Trucost 2016.

Top down methodology:

TEEB Animal Husbandry

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APPENDIX I. OVERALL APPROACH

The process followed for the quantification and valuation of natural capital impacts in the top down approach is presented in the figure below. This process is applied to the three livestock sectors selected on the study: beef, dairy milk and poultry meat production.

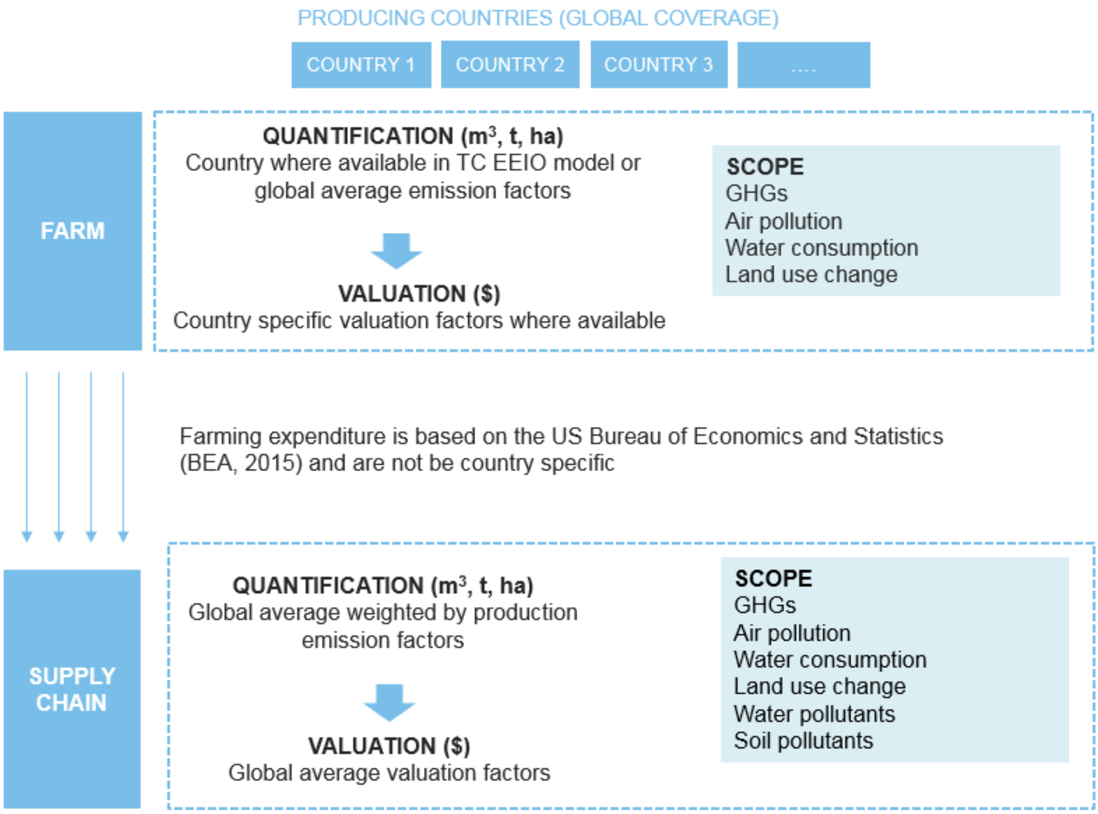

FIGURE 1. OVERVIEW OF THE METHODOLOGY USED FOR THE TOP DOWN APPROACH.

The description of Trucost's EEIO model is provided in Appendix II, and the different valuation methodologies in Appendix III.

APPENDIX II. TRUCOST'S ENVIRONMENTALLY EXTENDED INPUT-OUTPUT (EEIO) MODEL

OVERVIEW

Environmental impacts directly attributable to a business are calculated according to Trucost's environmental matrix, which contains expenditure information and environmental intensities per unit of output across over 400 sectors. The environmental expenditures are used in conjunction with the environmental intensities in order to model the impacts across the economy associated with the activity of a company within one of these sectors. The environmental data that is used within the EEIO comes from a number of sources including FAO, LCA databases such as Agri-Footprint and UNFCCC. Trucost has been collecting environmental data since 2000, and is therefore able to test this model based against 14 years' of data on quantitative environmental disclosures, from thousands of companies, which analysts engage with annually.

The EEIO can be segregated into two parts – the 'direct' and 'indirect' models. The direct model estimates the impacts resulting from the operations of a business, for example, the emissions coming from on-site fuel use or the impacts associated with applying fertilisers. The indirect model estimates the impacts from the activities from upstream suppliers. These are businesses that produce the inputs so that a business can operate. This can include the impacts associated with producing fertilisers, pesticides as well as the transportation of purchased goods. More details on the direct and indirect models can be found below.

TABLE 1: THE KEY COMPONENTS OF TRUCOST'S EEIO MODEL

Component	Justification
Direct Model	**Environmental Matrix** The environmental impacts of sectors are calculated using country-specific impact factors. Market traded commodities extracted and water resources are measures at a local level.
Indirect Model	**Input-Output (IO) Factors** IO factors for the flow of goods and services between sectors are created from the U.S. Bureau of Economic Analysis (BEA) benchmark make and use tables.

DIRECT MODEL

Each sector within the environmental matrix contains an average impact per dollar of output for over 100 impacts which are derived from governmental, life cycle assessment and academic data. Trucost tests this data against the many thousands of disclosures it collects from companies during the annual engagement programme.

