 14, no. 2 (2005), https://doi.org/10.3197/0963271054084966. Gollier, "Valuation of natural capital under uncertain substitutability."

[193] Figure 3: Adler et al., "Priority for the worse-off and the social cost of carbon."

multiplying or dividing by this number it appears that footprint (t CO2-eq emitted) and impact (cost to society) become interchangeable. It should be remembered though that footprint is a quantity and impact is value. The same quantity can change in value over time and due to context. Currently more carbon is bad because we have too much in the context of current and projected CO2-eq levels in the atmosphere. In terms of net value to society carbon used to be good because of the production and material improvements it enabled. The balance between the value carbon emissions enable (the cost in shifting production and material improvements – abatement costs) and the present and future value loss in context (social cost) is what economics attempts to determine (Figure 16).

Because of the global effect of carbon one tonne emitted anywhere in the world contributes to radiative forcing everywhere. Local differences in the consequence of increased radiative forcing are not attributed to local emissions. Where a tonne CO2-eq was emitted makes no difference to its impact. The context of the footprint is also treated globally. The conditions (the atmosphere and its present carbon content) are global and an actor's contribution goes into a pool of 52 Gt CO2-eq emitted annually[194] which is traced to impact. There is no contextual distinction except for scaling through global warming potential of different GHG gases to convert them to CO2-eq. That is, there is no distinction in impact in current carbon costing whether the t CO2-eq emitted it is from burnt coal for electricity, burnt fuel for transport, calcium carbonate decomposition in manufacturing cement, or methane belching ruminants.

The situation for carbon that makes footprint and impact readily interchangeable is not repeated for the quantities associated to other major food system impacts[195]. There are large variations in impacts according to where emissions, pollutants, water extraction, ha of land-use change, etc. occur. This has been highlighted for natural capital and agricultural supply

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[194] p. 9 IPCC, *IPCC Special Report on Climate Change, Desertification, Land Degradation, Sustainable Land Management, Food Security, and Greenhouse gas fluxes in Terrestrial Ecosystems*.

[195] H. Neufeldt et al., "Beyond climate-smart agriculture: toward safe operating spaces for global food systems," *Agric Food Secur* 2 (2013), https://doi.org/10.1186/2048-7010-2-12. R. Neff, *Introduction to the US Food System: Public Health, Environment, and Equity* (Wiley, 2014). C. Abhishek, G. David, and M. Alexander, "Multi-indicator sustainability assessment of global food systems," *Nature Communications* 9, no. 1 (2018), https://doi.org/10.1038/s41467-018-03308-7. P. Prosperi et al., "Towards metrics of sustainable food systems: a review of the resilience and vulnerability literature," *Environment Systems and Decisions* 36, no. 1 (2016), https://doi.org/10.1007/s10669-016-9584-7; IPES-Food, Unravelling the food-health nexus: addressing practices, political economy, and power relations to build healthier food systems. O. de Schutter et al., *Advancing Health and Well-Being in Food Systems*, Global Alliance for the Future of Food (Toronto, 2015). Zurek et al., "Assessing Sustainable Food and Nutrition Security of the EU Food System—An Integrated Approach."

chains generally[196], for valuation of changes in ecosystem services[197], reactive nitrogen[198]; water use[199], land use[200], and regularly mentioned in studies of environmental valuation[201].

The last section mentioned the differences in the impact of a can of soft drink in the context of diet and exercise rates. The last section mentioned the difference in impact from extracting the same volume of water from a renewing catchment for phosphorus mining in North Carolina compared to a non-renewing aquifer for wheat farming in Pakistan. Changes to renewable and non-renewable capital stocks provide one clear contextual difference for valuations of capital changes.

To highlight water, the Water Footprint Manual views it as inappropriate to assign a single marginal value to the total water footprint of a company or product[202]. Water footprint and impacts are not readily interchangeable. Water extraction in one location is not going to have a global effect. Economies downstream from extraction or pollution will be affected. Water extraction by the food system globally has a global effect - 70% of all freshwater extraction is for agriculture - which is highly varied[203].

For food impact, a substitute for the simple formula between carbon footprint and impact of multiplying by the marginal valuation - a single number – is multiplication of a matrix of marginal valuations against a vector of spatial and contextual footprints (this is described from p. 101).

A spatial and contextual footprint means the units of emissions, pollutants, water extraction, ha etc. within a specific geographic boundary incurred by a specific method of extraction, production, delivery, consumption, etc. The spatial and contextual distinctions which make a significant difference in accounting for the major external costs of food systems are what

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196 E. T. Addicott and E. P. Fenichel, "Spatial aggregation and the value of natural capital," *Journal of Environmental Economics and Management* 95 (2019), https://doi.org/https://doi.org/10.1016/j.jeem.2019.03.001. Section 3: B. Notarnicola et al., "The role of life cycle assessment in supporting sustainable agri-food systems: A review of the challenges," *Journal of Cleaner Production* 140 (2017), https://doi.org/10.1016/j.jclepro.2016.06.071.

197 Section 5.5: de Groot et al., "Global estimates of the value of ecosystems and their services in monetary units." 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. S. Schmidt, A. M. Manceur, and R. Seppelt, "Uncertainty of Monetary Valued Ecosystem Services – Value Transfer Functions for Global Mapping," *PLOS ONE* 11, no. 3 (2016), https://doi.org/10.1371/journal.pone.0148524.

198 D. J. Sobota et al., "Cost of reactive nitrogen release from human activities to the environment in the United States," *Environmental Research Letters* 10, no. 2 (2015), https://doi.org/10.1088/1748-9326/10/2/025006. A. Leip et al., "Nitrogen-neutrality: a step towards sustainability," *Environmental Research Letters* 9, no. 11 (2014), https://doi.org/10.1088/1748-9326/9/11/115001.

199 D. Pimentel et al., "Water Resources: Agricultural and Environmental Issues," *BioScience* 54, no. 10 (2004), https://doi.org/10.1641/0006-3568(2004)054[0909:WRAAEI]2.0.CO;2. B. L. Keeler et al., "Linking water quality and well-being for improved assessment and valuation of ecosystem services," *Proceedings of the National Academy of Sciences* 109, no. 45 (2012), https://doi.org/10.1073/pnas.1215991109.

200 Vidal Legaz et al., "Soil quality, properties, and functions in life cycle assessment: an evaluation of models."

201 p. 31: COWI, *Assessment of potentials and limitations in valuation of externalities*, The Danish Environmental Protection Agency (Copenhagen, 2014). FAO, *Food wastage footprint: full-cost accounting*.

202 Appendix VI: Hoekstra et al., *The Water Footprint Assessment Manual: Setting the Global Standard*.. P. Reig et al., *Volumetric Water Benefit Accounting (VWBA): A Method for Implementing and Valuing Water Stewardship Activities. Working paper*, World Resources Institute (Washington DC, 2019), https://wriorg.s3.amazonaws.com/s3fs-public/volumetric-water-benefit-accounting.pdf.

203 Pimentel et al., "Water Resources: Agricultural and Environmental Issues."

matter[204]. What a complete list of these divisions we leave for the development of food footprint protocols and food system non-financial accounting standards. This section is concerned with the evidence that the distinctions do matter and what level of resolution in spatial and contextual divisions is possible and practical for comparable valuations to inform food system transformation. If the resolution is too coarse the error bars in estimates will be too large and not trusted. Also, users will not be able to highlight the differences in impact from their distinct production practices. Too fine a resolution then energy and time are wasted on perturbations to valuation numbers that will not make much different to global scale transformation.

When considering the difference between impact and footprint the report advocates distinguishing footprints spatially and contextually into “sources of impact now” and impact occurring in economies distinguished in space and time “receivers of impact now and in the future”. This is a standard view at least in environmental valuation (Figure 18)[205].

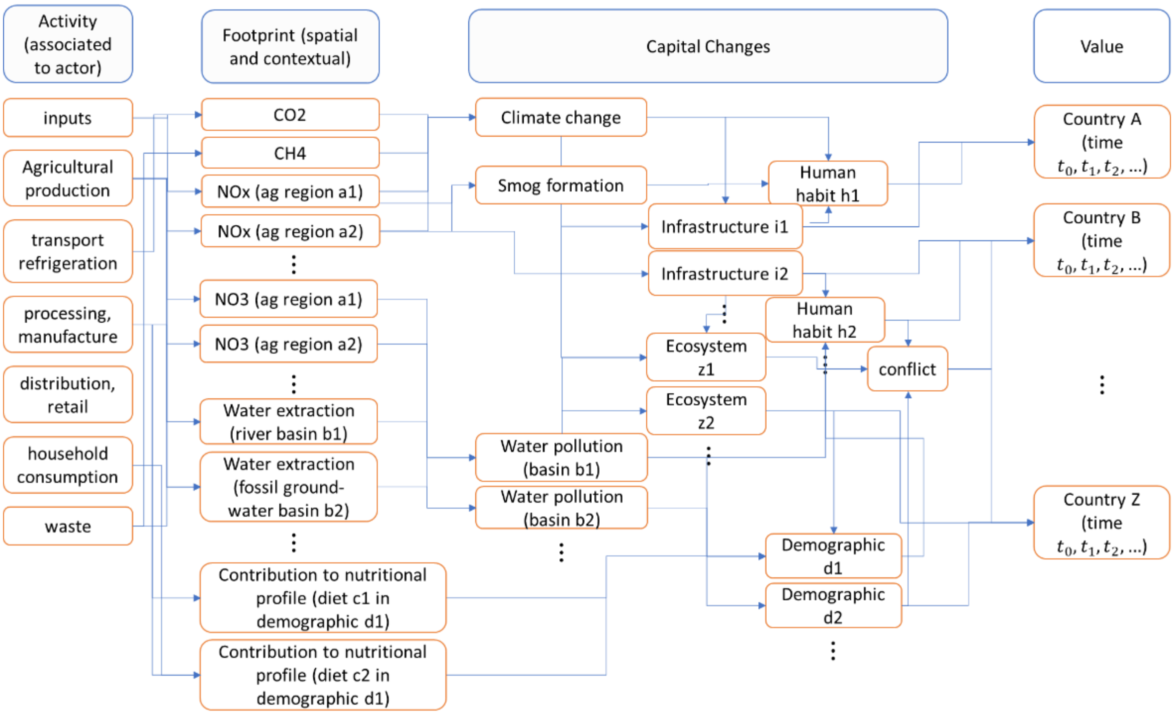

Figure 18: Outside of carbon costing, food impact costing will depend on where and in what context the footprints occur, where when and in what context the capital changes occur, where and when economic value changes occur. We are interested in impact calculation of the activities of food system actors, which means we trace their activity (from the left-hand side) to a footprint and then to impact to society. Valuation of the dependencies of the food actors would start with the actor on the right-hand side (at their value gain and loss) and the costs they occur from capital changes, and then trace that back to whose activities. Conceptually the scope on the left- and right-hand side can be targeted: the impact of actor A on actor B (equivalently the dependencies of actor B on actor A). (Source: adapted from Figure 9 de Bruyn et al., *Environmental Prices Handbook EU28 Version*)

For distinguishing impact in space and time the economic effects occur in what should be viewed as different economies. For example, the health effects of consumption and economic consequences of improved human capital and shifting health expenditure occur in the

[204] p. 31: COWI, *Assessment of potentials and limitations in valuation of externalities*., S. J. Vermeulen et al., "Addressing uncertainty in adaptation planning for agriculture," *Proceedings of the National Academy of Sciences* 110, no. 21 (2013), https://doi.org/10.1073/pnas.1219441110.
[205] de Bruyn et al., *Environmental Prices Handbook EU28 Version*. 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.

consumption country. The health effects of production and the economic consequences of pesticide application or fertiliser leakage occur in the production country or other countries down-wind or downstream.

As the social costs vary in terms of the origin and context of the footprint, and the economy and time period in which the impacts occur, food impact costing involves many shadow prices (described from p. 101). The social cost of carbon avoids this because of the indistinguishable effects of the origin of emission and its global impact. Other shadow prices, for example for water, nutrient pollution and malnutrition, are very dependent on context. The social cost(s) of obesity, like carbon, have intergenerational components. Unlike carbon which has a clear footprint unit (t CO2-eq emitted) additional research will be required to determine appropriate footprint and impact pathways with spatial and contextual distinctions for health impacts. A food system non-financial capital accounting standard would guide what to measure and disclose in terms of other footprints, guide transacting the contributions to value and impact along the food and agriculture sector's complex value chains and provide a standard set of quantities on which to base shadow prices.

So far, the picture has been where footprint occurs and where damage occurs, i.e. social costing. What about abatement costing?

There are no standardised food system footprints equivalent to carbon footprints yet and few disclosure and offset opportunities equivalent to carbon disclosure or carbon offset. Offset allows equalisation of price – converting carbon emission rights into a global commodity, whoever can abate emissions at the lowest price – and the realisation of a global abatement curve. Carbon is estimated to produce less than one-third of global food system social costs[206]. Abatement of food system impacts is not mostly of carbon with the other footprints requiring negligible consideration. Offset needs to occur in the same catchment for water extraction and water pollution[207]. This requires local abatement measure or local offset markets. So spatial and temporal distinction in impacts have consequences for both social and abatement costing.

What geographic scope exists already that may be suitable and practical for shadow prices to inform food system transformation?

The System of Extended Economic Accounting – Agriculture, Forestry and Fisheries (SEEA-AFF) includes national accounting of carbon footprint, water footprint, pollutants and food loss. This footprint accounting is too coarse for impact valuation or impact offset. The data going into calculation of the national accounts is of more interest. The footprints accounted for in the SEEA-AFF include a common list of environmental physical accounting (see case studies from p. 128): flow account for water abstraction; flow account for water distribution and use; flow account for energy use and GHG emissions; flow account for nitrogen and phosphorous, and pesticide use. In terms of contextual scope for land use, SEEA-AFF considers land areas used for agriculture, forestry, aquaculture, maintenance and restoration of environmental functions.

The System of Extended Economic Accounting – Experimental Ecosystem Accounting (SEEA-EEA) recognises that capital changes do not accord with national boundaries. The SEEA-EEA is spatially specific to ecosystem[208]. The physical accounting and consideration of valuations in the SEEA-EEA are more akin to considerations for a food system non-financial accounting standard.

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206 FOLU, *Growing Better: Ten Critical Transitions to Transform Food and Land Use, The Global Consultation Report of the Food and Land Use Coalition.*
207 Appendix VI: Hoekstra et al., *The Water Footprint Assessment Manual: Setting the Global Standard*..
208 UN et al., *System of environmental-economic accounting 2012 : experimental ecosystem accounting*, United Nations Organization (New York, 2014).

Though not formalised into an accounting standard, a tremendous amount of consideration and modelling exists for capital changes associated to food system activities. Spatial and contextual boundaries for footprints do not need to be considered from scratch. Nor the understanding how the footprints align to capital changes, and capital changes to subsequent capital changes, along the chain of outputs and outcomes. The integrated assessments models (IAMs) used to determine the social cost of carbon are attached to existing climate models. The IAMs connect economic modelling, in some cases just direct economic valuations from previous literature, to the climate modelling. The same approach – a process of attaching economic modelling or collating agreed economic valuations from literature to food system modelling - is a feasible start for food impact costing.

We provide an example of the type of resolution in food system models.

We mentioned previously that the IMPACT model divides the land surface of the globe into 320 units of food production with 36 crop and 6 livestock production categories which overlap a similar division of associated water basins[209]. The food production units and water basins have some coincidence, but not entirely (Figure 19). Neither coincide with national boundaries.

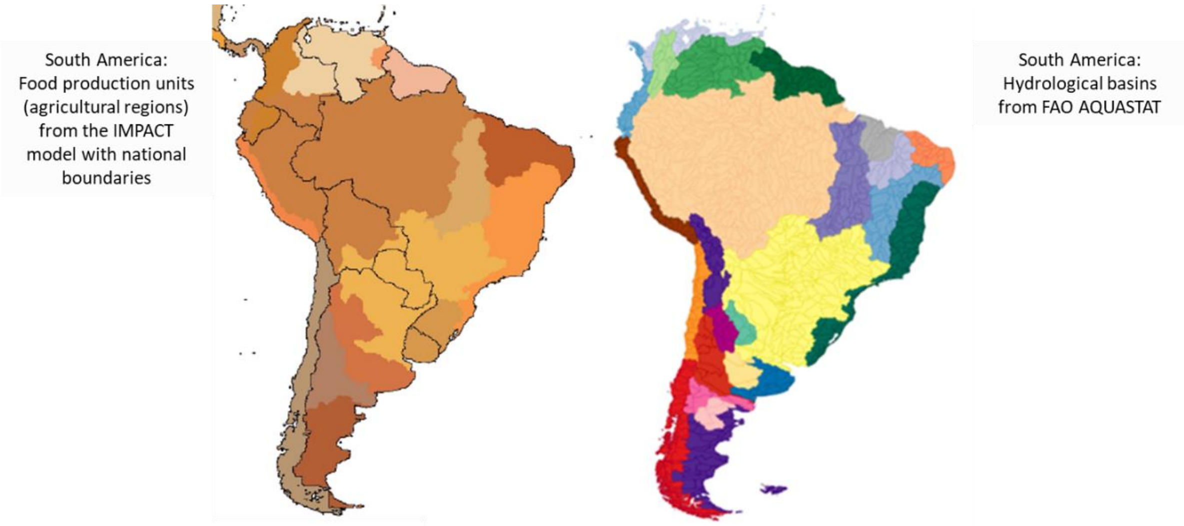

Figure 19: IMPACT food production units in South America compared with national boundaries and hydrological basins (Sources: Robinson et al., *The International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT): Model description for version 3* and FAO Geonetwork http://www.fao.org/geonetwork/srv/en/metadata.show?id=37174)

The 36 crop and 6 livestock production categories are likely not enough contextual resolution. Production context such wholly grass-fed livestock meat versus intensively finished livestock meat may be relevant to impact valuation although the distinction between these contexts is highly debated for CO_2-eq emissions[210]. Polarisation in what distinctions matter, and how much in the end in terms of impact costings, is one of the contributing reasons for the convergence toward a societal process for a footprint protocol and shadow prices as recommended from p. **Error! Bookmark not defined.**.

[209] Robinson et al., *The International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT): Model description for version 3*.

[210] P. L. Stanley et al., "Impacts of soil carbon sequestration on life cycle greenhouse gas emissions in Midwestern USA beef finishing systems," *Agricultural Systems* 162 (2018), https://doi.org/10.1016/j.agsy.2018.02.003; T. Garnett et al., *Grazed and confused? : Ruminating on cattle, grazing systems, methane, nitrous oxide, the soil carbon sequestration question - and what it all means for greenhouse gas emissions*, Food Climate Research Network (London, 2017), https://www.fcrn.org.uk/sites/default/files/project-files/fcrn_gnc_report.pdf.

As mentioned in the section on parity, spatial and temporal disaggregation of changes in economic value at the national level are crude approximations of the effects caused by capital changes. The existence of economic data at national levels make it a pragmatic choice of resolution. Shadow prices disintegrated into national and temporal value changes with respect to spatial and contextual footprint quantities overall provide a sufficient resolution for initial measures of inequity and substitution as discussed from p. **Error! Bookmark not defined.**.

Measurement of the differences in capital changes of spatial and contextual footprints at a finer resolution than broad commodities and agricultural regions, water catchments, populations distinguished by diet, age, sex, exercise level, etc. exist in a vast collection of site or context specific literature studies, models and some lifecycle analysis databases. Costing at this resolution is currently infeasible. This literature is the basis for informing costing at a broader resolution. Similarly, a patchwork of very specific valuations exists in a vast collection of site or context specific literature across many disciplines. The most cited studies for valuations are those that attempt to collate the studies. Matching the two ends, footprints working forward from the left side in Figure 18 and valuations working back from the right side in Figure 18, for comparable impact valuation of food products and companies that have footprints across the globe is a large task. It requires an ongoing process appropriate to the scale of use of social or abatement costing.

A spectrum of models and data to inform shadow pricing is discussed from p. 164. The argument is made there that the resolution above sits currently in the optimum between a practical ability to assign credible shadow prices and simplifications like global valuation factors. The optimum will shift over time. Heterogeneity of capital changes in food products – exactly who has eaten them, which factory in which social conditions has produced them, and on which farm were the commodities grown, is outside the scope of this report. It is an aspiration for technology to track and account the footprints and capital changes at this level of resolution. The resolution suggested is broader to make possible and practical comparable valuations. The present priority is to obtain impact costings that measure useful gross differences in value change due to companies, practices and products. For use in initial policy or market corrections that make major steps to food system transformation.

Scenarios

Last section discussed the variation that the same quantity of footprint, incurred in a different spatial location or context, can have on a shadow price.

As discussed under models and data to determine capital changes, and under carbon costing, the complex models used to determine capital changes do not depend only on the footprint of the actor. It is a function of the present and future levels of societal footprint and other socio-economic drivers and determinants of value. The degree of dependency of the shadow price on these factors will depend on the footprint; short-lived impacts are less dependent on future paths. However, the atmosphere and many terrestrial systems, including soil, can take long periods of time to equilibrate with introduced pollution changes. The same applies of human systems and health damage. We have referenced several potential intergenerational features of food system impact. More research is required to determine the potential contribution of lock-in effects to food impact costing outside of carbon.

The ideal integrated models of capital changes would endogenously include temporal effects in the calculation of full impacts. Meaning that the model would include the feedbacks from climate damage on the economy as well as production factors such as technology. That damage would adjust the level of emissions, which in turn calculates the climate damage in a dynamic progression. The integrated assessments models (IAMs) used to determine the social cost of carbon connect economic modelling to the climate modelling, but they do not feedback changes in emissions trajectories. Emissions trajectories, and what is happening to economic growth outside climate damage, is specified exogenously. It is set in each time step externally to the IAM.

Whatever complex of models are used to assess capital changes from spatial and contextual footprints incurred by food systems will require exogenously set variables. The relevant questions are which variables? What is the degree of lock-in effect from incurred spatial and contextual footprints, and what other assumptions are relevant to estimating gross differences in value change due to companies, practices and products for fiscal policy or market corrections that make major steps to food system transformation?

Climate science standardised scenarios to be used in the estimation of climate impacts. Societal emissions now and into the future (RCPs) and the socio-economic drivers into the future which might coincide with those radiative concentration pathways (called SSPs). Food systems science has developed scenario methods and scenario sets designed to examine different combinations of the variables that will make major differences to food system outputs in the future[211]. The scenarios are not standardised to the degree of RCPs and SSPs. Food system outputs are not all the major societal sources of CO2-eq, air pollutants, water pollutants, factors in human health risks from food consumption, and changes in socio-economic states (in some spatial locations and contexts they will be dominant however). However, it is likely that aspects of scenarios that are used to determine changes in the food system will overlap with the aspects that would cause large difference to future impacts caused by the food system now.

Scenarios are not only relevant for social costs. Abatement costings represent potential abatement provided by products and practices if they were taken up at a specified scale. How much abatement the products and practice provide, what is their price in the market, and whether the scale assumed is realised through either demand or government intervention is highly uncertain. Specification of these possibilities all depend on the kind of exogenous parameters found in food system future scenario sets. The issue of uncertainty in demand in relation to the abatement value of food products and practices is discussed on p. 105 and from p. 157.

Scenarios are essential to footprint reduction targets for food system impacts.

There is evidence that scenarios cause large changes in valuation estimates: UN population forecasts to 2100 can cause ±50% change to the social cost of carbon[212]; the abatement cost of carbon used by the Dutch Environmental Prices Handbook has a lower value of 57 2015€/t

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211 M. Reilly and D. Willenbockel, "Managing uncertainty: a review of food system scenario analysis and modelling," *Philosophical transactions of the Royal Society of London. Series B, Biological sciences* 365, no. 1554 (2010), https://doi.org/10.1098/rstb.2010.0141; J. R. Beddington, *The future of food and farming : challenges and choices for global sustainability ; [final project report of the UK Government Foresight Global Food and Farming Futures]* (London, UK: The Government Office for Science, 2011). WRAP, *Food futures: from business as usual to business unusual*, The Waste and Resources Action Programme (Banbury, 2016). H. C. J. Godfray et al., "The future of the global food system," *Philosophical Transactions of the Royal Society of London B: Biological Sciences* 365, no. 1554 (2010), https://doi.org/10.1098/rstb.2010.0180. WEF and Deloitte Consulting, *Shaping the Future of Global Food Systems: A Scenarios Analysis*, World Economic Forum (Geneva, 2017). R. O. Valdivia et al., "Representative Agricultural Pathways and Scenarios for Regional Integrated Assessment of Climate Change Impacts, Vulnerability, and Adaptation," in *Handbook of Climate Change and Agroecosystems*, ed. C. Rosenzweig and D. Hillel, Series on Climate Change Impacts, Adaptation, and Mitigation (London UK: Imperial College Press, 2014).

212 E. K. Robert and K. M. Bryan, "The U.S. Government's Social Cost of Carbon Estimates after their First Year: Pathways for Improvement," *Economics : the Open-Access, Open-Assessment e-Journal* (2011).

and a higher value of value of 94 2015€/t based on revising emission targets in the Dutch High and Low WLO scenarios[213]; an estimate of damage to global ecosystems service to 2050 differed by up to $81 trillion/yr by 2050 in four alternative global land-use and management scenarios[214]; and a FOLU valuation of the global food system projects a difference of $10.5 trillion/yr by 2050 in two global scenarios[215].

The studies mentioned illustrate the potential ranges of valuation estimates. Some of the ranges involve comparisons of business-as-usual against aspirations for the future (normative scenarios). Normative scenarios have distinct value for policy and target setting[216]. However, for risk pricing and valuation estimation scenarios need to be assessed against the chance they manifest the future at that date[217]. The distribution over these valuation ranges is essential information. Critics of assigning probability to scenarios often ignore that the other essential choice in risk pricing is the measure of risk. Risk pricing includes the option of a full precautionary approach as much as use of the expected value.

Ethical choices in valuation

We summarise the ethical choices in the process of Figure 17 that have been discussed.