The sources used to determine direct factors for agricultural sectors are described below. Non-energy related greenhouse gases data, such as enteric fermentation, was sourced from the UNFCCC on a country-by-country basis or from the FAOSTAT Emissions Database, based on IPCC Tier 1 Guidelines. Simapro's Agri-footprint library (Simapro, 2014a) and Ecoinvent library (Simapro, 2014b) were used to quantify energy related greenhouse gases emissions and air pollutants. Water consumption was determined using data from Mekonnen and Hoekstra (2010) at a country level. Land use for ruminants was estimated using SOL-M (FiBL, 2012). Land use for poultry was calculated combining the distribution of intensive and extensive systems for different regions (FAO and ILRI, 2011) and respective animal densities (FAO, 2004; LEI Wageningen UR, 2013). Pesticide use factors were determined using NCFAP (2008) and FAO (2009). Production quantities and price of commodities per country were sourced from FAO (2011a) and FAO (2011d) respectively.

Where available, Trucost applied country specific factors. Otherwise, Trucost applied global average factors weighted by production value.

INDIRECT MODEL

Indirect or supply chain impacts are calculated according to Trucost's indirect model. This is constructed from supply and use tables published by the United States Department of Commerce, Bureau of Economic Analysis (BEA, 2015). BEA compiles data from a wide range of sources including the Economic Census (conducted every 5 years) and annual surveys for specific industries including the agricultural; mining; manufacturing; wholesale trade; retail trade; transportation, communications, and utilities; finance, insurance, and real estate surveys. Data is collated and homogenised so that each industry's inputs reflect as far as possible, a unique set of inputs for over 400 industries.

IO tables are created detailing the ratio of expenditure from one sector with every other sector of the economy, termed "intermediate demands". It is largely due to this level of detail that Trucost has chosen to use the U.S. economy as a proxy for the world economy as a starting point for the creation of its indirect model. Additionally, the U.S. economy has the advantage of being highly diversified so that major commodities can be included.

However, some sectors which are important from an environmental perspective, such as power generation, are highly aggregated, and the U.S. BEA data have insufficient detail on many sectors within the agricultural industry. In these cases, Trucost has disaggregated the IO tables proportionally. For example, power generation is represented by seven separate sectors within the Trucost model. Trucost has further extended the indirect model to create indirect input-output factors for an additional 80 sectors, as well as incorporating life cycle analysis and process benchmark data. Finally, the indirect model is refined by disclosures to Trucost from its universe of over 4,500 companies which is collected through an annual engagement program.

APPROACH

The table below outlines the key methodological steps in this process as well as giving some examples at each of these stages.

TABLE 2: STEPS TAKEN IN TRUCOST'S ESTIMATION OF ENVIRONMENTAL IMPACTS

Methodological Steps	Examples
Selection of the sector(s) of interest from a list of 531 sectors	Soybean farming; natural gas extraction; coal power generation; industrial gas manufacturing
Definition of the functional unit to be used	1 tonne of soybeans; 1 million cubic feet of natural gas; 1000 MWh; US$1 million revenue
Modelling of operational environmental impacts	These are calculated using country-specific or global average factors. Data is utilized from a wide array of supra-national, international, national, and industry bodies across a wide range of sectors and geographies. Impacts are calculated in one of seven categories including: - Greenhouse gas emissions - Air pollutants - Land pollutants - Water pollutants - Waste generation - Water consumption - Land use
Modelling of supply chain environmental impacts	By adapting 'make and use' tables from the United States Bureau of Economic Analysis, Trucost estimates the environmental impacts of sectors within supply chains by applying environmental intensities to the flows of monetary transactions. The US economy is therefore used as the benchmark for national economies around the world. The same impacts captured as part of the operational modelling are considered for the supply chain modelling.
Calculation of total environmental impacts	Total environmental impacts include pollutant emissions and resource use from operational and supply chain activities. Total environmental impacts are calculated in terms of metric tons, cubic meters, or square meters per functional unit (for example per unit of revenue).
Outputs	Over 100 quantified environmental impacts are classified into the categories listed above, which enables: - Identification of the countries or regions generating the greatest absolute and relative environmental impacts - Identification of the most material environmental impacts for each country or region - Comparison of operational versus supply chain impacts

STRENGTHS AND WEAKNESSES

IO modelling assumes generic flows behind sectors, as described in the indirect model above. On a global basis, this can be adjusted using multi-regional IO modelling, or a hybrid approach as suggested by Trucost for this project. Multi-regional IO modelling adjusts for trade between regions to estimate embedded impacts in products more accurately. Trucost recommends adopting a hybridised approach to adjust for regional variations in environmental impacts as described above. This is because single region IO models have greater granularity: Trucost's EEIO model includes over 400 sectors whereas multi-regional IO models usually include 80 sectors.

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APPENDIX III. VALUATION METHODOLOGIES

VALUATION FRAMEWORK

Trucost's valuation framework builds on an approach proposed by Keeler et al. (2012). The approach follows a four-step process which is outlined in the table below.

TABLE 3: STEPS TAKEN IN TRUCOST'S VALUATION FRAMEWORK ADAPTED FROM KEELER ET AL. (2012)

Valuation Framework Steps	Examples
Identify actions and beneficiaries of interest	Local communities or users of specific natural resources
Identify shared physical characteristics of the biophysical and economic models	The identification of the attribute you are valuing, such as the changing concentration of pollutants, or change in water clarity
Select appropriate biophysical models	The identification of how the changing biophysical conditions affect the selected beneficiaries. For instance, how the changing concentration of pollutants reduces life expectancy and quality of life, measured in terms of disability adjusted life years (DALY)
Select appropriate economic models	Selecting the appropriate monetary valuation method to value the change in biophysical conditions, such as the value of a life year (VOLY) to value human health impacts

The following steps highlight how the approach described above can be applied to assign monetary values to the impacts on human health and ecosystems resulting from increasing chemical concentrations in the atmosphere due to the use of pesticides:

1. The first step involves measuring changes in physical conditions, such as an increase in the concentration of a pollutant in the atmosphere, land, or water.
2. The second step requires biophysical modelling of the impacts caused by changing physical conditions. This includes identifying factors such as the endpoint of pesticides in the environment, for example human beings, and quantifying the change in the biophysical indicator that is to be valued, for example the change in the quality of human health. This is measured by the change in disability adjusted life years (DALYs) and can be caused by the ingestion or inhalation of pesticides. Another endpoint for pollutants could be terrestrial ecosystems, and the quantification of the subsequent biophysical change is its effect on biodiversity, measured in terms of the potentially disappeared fraction of species (PDF).
3. The final step involves the economic modelling component of the valuation. This includes the identification of the final recipient of the impact, such as local populations who are negatively impacted by ingesting or inhaling pesticides, and then selecting an appropriate valuation technique to monetize the change in biophysical conditions. In this instance, Trucost uses the value of a life year (VOLY) to assign monetary values to the change in human health. For the effect on ecosystems in this example, Trucost values the loss of

ecosystem services resulting from the impact on biodiversity and the decreased functioning of those ecosystems.

For a detailed description of the methods and data employed by Trucost, please refer to the valuation methodology documents highlighted in the table below. The drivers listed can refer to the emissions of pollutants or resource use resulting from human activities.

TABLE 4: TRUCOST VALUATION METHODOLOGIES

Driver	Valuation Methodology
Greenhouse gas emissions to air	Greenhouse gas (GHG)
Emissions of other air pollutants	Air, land, and water pollutants
Emission of pollutants to land	Air, land, and water pollutants
Emission of pollutants to water	Eutrophication
Water consumption	Water consumption
Land use change	Land use change

For more information on the valuation methodologies above, as well as sensitivity analysis for selected parameters, please refer to the full Trucost valuation methodology at Trucost (2015).

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GHG EMISSIONS

1. OVERVIEW

1.1. GENERAL PROCESS

Trucost values greenhouse gas (GHG) emissions using the social cost of carbon (SCC). The SCC is typically considered best practice as it reflects the full global cost of the damage generated by GHG emissions over their lifetime in the atmosphere. The SCC can be used to monetize the impact of GHG emissions globally, which is not the case when using market prices found in emissions trading schemes (ETS), nor when using the marginal abatement cost (MAC). GHG emissions are usually expressed in metric tons of carbon dioxide equivalents (CO_2e)[1].

Emission trading schemes are generally promoted for their flexibility to reduce emissions at the lowest cost for the economy, as well as their steadily increasing global reach (World Bank Group, 2014). However, traded market prices currently face a number of limitations which restrict their effectiveness in decision-making. For example, they do not reflect non-traded carbon costs nor the impact of other market-based mechanisms such as subsidies for fossil fuels or low-carbon technologies (Krukowska, 2014). Traded carbon prices have also been historically slow to come about, schemes have not been distributed equally, and they can be impacted by sudden economic changes which reduces the carbon price to levels that undermine the incentive for polluters to cut emissions (*Ibid*).

The marginal abatement cost is based on the known actual costs of existing reduction efforts. This renders it a valuable tool for informing policy discussions, prioritizing investment opportunities and driving forecasts of carbon allowance prices. Despite this, it too does not reflect non-traded carbon costs, and thus severely underestimates the true cost of GHG emissions. The MAC is highly time and geography specific with costs of reduction fluctuating over time, by sector and by geography, and estimates are influenced by fossil fuel prices, carbon prices and other policy measures.

The SCC is an estimate of the monetized damages associated with an incremental increase in GHG emissions in a given year. To estimate the SCC, Integrated Assessment Models (IAMs) are used to translate economic and population growth scenarios, and the resulting GHG emissions, into changes in atmospheric composition and global mean temperature. Trucost bases its SCC valuation on the work conducted by the Interagency Working Group on the Social Cost of Carbon. Trucost uses the values reported at the 95th percentile under a 3% discount rate, which represents higher than expected impacts from temperature change (IWGSCC, 2013). This decision has been taken to address material methodological omissions that arise due to modelling and data limitations, such as the unknown nature of resulting damages, and because the latest scientific data and methods incorporated into these models naturally lags behind the most recent research. Table 5 summarizes the valuation of GHG emissions.

TABLE 5: YEARLY US EPA REVISED SCC, 2010-2014 (USD PER METRIC TON OF CO_2)

Year	Social Cost of Carbon, US$
2010	93
2011	101
2012	107
2013	113

[1] Carbon dioxide is only one of many GHGs, such as methane, nitrous oxide, hydrofluorocarbons, perfluorocarbons, and sulfur hexafluoride. Carbon dioxide equivalents (CO_2e) is a measure that relates the impact of other GHGs to carbon dioxide over the same lifetime, usually 100 years.

Year	Social Cost of Carbon, US$
2014	120

2. VALUATION METHODOLOGY SUMMARY

2.1. IMPACTS ON HUMAN HEALTH AND ECOSYSTEMS

2.1.1. Biophysical & Economic modelling

Over 300 studies attempt to put a price on carbon, quantifying and valuing the impact of climate change on agricultural productivity, forestry, water resources, coastal zones, energy consumption, air quality, tropical and extra-tropical storms, property damages from increased flood risk and human health. The IAMs approximate the relationship between temperature changes and the economic costs of impacts. These economic costs arise from changes in energy demand, changes in agricultural and forestry output, property lost due to sea level rise, coastal storms, heat-related illnesses, and diseases such as malaria.