- What to include and not to include in the scope of the impact pathways leading to total value loss or gain. Actors that selectively omit some impact pathways of loss and include other impact pathways of gain can distort impact valuation.
- Failure to disclose a credible footprint through lack of, or selective, data distorts impact valuation.
- Choice of welfare measure. Impact valuation, implicitly, is a measure of change in welfare that is being approximated by shadow prices. Choice of shadow prices includes choice of welfare as an implicit measure of social and human well-being. Included here is the ethical concern of monetary estimates.
- Choice in parity. Using PPP, designed to compare countries on the provision of individual utility from consumption of produced goods, to compare DALYs and more inclusive well-being measures with produced capital is contentious. Parity choices make a significant difference to climate costing. Most of the other food impacts are regional with 80% of global total calories produced, processed and consumed (or wasted) in the same country. Currently 20% of calories in agricultural and food commodities are traded, which is projected by the FAO to increase and may also decrease in heterogeneity[218]. Parity choices will be required to calculate the impact for products and companies involved in global value chains, or for governments or investors to compare actors operating within different countries. In the analysis cited in footnote 218, financial capital flows are expected to increasingly concentrate in

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[213] p. 95: de Bruyn et al., *Environmental Prices Handbook EU28 Version*.
[214] I. Kubiszewski et al., "The future value of ecosystem services: Global scenarios and national implications," *Ecosystem Services* 26 (2017), https://doi.org/10.1016/j.ecoser.2017.05.004.
[215] FOLU, *Growing Better: Ten Critical Transitions to Transform Food and Land Use, The Global Consultation Report of the Food and Land Use Coalition.*
[216] 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.
[217] S. Kaplan and B. J. Garrick, "On the quantitative definition of risk," *Risk Analysis* 1, no. 1 (1981).
[218] L. L. Porfirio et al., "Economic shifts in agricultural production and trade due to climate change," *Palgrave Communications* 4, no. 1 (2018), https://doi.org/10.1057/s41599-018-0164-y. FAO, *The State of Agricultural Commodity Markets 2018. Agricultural trade, climate change and food security*, The Food and Agriculture Organization of the United Nations (Rome, 2018), http://www.fao.org/3/I9542EN/i9542en.pdf. https://resourcetrade.earth/stories/food-security-trade-and-its-impacts#top

developed or BRIC countries. In terms of market value traded food products constitute much more than 20%. Traded products are higher-value products which accumulate in higher PPP countries[219]. The percentage of global impact attributable to traded products has not been identified even using PPP (which is likely to be higher again than 20% due to the proportion of animal products traded internationally). The implication is that choice of parity matters in food impact costing. Substitution along food value chains is likely a major sensitivity for parity choices outside of carbon. Environmental and health costs are incurred in producing or consuming countries while social benefits accrue from financial capital flows in potential third countries.

- Ethical choice in discounting. Discounting is a major factor for carbon costing. Intergenerational costs are present for food impacts outside of carbon, but whether it is as sensitive is unclear. Some part of the discounting rate is linked to scenario projections of growth and future marginal utility. Another part is a purely ethical choice of consumption for enjoyment of the present generation. It is likely that projection of societal footprints is a larger uncertainty for food impact costing outside of carbon than time preference.

Variation in valuations from different choices have real or perceived ethical implications. Businesses that make these implicit choices in valuations themselves, or by using calculations of shadow prices in literature that have (using the linear model of next section), are increasing their contestability with government and civil society.

Our argument is that variation due to ethical choices as well as variation in numbers from other choices and sources should be treated together. Agreed and comparable marginal valuation inclusive of ethical choices should be taken out of individual choices by actors and placed into a societal process. Ethical choices by definition conform with societal norms or expectations of what is right. By allowing uncertainty and risk pricing in the marginal valuation, the societal process has even greater flexibility to not make singular ethical choices. It can include ranges to accord with the plural views. The building of a distribution of valuation estimates and the measure of risk is a societal process, as society globally is the bearer of social costs. What to include (footprint and the impact pathway structure informing shadow pricing) should similarly be defined by a common food system non-financial accounting standard. What form the marginal valuation numbers should take for food impact costing is discussed next section.

There is no simple way to avoid concerns about the monetisation of intrinsic value. Money is an instrument of exchange value. Monetary value is centralised and discovered through frequent transactions. Inclusive monetary estimates that inflate the sensitivity of exchange value to social and human well-being factors still need to be careful about substitution. The disintegration of shadow prices proposed in the next section has the potential to extract additional statistics about substitution in the impact valuation of companies and products.

There are ethical arguments for monetary estimates. Exactly because of the connection to exchange value and market dynamics. The evolution to the present food system has prioritised short-term value – food provides calories and nutrition, it is tasty, it provides immediate physiological and psychological satisfaction and comfort. Providing this short-term value has been the triumph of the present food system. Once a resource is seen as abundant and not scarce, monetary value decreases according to the subjective theory of value. Though food is essential to life agricultural production now sits at 4% of global PPP GDP. Low costs of food, allowing incomes to be spent on other goods of greater marginal utility, and short-term

[219] G. K. MacDonald et al., "Rethinking Agricultural Trade Relationships in an Era of Globalization," *BioScience* 65, no. 3 (2015), https://doi.org/10.1093/biosci/biu225. M. Porkka et al., "From food insufficiency towards trade dependency: a historical analysis of global food availability," *PloS one* 8, no. 12 (2013), https://doi.org/10.1371/journal.pone.0082714.

satisfaction fits well with short-term political cycles. Which presently elected national government wants to tell their constituents what to eat through regulation or through taxation[220]? The answer is Mexico with a sugar tax on clear impacts on national well-being and productivity that began to demonstrably offset short-term value gain[221].

The presence of lock-in and secondary effects does not always make the value offset immediate or visible. Secondary effects from food impacts include mass migration and political destabilisation. Food policy is complex, raising political barriers[222]. An important argument for agreed monetary food impact costing is exposing and pricing longer-term value losses into the political-economy as a counter to short-term political dynamics. Enabling economic mechanisms to invest in offsetting or creating that longer-term value. This was an important outcome of carbon costing; though it is not completely safe from short-term political challenge[223]. The same applies if a tandem food system and economic community were able to promote and calculate, for example, the social cost(s) of obesity and malnutrition to perform the same function. Though the costs are plural and not global (there is some argument for a transferable component of common harm in emerging global diets[224]) an intergovernmental body, or alliance of institutional actors, may succeed in promoting impact costing and business opportunities in avoiding those costs.

Food impact costing does not need to get the ‘correct’ answer. An attempt to determine the social costs and benefits of food products to an unending degree of precision according to the myriad of processes constituting and connecting to and from the food system is a rabbit hole. What should be in and out of scope for impact pathways is unsolvable and is a choice that is agreed; it is scientifically guided rather than scientifically established. The opportunity to intervene in market failure in the direction of food system transformation is the guiding principle for costings[225]. In economics the market does the costing of the minute details, the fine scale tuning discovered by value in exchange rather than calculated. The purpose of shadow prices are not to predict the price of footprint as a commodity nor to provide an exhaustive catalogue of damage costs, but to enable the wedge of a benchmark, and to enable the experiments (introduction of internalisation) through which refinement of value around the benchmark can be discovered and centralised. The risk of not including or missing a major damage cost or impact pathway is lessened both by the emphasis on a societal process and the introduction of risk pricing to incorporate error bars into the benchmark.

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[220] L. Wellesley, C. Happer, and A. Froggatt, *Changing climate, changing diets : pathways to lower meat consumption*, Chatham House report, (London: The Royal Institute of International Affairs, Chatham House, 2015).

[221] Ng et al., "Did high sugar-sweetened beverage purchasers respond differently to the excise tax on sugar-sweetened beverages in Mexico?."

[222] D. Mozaffarian et al., "Role of government policy in nutrition—barriers to and opportunities for healthier eating," *BMJ* 361 (2018), https://doi.org/10.1136/bmj.k2426. R. Carey et al., "Opportunities and challenges in developing a whole-of-government national food and nutrition policy: lessons from Australia's National Food Plan," *Public Health Nutr* 19, no. 1 (2016), https://doi.org/10.1017/s1368980015001834. E. M. Ridgway, M. A. Lawrence, and J. Woods, "Integrating Environmental Sustainability Considerations into Food and Nutrition Policies: Insights from Australia's National Food Plan," *Front Nutr* 2 (2015), https://doi.org/10.3389/fnut.2015.00029. K. Parsons and C. Hawkes, *Brief 5: Policy Coherence in Food Systems. In: Rethinking Food Policy: A Fresh Approach to Policy and Practice*, Centre for Food Policy (London UK, 2019).

[223] A. Revkin, "Trump’s attack on social cost of carbon could end up hurting his fossil fuel push," *Science* (2017), https://doi.org/10.1126/science.aap7709.

[224] B. A. Swinburn et al., "The Global Syndemic of Obesity, Undernutrition, and Climate Change: The Lancet Commission report," *The Lancet* 393, no. 10173 (2019), https://doi.org/10.1016/S0140-6736(18)32822-8.

[225] Vermeulen et al., "Addressing uncertainty in adaptation planning for agriculture."

Footprint is a quantity from production under human control the same as the production and consumption of the product incurring the footprint. The price of wheat is not the value of the land, the price of carbon is not the value of the earth. Pricing is a mechanism designed to match quantity of production (for a quantity controlled by humans) with human and social well-being. Conceptually food impact costing involves shadow prices of footprint. In impact frameworks footprint changes conceptually factor through capital changes. This introduces the implicit valuation of capital (natural, social and human) as part of the marginal valuation of footprint quantities. There is a long debate on the ethical implications of implicitly valuing nature and humans[226]. However, it is not clear there is a pretence that costing of footprints (in the absence of exchange mechanisms presently for pricing) is philosophically different than valuing market goods. Both include implicit and flawed partial representation of the value of the underlying capital to achieve similar ends. When wheat becomes scarce the price rises to stimulate production and capital in all its forms is very much part of the implicit function between the amount desired for social and human well-being and the capacity for production. When footprints become abundant the price rises to reduce production[227]. The hope is we should never reach the total impoverishment required to know the true value of the fundamental capitals. The pricing of footprints should accelerate with the quantity of footprints to a degree which excludes any feasible economic position of environmental and social collapse.

As mentioned, many of the ethical choices are pushed into valuation factors, which perform most of the process of a valuation in Figure 17. Choices become implicit in which valuation factors are chosen.

Valuation factors

The last section illustrated features of valuations of food system impact and the calculations required (Figure 17): calculating actor footprint; calculating capital changes across space and time from footprint using complex models in the context of the present and future levels of societal footprint and other socio-economic drivers and determinants of value; and a monetary representation of present and future economic value changes associated to the capital changes. Parity and discounting together are used to compare impact (the economic value changes) across space and time. The last section also discussed the potential errors in the calculation.

Lining up the data and modelling for impact valuations and justifying ethical choices is a considerable task.

There are some standardised modelling suites for ecosystems by large university modelling groups, e.g. Stanford Natural Capital project or King College London[228].

There are some extremely large population level studies with complex determinations of attribution of dietary intake to health outcomes[229]. There are limited equilibrium food economic models geared to either welfare costing of understanding follow-on effects from footprint

[226] V. Anderson, ed., *Debating Nature's Value: The Concept of 'Natural Capital'* (Cham: Springer International Publishing, 2018). G. Folloni and G. Vittadini, "Human capital measurement: a survey," *Journal of Economic Surveys* 24, no. 2 (2010), https://doi.org/10.1111/j.1467-6419.2009.00614.x.
[227] van Grinsven et al., "Costs and Benefits of Nitrogen for Europe and Implications for Mitigation."
[228] https://naturalcapitalproject.stanford.edu/; https://blogs.kcl.ac.uk/eoes/2016/06/07/costing-nature-tool-to-support-sustainable-decisions/
[229] Afshin et al., "Health effects of dietary risks in 195 countries, 1990–2017: a systematic analysis for the Global Burden of Disease Study 2017."

abatement, e.g. IMPACT at IFPRI or GLOBIOM at IIASA[230]. There are some published national abatement curves for carbon emissions in agriculture in the literature (footnote 243).

Data would have to be specifically compiled. Local models and monitoring exist for specific water catchments or agricultural regions. Piecing them together to determine the impacts of large corporations requires significant resources and expertise found presently only in national or international organisations like UN Environment. There are some intergovernmental efforts to align footprint calculations for environmental footprints, e.g. the product environmental footprint (PEF) scheme of the EU[231].

It is beyond the ability and resources of most food system actors and users to explicitly acquire each component and integrate them into a valuation. Many large food companies have limited data presently on their own footprints[232]. Explicit valuations require many choices and extrapolations of missing components to develop an integrated model. Making them difficult to compare and validate as discussed last section and evidenced further by the case studies from p. 128. Without incentives for using the valuations there would seem to be little to justify the effort in compiling them.

The social and marginal abatement costs of carbon are valuation factors. Valuation factors are an extremely practical means to value externalities. They are easy for government and business to use, even small and medium enterprises, supposing that the material footprint of any activity has already been calculated. The valuation factor is multiplied by the appropriate footprint. For example, tonnes of carbon equivalent emissions get multiplied by the social cost of carbon. The valuation factors are the marginal costs associated to individual footprint quantities. As explained below, it is a linearization of the process in Figure 17.

Carbon costings demonstrated the complexity of determining valuation factors. Valuation factors are doing a lot of heavy lifting (Figure 20). Behind the numerical value of a valuation factor is a tremendous calculation. A calculation fraught with uncertainties of modelling cumulative impacts into the future, trade-offs, scientific disagreement, choices in valuation approach, the ethics of implicit exchanges of welfare value across nations and generations. Volumes of scientific literature on food systems and their environmental and social impacts, and volumes of economics, are dedicated to the territory covered by these single numbers. The permutations of choices that could be substituted into the same calculation of a shadow price produces enormous variation (Figure 14 illustrates the partial variation for the social cost of carbon). It is not clear the variation can be reduced due to the irreducible factors describe in the last section involving ambiguity, epistemological uncertainty and ethical choices.

Like carbon costing, the difficulties, choice and variations in food impact costings would be best served by a societal process rather than selective use of shadow prices from literature.

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[230] C. Rosenzweig et al., "Assessing agricultural risks of climate change in the 21st century in a global gridded crop model intercomparison," *Proc Natl Acad Sci U S A* 111 (2014), https://doi.org/10.1073/pnas.1222463110.

[231] B. Vanessa et al., "Product Environmental Footprint (PEF) Pilot Phase—Comparability over Flexibility?," *Sustainability* 10, no. 8 (2018), https://doi.org/10.3390/su10082898; S. Manfredi et al., "Comparing the European Commission product environmental footprint method with other environmental accounting methods," *The International Journal of Life Cycle Assessment* 20, no. 3 (2015), https://doi.org/10.1007/s11367-014-0839-6. https://ec.europa.eu/environment/eussd/smgp/ef_transition.htm

[232] https://agfundernews.com/big-agrifood-companies-supply-chains.html

Besides making it simpler for the food sector, and providing a comparative basis for food economic policy, it enables the difficult task of determining the correct risk premiums to be included in the process. The transfer of risk to society of the uncertainty in the value loss from food impacts is likely to be omitted in a diversity of explicit first- and third-party estimates because of its difficulty.

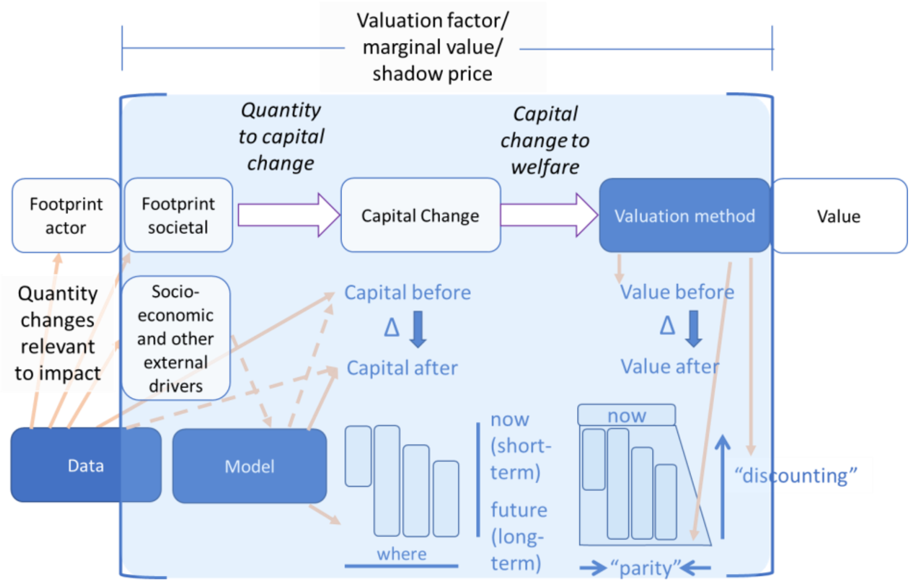

Figure 20: Valuation factors, as shadow prices associated to footprint quantities, that reduce valuation to multiplication of the actor's footprint times the valuation factor. Implicit within valuation factors are most of the measure and value steps in impact frameworks, and calculation and choices of models, data, impact pathways, measurement of welfare and ethics of implicit exchanges of welfare across nations and generations.

Businesses being aware of the components in valuations that they create or use can lead to disclosure of them and sponsor comparability in the methods.

Businesses have the same playing field if valuation factors for food impact and their uncertainty were agreed. This incentivises the sector to co-invest in the societal process for better information about impacts and valuation to reduce the uncertainty and so reduce the risk price. Businesses can compete on footprint reduction and on disclosure.

Food system impact valuation involves determining social and abatement costs for the material environmental, social and human health impacts of food systems. While carbon costing is a sound basis from which to begin food impact costing, there are unique challenges are not found in the process of costing carbon. The next section is technical. Readers looking to applications should briefly understand equation (1) below and move to the section on social or abatement costs from p. 105.

Linear Model

The approach being used in practice of valuation factors multiplied by the footprint of the actor and added corresponds to a linear model of the valuation function V in footprint quantities f introduced on p. 61.

Shadow prices of footprint quantities

As before denote a vector of footprint quantities

$$f = [f_1, \cdots, f_n].$$

For instance, the first term in the footprint f_1 might be t CO2-eq emitted into the atmosphere by society after a certain date.

Denote by V the function in Figure 11 that takes a list of present footprint quantities f and assigns to them a monetary amount relating to economic value $V(s(f), f)$. If a food system actor is responsible for a change in footprint from f to $\hat{f}$ (the amount of generated CO2-eq emissions, leached nitrogen, improvement of community access to drinking water, food products sold that caused preventable death and disease compared to reference diets, etc.) then Taylor's theorem approximates the change in economic value, or impact, by

$$V\big(s(\hat{f}), \hat{f}\big) - V(s(f), f) = J_V(s(f), f) \cdot \big(\hat{f} - f\big) + error \qquad (1)$$

The difference in footprint, $\hat{f} - f$, is the footprint of the actor. For example, $\hat{f}_1 - f_1$ would represent the t CO2-eq emitted by the actor per annum. Here s is a list of other determinants of value of the kind mentioned above, such as socio-economic drivers, that may depend on the footprint.

The dot product notation represents multiplying component-wise then adding the terms

$$J_V(s(f), f) \cdot \big(\hat{f} - f\big) = \frac{\partial V}{\partial f_1}(s(f), f) \times (\hat{f}_1 - f_1) + \cdots + \frac{\partial V}{\partial f_n}(s(f), f) \times (\hat{f}_n - f_n).$$

The vector of shadow prices of footprint quantities, or marginal valuations, or valuation factors, is denoted by[233]

$$J_V(s(f), f) = \left[\frac{\partial V}{\partial f_1}(s(f), f), \cdots, \frac{\partial V}{\partial f_n}(s(f), f)\right], \qquad f = [f_1, \cdots, f_n].$$

In this case the first term in the footprint $\frac{\partial V}{\partial f_1}(s(f), f)$ would be the social cost of carbon given the societal footprint f and other factors such as socio-economic drivers specified exogenously by s. Even in this linear approximation to the change in economic value due to the change in footprint due to the actor, the shadow prices still depend on the societal footprint and additional factors. As described earlier this dependency is what is reflected in the variation in the social cost of carbon (a shadow price) due to assumptions in scenarios of emission trajectories and other socio-economic factors.

Equation (1) represents the linear model used in practice, including the components identified in Figure 11: the actor footprint $\hat{f} - f$, the societal footprint f, and other external drivers s. **With a few exceptions that are noted, all the food system impact valuations case studies from p. 128 use equation (1) to calculate a food system impact valuation.** It is the change in footprint due to the actor(s) in one dimension of footprint over the temporal scope of the valuation multiplied by shadow price for that dimension of footprint to get a change in value from that dimension, then value change from each of the dimensions of footprint are added together. The shadow prices in case studies are obtained from literature or from high level bodies such as the Carbon Pricing Leadership Coalition.

The error term in equation (1) needs consideration. First the linear terms.

The determinants of value s include other economic quantities besides socio-economic drivers. Some socio-economic drivers may not change much with respect to changes in footprint but the commodities whose production created the footprint itself change if footprint changes. These could be omitted by a user as part of the impact valuation, since it is designed

233 Dasgupta and Duraiappah (2012) define the shadow price or value of a capital asset as the monetary measure of the contribution a marginal unit of that asset is forecast to make to human well-being: Dasgupta and Duraiappah, "Well-being and wealth."

to value benefits and costs outside of production (e.g. external costs). If s changes with the societal footprint f the chain rule implies that the shadow price is composed of the changes in economic quantities associated to footprint changes, and a residual part that does not factor through the economic quantities included in s:

$$\frac{\partial V}{\partial f_1}(s(f),f) = \sum_{m=1} \frac{\partial V}{\partial s_m}(s(f),f) \times \frac{\partial s_m}{\partial f_1}(f) + \frac{\partial V}{\partial f_1}(s,f)\ . \quad (2)$$

The implications of what is included within s has been discussed already in detail. It relates primarily to the boundaries and scope of the impact pathways – what changes because footprint changes. Some of the effects mentioned as subsequent economic costs outside of direct health damage costs are any corrective effect of those costs, i.e. the adjustment of value when expenditure is added or removed from the health sector due to the production and consumption of food products. When economic quantities relevant to value are assumed not to change from the actor's contribution to footprint increase ($\frac{\partial s_m}{\partial f_1} = 0$), this is the same as assuming that they are constant determinants of value independent of footprint. One of the assumptions relating to using the linear model is that most of the major economic benefits and costs have been accounted for in the calculation of the shadow price of the footprint, any terms omitted are assumed to be insensitive to footprint changes. If subsequent economic effects have been missed, they are absorbed by the error term and it is unknown if they are of similar magnitude to the valuation without error estimates. This relates to the first mentioned point of ethical implications on p. 86: omitting some impact pathways of value loss and gain can distort impact valuation.

Scarcity and interaction terms

The error also absorbs non-linear terms. The second order terms in Taylor's expansion are

$$V\big(s(\hat{f}),\hat{f}\big) - V(s(f),f) = J_V(s(f),f)\cdot\big(\hat{f}-f\big) + \mathrm{H}_V(s(f),f)\big(\hat{f}-f\big)\cdot\big(\hat{f}-f\big) + error \quad (3)$$

where $\mathrm{H}_V(s(f),f)$ is the Hessian matrix:

$$\mathrm{H_V}(s(f),f)\big(\hat{f}-f\big)\cdot\big(\hat{f}-f\big) = \frac{1}{2}\sum_{i,j=1}^{n}\frac{\partial^2 V}{\partial f_i \partial f_j}(s(f),f) \times (\hat{f}_i - f_i) \times (\hat{f}_j - f_j).$$

Calculating second order effects requires the actor footprint $\hat{f} - f$ and estimating the Hessian. The terms when $i = j$,

$$\frac{\partial^2 V}{\partial f_i^2}(s(f),f),$$

represent resource scarcity. They are the change in the shadow prices for a footprint quantity as that footprint quantity changes. For example, if water is extracted from an already low capital stock of water in a location, then the impacts and costs increase at a disproportionate rate. This term reflects that the value of water is greater when there is less supply[234]. Similarly, the value of reducing CO2-eq emission increases the higher the amount of societal emissions. However, the level of individual actor's emissions compared to global emissions is usually quite low, and it is usually assumed the economic value loss with respect to global emissions

234 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. J. Allouche, "The sustainability and resilience of global water and food systems: Political analysis of the interplay between security, resource scarcity, political systems and global trade," *Food Policy* 36, Supp 1 (2011), https://doi.org/http://dx.doi.org/10.1016/j.foodpol.2010.11.013.

is more sensitive to the stock of existing emission than the flow[235]. That extraction is more proportional to the stock will probably result in larger second order effects for other food impact footprints than for the social cost of carbon. The model of water scarcity of Pfister (2009) (footnote 234), widely used by the consultant TruCost for impact valuations, is non-linear in marginal extraction.

The terms in the Hessian when $i \neq j$,

$$\frac{\partial^2 V}{\partial f_i \partial f_j}(s(f), f),$$

correspond to interactions between footprints relating to value loss. They are the change in a shadow price of one footprint as other footprints change. For example, how a shadow price for obesity increases as CO2-eq emissions increase or how a shadow price for nutrient pollution increases as CO2-eq emissions increase. Unlike carbon costing, food impact costing features multiple footprints. Interactions terms of carbon, market prices (abatement of carbon can have a co-benefit of reducing prices) and marginal economic costs from other environmental and social footprints have been studied[236]. For example, Figure 5.16 of the IPCC Report *IPCC Special Report on Climate Change, Desertification, Land Degradation, Sustainable Land Management, Food Security, and Greenhouse gas fluxes in Terrestrial Ecosystem* examines the synergies and trade-offs between achieving targets within SDG 2 (zero hunger/food security) and SDG 13 (climate action). Interactions include that emissions through change in climate contribute to water scarcity (change in shadow prices for water) and acidification. Land-use and acidification contributions to acceleration of climate costs (changes in the shadow price for carbon) through effectively changing emission trajectories by reducing the ongoing potential for natural carbon sequestration[237]. DALYs saved increase population with potential scarcity effects. Radical changes in agricultural incomes (removing social costs of poverty) would have unknown effects in terms of displacing labour and production to or from lower emitting sectors and demographics to higher emitting sectors and demographics[238].

The first order effects of co-benefits or trade-offs on shadow pricing are part of the interaction terms $\frac{\partial^2 V}{\partial f_i \partial f_j}$ when the dependence on s is expanded by the chain rule. Synergies and trade-offs between the footprint categories and impact pathways of the food system are complex, and the author is unaware of quantitative estimates of the magnitude of potential interaction terms.

Whether the errors from non-linearity are significant, or will make a significant difference for economic food policy designed to reduce food system impacts, is unknown because they have not been much investigated. Without including the second order effects it is hard to judge whether they are comparable to the first order terms. If economic value is non-linear (e.g. rapidly declining) with increasing footprint then these terms will count. They count increasingly

[235] R. Clarkson and K. Deyes, *Estimating the social cost of carbon emissions*, Government Economic Service working paper, (London: HM Treasury, 2002).
[236] For impact pathways of climate change see 3.6.3.2 of Kolstad et al., "Social, Economic and Ethical Concepts and Methods." See Chapter 7 also of IPCC, *IPCC Special Report on Climate Change, Desertification, Land Degradation, Sustainable Land Management, Food Security, and Greenhouse gas fluxes in Terrestrial Ecosystems*., synergies and trade-offs are a central theme of the IPCC report. P. Smith and J. E. Olesen, "Synergies between the mitigation of, and adaptation to, climate change in agriculture," *J Agric Sci* 148 (2010// 2010), https://doi.org/10.1017/S0021859610000341.
[237] https://www.ucsusa.org/resources/co2-and-ocean-acidification
[238] Section 7.5.6.2: IPCC, *IPCC Special Report on Climate Change, Desertification, Land Degradation, Sustainable Land Management, Food Security, and Greenhouse gas fluxes in Terrestrial Ecosystems*.

more if the difference $\hat{f} - f$ is comparable to the societal footprint. That is, they are more, and likely manifestly, significant for impact valuations of significant changes to the food system.

For example, in the social case studies 1-3 the economic valuation of social costs would involve comparing the present economic value with the counterfactual represented by changes in food loss and waste, the global livestock sector, and the global food system respectively. Errors from second order effects including scarcity and interactions should be expected in these cases. The distortion effects of scarcity and interaction in equation (3) are among the non-linear effects that significantly affect the ability to add up (linearly aggregate) many valuations based on small footprint changes to obtain large scale valuations. Toman's critique of the total value of ecosystem services was based on this argument[239]. The valuation of sectors, and potentially large companies with large shares of societal footprint, may need to consider this effect.