Out of the many studies that attempt to calculate the SCC, Trucost has chosen to use SCC estimates provided by the Interagency Working Group on the Social Cost of Carbon based in the United States (IWGSCC, 2013). The reasons for this include:

- Calculations are based on three well-established Integrated Assessment Models, which render the estimate more robust and credible than other approaches.
- The SCC takes into account the timing of emissions, which is key to the estimation of the SCC. For example, the SCC for the year 2020 represents the present value of the climate change damages that occur between the years 2020 and 2300, and are associated with the release of GHGs in 2020.
- Results are presented across multiple discount rates (2.5%, 3% and 5%) because no consensus exists on the appropriate rate to use. This allows flexibility in the choice of discount rate according to project objectives.
- The methodologies employed are continuously improved through regular feedback workshops, engagement with experts, and integrating the latest scientific evidence. As a result, the latest 2013 update provides higher values than those reported in the 2010 technical support document, and incorporates updates of the new versions of each underlying IAM.

LIMITATIONS

SCC valuations are contingent on assumptions, and in particular the discount rate chosen, the emission scenarios and equity weighting. These are highlighted briefly below.
Despite being the most complete measure of the damage caused by GHG emissions, SCC estimates have attracted criticism as they omit or poorly quantify some major risks associated with climate change. For instance, Tol's FUND model (FUND, 2015) omits social unrest, disruptions to economic growth, and ocean acidification. Other impacts that have been omitted in similar approaches include the loss of biodiversity, habitat and species extinction, and damages from Arctic sea ice loss and changing ocean circulation patterns (Howard, 2014; Kopits, 2014).

Three well-established IAMs, which form the foundation of the IWGSCC's estimates, have received most attention in the literature: DICE 2010, FUND 3.8, and PAGE09. Some of the limitations of these models are summarized below:

- Extensive experiments with DICE have shown that with small, reasonable changes to the basic data, DICE can yield very different projections.
- The FUND model was found by the Heritage Foundation's Centre for Data Analysis (CDA) to be extremely sensitive to assumptions; so sensitive that at times it even suggests net economic benefits to GHG emissions (Dayaratna and Kreutzer, 2014). According to the FUND model, change in temperature up to 3°C is contributing beneficially to the environment (IWGSCC, 2010).
- PAGE sets a relatively high temperature threshold for the onset of catastrophic damages.

SCC estimates also range from negative values up to four-figure estimates. This is mainly due to four factors that are outlined below:

- **Emissions scenarios:** The assumptions made on future emissions, the extent and pattern of warming, and other possible impacts of climate change, then deriving how these factors translate into economic impacts.
- **Equity weighting:** This refers to the spatial and temporal dimensions of climate change impacts. Some studies take account of equity weightings which adjust SCC estimates for differences in climate change impacts depending on the development and wealth of nations (Stern, 2006; Tol, 2011).
- **Uncertainties:** The variation in SCC valuations is influenced by uncertainties surrounding estimates of climate change damages and related costs.
- **Discount rate:** Higher discount rates result in lower present day values for the future damage costs of climate change. The long time horizon of climate change impacts makes the choice discount rate crucial as well as controversial (IPCC, 2014). For example, Stern (2006) uses a discount rate of 1.4% compared to a range of between 2.5% and 5% by the US EPA (2013).

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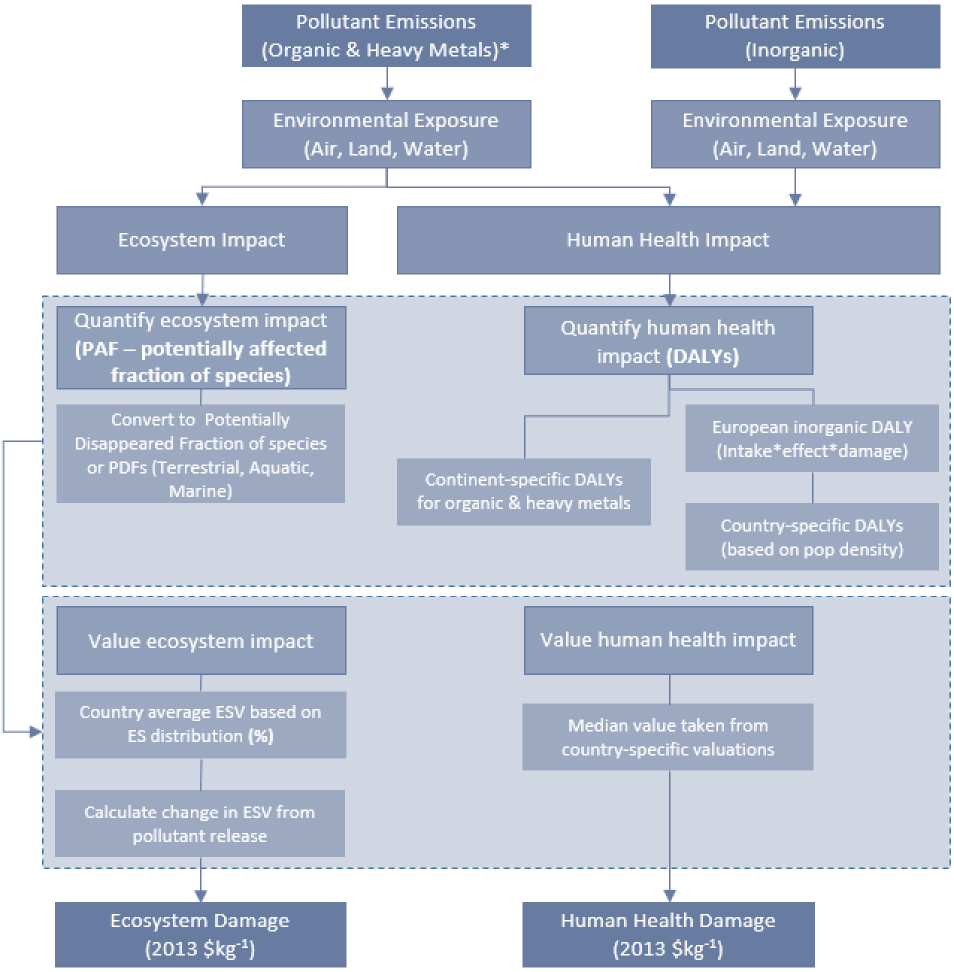
AIR LAND AND WATER POLLUTANTS

1. OVERVIEW

1.1. GENERAL PROCESS

Figure 2 summarises the overall approach used to value the emission of air, land, and water pollutants. The first shaded box indicates the steps taken to quantify the environmental impacts of these pollutants, while the second indicates the steps taken to value these impacts.

FIGURE 2: GENERAL OVERVIEW OF TRUCOST VALUATION PROCESS FOR AIR, LAND AND WATER POLLUTANTS



ESV: Ecosystem Services Value

DALY: Disability Adjusted Life Years

ES: Ecosystem Services

Inorganic pollutants include carbon monoxide (CO), sulphur dioxide (SO2), nitrous oxides (NOx), ammonia (NH3), particulate matter (PM), and volatile organic compounds (VOCs)

*Organic pollutants and heavy metals are grouped together due to the similarity in methodology, not chemical properties.

2. VALUATION METHODOLOGY SUMMARY

2.1. IMPACT ON HUMAN HEALTH

2.1.1. Biophysical modelling

ORGANIC SUBSTANCES AND HEAVY METALS

Trucost uses disability adjusted life years (DALYs) as a measure of the impact on human health from environmental impacts. In order to calculate the quantity of DALYs lost due to the emission of pollutants to air, land and water, Trucost used USES-LCA2.0 (EC, 2004; National Institute of Public Health and the Environment, 2004). This model, originally developed in the context of life cycle assessment (LCA) studies, calculates the quantity of DALYs lost due to emission of over 3,300 chemicals to: freshwater and seawater; natural, agricultural and industrial soil; and rural, urban and natural air. USES-LCA2.0 takes into account the impact of cancer and non-cancer diseases caused by the ingestion of food and water, and the inhalation of chemicals.
The output of this analysis step is the number of DALYs lost due to the emission of each pollutant, to a specific media, at the continental level.

Note that organic substances and heavy metals are grouped together due to the similarity in methodology, not their chemical properties.

SULPHUR DIOXIDE, NITROGEN OXIDE, AND PARTICULATE MATTER (PM10)

USES-LCA2.0 does not estimate DALY impacts for common inorganic air pollutants such as sulphur dioxide, nitrogen oxide and PM10. Adaptation of USES-LCA2.0 to model these substances would result in higher than acceptable uncertainty due to the different characteristics of organic and inorganic substances. Trucost conducted a literature review to find an alternative method to quantify the DALY impact of emission of these pollutants.

2.1.2. Economic Modelling

Once the quantity of DALYs lost is calculated, several valuation methods can be used to put a monetary value on a DALY, such as the cost of illness, the value of a statistical life (VSL), and the value of a statistical life year (VOLY).

Trucost decided to use the WTP technique utilized in the VOLY method to value DALYs, as it encompasses most aspects relating to illness and expresses the value of a year of life to the wider population. To value DALYs, Trucost used the results of a stated preference study conducted for the New Energy Externalities Development for Sustainability (NEEDS) project (Desaigues et al., 2006; 2011). This is a proactive cost estimate, which takes into account the perceived effects of morbidity. The value of a life year used in this methodology is just in excess of $46,500.

2.2. IMPACT ON ECOSYSTEMS

2.2.1. Biophysical Modelling

ORGANIC SUBSTANCES AND HEAVY METALS

USES-LCA2.0 models the impact of polluting substances emitted to air, land and water, on terrestrial, freshwater and marine ecosystems. This model was adopted by Trucost for assessing the ecosystem damage caused by organic substances and heavy metals. It follows the same modelling steps as for human toxicity, namely exposure assessment, effect assessment, and risk characterization. USES-LCA2.0 has also been adapted to generate results at a continental level.
USES-LCA2.0 estimates the potentially affected fraction of species (PAF) due to the emission of pollutants to air, land and water. It is important to note that affected species need not disappear. Trucost adjusted the PAF results to reflect the proportion of species disappeared (PDF) using assumptions from the Eco-Indicator 99 model (Goedkoop & Spriensma, 2000). This was done to match the valuation methodology, which uses PDF (and not PAF) as an input due to data availability.

OZONE, SULPHUR DIOXIDE, NITROGEN OXIDE, AND PARTICULATE MATTER (PM10)

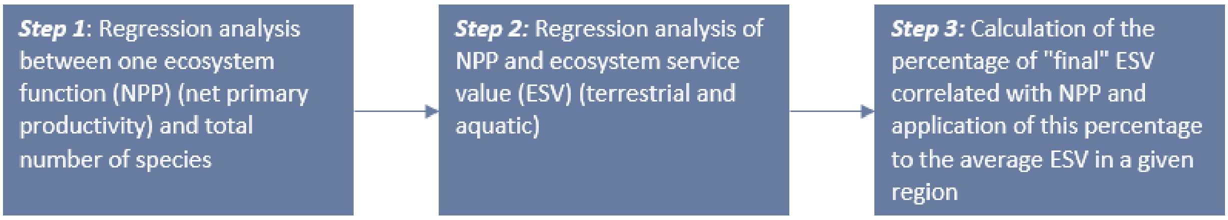
Impact on ecosystems has not been included for ozone, sulphur dioxide, nitrogen oxides and PM10.