Without further study it is difficult to recommend the degree to which standardisation of shadow prices should extend to the Hessian. Formalising conceptual impact pathways would assist in understanding synergies and trade-offs for economic value loss or gain along the impact pathways and provide a basis for estimating second order effects by concentrating on footprints that interact.

Economic analyses will often use the assumption of constant prices ($\frac{\partial^2 V}{\partial f_i \partial f_j} = 0$). The linear model in (1) removes the effects of resource scarcity and synergies and trade-offs. Wealth changes over small time periods are valued using linear approximation leading to assumptions that shadow prices are constant over those time periods[240].

Based purely on dependence of the error on the magnitude of footprint changes, the error terms are less significant for impact valuations of products. Aggregating impact valuations of products back to sector scale will reintroduce the significance of non-linear errors.

The marginal abatement case studies 4-9 are either of smaller scale operations or individual products. The first-order linear approximation in equation (1) is more likely to be valid in those cases. However, potential omission of relative terms from equation (2) feature as sources of error.

A food system non-financial capital standard that considers formalising conceptual impact pathways will assist in improving practical and comparable impact valuation by indicating the the determinants s in equation (2) that should be included within the consideration of shadow pricing for impact valuation. Formally, impact pathways should specify the major determinants of shadow prices.

Optimal reduction and abatement costing

Multiple dimensions of footprint complicate the picture between the value of abating food system footprints and the portfolios of abatement measures and abatement costs for food impact. A key challenge is understanding co-benefit opportunities or trade-offs between the dimensions of food system impacts[241].

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[239] Toman, " Why not to calculate the value of the world's ecosystem services and natural capital."

[240] R. Yamaguchi, M. Islam, and S. Managi, "Inclusive wealth in the twenty-first century: a summary and further discussion of Inclusive Wealth Report 2018," *Letters in Spatial and Resource Sciences* 12, no. 2 (2019), https://doi.org/10.1007/s12076-019-00229-x.

[241] Niles et al., "Climate change mitigation beyond agriculture: a review of food system opportunities and implications."

As discussed for costing carbon, social costs SC and abatement costs AC are two approaches to the valuation function V.

The interpretation of $V(f) = SC(f)$ is the total social costs incurred given present societal footprint f (loss of economic value in the trajectory of a baseline economy into the future). The impact valuation measures the change in social costs due to the actor (equation (1)). The Jacobian $J_{SC}(f)$ represents a vector of estimates of marginal social costs with respect to each footprint quantity. That is, the damage from one more unit of emission, etc. given the existing footprint f. The Hessian represents scarcity in terms of the larger the footprint the greater the marginal damage, and co-benefits and trade-offs in terms of the damage from increasing one unit of two footprint quantities at the same time may be more and less than the sum of their marginal damages.

The interpretation of $V(f) = AC(f, q)$ for abatement costs is the total cost of the least cost abatement portfolio that reduces the footprint from f to a footprint reduction target q (cost of an abated economy with footprint $f - q$ obtained by substituting the abatement portfolio for baselines in the baseline economy with footprint f). The impact valuation estimates the change in abatement cost required to meet the footprint reduction target $q + \hat{f} - f$ (equation (1)). The Jacobian $J_{AC}(f)$ represents a vector of estimates of marginal abatements costs. That is, if one unit e_j of footprint is added in footprint dimension j, what is the cost of the abatement measure that needs to be added to the abatement portfolio to achieve footprint reduction $q + e_j$. The Hessian represents scarcity of abatement measures in terms of the larger footprint reduction required the more expensive the abatement measures become, and co-benefits and trade-offs in terms of the cost of an abatement measure that reduce two footprint quantities at the same time may be more and less than the sum of the cost of abatement measures that reduce the footprint quantities individually.

The building of an abatement cost function is conceptually the same as carbon costing, but harder to do in practice.

In Figure 16 there was one direction for footprint reduction: reducing carbon emissions. For food systems what is the optimal direction for reducing social costs? Should societal or industry be focussed on reducing footprints associated to human health costs as a priority over abatement of environmental pollution? Co-benefits and trade-offs for both social costs and abatement measures make a difference; a point discussed in the economic theory of change from p. 25. The vector of footprints relevant to food impacts means that there are different paths for footprint reduction. When footprint is a vector multiple footprint reduction targets can offer the same abatement of social costs (an impact target), the optimal footprint reduction target should be chosen according to minimising the abatement cost (Figure 21).

The priority order in the portfolio of abatement measures achieving the optimal footprint reduction coincides with the path of steepest ascent in q directions on the surface $SC(f) - SC(f - q) - AC(f, q)$ where f is the current societal footprint and q is the variable reduction. Societal footprint reduction targets that are staged toward an optimal footprint should follow, as clearly as society can estimate, the path of steepest ascent. The direction of this path depends on co-benefits and trade-offs for social costs and abatement costs (Figure 21).

If trade-offs are prevalent then prioritising abatement of one footprint over another may be the optimal path. If co-benefits are prevalent an abatement portfolio of mixed measures achieving reduction in multiple footprints may be optimal. Co-benefits here relate to both social costs and abatement. Co-benefit in abatement measures means that achieving footprint and social cost reduction can cost less than the most cost-effective reduction measure of individual footprints combined.

Affordable measures that achieve co-benefits in footprint reduction may be optimal paths to achieving reduction of social cost. Cheaper measures may exist for reduction of individual footprints, but the total cost along the trajectory of the marginal abatement surface to reach the intersection with the marginal social cost surface may be higher.

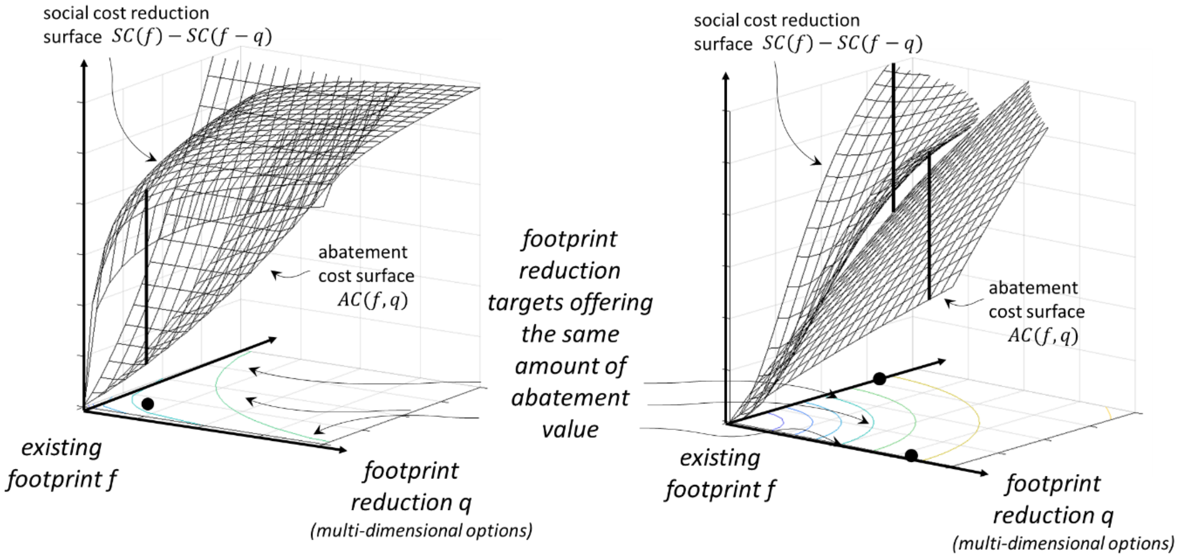

Figure 21: Complications from trade-offs in setting footprint reductions targets for food systems: finding the target associated to the most reduction of social costs for the least cost (optimality), and the different strategies for prioritising footprint reduction in competing dimensions in the presence of co-benefits and trade-offs. With co-benefits in the left panel footprint reduction is most effective with abatement portfolios of mixed measures. With trade-offs in the right panel footprint reduction is most effective with abatement portfolios prioritising one footprint that minimally effects other footprints. Optimal footprint reduction targets are large dots in either panel

Most food system actor impact valuations will not be concerned with optimal trajectories until engaged in a societal process for refining targets or policies on achieving impact reduction targets. Food sector sustainable products and sustainable practices are abatement measures. Their practical goal is to offer the most abatement value per unit of cost compared to the products and practices they substitute. Trajectories of footprint reduction become relevant in the demand of products and practices stimulated by social cost reduction policies. If strong trade-offs exist in the marginal social cost surface, products and practices that address the priority footprint direction efficiently may be incentivised over product and practices that attempt to abate several footprint dimensions at once.

Optimality is the conceptual basis for marginal abatement costing of food system impacts. The potential to achieve impact reduction from multiple footprint reduction targets, or multiple trajectories to achieve a set footprint target, makes building marginal abatement portfolios for food system impacts a complicated exercise. The many options available for abatement introduces uncertainty as to the completeness of the lowest cost abatement portfolio. In practice, as for carbon costing, a valuation of food system impacts based on abatement costing introduces uncertainty even though the abatement measures may be concrete and already on the market. The uncertainty in abatement cost is not just in the costs, but in the social cost being abated. Pricing uncertainty into valuations is not avoided by an abatement cost approach.

There is uncertainty in whether potential abatement will be realised. Research has identified diets that have lower impact on human and natural capital – clear co-benefits[242]. Using fiscal policy to push demand along this trajectory may not work if demand is not responsive and higher prices are mostly absorbed into household budgets. If this happens revenue could be pushed into lowest cost (more efficient on a per footprint basis) measures through offset markets. The overall social benefit achieved from the revenue compared to the dietary change may not be as great. The uncertainty in realising potential abatement measures and what baseline measures they displace, especially in the predominately private provision of food products, is discussed under abatement demand from p. 105 and p. 155. This translates into uncertainty in the marginal abatement cost, explained from p. 105.

In summary, abatement costing for food system impacts is not developed like carbon costing. Energy is a traditional infrastructure, with large or at-scale capital investment and technological challenges (e.g. carbon capture). Food is much more heterogenous in abatement measures available. For the CO2-eq emissions dimension marginal abatement curves for agriculture have been developed at national and subnational scales[243]. In practice, existing emissions marginal abatement curves for the food system are not that easily transferrable to build abatement as a surface over a multi-dimensional footprint. Co-benefits and trade-offs in other footprints have not generally been considered in the building of a least cost curve for emissions reduction. It also unclear what efficiency gains (negative abatement) would provide in terms of footprint reduction. This research question was already proposed on p. 20.

More research, highlighted from p. 25, is required to develop marginal abatement costing as a valuation method for food system impacts. Some abatement costs are used in the case studies 1-9. They are obtained from external studies and do not reflect a marginal abatement valuation for food system impact specifically in the sense above. They reflect least costing for abatement measures from individual footprints. From p. 105 we discuss the feasibility of mixing social and abatement cost estimates for shadow prices.

Attribution implicit in valuation factors

A comment on attribution. When a valuation factor is given then attribution is split (Figure 22), and it is partly determined by footprint disclosure (by the company or a monitor) and partly determined within the calculation of the valuation factor. If the calculation of the valuation factor cannot be split apart (case studies below show the mixture of third-party calculated valuation factors used in practice) the attribution cannot directly be calculated. Clear language should be used for the term attribution of what and valuation of what (Figure 22).

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242 Afshin et al., "Health effects of dietary risks in 195 countries, 1990–2017: a systematic analysis for the Global Burden of Disease Study 2017."; Clark et al., "Multiple health and environmental impacts of foods."; Willett et al., "Food in the Anthropocene: the EAT–Lancet Commission on healthy diets from sustainable food systems.",

243 Bockel et al., *Using Marginal Abatement Cost Curves to Realize the Economic Appraisal of Climate Smart Agriculture Policy Options*; V. Eory et al., "Marginal abatement cost curves for agricultural climate policy: State-of-the art, lessons learnt and future potential," *Journal of Cleaner Production* 182 (2018), https://doi.org/10.1016/j.jclepro.2018.01.252; D. Moran et al., "Marginal Abatement Cost Curves for UK Agricultural Greenhouse Gas Emissions," *Journal of Agricultural Economics* 62, no. 1 (2011), https://doi.org/10.1111/j.1477-9552.2010.00268.x. R. H. Beach et al., "Mitigation potential and costs for global agricultural greenhouse gas emissions 1," *Agricultural Economics* 38, no. 2 (2008), https://doi.org/10.1111/j.1574-0862.2008.00286.x; R. H. Beach et al., "Global mitigation potential and costs of reducing agricultural non-CO2 greenhouse gas emissions through 2030," *Journal of Integrative Environmental Sciences* 12, no. sup1 (2015), https://doi.org/10.1080/1943815X.2015.1110183; K. Tang et al., "Marginal abatement costs of greenhouse gas emissions: broadacre farming in the Great Southern Region of Western Australia," *Australian Journal of Agricultural and Resource Economics* 60, no. 3 (2016), https://doi.org/10.1111/1467-8489.12135.

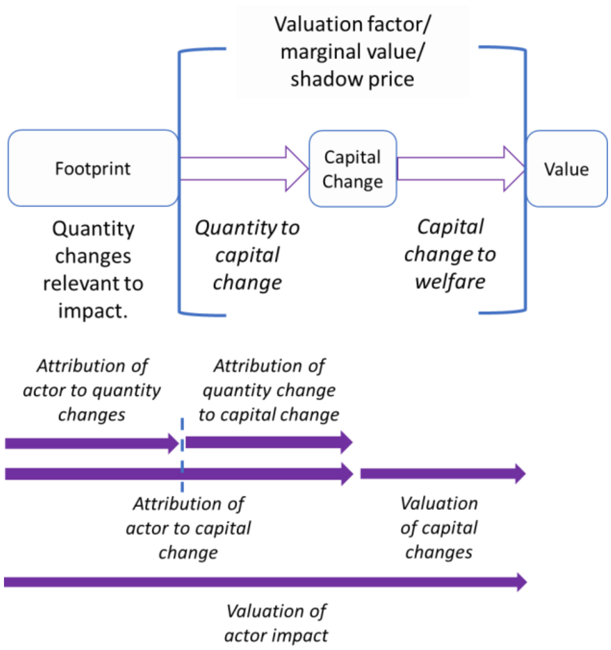


Figure 22: Highlighting the break within marginal valuation of the attribution of capital changes from Figure 11. Attribution of capital changes to actors is partly determined by footprint and partly determined within the calculation of the valuation factor

Valuation factors are a combination of: (a) determining how much capital change is attributable to a unit change in quantity; and (b) the valuation of capital changes from (a).

An attribution of capital changes to an actor is a function from that actor's footprint to capital changes. As we discussed for the valuation function, an attribution function would, and should, be dependent on the total footprint (e.g. ecosystem damage depends jointly on climatic changes and pollutants in a non-univariate way) of the actor, and of other actors, and is not just linear in the units (the extraction of a ten times more water is likely to cause more capital change than ten times the capital change of the original extraction of water). Complex biophysical models of climate, agriculture and ecosystems, across the literature, act as multi-variate, non-linear functions from quantities to capital change.

Valuation factors split the multi-variate (depending on all the quantities in footprint as a vector) and non-linear nature of attribution apart into a univariate (depending on each quantity separately, e.g. carbon footprint) and linear approximation of the attribution function in the total valuation of actor impact.

The change of climate parameters (statistics of weather) like temperature attributable to emissions of actors, can be intermediate within the valuation factor, e.g. a midpoint in the calculation of carbon footprint to natural capital change outside of the atmosphere. Attribution of climate change is partly within the calculation of the social cost of carbon (Figure 12 on p. 51). The case studies are not uniform in the footprint they measure, and sometimes attribution is ambiguous because of causal connections in capital change. So, the most general simple formula is attribution of a change of quantity to an actor, and a marginal value with respect to a change in that quantity. For example, some studies might attribute a temperature change to an actor or activity, and then associate an economic cost of lost value flows from land per degree Celsius of temperature change.

Attribution within valuation needs to specify what type of capital change or it is ambiguous (Figure 23). If the natural capital change is considered to be land degradation, then temperature is a midpoint in the previous example and part of the attribution of land degradation. If the natural capital change is considered to be atmospheric (temperature as a flow of atmosphere) then land degradation is pushed into the valuation of the atmospheric change and temperature change is a capital change. The end value of the actor's footprint should be agnostic to this ambiguity, but in practice the ambiguity leads to many versions of the same calculation factoring through different marginal valuations, e.g. the partial derivative of value with respect to deg C versus the partial derivative of value with respect to ha of land degradation. This is evident across the mixture of first and third-party calculated valuation factors used in case studies from p. 128, and in the different models for the social cost of carbon.

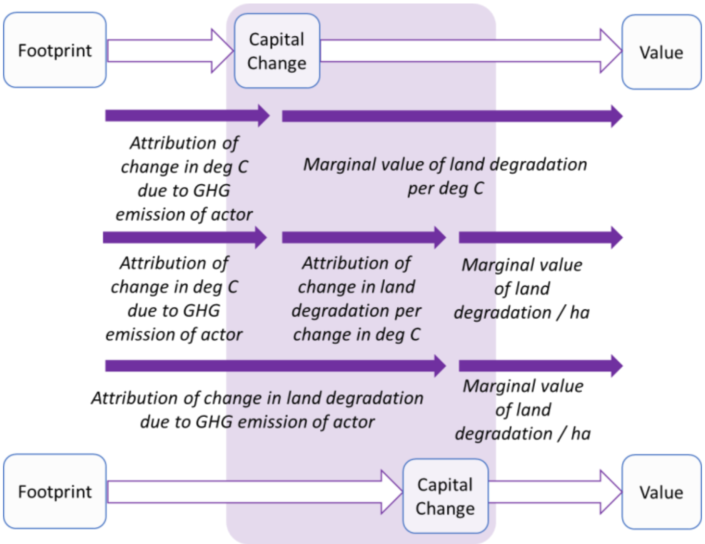


Figure 23: Ambiguity in attribution of capital change and valuation of capital change.

Some of the case studies use a shadow price for a capital change. That is, as a valuation factor is a combination of: (a) determining how much capital change is attributable to a unit change in quantity; and (b) the valuation of capital changes from (a), they use a shadow price in (b) and an estimate for (a). Mathematically, this is an application of the chain rule and footnote 248 indicates how to reframe the linear model of valuation explicit linear model to use shadow prices associated to capital change instead of footprint change.

The UNEP Inclusive Wealth Report methodology uses shadow prices with respect to the quantities of capital changes because it looks at global capital changes directly and has no need to attribute changes in those capitals to individual actor(s). The wealth of the global community is being measured and the global community is responsible for any attributable capital change[244].

It is recommended that practical and comparable valuation for users be based on shadow prices of footprint changes and not capital changes (Figure 20 and equation (1)):

- The actor is unlikely to be able to report on their capital changes, e.g. for climate change or for health changes. Footprint changes are more immediate to the activities of the actor. Attribution modelling as discussed above is difficult enough for society.

[244] Chapter 7 and Methodology Appendices: UNEP, *Inclusive wealth report 2018 : measuring progress towards sustainability*.; Yamaguchi, Islam, and Managi, "Inclusive wealth in the twenty-first century: a summary and further discussion of Inclusive Wealth Report 2018."

- Given the complex interactions between capitals it will be difficult for non-experts to use shadow prices with respect to capital, i.e. the additional ambiguity as above.
- It is natural to put the ambiguity and epistemological uncertainty of the complexity of capital changes into the uncertainty of the shadow prices of footprint quantities which should be priced by a societal process.

Shadow prices of capital changes play an important technical role in calculating shadow prices of footprint changes, e.g. within the social cost of carbon. An accounting framework formalising footprints and impact pathways would help to lessen the ambiguities in capital changes. The LCA community faced a similar issue on what are called midpoints and endpoints, which was partly resolved by the development of the ReCiPe method[245].

While marginal valuations of footprint are recommended for practical and comparable valuation of food system impacts, and attribution becomes implicit in food impact costing as part of the societal model building of shadow prices for footprint quantities, attribution remains important on its own. Parity measures based on capital changes and not just on national economies are a potential technical adjustment. Equity statistics on implicit substitutions of value derived from different capitals would be based technically on attribution and valuation of capital changes. Both shadow prices of capital changes and shadow prices of footprint changes are needed. The recommendation is that the former are more technical and an intermediary for the latter which is more direct to the domain of users and more direct for the purpose of changing a quantity controlled by humans.

Spatial, contextual and temporal factors

When considering impact and footprint it was advocated to distinguish footprints spatially and contextually into “sources of impact now” and impact occurring in economies distinguished in space and time as “receivers of impact now and in the future”.

These distinctions lead to a refinement of the linear model on p. 91. This model is advocated as the basis for practical and comparable impact valuation. It has enough distinction to reduce gross errors in valuation of impacts along the global value chains of the food sector if global footprints for water, etc. were used. This model is also the basis recommended for societal development of shadow prices, for risk pricing, for an explicit formulation that allows clear comparability in parity and discounting and lastly, but not least important, for the ability to examine equity in implicit exchanges of non-financial value. The spatial and contextual distinction for footprints is no more detailed conceptually than present LCA.

As before denote a vector of footprint quantities

$$f = [f_1, \cdots, f_n].$$

The vector is now longer; the index $i = 1,2, \ldots, n$ relates to a vector of footprint quantities such as emission of pollution, water extraction, etc. but each one may have further spatial and contextual footprints at the kind of resolution discussed on p. 78.

For instance, the first terms in the footprint $f_1, f_2, f_3, \ldots$ might relate to GHG emission. We noted for climate change effects carbon emission has a global footprint. It could contextually be distinguished into tonnes of CO2 (Carbon Dioxide), CH4 (Methane), NOx (Nitrous Oxide) emitted. NOx from agriculture can also cause air pollution close to the source of emission[246]. This would be a separate impact pathway as it leads to different spatial and temporal changes

[245] M. Huijbregts et al., *ReCiPe 2016 : A harmonized life cycle impact assessment method at midpoint and endpoint level. Report I: Characterization*, National Institute for Public Health and the Environment (Bilthoven, The Netherlands, 2016), http://rivm.openrepository.com/rivm/handle/10029/620793.
[246] M. Almaraz et al., "Agriculture is a major source of NOx pollution in California," *Science Advances* 4, no. 1 (2018), https://doi.org/10.1126/sciadv.aao3477.

in economies than its effects as a GHG (Figure 18). If NOx footprint were separated out, it would need to be spatially explicit to reflect differences in conditions for smog formation and affected populations. If each of the 320 food basins of global agricultural production used in the IMPACT model were used as the sources of NOx pollution then $f_1, f_2, f_3, \dots, f_{322}$ might relate to CO2 footprint (global), CH4 footprint (global), and then NOx spatially distinct footprints. The carbon component of shadow prices relating to $f_3, \dots, f_{322}$ are social costs of carbon since NOx acting as a GHG has global impact. The air pollution component of shadow prices relating to $f_3, \dots, f_{322}$ are not identical, they will change depending on economic value change they cause in a national economy in a specified time period.

For economic value change, we advocate for an initially *undiscounted* vector of value output

$$V = \begin{bmatrix} V_1 \\ V_2 \\ \vdots \\ V_m \end{bmatrix}.$$

Each value function is an *undiscounted* monetary measure of welfare in a national economy in a time period leading into the future. There are 195 nations, $V_1, \dots, V_{195}$ might be the measure of welfare for all nations over a time period 2015-2020, $V_{196}, \dots, V_{390}$ might be the measure of welfare for all nations over a time period 2020-2030. The time period might cover 100 years (in which case $m \geq 1000$). These figures are illustrative only. The temporal scale should not be linear stretching into the future, 5 log-scaled time periods might be used, etc.

Besides footprint f, each value function for a national economy and time will also be a function of other determinants of value. These need only be formally recognised so we keep the notation $s(f)$. The determinants of value depending on present societal footprint levels play the same conceptual role. Their influence on value in the context of the footprint change could be refined to the national level if feasible. At least for scenarios this implies the opportunity for global socio-economic scenarios to be scaled down to regional or national effects; the effects at future time periods are usually already specified. Other economic determinants, e.g. in models of national economies and trade, will need separate consideration. The value function is then

$$V(s(\cdot),\cdot): \mathbb{R}^n \rightarrow \mathbb{R}^m.$$

The impact valuation, that is, the change in economic value in each nation in each time period due to an actor's contribution $\hat{f} - f$ to present spatial and contextual footprint f is the same formula as before

$$V\big(s(\hat{f}),\hat{f}\big) - V\big(s(f),f\big) = \begin{bmatrix} V_1\big(s(\hat{f}),\hat{f}\big) - V_1\big(s(f),f\big) \\ V_2\big(s(\hat{f}),\hat{f}\big) - V_2\big(s(f),f\big) \\ \vdots \\ V_m\big(s(\hat{f}),\hat{f}\big) - V_m\big(s(f),f\big) \end{bmatrix}. \quad (4)$$

The terms in the vector represent impact in a nation and during a time period. Note that impact in a nation might depend on spatial footprint well outside national boundaries. NOx pollution in food basin 2 might affect national economy 1, 2 and 3 in the next 5 years. The food basin might be in nation 1, or it might straddle nation 1 and 3, or it might be in none of the nations but plume from the emission source in food basin 2 drifts over nations 1, 2 and 3. These kinds of considerations are already well established in many of the existing models behind environmental pricing, e.g. the NEEDS model and the CE Delft EU28 handbook of environmental prices. The interactions between spatial and contextual footprint change and national and temporal impacts are the least resolution required of formal impact pathways.

These pathways will also be represented in the matrix of shadow prices in the first order approximation of equation (4) below.

We introduce the full linear model of the process in Figure 11.

If a food system actor is responsible for a change in spatial and contextual footprint from f to $\hat{f}$ (say extraction of freshwater from the Paraná Basin in Brazil for the production of irrigated soy) then Taylor's theorem approximates the change in economic value, or impact, by

$$V\big(s(\hat{f}),\hat{f}\big) - V(s(f),f) = J_V(s(f),f)\big(\hat{f} - f\big) + error \tag{1}$$

The difference in footprint, $\hat{f} - f$, is the spatial and contextual footprint of the actor produced now. The matrix of shadow prices

$$J_V(s(f),f) = \begin{bmatrix} \frac{\partial V_1}{\partial f_1}(s(f),f) & \cdots & \frac{\partial V_1}{\partial f_n}(s(f),f) \\ \vdots & \ddots & \vdots \\ \frac{\partial V_m}{\partial f_1}(s(f),f) & \cdots & \frac{\partial V_m}{\partial f_n}(s(f),f) \end{bmatrix}$$

is the Jacobian of the function $V(s(\cdot),\cdot)$. To be clear the shadow price

$$\frac{\partial V_i}{\partial f_j}(s(f),f), \quad i = 1, \dots, m \;\; j = 1, \dots n$$

represent the impact according to the monetary measure V_i (change of economic value in the a country, say Uruguay, in the period 2020-2030) per unit of the footprint f_j (which corresponds say to per m^3 of freshwater extracted now from the Paraná Basin in Brazil).

There are country estimates of the social cost of carbon[247]. From integrated assessment model calculations the social costs in a time period without discounting can be extracted. For climate change impact and a few other environmental pollutants the model does not require more information than already exists on footprints, impact pathways and shadow prices. For other dimensions of footprint the model is asking a lot more. This is the resolution required though to distinguish impact in the food sector's global but heterogenous value chains with footprints both upstream and downstream into waste and effects from human consumption. Determining the social costs at the coarse resolution discussed is not beyond a societal process and could bring together many of the modelling pieces across disciplines that the scientific community already has. There may be over a million shadow prices in the Jacobian. The Jacobian will generally be very sparse. For example, local effects in water basins are only going to affect a few countries and many effects will not appear in later time periods. There will likely be a repetition of terms. Tractability of the Jacobian relies on other computationally convenient assumptions. One of those conveniences is pure pragmatism. In the consideration of global impact due to food systems, it is the major social costs, and representations of the major impact pathways involving transfers of footprints to costs that need to be embodied in the Jacobian of shadow prices. Small costs and minor pathways should be absorbed as noise into the error term and dealt with by risk pricing, especially so for later time periods.

The impacts across nations and time periods are not yet compared a parity choice and discounting. They are not yet substituted if some are positive and some are negative. Denote the parity and discount vector

[247] Ricke et al., "Country-level social cost of carbon."; Adler et al., "Priority for the worse-off and the social cost of carbon."; W. R. Cline, *Global Warming and Agriculture: Impact Estimates by Country* (Washington DC: Center for Global Development, 2007).

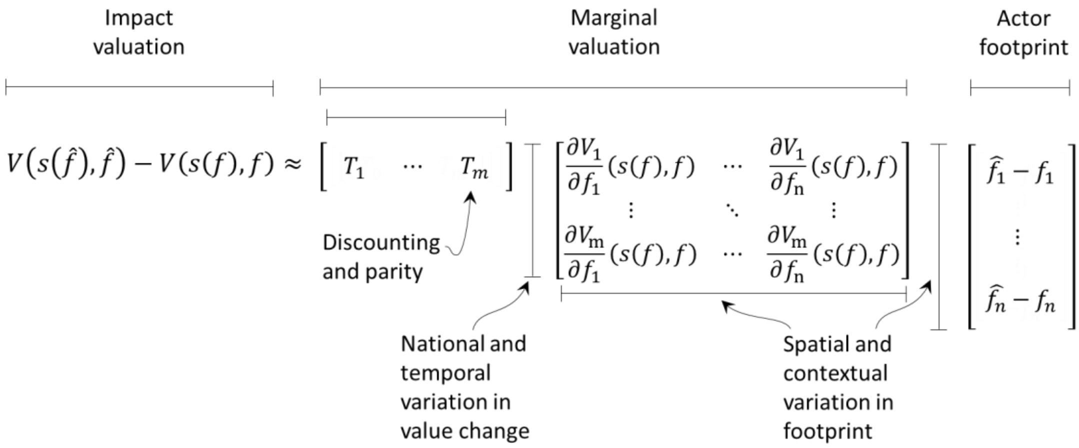
$$T = [T_1, \cdots, T_m].$$

The weightings in T can be decomposed into the usual forms of parity weighting terms $T_1, \cdots, T_{195}$. The rest of the terms can be obtained by compound growth using a social discount rate. At this level of resolution the discount rate can be country specific and it could involve a decreasing social discount rate as recommended in the discussion from p. 73. Using different parity weightings for different capital effects (e.g. PPP for produced capital and priority for human capital) is possible but not without a more complicated model[248].

Using matrix multiplication the linear model of the valuation of impact associated to the actor with spatial and contextual footprint $\hat{f} - f$ is

$$T\ J_V(s(f), f)\ (\hat{f} - f). \tag{5}$$

To be explicit how this model is a linear model of the process in Figure 11 and Figure 17:



Note that the present comparable value function

$$T\ V(s(f), f)$$

is not vector valued. It reverts to the scalar form on p. 91 with shadow price vector

$$J_{TV}(s(f), f) = T\ J_V(s(f), f).$$

What has been suggested is that it is most useful to deconstruct the calculation of the shadow prices discussed on p. 91 into a minimum level of national, temporal, spatial and contextual detail. The extra burden on actors is reporting spatial and contextual footprint. The extra burden overall is mostly on the calculation of shadow prices. Second order corrections to this

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248 A further application of the chain rule provides a linear model of the process in Figure 17: assume a vector attribution function $C = [C_1(z(f), f), \ldots, C_p(z(f), f)]$ as a list of function of capital stocks changes against footprints given extra determinants of capital changes z. Assuming all footprint changes create value changes by factoring through capital changes then there is a valuation function $U = U(v(C), C)$ from capital stock changes to economic value such that

$$V(s(f), f)\ (\hat{f} - f) = U\left(v(C(z(f), f)), C(z(f), f)\right)\ (\hat{f} - f).$$

The undiscounted linear model is

$$J_V(s(f), f)\ (\hat{f} - f) = J_U(v(C), C)\ \ J_C(z(f), f)\ (\hat{f} - f).$$

The Jacobian J_U is the matrix of shadow prices with respect to capital changes, and J_C is the attribution matrix of rates of capital changes from footprint changes. These are first order estimates of the processes of valuation of capital changes and attribution of capital changes. The linear model has three terms corresponding to the three steps of the process in Figure 17. In this three-term model parity scaling based on the kind of capital changed could be implemented. It is also the conceptual basis for understanding potential substitutions of welfare from non-financial or non-produced capital changes in one location to welfare from financial or produced capital in another location.

linear model could proceed as before in terms of the Hessian, which can be constructed from $H_{TV} = T \cdot [H_{V_0}, \cdots, H_{V_m}]$. Hessians would be an extra burden on a societal process above the calculation of shadow prices. Pragmatism should again be the main computational consideration. If calculated, the Hessians should feature the major scarcity concerns, and the major synergies and trade-offs that might distort policy choices. The Hessians should be very sparse, reflecting that all else being equal most shadow prices are approximately constant. Minor deviations, increasingly so for later time periods, should be absorbed as noise into the error term and dealt with by risk pricing.

The model in equation (5) relies on a choice of parity and discounting (potentially from a common set of choices linked to the socio-economic drivers embodied in s), a common Jacobian of shadow prices, and the spatial and contextual footprint of the actor[249].

Social costs or abatement costs

Abatement measures which reduce carbon footprint were discussed under the abatement cost of carbon on p. 56. Portfolios of abatement measures were also discussed that result in achieving a total reduction target for carbon footprint.

Are sustainable products and practices in the food sector which offer reduction of food impact footprints compared to a baseline product or practice abatement measures in a similar sense? If a target for food system transformation were represented by a footprint reduction target, what is the value of sustainable products and practices in the food sector as contributions toward that target?

Sustainable food products and practices as abatement measures

For sustainable products and practices that substitute a baseline product or practice to be abatement measures the assumption is that they offer, all else being equal, the same private value to consumers or procurers of goods as the baseline product or practice. The additional cost of the sustainable products and practices to match that value is the abatement cost. The reduction in footprint from substitution of the baseline product or practice is the abatement. The abatement value is the social benefit associated to the abatement.

To explain the relationship in basic terms. The difference between a social cost and abatement cost is the difference between incurring value loss in the baseline (a social cost) and averting that value loss by the cost of doing something (abatement). Suppose a $100 visit to the doctor now saves a $1000 operation in a year's time if nothing was done. Assume no pain and suffering over the year and the visit to the doctor is as traumatic as the operation. The abatement value is $1000 (discounted back one year). The abatement cost is $100. The visit to the doctor is the abatement of the operation. Outside of the cost, both have the same private value (fixing the medical problem).

The assumption that sustainable products and practices match the private value to the users of baselines can be complicated to determine for the food sector. Unfortunately, all else is not equal.

Sustainable energy which offers the same amount of kilowatts for a lower carbon footprint will be approximately substitutable for consumers willing to pay the higher cost. Kilowatts represent approximately the same private value in use.

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[249] This model approximates a conceptual model in space, time and context of higher resolution. Conceivably $V(y,t,s(y,t,f(x,c)),f(x,c))$ where (x,c,y,t) are spatial, temporal and contextual variables respectively. In the matrix model described the index m conflates the variation of monetary estimates in space and time (y,t) and the index n conflates the dependence of economic value change in spatial and contextual differences in footprint (x,c).

Sustainable food products offering the same amount of calories and nutrients may not be considered to have the same private value in use. Consumers might react more strongly to other determinants of value compared to an energy product. The sustainability story attached to the product might make it more valuable to some consumers. The taste difference between a plant-based protein product and its equivalent animal-based protein product might make the product less valuable to some consumers. For food products these are major factors in private value. Adjustments to economic value were raised when discussing the abatement cost of carbon. Sustainable food products and practices will often have a clear cost difference to baselines, in the sense of the cost difference between one litre of plant-based milk and animal-based milk, the cost difference to produce one kg liveweight of wholly grass-fed beef versus intensively finished beef, or the cost per ha to implement a sustainable farming practice versus the baseline practice. LCA and other methods can determine the footprint difference because there is a clear functional unit. What is not clear is whether, at that cost difference, the products have the same private value.

Regulatory measures based upon forcing demand change might not care about the private value. Many literature studies take the social value perspective on matching calorie and nutrient delivery at the scale of the global population. Voluntary measures based upon responding to changing demand, or the responses to attempts to force demand, will be sensitive to private value. The provision of food products is largely a private service.

Several options and interpretations are conceivable as corrections when private value equivalence is hard to determine. One is the injection of additional investment costs – these costs are the additional amount required to develop the abatement products until they match the private value of the baselines. These costs could be added to the price difference to form the abatement cost. Another is social cost adjustment. An abatement product with price difference as the abatement cost would then provide social cost reduction from footprint reduction and an additional social cost correction from the difference in private value. This approach would require food system transformation targets to be stated in terms of social cost reduction instead of footprint reduction, which we discuss below. Another approach is discovery of equal value product substitution. This would require simulation or empirical research on the equilibrium abatement cost in market to understand the products and practices that the sustainable product or practice at the price offered substitutes.

In trying to align the social value perspective (which should determine the abatement value) and the private value perspective (which will likely be a main determinant in abatement costs) we recommend a form of equilibrium abatement cost adjustment. The abatement of an abatement measure is dependent on the abatement portfolio(s) it appears in. The contribution of the abatement measure to an abatement portfolio is in the total amount of abatement it offers. This requires a projection of the demand of total substitution of the sustainable product for baselines. The private value matching is not per good or practice (some consumers will never find plant-based dairy equivalent to animal-based dairy even with a negative abatement cost), but in the total amount of substitution of present goods by the sustainable alternatives (how many consumers did find plant-based dairy equivalent or better than animal-based dairy at the abatement cost). From the products or practices displaced the total abatement cost and the total footprint abatement can be estimated. Marginal abatement costs and footprint abated per unit could then be calculated. To form an abatement portfolio with adjusted marginal abatement costs, this would have to be repeated for each abatement measure. Every time an adjusted marginal cost was calculated, the new demand profile (the substituted products and the previous baseline) become the new baseline. This is to ensure that the abatement is maximised for the abatement measures with the lowest adjusted marginal cost and substitution of a baseline product does not occur twice.

The same comments above apply to investment in companies and initiatives offering sustainable products and production practices. They, the companies and initiatives, represent portfolios of abatement measures.

In the total abatement method outlined, uncertainty in demand produces uncertainty in total abatement. This introduces uncertainty in the marginal abatement cost of an abatement portfolio designed to meet a footprint reduction target. To explain this in simple terms we revert to Figure 15. For food products which act as abatement measures (individual columns in the abatement curve in Figure 15), the height of the column, which is the marginal abatement cost of that measure, may be uncertain if price differences with equal value substitutes are unknown, the width of each column (now a volume in the several dimensions of footprint for food impact) is uncertain because of uncertainty in demand, and hence what is the next most expensive abatement measure in the directions of the individuals footprints once the footprint reduction target is met is uncertain. If such abatement portfolios could be constructed with their uncertainty, this would be the equivalent of marginal valuation of food impacts using abatement costing (and, without uncertainty, form the abatement surfaces in Figure 21).

We reiterate the difference between the marginal abatement cost of a product or practice (the height of a column in Figure 15) and the marginal abatement cost of a portfolio of products and practices (the height of the last column in Figure 15). The terminology is not inconsistent. The marginal abatement cost of a portfolio with one abatement measure in it is the marginal abatement cost of that measure. If the portfolio has more than one measure in it then there can be a difference between the marginal abatement cost of a measure in the portfolio, and the maximum marginal abatement cost of a measure in the portfolio (Figure 24).

One implication of the above discussion is that the smaller the correction to abatement costing, likely the lower the uncertainty in achieving abatement value. Products that offer, all else being equal, the same private value will likely have clearer demand trajectories by direct substitution. Costed investment in food technology that enables plant-based meat and dairy products to be direct substitutes (taste, experience, nutrition, etc.) to animal-based meat and dairy reverts the marginal abatement cost to the price difference between the direct substitutes[250].

Another implication from the difficulty in abatement costing for food products is zero-revenue taxation. Suppose that the marginal abatement cost of an abatement portfolio meeting a food impact footprint target was used as the basis for a tax on food sector activities that created footprints. Further, suppose the revenue from the tax was used to offset the total abatement cost of the portfolio to stimulate additional demand and achieve the footprint reduction target more rapidly. One way to allocate the revenue is based proportionally on the substitutes of the taxed product (reducing the price of direct competitors to the increased price product). This allocation becomes much clearer with same private value direct substitutes versus discovering empirically an equal value basket of substitutes.

Footprint targets versus impact targets

Social costs and abatement costs are two approaches to valuation discussed for costing carbon. They use the same formula for impact valuation (equation (1) on p. 91), except the valuation factors substituted into the equation are either marginal social costs or marginal abatements costs.

[250] There could be an opposite argument. Novel products will have greater uncertainty in which products they substitute, but their novelty may allow them to establish a displacement of baselines. It is unclear without further research if more expected total abatement would be achieved through novel products or direct substitution of existing products, or a mixed approach is complementary to balance abatement cost and risk to achieving abatement.

Impact valuation using marginal social costs measures the change in social costs due to the actor. For a sustainable product or practice the impact valuation uses the abatement (footprint reduction) from substitution of a baseline. This would be the abatement value of the product or practice. If society had a target for reducing social costs from the food system (what we call an impact target), then the abatement value represents the contribution of the sustainable product or practice to that target. The incentive for sustainable products or practices in this view depends on how much the abatement value is internalised into the value chain of those products and practices – either subsidies are received directly, or demand is increased, or costs lessened (discussed further on p. 155).

For a sustainable product or practice, impact valuation using marginal abatement costs indicates the money saved from paying abatement costs to achieve a footprint reduction target. This amount will be less than the abatement value of the product or practice (only at the optimal footprint reduction are marginal social costs and marginal abatement costs equal - Figure 16). If the impact valuation using marginal abatement costs is higher than the abatement costs of the product or practice, this indicates that sustainable product or practice should be part of an abatement portfolio to achieve the footprint reduction target. The incentive for sustainable products or practices in this view depends on how much achieving the footprint reduction target is incentivised through internalisation.

Why consider impact at all? Why not set a footprint target and assess sustainable products and practices purely on their footprint? Valuation is the economics required to incentivise achieving the footprint target. First, what should the targets be and where? Abatement value is a measure of the relative importance of footprint reduction which spatially and contextually varies as mentioned. Abatement costing indicates the cost effectiveness compared to other measures in achieving the footprint target.

In practice both points of view are valuable[251]. Without understanding the social costs, it is difficult to determine which footprint changes optimise welfare. Without abatement costs, it is difficult to determine what impact target optimises welfare. In terms of whether an impact valuation of sustainable products or practices should use marginal social costs or marginal abatement costs, it is presently unclear what will be the major viewpoint of those offering incentives – meeting footprint targets at least cost or achieving the most social benefit.

Damage costings associated to food system impacts are presently more developed than abatement costings, which resolves the issue for the case studies. Case studies 4-9 involve mostly damage based valuation factors and we view them as estimates of marginal abatement value.

Are footprint reduction targets and impact targets interchangeable? Footprint reduction is a proxy for social cost reduction (Figure 16). From the perspective of economic food policy, the footprint reduction target should match the optimal reduction of social costs or is part of a graded set of targets toward the optimum.

Many different footprint targets could achieve the same impact target. The collection of abatement portfolios whose total abatement value achieves an impact target is different from the collection of abatement portfolios whose total abatement achieves a footprint target. The abatement portfolio that achieves an impact target at lowest cost will select out some of the footprint reduction targets that achieve the impact target.

[251] LCA literature captures an extensive discussion distinguishes between attributional (footprint) and consequential (impact) LCA: 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.

The difference between footprint and impact highlighted on p. 78 mean that, in practice, going back and forth between footprint targets and impact targets is not straightforward. Footprint targets will have to be spatially and contextually disintegrated to associate them to an impact target. The many ways to do this mean that a global footprint reduction target (the food system should reduce globally this amount of CO2-eq emissions, this amount of water extraction, this amount of nitrogen leaching, etc.) could be associated to several impact targets depending on where the reduction is achieved. Evidently the greatest of those impact targets (the most social cost reduction) is the desirable way to disintegrate total footprint reduction into spatial and contextual footprint reduction. The configuration of the spatial and contextual footprint targets associated to the highest impact target will depend critically on parity and discounting. Therefore, whether the footprint reduction targets are viewed as equitable is unclear. To an impact target there could be a great many regional and production permutations.

This is a possible way to simplify target setting: a global footprint target, which is disintegrated into a spatial and contextual footprint target according to maximising the social benefit from that footprint reduction. At least as a start point for political agreement.

In the next section we discuss example footprint targets for food system transformation. In the case studies, we discuss an impact target from a 2019 FOLU report.

Mixing social and abatement costs in valuations

Some of the case studies from p. 128 use a mixture of marginal social costs and marginal abatement costs in equation (1). It is not entirely clear how to interpret and use the valuation.

One of the footprints changes like carbon is being priced for least cost achievement of a 2 degree target, while for the other footprints there is no target. The activity is being valued according to cost-effectiveness in some dimension of footprint and social benefit in others. Mixing costs and value is problematic for economics and accounting[252]. In practice marginal abatement costs can be viewed as lower bounds on marginal social costs, and marginal social costs as upper bounds of marginal abatement costs. This view is interpreting the mixed valuation as either a value or a cost. The former is ignoring the footprint reduction setting implicit in abatement costs. The latter requires footprint reduction targets to be augmented and consistent.

For the case studies, the mixing does not change the valuation amount much. The marginal abatement costs used are mostly marginal abatement costs for carbon, and the values of carbon abatement costs are within the central to high ranges of the IWGSCC social cost of carbon. It is the interpretation which changes.

In an optimal economy the marginal social costs equal the marginal abatement costs. Is this an assumption that can be used to turn social costs into abatement costs and abatement costs into social costs? This also needs careful interpretation. For example, suppose the marginal abatement cost of carbon was calculated for an emissions target for a 2 deg world. Assuming that a 2 deg world is the optimal outcome (any less carbon emission and the social and human welfare of developing nations would have suffered from impaired use of carbon for production and growth, any more and climate change damages would start to outweigh the benefit gains), then the marginal abatement cost of carbon is equivalent to the social cost of carbon in a 2 deg world, i.e. the damages produced per tonne of extra emission in that world. This is not the marginal valuation of the social cost of carbon for other equilibrium temperature outcomes, but with a specific assumption about the future and the carbon emissions trajectory. At the optimum, marginal abatement costs are conceptually social costs but in futures where the

[252] p. 136 OECD et al., "System of Environmental Economic Accounting 2012 : Experimental Ecosystems Accounting."

optimal footprint reduction has been achieved, and achieved very rapidly in relation to the timescale of the impact pathway for the various footprints[253].

Case study 3, an impact valuation of the global food system, uses some valuations that are not social costs. They provide examples to illustrate the difference between marginal social costs and abatement costs.

In case study 3 there is a valuation of rural welfare as an impact of the global food system. The footprint is the number of people working in agriculture below the World Bank poverty line of $5.50/day. The footprint target is zero people working in agriculture below the World Bank poverty line. An annual marginal abatement cost is calculated at $5.50 x 0.4 x 365.25 /pp rural in poverty/yr (40% is the average rural poverty gap), which is the average annual cost to raise the income of one person below the World Bank poverty line above the poverty line. This is not a calculation of the social costs of poverty. The assumption is the social costs of poverty would be abated by this level of income.

Another valuation in case study 3 is of private benefits from overapplication of fertiliser. The footprint is a calculation of the global overapplication of fertiliser in tonnes. The average market price of fertiliser per tonne is used as the valuation factor. A correction to the additional welfare from the saved private costs against the welfare losses from decreased activity in the agriculture input sector is not applied. This private benefit is a social benefit when corrected. It can also be interpreted as a negative abatement cost if there was a target involving fertiliser overapplication reduction.

Adding marginal abatement costs with the same footprint dimension must be done with care. The same care as required for carbon emission reduction accounting[254]. Assumptions in the abatement portfolios and how to combine them together determines the marginal abatement costs of the combined portfolios. The ability to trade footprint reduction lowers marginal abatement costs and makes footprint reduction more efficient (Figure 24). This is the argument

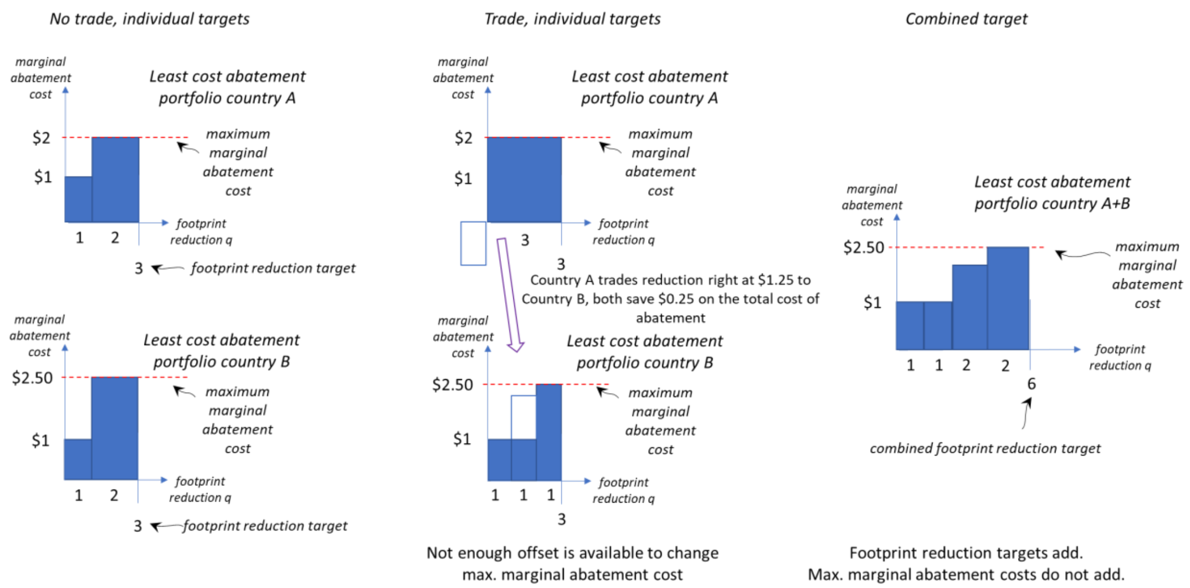

Figure 24: Simple illustration of efficiency in footprint reduction trading for footprints that can be offset, and that marginal abatement costs do not add when footprint reduction targets can be combined.

[253] J. R. Lamontagne et al., "Robust abatement pathways to tolerable climate futures require immediate global action," *Nature Climate Change* 9, no. 4 (2019), https://doi.org/10.1038/s41558-019-0426-8.
[254] L. Schneider et al., "Double counting and the Paris Agreement rulebook," *Science* 366, no. 6462 (2019), https://doi.org/10.1126/science.aay8750.

for the efficiency of carbon trading. The inability (or prohibitive cost) to trade non-carbon footprint reduction is one of the reasons for the disintegration of marginal valuations on p. 101 into a Jacobian matrix with spatial and contextual footprint distinctions. Is a cubic metre of water extraction saved in the UK going to offset the damages of a cubic metre of water extracted in Brazil? It is not only marginal social costs that require this breakup because of the different damages that the same footprint might occur. The inability to globally trade abatement measures or the adjustment to their costs to do so, makes calculating global portfolios of abatement measures applied to global footprint reduction targets very complicated outside of carbon.

There are limitations on how much technology and practice improvements, even at high costs, can enable footprint reduction in the production of food[255]. Likely some abatement costs in a food system abatement portfolio will be stimulus measures to change demand[256].

Adding together marginal abatement costs across different footprints dimensions also require corrections or understanding of the potential error in the valuation. Most of the marginal abatement costs are likely to be literature estimates of abatement portfolios for that footprint dimension singularly (carbon, reactive nitrogen, health care cost abatement, etc.). Abatement portfolios of mixed abatement measures with co-benefits addressing multiple footprints toward a food footprint reduction target may have lower marginal abatement costs.

Combining the footprint reduction targets from abatement portfolios that consider footprint singularly needs consideration. It is not as simple as adding targets together like they are orthogonal. That is, taking the marginal abatement cost for carbon from an abatement portfolio with 100Gt of CO2-eq reduction target by 2030 and the marginal abatement cost for nitrogen from an abatement portfolio of 1000 Tg N reduction target by 2030[257] provides the marginal abatement costs for carbon and nitrogen for a combined reduction target of 1000 Tg N and 100Gt Co2-eq by 2030. In addressing the global nitrogen challenge, other non-nitrogen footprints will increase or decrease (e.g. the energy used to produce nitrate fertiliser) and potentially alter whether footprint targets are being met in other dimensions[258].

Overall, because of the complexity in abatement costing and the need to be consistent about multidimensional targets for the food system and the underlying abatement portfolios, it is recommended to use social costs until abatement costings for food impacts are further developed and compiled.

[255] C. M. Anderson et al., "Natural climate solutions are not enough," *Science* 363, no. 6430 (2019), https://doi.org/10.1126/science.aaw2741; 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.

[256] Bajzelj et al., "Importance of food-demand management for climate mitigation."

[257] UNEP Emission Gap report UNEP, *Emissions Gap Report 2019*, United Nations Environment Programme (Nairobi, 2019), https://www.unenvironment.org/resources/emissions-gap-report-2019. staying on the 2 deg C warming target requires a 20% reduction from present trajectory from 2020 to 2030, which amounts to 100 Gt CO2eq. Liu et al., "Reducing human nitrogen use for food production." estimated 171 Tg N / yr input into food production in 2015, which grows linearly to 100 Tg N/yr extra by 2030. It is estimated 77% lost based on present day. This is a 2000 Tg N loss N from food production and consumption between 2020 and 2030. The International Nitrogen Initiative supports a global goal to halve reactive nitrogen waste by 2030 http://inms.international/news/ini-commits-support-global-goal-halve-nitrogen-waste-2030-support-inms-project S. Reis et al., "Synthesis and review: Tackling the nitrogen management challenge: from global to local scales," *Environmental Research Letters* 11, no. 12 (2016), https://doi.org/10.1088/1748-9326/11/12/120205.

[258] Reis et al., "Synthesis and review: Tackling the nitrogen management challenge: from global to local scales."