2.2.2. Economic Modelling

VALUING THE IMPACT ON ECOSYSTEMS IN THIS STUDY

Trucost's approach to valuing a change in the PDF of species follows a three-step process, as shown in figure 3.

FIGURE 3: STEPS FOR CALCULATING THE VALUE OF ECOSYSTEM SERVICES LINKED DIRECTLY TO BIODIVERSITY



In this methodology, Trucost decided to assess the link between biodiversity, measured species richness (IUCN, 2015), net primary productivity (NPP) (Costanza et al., 2007), and ecosystem service value (ESV). NPP was chosen over other ecosystem processes, such as nutrient cycling, due to data availability and its direct link with key ecosystem services. A monetary value for the provisioning, regulating and cultural services by terrestrial ecosystem type was first calculated based on the analysis of De Groot et al. (2012) using the specific ecosystem split per country (Olson et al., 2004). De Groot et al. calculate the minimum, maximum, median, average and standard deviation for each service provided by key terrestrial and aquatic ecosystems. Finally, Trucost calculated the percentage difference pre- and post-change of ESV at a country and substance level, and applied this percentage to the average value of one square meter of natural ecosystem in a given region. This aligns with the results of USES-LCA2.0, which calculates change of species richness, or PDF, at a continental level.

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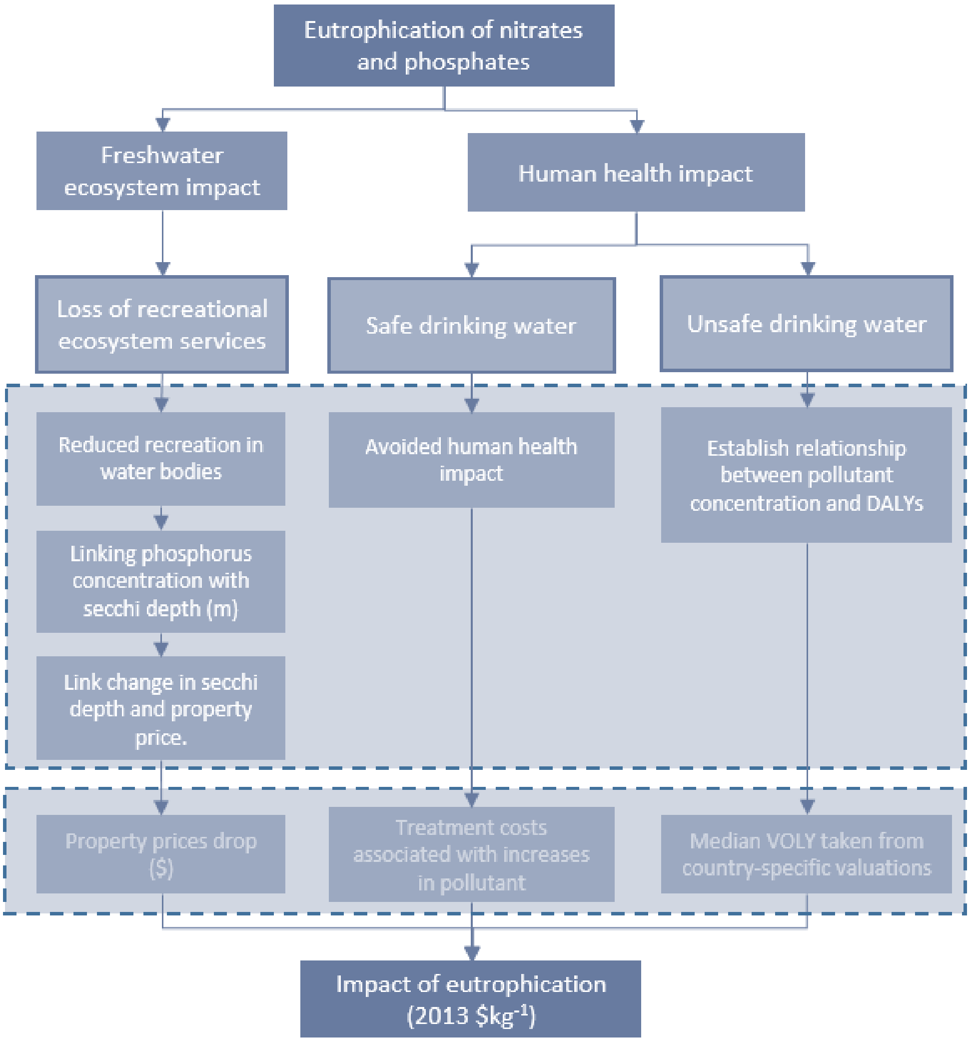
EUTROPHICATION

1. OVERVIEW

1.1. GENERAL PROCESS

Figure 4 summarizes the high-level steps taken to value the impacts of eutrophication. Not all of the possible impacts have been included in the current methodology, such as the loss of fish yields in freshwater and marine ecosystems, and the loss of recreational services in marine ecosystems.

FIGURE 4: GENERAL OVERVIEW OF TRUCOST VALUATION PROCESS



2. VALUATION METHODOLOGY SUMMARY

2.1. IMPACT ON HUMAN HEALTH

2.1.1. Biophysical Modelling

Water pollution can directly impact human health when unsafe drinking water is consumed. However, water is also treated to prevent the negative impacts of polluted water consumption and this comes with an economic cost. Therefore, to account for the true impact on human health, it is necessary to look at the economic costs of both safe and unsafe drinking water.

UNSAFE DRINKING WATER

Trucost used the data from the EXIOPOL study to calculate the median years of life lost (YLL) per 100,000 males and females within a country due to the consumption of unsafe drinking water. Population data obtained from the World Bank allowed YLL to be made country-specific via adjustments for the demographic breakdown of each nation by gender. The biophysical indicator used for determining YLL was the concentration of nitrates in drinking water.

To calculate the percentage of the national population exposed to unsafe drinking water, Trucost assumed that water was taken directly from freshwater lakes. For this approach, it was necessary to estimate the catchment area from average-sized lakes within each country to determine the proportion of the national population that were most likely to be affected by drinking unsafe water caused by eutrophication. Trucost assumed a three kilometer catchment area for each national average-sized lake. This was selected from a study that found that the majority of the world's population live within three kilometers of a freshwater source (Kummu et al., 2011). The population density of each country was applied to calculate how many people live in the catchment area.

Finally, the percentage of the population with access to safe drinking water (World Bank Group, 2015) was removed from the calculation so that the valuation was only applied to those who were expected to be reliant on the consumption of unsafe drinking water.

Trucost used YLL as a proxy for DALYs as no information on the years of healthy life lost due to disability (YLD) from consuming eutrophic drinking water could be sourced.

SAFE DRINKING WATER

For the proportion of water that is safe to drink, there is an economic cost associated with cleaning the water to a high enough quality. The model used in this approach requires an input of phosphorus yield in a watershed in order to calculate the cost of treating eutrophic water. Information reported by the Nature Conservancy (McDonald & Shemie, 2014) was used to determine the incremental change in phosphorus from an initial sediment yield, which could be used to calculate the biophysical metric.

2.1.2. Economic Modelling

UNSAFE DRINKING WATER

Once the total YLL (hence DALYs) lost is calculated, several valuation methods can be used to put a monetary value on a DALY, such as the cost of illness, the value of a statistical life (VSL), and the value of a statistical life year (VOLY).

Trucost decided to use the WTP technique utilized in the VOLY method to value DALYs, as it encompasses most aspects relating to illness and expresses the value of a year of life to the wider population. To value DALYs, Trucost used the results of a stated preference study conducted in the context of the New Energy Externalities Development for Sustainability (NEEDS) project (Desaigues et al., 2006; 2011). This is a proactive cost estimate, which takes into account the perceived effects of morbidity. The value of a life year used in this methodology is just in excess of $46,500.

SAFE DRINKING WATER

With increasing sedimentation and nutrient load, the cost of removing sediments increases. A reduction in sedimentation from nutrient pollution by an average of 10% reduces treatment costs by 1.9% (McDonald & Shemie, 2014). This paper presents the relationship between phosphorus yield (tonnes of phosphorus per square kilometer of watershed) and treatment cost. The method was applied to calculate the total cost of water treatment after the unit mass of phosphorus has been applied in the watershed.

2.2. IMPACT ON ECOSYSTEMS

2.2.1. Biophysical Modelling

Trucost used the hedonic pricing approach in this methodology to quantify the impact on ecosystems, which estimates the effect of eutrophication on waterfront property prices, as these are significantly affected by water clarity (Gibbs et al., 2002). Secchi depth is the most widely used measure of water clarity, and a link between secchi depth and phosphorus level has been used to quantify the biophysical effect of eutrophication (Downing et al., 2010). This relationship has been investigated as early as the 1970s (see Canfield & Bachman, 1980).

Trucost calculated the increase in phosphorus equivalent concentration, in a national average-sized lake, associated with the use of one kilogram of nitrogen or phosphorus. Trucost calculated the marginal cost of an increase in eutrophication due to excess nutrient loading. The phosphorus concentration increase was calculated for an average-sized freshwater lake in a country. Using GIS data and the Global Lakes and Wetlands Database (Lehner & Döll, 2004), the median area of a lake, and the average perimeter of a median lake, was calculated for each country.

Trucost then converted the change in excess nutrient concentration into the change in secchi depth, and used the percentage change in secchi depth as the metric for valuation.

2.2.2. Economic Modelling

Trucost used data from three studies (Krysel et al., 2003; Gibbs et al, 2002; Michael et al., 1996) in the US, comprising a total of 44 estimates of water frontage price decreases (per foot) due to a one meter reduction in secchi depth, and calculated the median value.

Trucost adjusted the value for each country and calculated the price per waterfront meter. Finally, the value per waterfront meter for each country was applied to the perimeter of the average-sized national lake to establish the hedonic cost of eutrophication at a country-level.