Targets for food system transformation

Sustainable products and practices require reduction target benchmarks to be assessed as cost-effective abatement or reducing social cost and proportionally incentivised. Setting consistent footprint or impact targets for food system transformation is a consensus exercise. There are several high-level reports indicating targets for footprint reduction for the global food that add to or synthesise an existing large literature base. There exists no body like the United Nations Framework Convention on Climate Change (UNFCCC) that brings national bodies, international bodies and industry together to agree on the relevant food system footprints and coalesce the targets into scientifically informed reductions in those footprints[259]. This section reflects briefly on the question of whether the food system needs to set its own targets, or whether the food sector should look to proportional contribution to existing targets and where they might be compiled from.

The drafting and signing of The Paris Agreement within the UNFCCC set a physical target of 2 deg Celcius global average temperature with respect to mid-nineteenth century global average temperature. The temperature target is a proxy to avoid social costs of climate change that cannot be avoided by adaptation. Mitigation in the context of climate change is emissions reduction – footprint reduction. Adaptation in the context of climate change is avoidance of social costs but not through footprint reduction. Mitigation and adaptation together are aiming at impact reduction. Translating the temperature target is not straightforward. The Paris Agreement set the 2 deg target and a desire for a 1.5 deg target. Subsequent work by the climate science community after 2015 is the latest science on what emissions targets accord with 2 deg and 1.5 deg. There is large uncertainty because of modelling assumptions[260]. Bodies like UNEP, with the Emission Gap report, act to synthesis the scientific literature into a footprint reduction target, which is roughly a 100 Gt CO2eq reduction (16%) from a baseline business-as-usual scenario over 2020-2030 for the 2 deg target, and 200 Gt CO2eq (32%) for the 1.5 deg target, with further large reductions after 2030[261].

In many national emission reduction and trade schemes agriculture is currently excluded, or is delayed from being included, from carbon accounts[262]. It is unclear then what proportion of a 100 Gt CO2eq target should be assigned to food system impact reduction. Proportionally the food system should have a 21-37 Gt CO2eq reduction target based on current contribution to global emissions (21-37%), with 14-30 Gt CO2eq of that total the contribution of agriculture and associated land-use. Contextually, if associated land-use is to become a carbon sink to achieve 2 deg targets, the target by 2050 will be a 100% reduction (carbon neutral) for associated land-use and no growth in CH4 and NOx emissions from present day[263]. What the spatial and further contextual breakdown of this footprint should be is part of an agreement process, acknowledging the larger social and human wellbeing benefits from carbon production in developing countries.

Similar targets come from global nitrogen reduction initiatives, of which agriculture contributes a tremendous share of global N pollution (mineral fertilizer production alone accounts for 53%

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[259] p. 484: Willett et al., "Food in the Anthropocene: the EAT–Lancet Commission on healthy diets from sustainable food systems."

[260] R. J. Millar et al., "Emission budgets and pathways consistent with limiting warming to 1.5 °C," *Nature Geoscience* 10, no. 10 (2017), https://doi.org/10.1038/ngeo3031, https://doi.org/10.1038/ngeo3031.

[261] Figure ES.4: UNEP, *Emissions Gap Report 2019*.

[262] https://theconversation.com/why-agricultural-groups-fiercely-oppose-the-carbon-tax-110248 https://theconversation.com/nz-introduces-groundbreaking-zero-carbon-bill-including-targets-for-agricultural-methane-116724 https://www.simpsongrierson.com/articles/2019/major-developments-for-the-zero-carbon-and-emissions-trading-reform-bills

[263] Figure 2, p. 463: Willett et al., "Food in the Anthropocene: the EAT–Lancet Commission on healthy diets from sustainable food systems."

of the present total human creation of reactive nitrogen)[264]. The International Nitrogen Initiative supports a global goal to halve reactive nitrogen waste by 2030. If applied proportionally to food production and consumption losses, over 2020-2030 would equate to a reduction target of 1000 Tg N for the global food system compared to business as usual[265]. Like carbon, the spatial and contextual breakdown of nitrogen reduction is also varied when social and human wellbeing are considered. Some parts of the world are recommended to increase their nitrogen footprint for food security and development, and other parts to drastically reduce their nitrogen footprint[266].

The food system can inherent targets from existing global societal initiatives in carbon, nitrogen, and water. For impacts from pesticides it is the main contributor, and its contribution to obesity and other disease could potentially be extracted from national health targets where they exist. High level reports on the food system aim to synthesise societal initiatives such as the UN Sustainable Development Goals (SDGs), The Paris Agreement, and planetary boundaries, with food system transformation targets.

Target setting is a priority for food system transformation research. From the introduction of the “Food in the Anthropocene” report of the EAT–Lancet Commission on healthy diets from sustainable food systems:

> “The absence of scientific targets for achieving healthy diets from sustainable food systems has been hindering large-scale and coordinated efforts to transform the global food system. This Commission brings together 19 Commissioners and 18 coauthors from 16 countries in various fields of human health, agriculture, political sciences, and environmental sustainability to develop global scientific targets based on the best evidence available for healthy diets and sustainable food production. These global targets define a safe operating space for food systems that allow us to assess which diets and food production practices will help ensure that the UN Sustainable Development Goals (SDGs) and Paris Agreement are achieved.”[267]

The EAT–Lancet Commission report provides global targets for CO2-eq emissions, biodiversity loss, freshwater use, reactive nitrogen and soluble phosphorus leakage, and land-use change. It also provides a reference diet which equates to a global malnutrition footprint reduction target for food consumption categories[268].

The targets can be compared with present day amounts to understand footprint reduction targets by 2050 compared to present day footprint. Health and environmental targets are integrated together. The EAT–Lancet Commission report provides global targets and indicates the need to regionalise and contextualise footprint reduction targets according to impact through an agreement process.

The Eat-Lancet targets are not targets across all material issues generated by the food system. There are other approaches including inferring targets from physical boundaries such as land boundaries[269]. Even though targets can be set with reference to the SDGs, it is not

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[264] Liu et al., "Reducing human nitrogen use for food production."
[265] Liu et al., "Reducing human nitrogen use for food production."
[266] B. Z. Houlton et al., "A World of Cobenefits: Solving the Global Nitrogen Challenge," *Earth's Future* 7, no. 8 (2019), https://doi.org/10.1029/2019EF001222. C. Lu and H. Tian, "Global nitrogen and phosphorus fertilizer use for agriculture production in the past half century: Shifted hot spots and nutrient imbalance," *Earth System Science Data Discussions* 9, no. 1 (2016), https://doi.org/10.5194/essd-2016-35.
[267] p. 447: Willett et al., "Food in the Anthropocene: the EAT–Lancet Commission on healthy diets from sustainable food systems."
[268] p. 448: Willett et al., "Food in the Anthropocene: the EAT–Lancet Commission on healthy diets from sustainable food systems."
[269] H. H. E. van Zanten et al., "Defining a land boundary for sustainable livestock consumption," *Glob Chang Biol* 24, no. 9 (Sep 2018), https://doi.org/10.1111/gcb.14321.

clear that the food system can achieve them. While co-benefits exist between physical environmental footprints (carbon, nitrogen, land-use, water), trade-offs exist between social and environmental goals[270]. While pushing down one target, another may rise. In terms of most environmental factors and health, the EAT-Lancet Commission report demonstrates win-wins. Assuming the global diet targets are achieved, environmental footprint reduction targets and preventable death and disease reduction targets can be achieved together. While international agreements can cap physical emissions and extractions, there is large uncertainty in the achievement of dietary targets. Strategies, including many internalisations (soft approaches to demand change, fiscal incentives, and fiscal penalties), are recommended in the EAT–Lancet Commission report[271]. Work on food system impact valuation, in terms of the underlying basis for social and abatement costing, is part of the follow-on work to investigate the means to achieve food system transformation to the targets identified.

The FABLE Consortium also identified global footprint targets in their report “Pathways to Sustainable Land-Use and Food Systems”[272]. Consisting of health and environmental targets like the Eat-Lancet Commission report it covers malnutrition (zero hunger and a target for dietary related preventable death), CO2-eq emissions, biodiversity and ecosystem services, freshwater use, reactive nitrogen and soluble phosphorus leakage, and land-use change. Except for the phrasing of the malnutrition footprint (the FABLE report does not recommend a detailed reference diet to achieve the DALY reduction), the global footprint categories and 2050 target values are very similar to the EAT-Lancet Commission targets (some of the FABLE targets are for 2030).

The FABLE targets are global. The main feature of the FABLE report is to identify pathways to the targets in the 18 countries that are part of the consortium. The pathways give detailed context over time indicating how the targets can be achieved, ultimately to build consensus for food system transformation. The FABLE targets do not currently include social capital targets as discussed in the FABLE report. The FABLE targets concentrate presently on health, environment and economics. The FABLE pathways offer potential skeletons for subsequent development of abatement portfolios, demonstrating feasibility and considering co-benefits and trade-offs amongst the three dimensions of health, environment and economics. Potential costings of broad investment for the pathways and policies are taken up by the later FOLU report which we discuss on p. 137. The modelling in the FABLE report shows the criticality of Chinese demand trajectories on achieving dietary and environmental targets[273].

In summary, there is enough scientific work to inform food system impact or footprint targets. The gap is in the political and societal process and structures to enable that process to develop agreement. For social cost reduction impact, targets indicate what should be achieved and where. Impact targets guide impact reduction incentives for sustainable products and practices. Abatement costings provide direction for fiscal, policy and market incentives amenable to national accounting. With the global value chains of the food system, it would be very difficult to consistently account and apply incentives to sustainable food products and practices based on abatement costings without global agreed footprint targets broken down spatially and contextually with consideration of impact pathways.

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[270] Scherer et al., "Trade-offs between social and environmental Sustainable Development Goals." Chapter 7: IPCC, *IPCC Special Report on Climate Change, Desertification, Land Degradation, Sustainable Land Management, Food Security, and Greenhouse gas fluxes in Terrestrial Ecosystems*.
[271] Table 6, p. 478: Willett et al., "Food in the Anthropocene: the EAT–Lancet Commission on healthy diets from sustainable food systems."
[272] p. 14: FABLE, *Pathways to Sustainable Land-Use and Food Systems. 2019 Report of the FABLE Consortium.*
[273] p. 45: FABLE, *Pathways to Sustainable Land-Use and Food Systems. 2019 Report of the FABLE Consortium.*

Variability and uncertainty

This section summarises the variation and uncertainty that has been highlighted in the previous sections. Each stage of the valuation process in Figure 17 has variation and uncertainty and it compounds from footprint to valuation (Figure 25). The compounding uncertainty manifests as enormous variation and uncertainty for valuation factors (Figure 20). Valuation factors concentrate into one numerical value a large part of the valuation process.

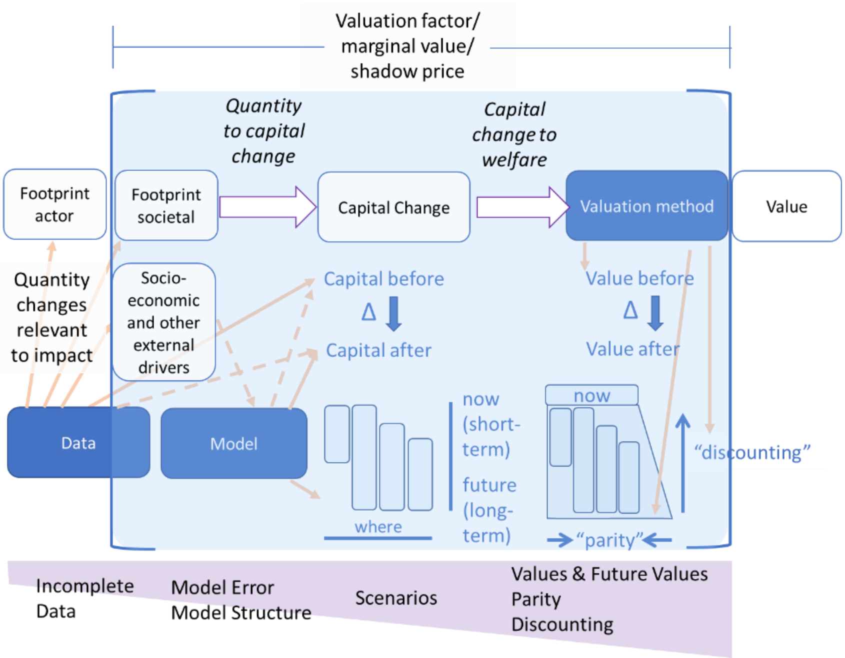

Figure 25: Compounding uncertainty along the valuation steps

The choices of data, models, scenarios, assumptions about including scarcity and interaction corrections, welfare measure, discount rate, and choice of parity, result in different valuations.

The data on the actor's footprint is often incomplete, either through lack of knowledge or lack of disclosure. Some footprint information is directly measured by the actor in their own operations or in their supply chain. Other actor footprint information, such as carbon emissions and nitrogen footprint, need the assistance of tools and third-party databases as discussed from p. 64. Variance exists across databases and different tools. The database and tools themselves have error bars relating to the footprint they are measuring. Lack of disclosure is a separate issue discussed below.

Calculating the societal emission footprint for carbon has large uncertainty by itself[274]. This is in addition to the uncertainty in what level of emissions relates to what level of warming, see footnote 260. Other societal footprint information is less monitored, with a range of estimates across literature. Approximating capital changes for the global, systemic, and long-term effects along impact pathways has inherent ambiguity and uncertainty from the use of models as discussed from p. 65 and p. 98. This results in modelling and modelling structure error[275]. In a

[274] M. Jonas et al., "Quantifying greenhouse gas emissions," *Mitigation and Adaptation Strategies for Global Change* 24, no. 6 (2019), https://doi.org/10.1007/s11027-019-09867-4. https://ghgprotocol.org/calculation-tools

[275] K. Beven, "On the concept of model structural error," *Water Sci Technol* 52, no. 6 (2005); Stern, "The Structure of Economic Modeling of the Potential Impacts of Climate Change: Grafting Gross Underestimation of Risk onto Already Narrow Science Models."; M. G. Morgan and M. Henrion, *Uncertainty: a guide to dealing with uncertainty in quantiative risk and policy analysis* (Cambridge, UK: Cambridge University Press, 1990); R. Knutti, "Should we believe model predictions of climate change,"

practical sense, using a range of different models provides an estimate for modelling structure error. Four models were used for the US IWGSCC estimates of the social cost of carbon[276] discussed from p. 51.

Long-term external drivers lead to a range of possible future impacts. Short-term uncertainty where responses are unknown also leads to a range of potential impacts. For example, responses of the economy to large production and consumption changes[277]. The uncertainty due to scenarios was discussed on p. 84.

The variation from choices and the uncertainty within those choices ascends from footprint to attribution of capital changes to valuation. Choices in welfare, discounting and parity were all shown to create significant uncertainty as discussed from p. 68 and p. 86. For social costs of carbon the combined tail variation toward higher values from discounting and parity can be several orders of magnitude. This variation is on top of that from footprint and modelling. Ambiguity in mixing social and abatement costs also creates error bars in valuations.

Within choosing a valuation factor there is an implicit choice of economic model and environmental, or social, or health models. Implicit choices of data relevant to other business and other sector footprints. Implicit choices of scenarios, values, discounting rate, and targets. Consideration in the choices spans food system theory, economic theory and their interface. The number of permutations in all the choices is the significant. A valuation factor represents a highly uncertain number.

What does a valuation factor look like when treated as an uncertain number? Figure 14 on p. 53 shows the social costs of carbon emission as a distribution of numerical values. Figure 14 is interpreted by the possible numerical values on the x-axis, and how likely that the social cost of carbon is that numerical value on the y-axis. This is the distribution of the social cost of carbon treated as an uncertain number. The (right-sided) tail of the distribution is the shape of the distribution as it moves to the right along the x-axis toward increasingly higher monetary values for the social cost of carbon. As the possible monetary values for the social cost of carbon get larger, the chance that such a large value will be realised as the cost incurred by society into the future gets less. The shape of the tail is always decreasing toward zero (under the assumptions from p. 40). Larger values get less likely. The rate at which the tail decreases toward zero is critical for understanding the risk posed to society by the possibility of larger than expected values. The rate at which the tail decreases as the uncertain cost gets larger is called the “fatness” of the tail.

The discussion and references from p. 51 evidence that the ascending uncertainty described above does accumulate in valuation factors in practice. The references in footnote 102 describe how the distribution for the social cost of carbon in Figure 14 is likely a sub-sample of the uncertainty, and the spread of estimates is conceivably larger. The marginal abatement costs of carbon are also uncertain numbers because it is unknown whether abatement measures will be adopted to the degree assumed in a marginal abatement curve. Even if adopted, whether they will achieve the given level of abatement at that abatement price.

Philosophical Transactions: Mathematical, Phsyical and Engineering Sciences 366, no. 1855 (2008); D. A. Stainforth et al., "Confidence, uncertainty and decision-support relevance in climate predictions," *Phil. Trans. R. Soc. A* 365 (2007); L. A. Cox, Jr, "Confronting Deep Uncertainties in Risk Analysis," *Risk Analysis* 32, no. 10 (2012).

[276] Dietz, "The Treatment of Risk and Uncertainty in the US Social Cost of Carbon for Regulatory Impact Analysis."

[277] S. Wynes et al., "Measuring what works: quantifying greenhouse gas emission reductions of behavioural interventions to reduce driving, meat consumption, and household energy use," *Environmental Research Letters* 13, no. 11 (2018), https://doi.org/10.1088/1748-9326/aae5d7. F. Brunner et al., "Carbon Label at a University Restaurant – Label Implementation and Evaluation," *Ecological Economics* 146 (2018), https://doi.org/https://doi.org/10.1016/j.ecolecon.2017.12.012.

Discount uncertainties are still present in abatement costing since the uncertainty in achieving optimal social and human welfare is pushed into the footprint reduction target.

The marginal social and abatement costs of carbon are not unique in being uncertain. The debate on valuation given large uncertainty is also not unique to carbon. Literature evidences a spread of nitrogen pricing estimates[278], a spread of ecosystem service pricing estimates[279], a spread of health valuation estimates[280], etc.

Inherently, costing non-financial food system impacts involves not only society eventually absorbing the damages or paying to avert them, but taking on risk because of the uncertainty in what those damages or payments will turn out to be. The risk is being transferred from business activity to society. Business get a certain outcome in terms of financial value from the production creating the footprint and society gains uncertainty in the damages or payments associated to that production in return. The countering risk is that society will lose welfare enabled by production if it reduces footprints. However, with present major food impact costs it is strongly expected that, like the distribution for the social cost of carbon in Figure 14, the uncertainty is skewed to the right-side, that is toward higher marginal costs from incurring footprint rather than marginal benefits.

We view non-financial valuation as inherently uncertainty, and take the position that it is more efficient to accept the uncertainty and cost it in, in practice and in theory, rather than make non-financial valuation like financial valuation where centralisation from many transactions in known exchange markets reduces the variation to practically zero. Even in financial capital where there are few transactions, valuations price in risk. Pricing in risk will involve adding a risk premium to the central values. In the presence of skewed distributions to the right (the greater weight of uncertainty is toward higher estimates of the social or abatement costs) this means the risk premium will increase the food impact costing. This also has the effect of making sustainable food products and practices more valuable as abatement measures. More valuable in terms in the reduction of damages (marginal abatement value) and in their cost-effectiveness in abating footprint (marginal abatement costing).

The UN 2018 Inclusive Wealth report, p. 107 comments:

> "The major challenge, however, is to estimate the shadow prices of the natural and ecosystem capital assets. For example, we do not have full knowledge of the production functions of life-supporting systems. Dasgupta and Duraiappah (2012) recognize that we may never get the shadow prices "right", instead we can simply try to estimate the range in which they lie."[281]

Can the uncertainty be reduced?

It is unclear at present where the major sensitivities lie for practical estimation of error bars. Variation does exist across different LCA databases in determining actor footprint, but is it a

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[278] van Grinsven et al., "Costs and Benefits of Nitrogen for Europe and Implications for Mitigation." L. Jones et al., "A review and application of the evidence for nitrogen impacts on ecosystem services," *Ecosystem Services* 7 (2014), https://doi.org/https://doi.org/10.1016/j.ecoser.2013.09.001.

[279] de Groot et al., "Global estimates of the value of ecosystems and their services in monetary units." P. Hamel and B. P. Bryant, "Uncertainty assessment in ecosystem services analyses: Seven challenges and practical responses," *Ecosystem Services* 24 (2017), https://doi.org/https://doi.org/10.1016/j.ecoser.2016.12.008. K. A. Johnson et al., "Uncertainty in ecosystem services valuation and implications for assessing land use tradeoffs: An agricultural case study in the Minnesota River Basin," *Ecological Economics* 79 (2012), https://doi.org/https://doi.org/10.1016/j.ecolecon.2012.04.020.

[280] Neumann et al., "A Systematic Review of Cost-Effectiveness Studies Reporting Cost-per-DALY Averted."

[281] p. 107: UNEP, *Inclusive wealth report 2018 : measuring progress towards sustainability*. Dasgupta and Duraiappah, "Well-being and wealth."

major contribution to the variance of the impact valuation? Similarly, outside of the lock-in effects of carbon, more research is required on the timeframe of food system impacts. Obesity effects are intergenerational, and they are major sources of impact from food systems, but how large is the intergenerational effect into the future, is it significant enough to increase the sensitivity of the final impact valuation to discount rate?

A feature of our recommendation for food impact costing, summarised from p. **Error! Bookmark not defined.**, is that marginal social and abatement costs need to be regularly updated. This updating affects the uncertainty as well. Over time the epistemological uncertainty will decrease, and more information is revealed. However, there are core of ethical choices described on p. 86 which cannot be removed. We view the uncertainty as unavoidable.

Estimating uncertainty and pricing risk makes determining valuation factors and impact valuations harder. Below we outline a simple technical approach to risk pricing attached to the linear model described from p. 101. The approach would make it no more difficult for business and society to calculate risk pricing. It would be simple to implement in software packages. It relies though on the distributions of individual shadow prices and their correlations being determined and agreed through a societal process. The latter is where the burden in risk pricing would rest.

Users can choose to ignore the uncertainty. The implicit nature of the choices behind valuation factors makes impact valuations done by different users who make their own, or pull them from different sources of literature, very difficult to compare and in some cases difficult to validate. The case studies from p. 128 evidence the variation in shadow prices used and in choices of footprint. Even if choices were interoperable, and different parameters for discounting, parity, and even different models could be substituted in and out of calculations so that two impact valuations could be compared on the same set of choices, there is still inherent and large uncertainty in many of the models. Insurance industry standards such as Solvency II increasingly require portfolios to be tested against multiple models. The catastrophe risk modelling community has responded[282]. It is a large effort to make "plug-and-play" integrated modelling platforms in this way. It is argued from p. 164 that an estimation of the uncertainty in shadow prices by scientific consensus across modelling studies would be a faster route to agreement and use than a user themselves having the capability to substitute different models of ecosystem damages, etc.

The uncertainty embedded in different models is inherently a representation of human lack of knowledge (Table 3). Many authors distinguish between stochastic or aleatory uncertainty (random processes), epistemological uncertainty (lack of knowledge) and ambiguity[283]. Decision making under these different types of risk is a developed area[284]. Pricing risk is a

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282 https://oasislmf.org/ P. McSharry, "Chapter 12 - Parsimonious Risk Assessment and the Role of Transparent Diverse Models," in *Risk Modeling for Hazards and Disasters*, ed. G. Michel (Elsevier, 2018). K. R. Royse et al., "The application of componentised modelling techniques to catastrophe model generation," *Environmental Modelling & Software* 61 (2014), https://doi.org/https://doi.org/10.1016/j.envsoft.2014.07.005.

283 Pate-Cornell, "The Engineering Risk Analysis Method and Some Applications." D. Ellsberg, "Risk, Ambiguity, and the Savage Axioms," *The Quarterly Journal of Economics* 75, no. 4 (1961), https://doi.org/10.2307/1884324.

284 Cox, "Confronting Deep Uncertainties in Risk Analysis." G. Loomes and R. Sugden, "Regret theory: An alternative theory of rational choice under uncertainty," *Economic Journal* 92, no. 4 (1982). R. J. Lempert and M. T. Collins, "Managing the risk of uncertain threshold response: comparison of robust, optimum, and precautionary approaches," *Risk Analysis* 27, no. 4 (2007). J. Rosenhead, "Robustness Analysis: Keeping your options open," in *Rational Analysis for a Problematic World Revisited: Problem Structuring Methods for Complexity, Uncertainty, and Conflict*, ed. J. Rosenhead and J. Mingers (Chichester, UK: Wiley, 2001).

form of decision making – it favours some options over others because the uncertainty is reflected in additional cost which is least preferred. We remain pragmatic and use probability theory to represent uncertainty despite other conceivable risk pricing mechanisms[285].

Table 3: The uncertainties mentioned for valuation factors involve different categories and degrees of uncertainty identified in the study of decision-making under uncertainty.

Degree	Data	Model
Almost certain	Observation	
Mild uncertainty (observed stable random processes) (established knowledge) (low ambiguity)	Interpolated, extrapolated, proxy	Well established models of physical processes. Predictable demographic trends. Statistical models of stable processes with sufficient data on populations
Deep uncertainty (rarely observed or non-stable random processes) (lack of knowledge) (ambiguity)		Integrated models. Speculative socio-economic drivers. Statistical models of non-stable processes, or with insufficient data, or applied to subpopulations. Bayesian modelling. Robust criteria.

Pragmatic spatial and temporal resolution for impacts were advocated on p. 78 and p. 101. There is a large amount of variance in marginal social and abatement costs at smaller resolutions than those advocated. Individuals projects may collect data on the ground to assess costs at this small resolution. As stated previously, this report focusses on larger scale assessment for first order corrections of economic activity toward global footprint reduction. The conclusion that greater spatial, temporal and contextual resolution implies greater certainty needs strong caveats. For example, benefit transfer of valuations create the impression of spatial resolution but are likely increasing uncertainty[286]. Benefit transfer might help estimate mean changes but should be treated as increasing the error bars around that mean.

There is a final argument for removing the uncertainty in valuation factors that we discuss again on p. 153. It is the argument that the central value of the distribution of valuation estimates can be taken (the average value). The argument is that, because there are many individual point sources of pollutants and many individual receivers of doses from those pollutants, the effects could be treated as independent. So, at aggregated scales, by the

[285] E. T. Jaynes and G. L. Bretthorst, *Probability theory: the logic of science* (Cambridge: Cambridge University Press, 2003). R. J. Lempert, M. E. Schlesinger, and S. C. Bankes, "When we don't know the costs or the benefits: Adaptive strategies for abating climate change," *Climatic Change* 33 (1996). J. W. Hall et al., "Robust climate policies under uncertainty: a comparison of robust decision making and info-gap methods," *Risk Analysis* 32 (2012). Kriegler et al., "Imprecise probability assessment of tipping points in the climate system."

[286] Schmidt, Manceur, and Seppelt, "Uncertainty of Monetary Valued Ecosystem Services – Value Transfer Functions for Global Mapping." COWI, *Assessment of potentials and limitations in valuation of externalities*.

central limit theorem the variation averages out and the central value of a valuation factor can be used. This is a very strong assumption on impact pathways. To apply it *carte blanche* to valuation, assumes, at the least, no co-dependency of the individual receivers on variation in discount rates and socio-economic drivers – which have been observed to dominate the uncertainty in some marginal value estimates. The centralisation also removes the risk premium. The centralisation assumption may apply to some food system impact pathways, but we reject it without greater evidence. It does not apply to climate change. Arguments on correlations on p. 23 and below make it unclear where it would apply without further evidence.

The next section is technical. It briefly describes implementing risk pricing practically in the linear model of valuation described in equation (5) on p. 104. To summarise the implications of risk pricing without technical details:

- The uncertainty has three main components, uncertainty in valuation conditional on attribution of capital change, uncertainty in attribution of capital change conditional on footprint, and the uncertainty in footprint. The uncertainty in the first two components is measured by, or in the control of, the societal process for setting marginal social or abatement costs associated to footprints. The uncertainty in footprint is measured by, or in the control of, business.
- One way to incorporate the uncertainty an impact valuation into a single value is with a risk premium.
- The risk premium is how much society should "charge" to take on the uncertainty in impact associated to the footprint produced by a product, practice, or company.
- The premium is a further chance for credibility and agreement in impact valuation – if set in collaboration with civil society and government who are the bearers, or represent the bearers, of risk.
- Businesses in the same sector have the same playing field if marginal social or abatement costs and their uncertainty were agreed. This incentivises the sector to invest in the societal process for better information about impacts and valuation to reduce the uncertainty and so reduce the risk premium.
- Businesses in the same sector can compete on impact reduction and on disclosure (more information about footprint reduces the uncertainty in footprint, which through the pricing mechanism, reduces the premium on the valuation for that company).
- It is more efficient to communicate uncertainty quantitatively in the distribution of valuations.
- Same conceptual pricing mechanism for internalising the uncertainty and variation if they are pushed into valuation instead of scope.
- Makes the valuation of less studied localised impacts, known to have large error bars, more credible as issues in methods such as benefit transfer are acknowledged in the distribution and become part of the pricing.
- The uncertainty is highly likely to be right-skewed (Figure 14), meaning a greater chance of higher costs. The risk premium will then be a positive amount added on to the expected impact cost.
- Care must be taken in consideration of the aggregated premium. There are correlated chances of above or below expected impact. If environmental damage such as that from climate change is high, then social damage and health damage is likely to be exacerbated or social benefits or not as likely to be as great. The risk premium is not applied to shadow prices individually and risk premiums do not add. In short, the risk premium on total impact of ten products may be more than ten times the risk premium attached to each product.
- Assumptions valid for market exchange value about centralising prices are unlikely to hold. Impact must be valued differently from expected and central limit theorem

assumption on normal financial markets. Uncertainty in impact costing is likely to exhibit a long tail from coincident and correlated impact– tipping points, coincidence of social and environmental damage (e.g. greatest impacts from climate changed expected in the tropical zones, which are least developed, energy-water and food couplings, livelihood and resource changes)[287].

- Risk premiums are likely to be dominated by uncertainty and correlations between the greatest impacts, e.g. carbon and health. Major non-market costs that pose significant joint risk to global welfare. Lesser considerations should be absorbed into standard errors. Research is required to: understand the lock-in generational effects from other footprints associated to major impact besides CO2-eq emissions; local effects occurring simultaneously globally (especially by the same physical or social mechanism); develop further quantitative estimates of synergies and trade-offs between the impacts created by food's multiple footprints as initiated in the 2019 IPCC report[288].
- Summing uncertain benefits and costs, even if they have the same expected benefit or expected cost, does not cancel the uncertainty out. Substitution of economic value is a consideration in summing uncertain benefits and costs.

Linear model with risk pricing

Figure 20 provides a conceptual conditional sequence of random variables on which to build a simple approach to risk pricing. Uncertainty methods exist for actor footprint calculation, e.g. uncertainty in lifecycle assessment[289]. There will uncertainty in the footprint associated to an actor denoted by the random variable

$$footprint(actor).$$

Given a certain footprint of one unit, denote the uncertain marginal valuation by

$$valuation \mid footprint.$$

Approximate the uncertain valuation of the actor by the product of the random variables

$$valuation(actor) = (valuation \mid footprint) \times footprint(actor).$$

A similar sequence can be used to express the linear model in footnote 248 which has explicit shadow prices of capital changes[290]. This product model assumes that the footprint random variable and the marginal valuation random variable are independent. What this means is that

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[287] Weitzman, "On Modeling and Interpreting the Economics of Catastrophic Climate Change."; Weitzman, "Fat-tailed uncertainty in the economics of catastrophic climate change."

[288] IPCC, *IPCC Special Report on Climate Change, Desertification, Land Degradation, Sustainable Land Management, Food Security, and Greenhouse gas fluxes in Terrestrial Ecosystems*.

[289] S. M. Lloyd and R. Ries, "Characterizing, Propagating, and Analyzing Uncertainty in Life-Cycle Assessment: A Survey of Quantitative Approaches," *Journal of Industrial Ecology* 11, no. 1 (2007), https://doi.org/10.1162/jiec.2007.1136. R. Heijungs and M. Lenzen, "Error propagation methods for LCA—a comparison," *The International Journal of Life Cycle Assessment* 19, no. 7 (2014), https://doi.org/10.1007/s11367-014-0751-0. R. Heijungs and M. Huijbregts, "A Review of Approaches to Treat Uncertainty in LCA," *Complexity and Integrated Resources Management*.

[290] Figure 17 provides the following conceptual conditional sequence. There will uncertainty in the footprint associated to an actor, denote the vector of random variables

$$footprint(actor).$$

Given a footprint of one unit, denote the uncertainty in the attributable capital changes by

$$capital\ change \mid footprint.$$

Given a capital change of one unit, denote the uncertainty in the valuation of the capital changes by

$$valuation \mid capital\ change.$$

Approximate the uncertainty in the valuation of the actor by the product of the random variables

$$(valuation \mid capital\ change) \times (capital\ change \mid footprint) \times footprint(actor).$$

when a footprint is observed, none of the marginal valuation numbers are observed to occur more frequently than others. It is unclear if this would be strictly observed. Likely those actors that are less willing to report, or less able to measure their footprint accurately, are associated to impacts that are higher than average, or less well known and likely underestimated. However, the major variance in shadow prices observed in practice are economic parameters weakly influence by individual actors. That footprint due to actor and shadow prices are treated as independent random variables simplifies a basic risk model.

Previous studies of impact valuation have noted that the uncertainty in the valuation can be approximated by a product of the uncertainty in footprint and the uncertainty in marginal valuation[291].

In the matrix model in equation (5) we used undiscounted national economic value in a time period into the future, and then applied a vector T of discounting and parity weights to turn the undiscounted national economic value into present comparable value and add them together to obtain the valuation. We also broke apart the footprint into spatial and contextual footprints.

We adjust the specification. Denote the uncertain footprint within a specific spatial boundary and context (corresponding to the index n) as a random variable

$$footprint_n(actor).$$

Given a certain footprint of one unit within a specific spatial boundary and context, denote the uncertain undiscounted national marginal valuation (corresponding to the index m) by

$$valuation_m \mid footprint_n.$$

Given a certain change in national economic value of one unit in a future time period, denote the uncertain discount rate or parity weight to compare national economies in present value by

$$present\ parity \mid valuation_m.$$

Multiplying these three random variables approximates the uncertainty in one of the terms in the sum represented by equation (5)

$$valuation_{m,n}(actor) = present\ parity \mid valuation_m$$
$$\times (valuation_m \mid footprint_n) \times footprint_n(actor)$$

We argue again that we should treat the uncertainty in discounting and parity as independent of the economic change in a national economy in a future time period due to the lock-in impacts of the footprint occurred by an actor now. This is not strictly going to be observed, but the discounting term will depend on growth up until the future time period and depend little on the future time period itself. For parity, we also assume that the economic effects of the actor are small enough that global distribution of wealth is dependent more on societal footprint and other exogenous assumptions.

We interpret the matrix model in equation (5) now in terms of the algebra of random variables. The Jacobian matrix of shadow prices is now a matrix of random variables reflected uncertain shadow prices

[291] COWI, *Assessment of potentials and limitations in valuation of externalities*. The comment of the reference p. 30, Section 4.3 about the uncertainty “Assuming that the assessment of the impact [footprint] and the assessment of the unit values [marginal valuation] are independent the overall level of uncertainty will be more or less similar to the most uncertain component…” is a little mystifying. The standard deviation of the product of two independent random variables is dominated below by the product of standard deviations. Therefore, the uncertainties in marginal valuation and footprint multiply and orders of magnitude add.

$$J_V = [J_V]_{m,n} = [valuation_m \mid footprint_n]_{m,n} .$$

We argued above that this matrix of random variables should not be replaced by the expected values of its terms, but that the shadow prices should be kept as random variables. A scientific process collating literature can estimate distributions for the uncertain shadow prices. Many of the literature studies indicate errors to valuations as well as central values. Using these error estimates or performing additional simplified error estimation, log-normal or similar right skewed distributions can be used to simplify the representation of shadow prices as random variables[292]. The vector of random variables representing uncertain footprint produced by the actor is

$$\hat{f} - f = \left[\hat{f}_n - f_n\right]_{n,1} = [footprint_n(actor)]_{n,1}.$$

The vector of random variables representing uncertainty or variation in discounting rate and parity

$$T = [T_m]_{1,m} = [present\ parity \mid valuation_m]_{1,m}.$$

How do we interpret the approximation to the impact valuation given by equation (5) when there is uncertainty in discount rate, parity, shadow prices, and footprint measurement,

$$V(\hat{f}) - V(f) \approx T\, J_V\, (\hat{f} - f) = \textstyle\sum_{m,n} valuation_{m,n}(actor) \qquad (6)$$

The assumptions above calculate $valuation_{m,n}(actor)$ as the product of three random variables assumed to be independent. This product can be standardised. For example, not much additional uncertainty is introduced into a log-normal approximation of this product if footprint uncertainty is standardised to uniform distributions over ranges. There are ways that these random variables can be calculated efficiently, assuming the matrices of random variables J_V and T were given with a simplified and standard form for specifying the uncertainty in footprint. The most important aspect we want to sketch is adding the random variables $valuation_{m,n}(actor)$ across the indices n and m. We *do not* assume that the random variables $valuation_{m,n}(actor)$ are independent.

For serious effects of global impact from the food system, we argue that there will be positive correlations that increase the uncertainty in the impact valuation estimate in (6). The correlations create additional risk. First, it is not entirely clear that discounting and parity terms over time should be treated as independent, general time series analysis of periods of low or high growth indicate autocorrelation. If global inequality is worse than expected, it is more likely to be that way in the next time period rather than a not infeasible, but less likely, global structural break. It is also not clear the impact across nations should be treated independent for global material issues for society. If impact is worse than expected from climate change in one country and at one time period, it will more than likely be worse than expected for other countries and neighbouring time periods. The same is likely to apply where we have underestimated the physical impacts of underlying biophysical and chemical processes. Those processes will largely cause shifts in impact in the same direction wherever they occur spatially. While it is less clear that footprints in different contexts such as environmental footprints and dietary footprints will have a correlated impact, it is to be suspected that worse than expected impacts from emissions will correlate in worse than expected health outcomes

[292] E. L. Crow and K. Shimizu, *Lognormal distributions : theory and applications*, Statistics, textbooks and monographs, (New York: M. Dekker, 1988).

(potentially due to auxiliary worsening of general public health in some countries from tropical diseases, desertification, heat stress, which amplifies dietary health impacts)[293].

There are effective analytic formulas for summing log-normal random variables with assumed covariance and estimating their statistics. As a simple example, assume the risk premium to be added onto the expected value

$$E\left(T\,J_V\,(\hat{f}-f)\right)$$

is the right side standard deviation

$$\sigma_+\left(T\,J_V\,(\hat{f}-f)\right).$$

The model described above, provided the matrices J_V and T were given, and provided two $m \times m$ and one $n \times n$ correlation matrix describing the correlations between discount and parity factors, between national impact within and between time periods, and between impacts from different footprints were given, could calculate a risk adjusted food impact costing

$$(E+\sigma_+)\left(T\,J_V\,(\hat{f}-f)\right) \qquad (7)$$

given the footprint $\hat{f}-f$. The risk premium is calculated for each actor depending only on their footprint $\hat{f}-f$. The terms T, J_V with correlations and the choice of the risk measure, which we chose as $E+\sigma_+$ as an illustration, should be determined by society as the risk bearer. That is, how much society is going to "charge" to take on the risk associated to the footprint $\hat{f}-f$.

Even though equation (5) is a linear model in actor footprint, meaning that the sum of the impact valuations is equal to the impact valuations of the sum of the footprints, the risk adjusted impact valuation (7) is not linear in actor footprint. Statistics of sums of correlated random variables are generally not linear. The risk adjusted impact valuation of the sum of two actor footprints may be higher than the sum of the risk adjusted impact valuations associated to each footprint individually.

The purpose of this section was to sketch technical details of an approach to standardising risk pricing for impact valuation. The technical difficulty and modelling choices for computational efficiency rest with the standardisation of shadow prices. Users of valuations from this method of risk pricing will not be working with distributions of shadow prices. Calculation involving distributions and correlations occurs "back-end" in software or calculation tools. The user obtains from the method a single numerical value (the output of equation (7)), which is the risk adjusted impact valuation. Food system actors provide their footprint in the form required by the user, which may require them to specify uncertainty in calculation of footprint.

Carbon footprint protocols provide advice on reporting uncertainty in carbon footprint[294]. Estimates of uncertainty in carbon footprints from common methods such as LCA have been studied[295]. Discussions of uncertainty in footprint measurement can be found for most other

[293] A. J. McMichael, R. E. Woodruff, and S. Hales, "Climate change and human health: present and future risks," *The Lancet* 367, no. 9513 (2006), https://doi.org/10.1016/S0140-6736(06)68079-3. IPCC, *Climate Change 2014 – Impacts, Adaptation and Vulnerability: Part A: Global and Sectoral Aspects: Volume 1, Global and Sectoral Aspects: Working Group II Contribution to the IPCC Fifth Assessment Report* (Cambridge, UK: Cambridge University Press, 2014).
[294] https://ghgprotocol.org/calculation-tools
[295] P. J. G. Henriksson et al., "Product Carbon Footprints and Their Uncertainties in Comparative Decision Contexts," *PLOS ONE* 10, no. 3 (2015), https://doi.org/10.1371/journal.pone.0121221.

environmental footprints of concern for food impact costing[296]. Without more research on the uncertainty in footprint estimation, it is unclear whether it is a major component of risk premiums.

A simple but direct use of the risk premium is to incentivise disclosure of footprints. Non-disclosure pushes risk onto society in the form of an inability to cost food system impacts and enable economic correction.

The user of a valuation can input the numerical value of disclosed actor footprints. The user can pre-assign a distribution to represent undisclosed footprints. This could be a uniform distribution associated to products in the same category. This represents not knowing what the footprint is, but assuming it sits somewhere in the range already observed for the activities whose impact is being valued. The user could apply the maximal entropy distribution given only the average footprint observed for that product or activity[297]. This represents not knowing what the footprint is given only the observed average for the industry. If the user wanted to penalise non-disclosure, they could condition either of these distributions on the maximum footprint observed. Conditioning the maximal entropy distribution associated to non-disclosure on the maximum observed, associates to the undisclosed footprint the maximum footprint observed for that activity, and uncertainty whether the non-disclosing actor's footprint is actually above the maximum (which may be why they choose not to disclose it). The conditioned maximum distribution would add a risk premium above the impact valuation associated to the maximum footprint. A higher value for the impact valuation could mean less incentives, failure to meet regulation, or more fiscal penalties. The consequences of the additional risk premium for non-disclosure compared to disclosure would act as an incentive to disclose. It could also incentivise companies moving through stages of better measurement of their footprint. Disclosure reduces the uncertainty in footprint, which through the pricing mechanism, reduces the risk price.

It does not matter for the method described whether footprint is disclosed in some dimensions e.g. carbon, and footprint not disclosed in others, e.g. nitrogen. The risk pricing method can compute a risk adjusted impact valuation with a mixture of disclosure and non-disclosure in footprints.

The model sketched approximates the compounding of uncertainties in Figure 25 by products and sums of random variables. We briefly discuss computation efficiency. The Jacobian of shadow prices from the linear model on p. 104 is replaced by a Jacobian of random variables representing uncertain shadow prices. The model we described on p. 104 might have n and m of the order of 1000. The Jacobian is a relatively sparse matrix for the reasons discussed on p. 104, but there are still many non-zero entries. Given the unavoidable uncertainty in shadow prices, the consideration of uncertainty should be performed, even in a simple way utilising log-normal approximation, within any process to establish shadow prices. That is, if society was going to invest in food impact costing, we have argued for the resolution required,

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[296] E. Solazzo et al., "Evaluation and uncertainty estimation of the impact of air quality modelling on crop yields and premature deaths using a multi-model ensemble," *Science of The Total Environment* 633 (2018), https://doi.org/https://doi.org/10.1016/j.scitotenv.2018.03.317; P. Holnicki and Z. Nahorski, "Emission Data Uncertainty in Urban Air Quality Modeling—Case Study," *Environmental Modeling & Assessment* 20, no. 6 (2015), https://doi.org/10.1007/s10666-015-9445-7; T. P. Tomich et al., "Food and agricultural innovation pathways for prosperity," *Agricultural Systems* 172 (2019), https://doi.org/https://doi.org/10.1016/j.agsy.2018.01.002; E. A. Davidson and D. Kanter, "Inventories and scenarios of nitrous oxide emissions," *Environmental Research Letters* 9, no. 10 (2014), https://doi.org/10.1088/1748-9326/9/10/105012.
[297] S. Guiasu and A. Shenitzer, "The principle of maximum entropy," *The Mathematical Intelligencer* 7, no. 1 (1985).

and the effort to generate and consider the Jacobian of shadow prices as simplified random variables is a small add to the effort to formulate a Jacobian of best guess single prices.

The correlation matrices, which are important, are new for the risk pricing approach. A pragmatic approach to correlation in the first instance would feature sparse correlation matrices, rough estimates, and concentration on correlation between the largest shadow prices. Analytic approximations to stochastic algebra are favoured over Monte Carlo simulation at this stage. Most users that want to substitute in footprints to compare them may not be able to simulate or implement “back-ends” that can perform the Monte Carlo simulation. Risk premiums based on other statistics such as the finance industry standard VaR would likely require importance sampling to gain additional confidence and computational efficiency[298].

The number of summands in equation (6) is very large. Without correlation the distribution of the impact valuation as a random variable (the total of the summands on the left-hand side of equation (6)) would certainly tend to a normal shape with a potentially very small standard deviation compared to the expected value (a negligible risk premium). This would be an artefact of the modelling. Arbitrary choices, such as increasing the resolution from national down to subnational, would introduce more terms in the summand and the tendency to normality is strengthened further. This is only valid under increased decoupling of variance in impact at lower resolutions. We reject the position that environmental prices centralise for the type of global issues of concern in food system impact valuation. Correlation of global and national activities means that it is likely that correlation will feature in the summation, leading to a retention of right-skew and non-trivial risk premium for the total of the summands.

We have not discussed substitution in the Jacobian of shadow prices. That is, when some shadow prices have probabilities of negative values (marginal social benefits or negative marginal abatement cost) and are being added to shadow prices with probabilities of positive values. Statistics of equity in implicit exchange of a gain in economic value for one party for a loss of economic value for another party will be discussed on p. **Error! Bookmark not defined.**. Uncertainty in substitutability is an additional consideration which would increase the risk premium in an impact valuation[299].

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[298] S. T. Tokdar and R. E. Kass, "Importance sampling: a review," *WIREs Computational Statistics* 2, no. 1 (2010), https://doi.org/10.1002/wics.56. P. J. Smith, M. Shafi, and G. Hongsheng, "Quick simulation: a review of importance sampling techniques in communications systems," *IEEE Journal on Selected Areas in Communications* 15, no. 4 (1997), https://doi.org/10.1109/49.585771.

[299] Gollier, "Valuation of natural capital under uncertain substitutability."

CASE STUDIES SUMMARY

Nine monetary impact valuation studies conducted by the public and private sector show the variation in practice in footprint, models and data, and valuation methodology. Precedent for pricing uncertainty are also found.

Overall, the case studies show that impact valuation can highlight the social costs that are not considered in the market.

Global, project and product valuation 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. It is found that 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.

It is found case study valuations are not directly comparable. 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 choice of footprint. Different valuation factors are used. Even though confidence intervals on quantity calculations and marginal valuation are estimated in literature sources 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 more 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 scenarios attached to 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 become 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.

CASE STUDIES

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[300].

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 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 those 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.

[300] SDSN and BCFN, *Fixing the business of food: the food industry and the SDG challenge*.

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)[301]. 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.

[301] FAO, *Food wastage footprint: full-cost accounting*.

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 used 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[302]. 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[303]. 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.

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

[302] W. Baltussen et al., *Valuation of livestock eco-agri-food systems: poultry, beef and dairy.*, Wageningen University & Research, Trucost & True Price (Wageningen, 2017).
[303] Details of data and model in TruCost, *Top-down methodology TEEB Animal Husbandry*.

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 303. 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 (Figure 14).

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[304]. 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).

[304] Pfister, Koehler, and Hellweg, "Assessing the Environmental Impacts of Freshwater Consumption in LCA."

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[305]. 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 for simpler calculations than the previous two global case studies. 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.

[305] FOLU, *Growing Better: Ten Critical Transitions to Transform Food and Land Use, The Global Consultation Report of the Food and Land Use Coalition.*

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[306].

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, as acknowledged, used no spatial and contextual marginal costs and quantities. It had no estimate of uncertainty.

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[306] 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 through 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 p. 98 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 on p. **Error! Bookmark not defined.**. 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 enters into the uncertainty in quantity and then uncertainty in the full valuation and so captured in risk pricing, as long as there is the ability to map the quantity calculations to those set by the accounting framework or set by the use.

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[307]. There are data sources for input-output with higher resolution than economic sectors[308].

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[309]. 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 average value, which is valid for statistically frequent events with, individually, small global economic consequences (insurance of automobile accidents for example), is inappropriate[310].

307 COWI, *Assessment of potentials and limitations in valuation of externalities*.
308 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.
309 van den Bergh and Botzen, "A lower bound to the social cost of CO2 emissions."; Pindyck, "The social cost of carbon revisited."; 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; Tol, "On the Uncertainty About the Total Economic Impact of Climate Change." CPLC, *Report of the High-Level Commission on Carbon Prices*.
310 Chapter 6, Y. Y. Haimes, *Risk Modelling, Assessment, and Management*, 2nd ed. (Chichester, UK: Wiley, 2004). Dietz, "The Treatment of Risk and Uncertainty in the US Social Cost of Carbon for Regulatory Impact Analysis."

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

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 non-compensatory transfers. To test equity concerns, comparable valuations would have the capacity to substitute alternate 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, so 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 from p. 109.

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, 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 309 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 case studies: valuation of Irish dairy[311]; a global valuation of crop and livestock production in 2015 (with boundary broader than beef, poultry meat and dairy milk), again by TruCost through a commission from the FAO[312]; the MARCH valuation of global health costs

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311 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.

312 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

attributed to the food system and the Sustainable Food Trust report on the Hidden Costs of UK Food[313]. Chapter 7 of the TEEB AgriFood Scientific and Economic Foundation report provides more examples of social cost 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 study *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) seen above as 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, per the discussion of footprint and impact targets on p. 107.

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 (Chapter 5 of the 2019 FOLU study) are, roughly, abatement mechanisms. Some 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 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 opportunity by 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 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 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 factors). In economics the marginal abatement value means the social benefit from one unit more of substitution of the baseline product or practice

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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)."

[313] 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). Fitzpatrick and Young, *The Hidden Cost of UK Food*.

by the alternative; discussed on p. 105. 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. Some of the societal costs may include intrinsic value not substitutable directly for monetary values. This is discussed further on p. **Error! Bookmark not defined.**.

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 opportunity is considering marginal abatement benefits and marginal abatement costs. Comparing them is social cost-benefit analysis or welfare-based cost benefit analysis[314]. 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, offset, 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 to consider, see business value drivers or business implications in the Protocols[315].

The baseline might be the same company, practice or product at a previous time[316]. 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[317], 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

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[314] M. Adler and E. Posner, "Rethinking Cost-Benefit Analysis," *Yale Law Journal* 109, no. 2 (1999), https://doi.org/10.2307/797489.
[315] p. 14, S&HCC, *Social & Human Capital Protocol*. p.9 NCC, *Natural Capital Protocol: Food & Beverage Sector Guide*.
[316] p. 30, Vionnet and Couture, *Measuring Value - Towards New Metrics and Methods*.
[317] A. Tversky and D. Kahneman, "The framing of decisions and the psychology of choice," *Science* 211, no. 4481 (1981).

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 on p. 105 and p. 107. 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 is the abatement value.

4: Marginal abatement by supplied commodity: Nestlé valuation of reduction in the social cost of palm oil supply[318]

Nestlé collaborates with New Britain Palm Oil Limited (NBPOL) and the Earthworm Foundation on responsible sourcing of palm oil in Papua New Guinea (PNG). 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 quantities published by NBPOL in its annual sustainability report 2017[319], the impacts of the interventions on the ground were valued in monetary terms at 2017$US 160 /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 plantation and 9483ha of high carbon stock (HCS) conserved land, mainly in PNG, with less than 10% of operations on 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 and Nestlé to better understand and optimize the impacts of Responsible Sourcing programs.

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.

Pathways: 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 several 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 conducts education programs (p. 44,48 NBPOL SR 2017), which improves livelihoods compared to a legal minimum supplier paying a minimum wage with no education programs. Using a previously developed approach on health utility of income, an increase in life expectancy and quality was calculated and converted into human capital using above average OECD productivity.

There were no joint effects identified, i.e. the holding of HCS forest did not substantially alter the efficacy of the WASH initiatives or premium payment.

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

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).

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, and the Novartis health-utility of income assessment[320]. Given the exploratory nature of this assessment, different valuation techniques have sometimes been mixed.

Quantities: Forest conserved results in carbon sequestration calculated in NBPOL SR2017 179837 t CO2-eq. A rainforest enclave of 4552 ha for community use is used to determine retention of ecosystem services. Increased carbon efficiencies on plantations and in mills compared to baseline (reduced fertiliser application, replanted oil palm and mill fuel and electricity) provided carbon abatement of 52721 t CO2-eq in 2017

Reduction in cases of diarrhoea and water availability outcomes 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 pp for NBPOL WASH program. Reduction of diarrhoea DALYs estimated at 9.24 DALYs/yr, which is equated to productivity saved of the annual labour of 9.24 pp.

NBPOL SR 2017 pays premium 13.7 2017PNK /t FFB. A harvest of 589524 t FFB by 16121 smallholder blocks combined with the premium is the income increase for smallholders. Novartis health-utility of income multiplier used. NBPOL pays 27% above minimum wage on average to 15700 field workers.

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

Marginal social costs: marginal valuations used

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

Ecosystem services: 2017$ 5604 ha/yr

Health utility of income: 2017$US 7.18 /t FFB smallholder produced, 2017$US 1306 /worker

Productivity: 2017$US 36955 /pp

Total abatement value: based on NPBOL operations in 2016/2017 compared to baseline

Natural capital benefits

- Avoided carbon emissions due to HCS preservation: 14 million 2017$US per year
- Avoided carbon emissions due to carbon efficiencies: 4.2 million 2017$US per year
- Retention of ecosystem services in enclave: 25.5 million 2017$US per year

Social and human capital benefits:

- Health impacts and time savings of water pumps provided: 12.1 million 2017$US per year
- Health utility of increased income for smallholder farmers and plantation workers: 24.7 million 2107$US per year.

Total abatement value of 81 million 2017$US per year for production of crude palm and palm kernel oil.

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 160 2017$US/tonne.

[320] 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 (MFFMs)[321]

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)[322]. MFFMs are established and managed vegetated strips of marginal farmland alongside field boundaries and waterways[323]. 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.

[321] This case study was contributed by Varun Vats, Syngenta.
[322] 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.
[323] 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)[324].

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 CO_2eq.

Footprints: ha of MFFMs implemented. CO_2eq 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 CO_2eq 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.

[324] de Groot et al., "Global estimates of the value of ecosystems and their services in monetary units."

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[325]. 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.

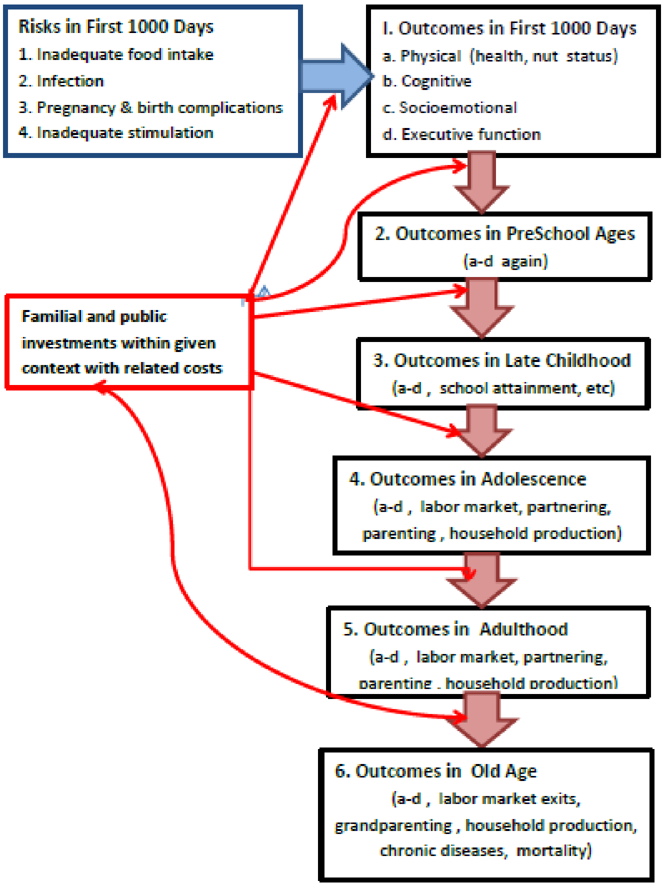

Figure 28: Lifecycle or impact pathway with benefits from later life stages (Source: Hoddinott et al. (2013))

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.

[325] 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[326]. 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.

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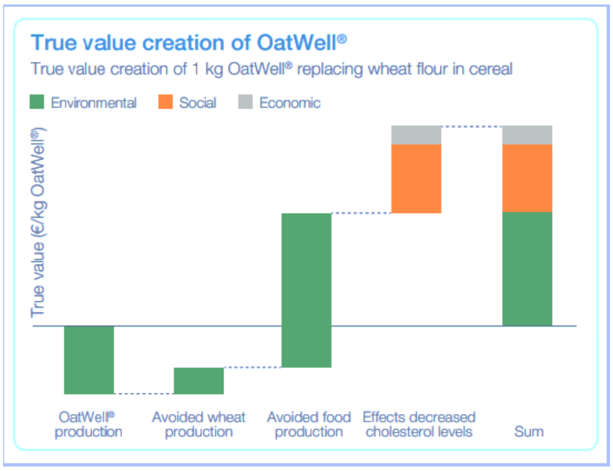
[326] Z. A. Bhutta et al., "Evidence-based interventions for improvement of maternal and child nutrition: what can be done and at what cost?," *The Lancet* 382, no. 9890 (2013), https://doi.org/10.1016/S0140-6736(13)60996-4.

7: Marginal abatement by product: DSM and OatWell®[327]

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[328]. 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[329]. Health effects of lower cholesterol were valued in the study. Increased satiation effect modelled by food not consumed.

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327 This case study description was contributed by Henk Bosch, DSM.

328 Detailed description of impact pathways in Section 5 and 6 of de Bruyn et al., *Environmental Prices Handbook EU28 Version*.

329 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.

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[330]. 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[331]. 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. 98). 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.

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330 Appendix B, de Bruyn et al., *Environmental Prices Handbook EU28 Version*.
331 Aalbers, Renes, and Romijn, *WLO-klimaatscenario’s en de waardering van CO2-uitstoot in MKBA's*.

8: Marginal abatement by product: Evonik Feed Supplement[332]

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[333] 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 17). 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.

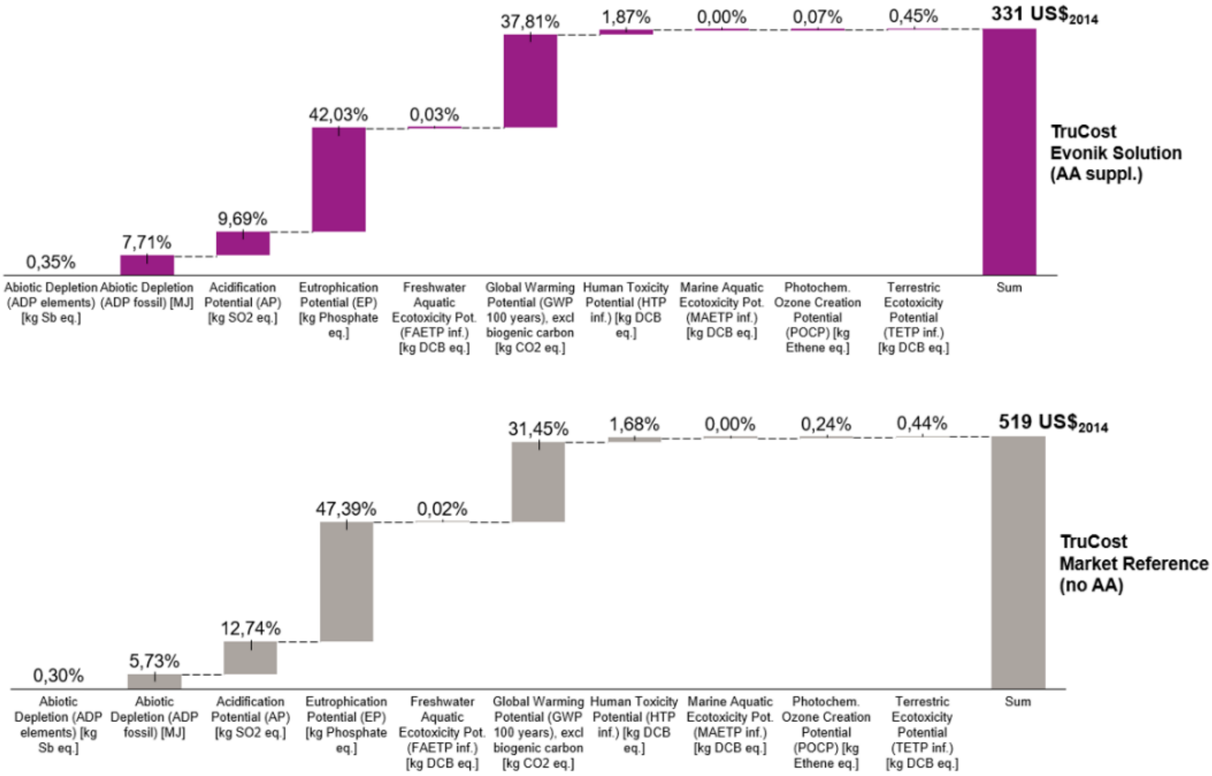

Figure 29: Lower marginal environmental costs 1 tonne LW broiler produced with supplement

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

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

333 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[334] 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[335]. 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 CO_2eq/t LW; 32 (AA suppl.) versus 65 (no AA) kg SO_2eq/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.

334 TruCost, *TruCost's Valuation Methodology*.

335 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[336]. 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.

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

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.

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

[336] 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 intervention. 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 where the products or practices share common quantities. For example, comparing livestock products on a marginal abatement value per kg protein basis[337].

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 to baselines are not across the same categories of benefit. It is also unclear, without reading into the detail of the individual studies, as there is no set footprint vector to report against, if negative effects in the substitution related to societal issues 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[338].

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. Ideally, formalisation of the major pathways of impact for food systems, its practices and products, should trace back to the completeness of the footprint for reporting on material issues for society. These features should be part of an accounting standard. Aggregation of marginal abatement is discussed further next section and on p. **Error! Bookmark not defined.**.

LCA is highly developed for environmental sources of capital change and several endpoints (human health, species loss and resource depletion) that influence welfare. 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

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[337] 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.*

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

context or spatial category at the resolution discussed from p. 78[339]. LCI models represent the calculation from the functional unit (the product or practice) to an inventory, then LCIA (CML or ReCiPe) calculates from that inventory to midpoints or endpoints. CE Delft valuation factors have the capacity to calculate from inventory, midpoint 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 in LCA 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, equivalent essentially to ReCiPe midpoints, to monetised values[340].

Development of a food systems accounting framework would determine a footprint that should be interoperable in the environmental categories with inventory or midpoint levels, or, potentially, some mix of inventory and midpoints that were not intersecting. 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 as opposed to 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 (as part of their impact pathways) for food system transformation. In summary, an accounting framework should be, through methods in data science such as ontologies, interoperable with standards in LCA.

The previous paragraph discussed footprint (quantity) calculation. Standardising valuation factors is discussed on p. 40, p. 86, p. 101 and p. **Error! Bookmark not defined.**.

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 probability distributions.

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 on p. 115, 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 like the normal distribution is the limit distribution for sums. 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

[339] Rebecca et al., "Life cycle assessment needs predictive spatial modelling for biodiversity and ecosystem services." Land Use: Vidal Legaz et al., "Soil quality, properties, and functions in life cycle assessment: an evaluation of models."

[340] The EU H2020 REFRESH project focusses on LifeCycle Costing (LCC) of LCA for EU food waste: 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*.. See also Pizzol et al., "Monetary valuation in Life Cycle Assessment: a review."

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. This maxim is useful for considering societal totals and we discuss the implications last section. To simplify, one can get away with using a single numerical value for the marginal value per unit and multiply by total quantity of units to arrive at value.

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 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 US2015$20/tCO2eq impact, and emission from production in Germany in 2019 gets reabsorbed into the global economy in a future world where carbon had say US2015$200/tCO2eq 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 as discussed last section. The individual is likely to have difficulty conceiving the context of the trade-off in markets affected by global large quantity changes.

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 of the valuation factors multiplied by the total footprint. Positive correlation means the product of average value of environmental prices 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 independent of variation in the impact associated to quantities of footprint occurring in different regions and contexts.

A large range of abatement value case studies exist under Social Return on Investment. Some interventions in original TEEB case studies relate to agriculture and aquaculture[341].

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)[342] as well as private benefits in the value chain.

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

[342] 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

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

The marginal abatement value is a signal, information, an indicator, 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 comes needs 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 be reported separately for a product or activity positioned in a value chain. Marginal abatement value should be retained as a vector of submarginals that report 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 non-compensatory and are not directly converted into financial benefit or cost through being sold or consumed. The transfer happens through internalisation. Internalisation involves change of prices as a representation of marginal social value and changes or constraints on footprint quantities. 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

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.

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 actor increases the value of the abatement product or practice to the procurer, increasing demand.

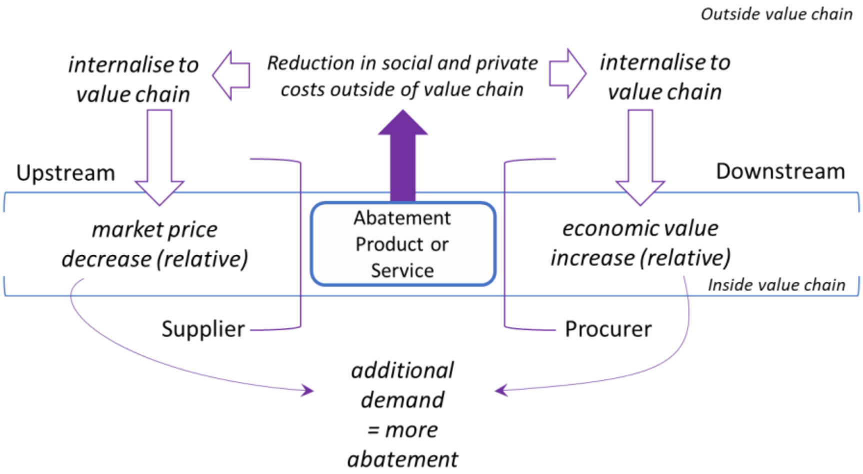

Figure 31: Demand for products or services as a function of abatement of societal costs factors through internalisation into the value chain of that product or service

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[343]. 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[344]. 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[345] (an internalisation) in response to demand signals from investors, society and consumers.

[343] S. N. S. Cheung, "The Fable of the Bees: An Economic Investigation," *The Journal of Law & Economics* 16, no. 1 (1973).
[344] 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.
[345] 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

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

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.

In order 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 explicitly 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 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 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. 105, 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 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 scenario 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[346].

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[347] 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[348]. The Institute for Sustainable Development and International Relations (IDDRI) has developed projection scenarios for abatement of carbon offered by scaling organic farming[349].

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.

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

[347] {Hirvonen, 2020 #1130}

[348] 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).

[349] 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[350], meaning it involves a projection of demand to achieve the targets in 2030 and 2050 described in the scenario and the FOLU report.

Modelling results in the “Better Futures” scenarios show 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 an aspiration for what the value could be for abatement opportunities. To understand the uncertainty or spread of valuations, 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.

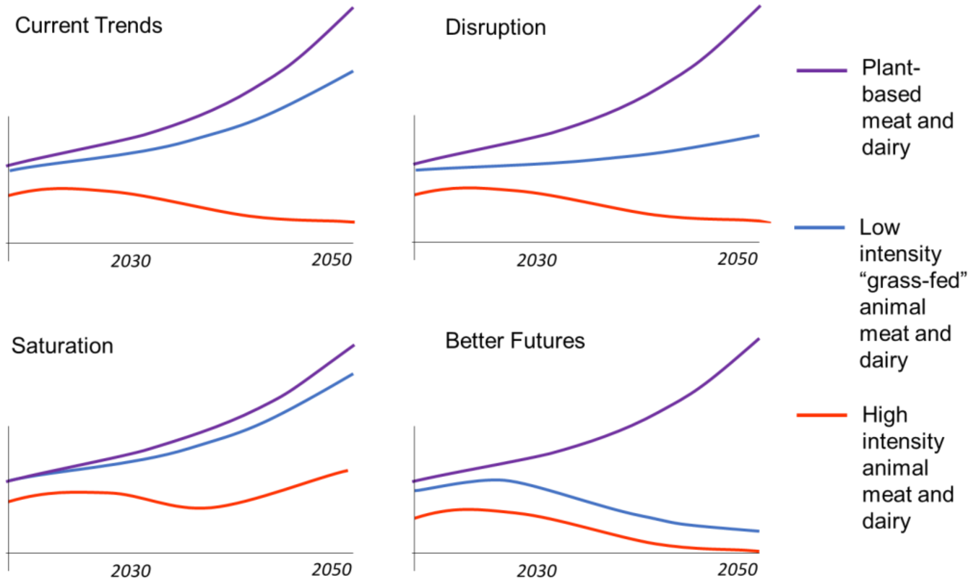

Figure 32: Alternative animal or plant meat demand projections as share of total. Illustrative only. Current Trends and Better Futures indicative of scenarios from FOLU report only. Current trends projects forward high growth in plant-based meat and dairy consumption displacing a share of low growth 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.

350 Wiebe et al., "Scenario development and foresight analysis: exploring options to inform choices."

In the "Better Futures" scenario the achievement of 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* also expresses some country-specific pathways of commodity use, consumption and practice based on abatement targets[351]. 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. Illustrative only, to indicative different possibilities of share of demand. Crude assumptions are made such as normalisation 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, etc. 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)[352]. Current Trends assumes that low intensity or sustainable intensification of animal production displaces high intensity[353]. 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[354]. 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[355].

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[356]. 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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[351] p. 28: FABLE, *Pathways to Sustainable Land-Use and Food Systems. 2019 Report of the FABLE Consortium.*

[352] OECD and FAO, *OECD-FAO Agricultural Outlook 2019-2028* (Paris: OECD Publishing, 2019). FAIRR, *Plant-based profits: investment risks & opportunities in sustainable food systems*. 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

[353] 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.

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

[355] 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.

[356] Bajzelj et al., "Importance of food-demand management for climate mitigation." 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 on p. 115. It is part of the uncertainty in attribution of capital change 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

Despite variability in the footprint units used in the case studies, the range of frameworks and literature on food system sustainability targets, metrics and impact pathways do align. 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 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 of 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)[357] 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

[357] 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).

footprint is complementarity with potential offset markets. Automatic registration of offset 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.

METHODS SUMMARY

This section comments on the development of impact valuation. It also provides an inventory of the methods, data and models mentioned in previous sections.

Forums for developing impact valuation repeat general terms such as "gathering the data", "measurement", "quantification" and "metrics". Contextualising the terms would help further development of methods. The section recommends distinguishing data and modelling required for footprint calculation, data and modelling required for capital changes, and data and modelling required for valuation of capital changes. Examples show that data and models associated to footprint, capital changes, and valuation are substantively different. They also vary in terms of sources, quality and resolution.

The section further recommends that the three components of valuation need to develop together. Little improvement in food impact costing overall is found if development was pushed into improving the precision of measuring an actor's footprint while methods to improve social and abatement costing languish. Incredible uncertainties and variation as to the impact that footprint creates remains unimproved by greater precision in an actor's footprint. For reducing global food system impact, disclosure efforts should be prioritised over more granular footprints that are relatively well-measured.

Though technology for smart farms and big data promise greater precision in footprint data, there is less focus on capital changes and human impacts. Many research projects and investments are being shaped around food safety and personalised nutrition and not on data collection relevant to impact. Food safety and personalised nutrition offer more immediate sources of return on investment. This is a missed opportunity. It will be missed if incentives for food system impact reduction are not increased.

Research is required to understand how the potential areas for the greatest improvement match with capability and resources: what form the improvements need to take, what aspects they need to include, where in terms of footprint, capital changes or valuation, their precision versus their practicality, and the importance of certainty in their calculation versus consensus around the calculation.

Previous sections argued from a practical, ethical and risk-bearing viewpoint that a societal process should standardise footprint through a food system non-financial accounting standard and set and update shadow prices associated to standardised footprint units. Using single shadow prices linked to global footprints is a mistake, it only works for the marginal valuation of carbon. It is suggested that more energy will be spent arguing the numbers or diverting the argument to the numbers rather than on economic action. Waiting for scientific precision in impacts from global modelling and monitoring is equally seen as a mistake. Economic measures for change in food systems are an imperative now; impact neutral as an aspiration for the food sector needs to come on the back of carbon markets and mechanisms. This section finds a database of shadow prices at the resolution suggested in previous sections strikes a balance between pragmatism and precision in calculation, accessibility and expertise, and need and maturity.

METHODS

Food system impact valuations are likely to continue to use marginal valuations taken from literature and different sources of modelling and monitoring data. Before listing a short inventory of indicative methods and resources a spectrum and timeline in the development of impact valuation is considered. The report has argued for the movement toward spatially and contextually explicit footprints and collections of marginal valuations. Food impact valuation is likely to be less effectual and more contested without spatial and contextual footprint. It has been argued, from practical (from p. 61), ethical (from p. 86) and risk-bearing (from p. 115) viewpoints that a societal process should standardise footprint through a food system non-financial accounting standard and set and update shadow prices associated to standardised footprint units. By considering steps in the development of impact valuation, it is argued that developing the accounting standard and shadow prices as a shared asset is an effective application of the time and resources of stakeholders toward using social and abatement costs of food system impact to contribute to food system transformation and incentivise sustainable products and practices.

Spectrum of approaches

The description of the steps in the valuation process (from p. 61), its ethical choices (from p. 86) uncertainty (from p. 115), and the examination of the case studies (from p. 128), evidence that it is unlikely agreement on food impact costing can be achieved through "having the data". That is, having enough precision to scientifically establish impact costings as "facts". It is unclear that, even with complete disclosure of the footprints of all food actors, and assuming that those footprints could be determined precisely by science, that the fiscal adjustment required from changing those footprints to achieve optimal social and human welfare would be equally precisely determined.

Data, meaning "facts collected together", is generally distinguished from information produced by modelling[358]. Impact valuation is an outcome of modelling with a complicated array of data used in models at different steps. Data and models are needed to calculate footprint, to estimate capital changes, to estimate changes in social and human welfare in different communities now and into the future (Figure 17). We distinguish data as the outcome of what can be observed or minimally interpolated from observation, and calculation and estimations as the outcome of modelling (Table 3). Distinguishing "data" and "modelling" is simplistic, but useful when forums about developing impact valuation attended by companies and civil groups with supporting institutions repeat general terms such as "gathering the data", "measurement", "quantification" and "metrics". Contextualising these terms by whether they refer to observations or calculations to determine footprint, whether they refer to the additional data or information required to calculate capital changes given the footprint, whether they refer to the calculation of attributable changes in capital quantity and quality, and whether they refer to estimated changes in welfare from capital changes, would help further development of methods (Table 4). The data required for footprint calculation is very different, both substantively and in terms of sources, quality and resolution, than the data required for capital changes, and different again from the data required for valuation of capital changes.

The Natural Capital Coalition Food & Beverage Guide illustrates clearly the distinctions between footprint, capital changes and valuation under Steps 05 to 07. It gives simple illustrations of data for the calculation of impact under each step, but the distinctions have yet to permeate. The complexity of food systems compared to the simplicity of examples obfuscates the large gulf between data and model in implementation.

The discussion on p. 67 gave examples of models and data for footprint. For example, sensors on-farm, pollution sampling of wastewater from factories, accident logs, etc. perform data

[358] https://www.lexico.com/en/definition/data; I. Tuomi, "Data Is More than Knowledge: Implications of the Reversed Knowledge Hierarchy for Knowledge Management and Organizational Memory," *Journal of Management Information Systems* 16, no. 3 (1999), https://doi.org/10.1080/07421222.1999.11518258.

collection. Lifecycle analysis databases are a mixture of collected data and calculation. Footprints obtained from Coolfarmtool[359] and inferred footprints from EEIO models, etc. are calculations.

The discussion on p. 65 gave examples of models and data for capital changes including the calculation of societal footprints. Different institutions and different tool-sets measure societal footprint compared to actor footprint. Global monitoring of environmental capital stocks and flows is undertaken by bodies such the UN Environment Programme (UNEP), or compiled from statistics and monitoring performed by national bodies (e.g. USGS[360]). The UN Food and Agriculture Organisation (FAO) collates national statistics in FAOSTAT and AQUASTAT relevant to the global environmental, social and economic state of the food system. Satellite and remote sensing is an increasing global monitoring capability. There is a wave of research and projects about smart farms, big data and smart supply chains. Many of these initiatives and investments are currently being shaped around food safety and personalised nutrition and not on data collection relevant to impact. Food safety and personalised nutrition are more immediate sources of return on investment. The opportunity to shape the data infrastructure that will be built into digital supply chains of the food sector to track impact may be missed. Monitoring of social capital at national and community levels is more diverse and less clearly articulated than environmental and health capital. There can be large barriers, in terms of technical knowledge and resources, to accessing detailed monitoring data. Most data are accessible in an aggregated form. Where capital stocks are not covered by direct monitoring, they must be interpolated or extrapolated by models. Institutions such as UNEP and FAO, and national bodies, are sometimes model developers for this purpose as well as collators of data. For capital changes associated to the food system there is an almost unmanageable diversity of models, from statistical, to integrated computer models, at global, national and local scale. The latest IPCC report on climate change, land use and food security, at 1542 pages with 96 Contributing Authors including over 7000 cited references[361], still covered only a sample of modelling conducted in relation to food system impact. Models for estimation and attribution of natural, social and human capital changes (also called impact assessment) are generally different than those used to extrapolate or estimate footprints at the scale of activities. Socio-economic scenarios used to set exogenous parameters for the models are another diverse academic industry, discussed from p. 84. Future food scenarios usually depend on other models to develop quantitative projections[362].

The WorldBank, the IMF, etc. have a diverse range of trade, human development and welfare indicators. Diverse sources of data are used in econometric statistical models of economic responses to inputs. Production factor models seek to identify the sensitivity of sectorial or national production statistics to time series data on suspected production factors. Surveys are used to calculate individual preferences for direct payments for non-financial services or substitutes for non-financial services. Simple or sophisticated models can relate preferences to economic statistics reflecting narrow or inclusive measures of welfare.

Figure 25 depicts compounding uncertainty from footprint to impact. The compounding is not just because the calculations are chained together in a conditional sequence. Footprint is more likely to be able to be measured or more directly informed by measurement. Attribution and

359 https://coolfarmtool.org/
360 https://www.usgs.gov/mission-areas/water-resources/data-tools
361 https://unfccc.int/news/land-is-part-of-the-climate-solution-ipcc
362 I. Y. R. Odegard and E. van Der Voet, "The future of food — Scenarios and the effect on natural resource use in agriculture in 2050," *Ecological Economics* 97 (2014), https://doi.org/10.1016/j.ecolecon.2013.10.005.

valuation become increasingly more modelled outputs, starting with physical processes and then quickly moving into socio-economic linked systems (Figure 33).

Table 4: Examples in the division of measurement and calculation (data and models) in the three conceptual components of impact valuation

	Footprint	Capital Change	Valuation
Data	sensors on-farm, pollution sampling of waste-water from factories, accident logs, some parts of LCA databases	national environmental surveys, water gages network, satellite and remote sensing	Human well-being surveys, national economic statistics, contingent and preference studies
Models	some parts of LCA databases, Coolfarmtool, EEIO models	UNEP-WCMC Madingley Model, FAO MOSAICC, FAO GLEAM CSIRO MAgPIE, GBD log dose-response models	Economic growth models, Integrated Assessment Models, Production function approach, Computable General and Partial Equilibrium economic models

The components of valuation need to develop together. There is little improvement in food impact costing overall if development was pushed into improving the precision of measuring an actor's footprint while methods to improve social and abatement costing languish (relying on existing diverse and partly applicable preference or contingent valuations spread through literature). Incredible uncertainties and variation as to the impact that footprint creates remains unimproved by greater precision in an actor's footprint.

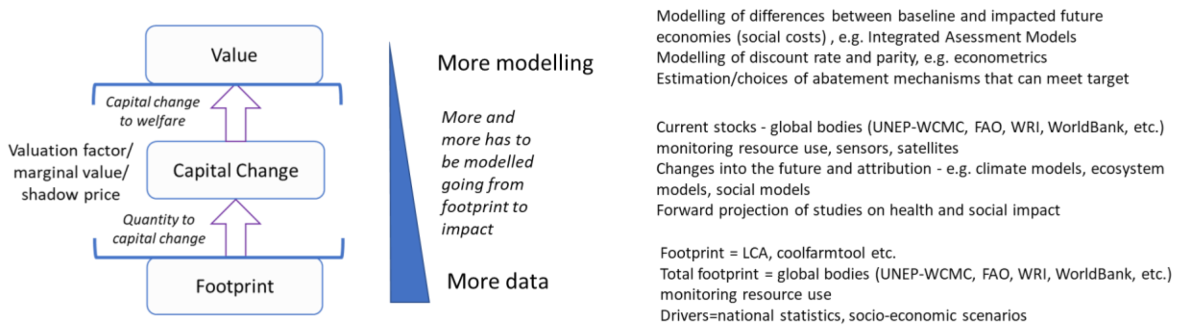

Figure 33: Footprint is more likely to be able to be measured or more directly informed by measurement. Attribution and valuation become increasingly more modelled outputs, starting with physical processes and then quickly moving into socio-economic linked systems

Achieving change toward food system transformation targets should guide the requirements of impact valuation and its development. It is unclear if, following a logical progression, precisely knowing footprint down to individual product level is going to achieve the largest reduction of impact from the food system[363]. Investing societal resources into achieving disclosure instead of non-disclosure should be prioritised over more granular footprint modelling for footprints that are already relatively well-measured. Case studies 1-3 are initial attempts to understand the sensitivity of impact, from a global food system perspective, to environmental, social and health concerns. Case study 3 identified approximately equal

[363] Leach et al., "Environmental impact food labels combining carbon, nitrogen, and water footprints."

impact from environment changes, social conditions and health. Research is required to understand how the determinants of the calculation of impact match with the capability and resources for improvement: what form the improvements need to take, what aspects they need to include, where in terms of footprint, capital changes or valuation, their precision versus their practicality, and the importance of certainty in their calculation versus consensus around the calculation.

Without that research, which will also need to consider the priorities of different uses, there is no value in suggesting incremental changes relating to specific sources of data or models. There are no Integrated Assessment Models (IAMs) associated to food impact costing, and we are unable to suggest incremental improvement in such modelling in the same way the current literature on climate costing improve method and knowledge.

Should such IAMs be built for food impact costing? Yes, eventually, but probably not yet. Existing "food system models" can be augmented and utilised to inform costing. Whether they can be sufficiently integrated with the economic features required to approximate the gradients to social or abatement cost surfaces over a vector of spatial and contextual footprint (that is, calculate shadow prices) is not clear. Building equilibrium models that couple economic, environmental, social and human health dynamic systems is a challenging task. Every food system impact valuation involves an "integrated model" in a broad sense to achieve a numerical calculation of impact. This is too ambiguous however to provide an academic focus for knowledge building and incremental improvement.

We make a recommendation on movement in a very broad direction. In previous sections, and formalised in the linear model described from p. 91 and on p. 104 we have advocated for a clear delineation between footprint, compared to capital changes and valuation of capital changes. Capital changes and valuation of capital changes involve societal footprints, socio-economic drivers, impacts on national economies, projections of economic growth and global equity concerns. The data and modelling capacity, and credibility, for the estimation of marginal valuations including what footprints should be measures seems to be firmly in the camp of national and international institutions and bodies, and a societal process involving these institutions, civil society and academia. Footprint calculation is firmly in the camp of the actors.

Using single numbers linked to total global footprint is a mistake, this only works for the marginal valuation of carbon. It will produce a value, and initiate a dialogue, and is the most practical. So many features of the calculation are contestable that it will be unlikely to enable the consensus on which to facilitate economic action. More energy will be spent arguing the numbers or diverting the argument to the numbers.

Waiting for global modelling and monitoring to come online that are standardised and useable is equally a mistake. Economic measures for change in food systems are an imperative now; impact neutral as an aspiration for the food sector needs to come on the back of carbon markets and mechanisms. Models for uses that require comparison between valuations is in the future. Comparable, interoperable, standardised modelling suites validated on extensive observations of capital stocks and changes is either some time off maturity or requires disproportionate resources to bring to maturity. Global monitoring and almost real-time observation by satellites or networks of sensors that are capable of high-resolution determination of physical, biological and chemical changes, or analogous networks of sensors and algorithms capable of measuring changes in community and public health, are still the future. Implementation of such systems are in the future, and the ability of individual companies or food system actors to access them to determine impact along global value chains is well into the future.

This suggests a present balance between pragmatism and precision in calculation, accessibility and expertise, and need and maturity (Figure 34)

The balance will shift in terms of standard practice into the future as technology and knowledge evolves.

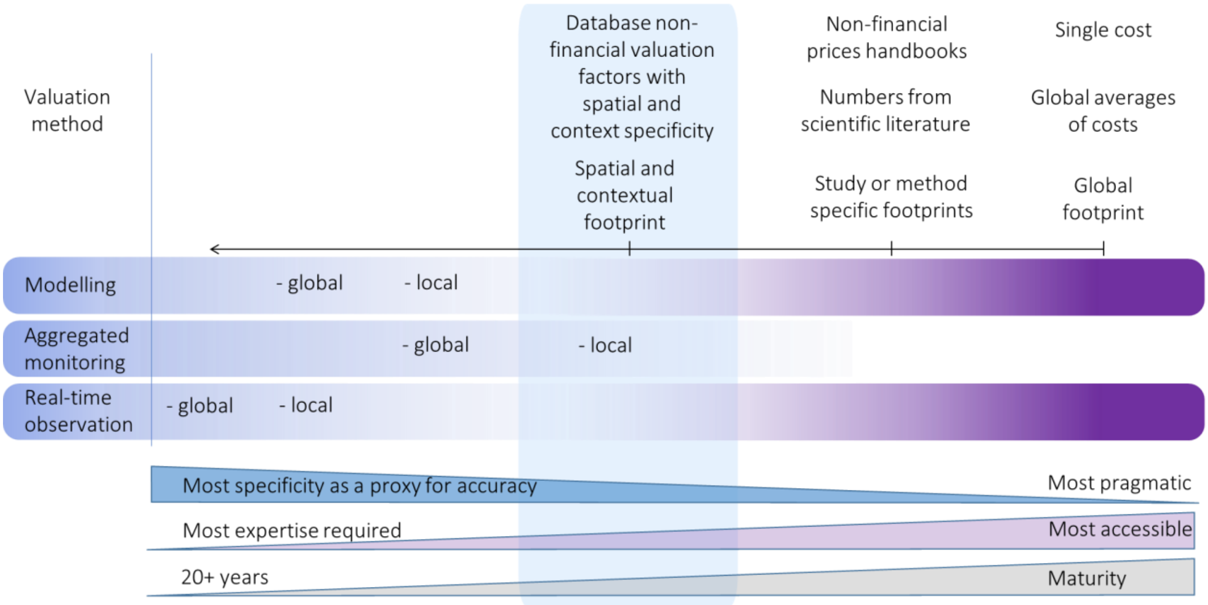

Figure 34: spectrum of approaches and development of impact costing tools moving toward the left over time. We argue that moving toward agreed and comparable food impact costing requires a pragmatic balance between spatial and contextual specification and feasibility in the ability to compile modelling and monitoring estimates into a database of valuation factors for common use. This is a step to left from the present use of national handbooks on environmental and social pricing, literature estimates, and a lack of uniformity in footprint.

Using costings and calculations ad hoc from literature is for local project analysis without comparison with projects in other locales, or for internal costing by companies. Agreed and comparable food impact costings require a consistent synthesis.

Non-financial marginal valuations provided by national handbooks are not comprehensive on the shadow prices needed for food impact costing, especially with a focus on achieving food system transformation. They predominately focus on environmental pollutants, some of which are a major concern for food systems and some of which are a minor concern or already regulated. The presentation of uncertainty is very limited. It is difficult for national handbooks to act as comprehensive guides for food impact costing as a common approach to which footprints should be measured (and so marginal valuations with respect to what) is missing. The food sector, as one of the most complex to associate impact costs to, needs its own development of shadow prices.

Databases able to link a marginal valuation in a footprint to where and how it was emitted, occurred, extracted or consumed at a broad contextual and catchment or subpopulation level are an intermediate step between lists in national handbooks and future integrated assessment models for food system impacts. As discussed on p. 78 and p. 101, the spatial and contextual specifics should be attached to the major distinctions in location and context relevant to impact. Experts groups, and national and international bodies, using models to inform and update valuation factors is significantly different from the models being useable and interfaced with the users themselves. This is an IPCC or IPBES style of consensus building, not an exercise in global equilibrium modelling capability[364]. The linear model described from p. 91 and p. 104 is linked to the development, or initial steps toward, such a database. In advocating risk pricing, being able to incorporate uncertainty through risk pricing is mostly aimed at facilitating consensus rather than a new scientific method. We suspect it would presently cost more in terms of time and money to develop a linked socio-economic food system model so definitive it creates the same level of consensus as a societal process aimed at establishing, setting, and updating a database of shadow prices for common use. The two are connected of course, the first will link to the second, and the second will sponsor the first. We are not arguing for an exclusive either or, but proportional priority for investment. Scientific consensus building is more than collating figures extracted from scientific literature, but less than a global modelling exercise.

An aim of this report is to stimulate additional examination between the three factors of: value in doing impact costing for the food system; the costs in upfront investment in the kind of database recommended; and the benefits once established.

As summarised on p. 89, food impact costing is a complicated task. Marginal valuations, though absorbing ethical choices, variations, and uncertainty, are easy to use for all parties if credible and established. From government, to agricultural producers, to large companies, to small and medium enterprises in the food sector. Large companies can measure their own footprints (upstream and downstream) as the actors which dominate the food sector in market share (and likely impact) terms. Government assistance in schemes such as the EU Product Environmental Footprint (PEF) perform footprint calculation for small and medium enterprises which dominate the food sector in terms of head count. Footprint tools and calculators are more advanced in the sector than impact calculators. Footprint to determine the health impact of consumed food products is already largely measured or modelled in the industry, as discussed on p. **Error! Bookmark not defined.**. Footprint associated to social material issues for society currently lags environment and health.

The use of marginal valuations is observed across the case studies from p. 128 and uses of food impact costing indicated from p. 27. However, the investment in the database of food system specific shadow prices is proportional to the take up of the uses and their contributions toward sustainable food systems. The Food System Impact Valuation Initiative is primarily a network to bring closer together the triad of actors in Figure 4 on p. 28, and match the development of food impact costing to users and uses.

The trade-off between resolution of footprint and impacts, resources available to conduct the impact costings, and the amount of change created by estimates, have been noted in previous impact valuation studies[365].

To summarise, it is the view of this report that valuation factors be used with caveats. A societal process toward a database of shadow prices at a pragmatic level of resolution – enough spatial, temporal and contextual detail to avoid gross errors but coarse enough to make compiling the database feasible. It is more important to get estimates that point in the right direction, within enough resolution to distinguish sustainable production methods, and gather a collective weight willing to promote and use scientifically based food impact costings rather than wait for synthesised and standardised modelling efforts to emerge from a myriad of scientific projects.

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[364] C. O. Flores et al., "Food Webs: Insights from a General Ecosystem Model," *bioRxiv* (2019), https://doi.org/10.1101/588665, http://biorxiv.org/content/early/2019/03/26/588665.abstract.

[365] p. 80: FAO, *Food wastage footprint: full-cost accounting*.. p. 13-20: COWI, *Assessment of potentials and limitations in valuation of externalities*. and p.26. The COWI report calls footprint "impact assessments", valuation of footprint "economic valuation", with marginal valuation called "unit values".

Additional comments on building a database are made under implications on p. **Error! Bookmark not defined.**. The database building would not be starting from scratch.

Inventory of methods

The following inventory collates many of the data sources, tools and models mentioned in the report. It lays no claim to comprehensiveness. Some of these models and techniques feature in the case studies, where strengths and limitations were discussed in more detail. Another project within the food true cost accounting community mentioned on p. 5 is developing a wider list of methods, tools and case studies. The list is structured according to the dimensions identified in previous sections: data or model; footprint, capital change, valuation; and spatial, temporal or contextual resolution.

Name and Link	Data or Model	Step of Valuation	Spatial, Contextual or Temporal Factors
TEEB AgriFood Evaluation Framework http://teebweb.org/agrifood/home/evaluation-framework/		Impact Framework	Specific to food system. Comprehensive, downstream and upstream.
Natural Capital Protocol Social and Human Capital Protocol https://naturalcapitalcoalition.org/natural-capital-protocol-food-and-beverage-sector-guide/		Impact Framework	Not specific to food system. Food & Beverage Guide with upstream natural capital examples.
Social Return on Investment (SROI) http://socialvalueint.org/		Impact Framework	Not specific to food and beverage. Generic approach.
E.Valu.A.TE https://www.cisl.cam.ac.uk/resources/natural-resource-security-publications/evaluate-practical-guide		Impact Framework	Specific to agriculture and upstream externalities.
FAOSTAT AQUASTAT http://www.fao.org/faostat/	National data with some calculation	Footprint calculation. Capital change calculation. Market valuation.	Emissions data for carbon footprint. Land-use indicators. Fertiliser use indicators. Pesticide application indicators. Production data for human consumption footprints. Trade. Market values.
LCI https://www.iso.org/standard/37456.html	Mostly data from studies, interpolated or extrapolated to other regions	Footprint calculator: GHG emissions	Life cycle inventory analysis. Full lifecycle possible, input to consumption to waste. Contextual detail built into the LCI model and dependant on

Name and Link	Data or Model	Step of Valuation	Spatial, Contextual or Temporal Factors
https://www.iso.org/standard/38498.html	and production lines	Ozone depletion Particulate matter and air pollutants Land and water acidification Human toxicity Water use Land use Resource Scarcity	database characteristics. Spatial detail depends on availability or aggregation in LCA databases.
Coolfarmtool https://coolfarmtool.org/	Model based on scientific data	Footprint calculator: GHG emissions Water Biodiversity	Agricultural production. Different land-use and management contexts. Different production contexts. See https://coolfarmtool.org/wp-content/uploads/2016/09/Data-Input-Guide.pdf Farm, fertiliser and energy inputs, and limited storage and processing. Calculation inferred spatially and contextually from the original study sites underlying the scientific data. More granular and specific than LCA databases.
Environmentally Extended Input Output (EEIO) https://www2.mst.dk/Udgiv/publications/2014/03/978-87-93178-33-5.pdf	Model based on input-output data and regression of environmental damage per sector.	Footprint calculator: GHG emissions Particulate matter and air pollutants Water use Land use	Upstream. Proportion of flow other of sectors into a target sector the economy is determined from an IO model. Little spatial distinction. The IO model is based usually on one developed economy. Then quantities of emission, pollutants, etc. assigned per value of subsector ("environmental intensities"), which is the EE part of the EEIO model. Footprint calculations are sector averages. Resolution is coarser than LCA. Environmental information may be hybridized with LCA. See COWI (2014).
SOL-m	Model	Footprint calculation:	FAO Sustainability and Organic Livestock model. Can back-calculate spatial footprints at national level. Contextual

Name and Link	Data or Model	Step of Valuation	Spatial, Contextual or Temporal Factors
http://www.fao.org/nr/sustainability/sustainability-and-livestock/en/		Production per country per commodity Nitrogen and Phosphorous application per country per commodity GHG emissions Land-use Pesticide use	difference concentrates on organic versus conventional agriculture.
World Bank https://data.worldbank.org/	Data	Capital changes: Socio-economic drivers and development	Statistics on populations, demographics, Human Development Indices (HDI), Corporate activity, etc.
Co$ting Nature Tool: Kings College London	Model	Capital change	Conservation priority, biodiversity, water quantity and quality, water provisioning services, carbon services, nature-based tourism are mapped, together with threats and pressures and vulnerability to hazards which can indicate priority capital changes. High spatial resolution data sources. Receivers of services also mapped. Users apply own valuation factors. https://blogs.kcl.ac.uk/eoes/2016/06/07/costing-nature-tool-to-support-sustainable-decisions/
Institute for Health Metrics and Evaluation (IMHE) Global Burden of Disease (GBD) database http://www.healthdata.org/diet	Model from underlying health data	Capital changes: Human preventable disease and death	DALYS attributable. Dietary risk factors (obesity, diabetes, non-communicative diseases, child growth failure) Air pollution Diaorheaa
Lifecycle Impact Assessment (LCIA)	Model	Capital changes. Changes in GHG emissions, Ozone depletion, Particulate matter and air pollutants, Land and water acidification, Human toxicity,	LCIA calculates from an LCI to midpoint capital changes, or impact pathways to endpoint impacts on human health, ecosystems and resource availability. ReCiPe 2016: https://www.rivm.nl/bibliotheek/rapporten/2016-0104.pdf

Name and Link	Data or Model	Step of Valuation	Spatial, Contextual or Temporal Factors
		Water use, Land use, Resource Scarcity to Human health impact (DALYs), Ecosystem impact (species lost), Resource scarcity (additional monetary cost)	CML 2016 https://www.universiteitleiden.nl/en/research/research-output/science/cml-ia-characterisation-factors
RAND study on Anti-Microbacterial Resistance https://www.rand.org/pubs/research_reports/RR911.html	Model	Capital changes and valuation	AMR shock to human morbidity and mortality and labour losses. Global general equilibrium economic model used to calculate costs under seven scenarios of AMR resistance. Regional morbidity and mortality and GDP losses over time.
Water Scarcity	Model	Capital Changes Water use	Designed to add water stress indicator to LCIA midpoint and calculate damages to LCIA endpoints. Human health functional model allowing input of local and contextual factors (variance of precipitation, water extraction, agriculture use, water stocks, HDI, malnutrition) with output in DALYs. Function is non-linear in water extraction, quadratic in HDI and linear in malnutrition rates. Pfister (2015).
Pesticides	Model	Capital change Pesticides	Pesticide exposure pathways of inhalation (workers), soil and drinking water contamination and vegetal consumption with human health effects in DALYs. Non-linear model with uncertainty analysis. Fantke (2016)
Stunting effects	Model	Capital Changes Malnutrition	Model to link dietary intake in first 1000 days (from conception) and link to outcomes in Adulthood and hence to income. Hoddinot (2013)

Name and Link	Data or Model	Step of Valuation	Spatial, Contextual or Temporal Factors
GLASOD/GLADA http://www.fao.org/land-water/land/land-governance/land-resources-planning-toolbox/category/details/en/c/1036321/	Model and database	Capital change: Land degradation	Degraded land. Qualitative severity of degradation, 12 types soil degradation types and 5 causal factors. Spatial explicit 1:10million scale global map. Updated by GLADA. Additional spatially explicit resources on soil see ISCRIC World Soil information: https://data.isric.org/geonetwork/srv/eng/catalog.search#/home
GLOBIOM https://www.globiom.org/	Model	Capital changes or total footprint calculation	Partial equilibrium model of agriculture, bioenergy and forestry sectors. Needs exogenous settings of GDP, population, technological advance and consumption demand. Endogenously determines agricultural land use, crop and livestock production, water use, estimates of fertiliser use, GHG emissions, commodity prices and yields. Environmental data spatially explicit collated and aggregated data based on 5 arcmin. Economic data national.
IMPACT https://www.ifpri.org/program/global-futures-and-strategic-foresight	Model	Capital changes or total footprint calculation	Partial equilibrium multi-market model. Needs exogenous settings of GDP, elasticities, population, and consumption demand. Endogenously determines agricultural land use, crop and livestock production, water use, GHG emissions, trade, commodity prices and yields. Environmental data spatially explicit collated and aggregated data based on 5 arcmin. Economic data national.
Natural Capital Project https://naturalcapitalproject.stanford.edu/	Model	Capital changes and valuation:	Integrated Valuation of Ecosystem Services and Tradeoffs (InVEST) modelling platform for natural capital.

Name and Link	Data or Model	Step of Valuation	Spatial, Contextual or Temporal Factors
		Ecosystem modelling.	Spatial resolution of ecosystems (sources of good and services) and human habitats (receivers of goods and services) integrated with GIS. From website: “InVEST is a suite of models used to map and value the goods and services from nature that sustain and fulfill human life.” Free and open source.
Shared Socio-economic pathways (SSPs)	Model	Scenarios	Socio-economic scenarios used widely in environmental change science. O’Neill (2014)
Representative Agricultural Pathways (RAPs)	Model	Scenarios	Part of the Agricultural Model Intercomparison Project (AGMIP), Valdivia (2014)
OECD Productivity Statistics https://www.oecd.org/sdd/productivity-stats/	Data with some calculation	Valuation	Productivity figures for standard valuations of improvements in DALYs.
EU-28 Handbook Environment prices https://www.cedelft.eu/en/publications/2191/environmental-prices-handbook-eu28-version	Model	Handbook of valuation factors	The CE Delft EU-28 handbook mostly adapts the EU funded NEEDS model of impact pathways to calculate shadow prices for environmental pollutants to air, water and soil. Structured to connect to LCI, LCIA midpoints and LCIA endpoints and harmonize pricing between them. See LCI and LCIA for priced quantities (or Tables 1-3 of Handbook). Uncertainty in EU-28 Handbook. Low-Central-High pricing is used. European prices.
FAO 2014 Food wastage footprint full-cost accounting study	Model	Table of valuation factors	Water (N and P eutrophication and pesticide contamination), biodiversity and soil valuation factors collected in Table 2 (p. 33) http://www.fao.org/3/a-i3991e.pdf
Nitrogen costs	Model	Table of valuation factors	Marginal valuation and ranges for air, soil and water nitrogen pollution in Table 1 van Grivsen (2013)

Name and Link	Data or Model	Step of Valuation	Spatial, Contextual or Temporal Factors
IWGSCC social cost of carbon	Model	Valuation factor	US EPA Interagency Working Group Social Cost of Carbon (IWGSCC) distribution of estimates for the social cost of carbon https://www.epa.gov/sites/production/files/2016-12/documents/sc_co2_tsd_august_2016.pdf
CPLC marginal abatement cost of carbon	Model	Valuation factor	Carbon Pricing Leadership Coalition (CPLC) range for the marginal abatement cost of carbon https://www.carbonpricingleadership.org/report-of-the-highlevel-commission-on-carbon-prices.
UK Treasury Green Book https://www.gov.uk/government/publications/the-green-book-appraisal-and-evaluation-in-central-governent	Data and models	Handbook of valuation factors	Describes role of discounting and SROI. Valuation factors on air pollution and water quality in Annexes, with links to other UK government sources of valuation factors. Also discusses substitution or "unmonetizable values".
TruCost methodology	Models	Valuation factors	Global averages used in GaBI software. Country factors proprietary. Environmental. GHG Emissions, air land and water pollutants, eutrophication, water consumption, land use. https://www.gabi-software.com/fileadmin/GaBi_Databases/Thinkstep_Trucost_NCA_factors_methodology_report.pdf.
Ecosystem Services Valuation Database (ESVD) https://www.es-partnership.org/services/data-knowledge-sharing/ecosystem-service-valuation-database/	Model (synthesis of literature)	Database of valuation factors	Searchable online database of valuation studies on ecosystem services. de Groot (2012)
Global Health Cost-Effectiveness Analysis (GHCEA) Registry	Model (synthesis of literature)	Database of valuation factors	Review of cost-per-DALY estimates with ranges. Neumann (2016)

Name and Link	Data or Model	Step of Valuation	Spatial, Contextual or Temporal Factors
http://healtheconomics.tuftsmedicalcenter.org/ghcearegistry			
Health Utility of Income https://www.valuingnature.ch/single-post/2018/07/20/VALUING-THE-IMPACT-OF-WAGES-ON-HUMAN-CAPITAL	Model	Valuation	Calculates health benefits of income. Is a function that inputs income and country and outputs DALY benefit. DALY benefit can be monetised. Linear regressions.
Global Value Exchange http://www.globalvaluexchange.org/	Synthesis of literature	Database of valuation factors	Global Value Exchange (GVE) ingested data from literature or reports to connect outcomes to valuations. Search on food lists 6 outcomes, 27 indicators of those outcomes and 127 valuations that have been. Valuations are specific to the study sites and participants. Links to the sources of the valuations. http://www.globalvaluexchange.org/news/b07bcb501c
Literature review	Model based on social discount rate review	Discount rate	Moore (2004) provides a review and a prescription for discount rates.
UK Treasury Green Book supplementary guidance: discounting https://www.gov.uk/government/publications/green-book-supplementary-guidance-discounting		Discount rate	In the United Kingdom, HM Treasury fixes the social discount rate for the public sector at 3.5% with recommended adjustments for intergenerational effects. See UK Treasury Green Book Table 8 and (Lowe 2008)
ReCiPe perspectives: individualistic, hierachistic, egalitarian	Model	Discounting	From ReCiPe 2016 LCIA method and utilised in CE Delft Environmental Prices Handbook. Individualist: proven cause-effect relationships, short-term perspective (20 years). Hierarchistic: facts backed by scientific and political bodies (100 years). Egalitarian: precautionary approach, long-term perspective (1000 years).
Currency Exchange Rates	Data	Parity	Compare national economies by currency exchange rates.

Name and Link	Data or Model	Step of Valuation	Spatial, Contextual or Temporal Factors
			https://www.imf.org/external/np/fin/data/param_rms_mth.aspx
Purchasing power parity (PPP)	Model based on consumption data	Parity	Compare national economies by ability to purchase basic goods. World Bank Intercomparison Program. https://www.worldbank.org/en/programs/icp
Global Utilitarianism	Data	Parity	Global PPP GDP per capita.
Prioritarianism	Model	Parity	Greater value for benefits to the socio-economically worst off. Applied in literature studies, e.g. Adler (2017)
Benefit transfer	Model	Parity	Applied ad hoc to transfer economic value from study sites to other sites https://link.springer.com/chapter/10.1007/978-94-017-9930-0_2
PPP GDP	Model based on economic data	Welfare measure	IMF, World Bank
Satisfaction complemented GDP	Model based on economic data	Welfare measure	Stiglitz (2009), Jones and Klenow (2010)
Wealth measures	Model based on economic data	Welfare measure	UN Inclusive Wealth 2018
PAGE	Model	Integrated model	Climate damages (see IWGSCC social cost of carbon)
DICE	Model	Integrated model	Climate damages (see IWGSCC social cost of carbon)
FUND	Model	Integrated model	Climate damages (see IWGSCC social cost of carbon)
NEEDS	Model	Integrated model	Air pollution damages (see EU-28 Handbook Environment prices)
LCA Software	Model	Integrated model	Allows LCI (footprint calculation), LCIA and pricing to be performed together. Environmental focus, e.g. SimaPro uses EU-28 Handbook Environmental prices and GaBI uses TruCost prices.

Listing the methods from the report shows that environmental and health considerations applicable to the food system impact valuation are the most developed. Social impact pathways the least.

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What is the cost of the food we eat? What is the value of the sustainable products and practices in the food sector? How do we balance the short-term and private value that food provides with the longer-term and externalised costs taking their toll on nature, the communities of workers producing and processing food, human health, and more?

This report examines food impact costing, and whether the way that carbon is costed in terms of social and abatement costs of carbon footprints can be adjusted to estimate the longer-term and externalised costs of food production, processing and consumption. It argues that a footprint protocol solidifying what to measure and how to track footprint reduction should be developed. It finds unavoidable ethical choices and order of magnitude uncertainties inherent in both social and abatement costing, recommending that a consortium of intergovernmental and institutional actors and experts in collaboration with the food sector process should compile, set and update shadow prices associated to food footprints.

A model is outlined for comparable valuation that uses shadow prices for where and how impact and footprints occur. Non-linear corrections to impact costing for scarcity and interactions created by food's multiple footprints, and risk-based corrections because of uncertainty, are among the topics discussed.

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)

December 2019

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