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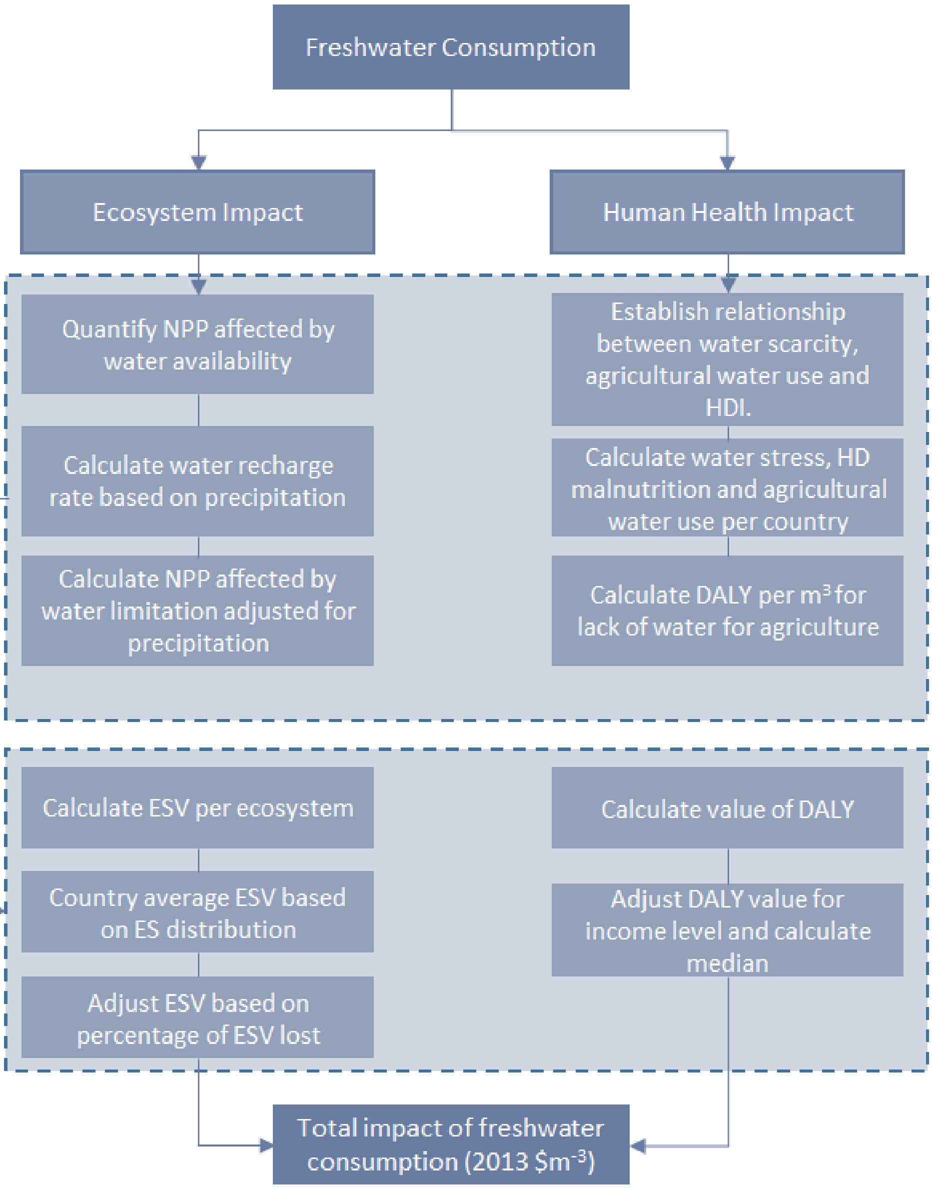
WATER CONSUMPTION

1. OVERVIEW

1.1. GENERAL PROCESS

Figure 5 summarises the overall approach used to value water consumption. The first shaded box indicates the steps taken to quantify the environmental impact of water consumption, while the second indicates the steps taken to value these impacts.

FIGURE 5: GENERAL OVERVIEW OF TRUCOST VALUATION PROCESS FOR WATER CONSUMPTION



LEGEND

NPP: Net Primary Productivity

ESV: Ecosystem Services Value

HDI: Human Development Index

DALY: Disability Adjusted Life Years

2. VALUATION METHODOLOGY SUMMARY

2.1. IMPACT ON HUMAN HEALTH

2.1.1. Biophysical Modelling

The quantification methodology for human health impacts due to water consumption was developed using an estimate of the disability adjusted life years (DALY) lost per unit of water consumed as reported in Eco-indicator 99 (Goedkoop & Spriensma, 2000). The impacts due to lack of water for irrigation are quantified in 'DALYs per cubic meter' of water abstracted.

In order to quantify human health impacts associated with malnutrition as a result of lack of water for irrigation, Trucost uses the methodology developed by Pfister (2011). This parameter is country-specific and depends on several variables such as water stress, share of total water withdrawals used for agricultural purposes, human development, and per-capita water requirement to prevent malnutrition.

2.1.2. Economic Modelling

Once the quantity of DALYs lost is calculated, several valuation methods can be used to put a monetary value on a DALY, such as the cost of illness, the value of a statistical life (VSL), and the value of a statistical life year (VOLY).
Trucost decided to use the WTP technique utilized in the VOLY method to value DALYs, as it encompasses most aspects relating to illness and expresses the value of a year of life to the wider population. To value DALYs, Trucost used the results of a stated preference study conducted in the context of the New Energy Externalities Development for Sustainability (NEEDS) project (Desaigues et al., 2006; 2011). This is a proactive cost estimate, which takes into account the perceived effects of morbidity. The value of a life year used in this methodology is just in excess of $46,500.

2.2. IMPACT ON ECOSYSTEMS

2.2.1. Biophysical Modelling

Impacts of water consumption on ecosystems were measured based on net primary productivity (NPP). NPP, which is the rate of new biomass production (by plants) that is available for consumption, is used by Trucost as a measure of how well an ecosystem is functioning. NPP was considered here as a proxy to measure impacts on ecosystems, as it is closely related to the vulnerability of vascular plant species (Pfister, 2011). Furthermore, vascular plants are primary products in the food chain and are therefore essential for the healthy functioning of an ecosystem (*Ibid*). In addition, it is assumed that damage to vascular plants is representative of damage to all fauna and flora species in an ecosystem (Delft, 2010).

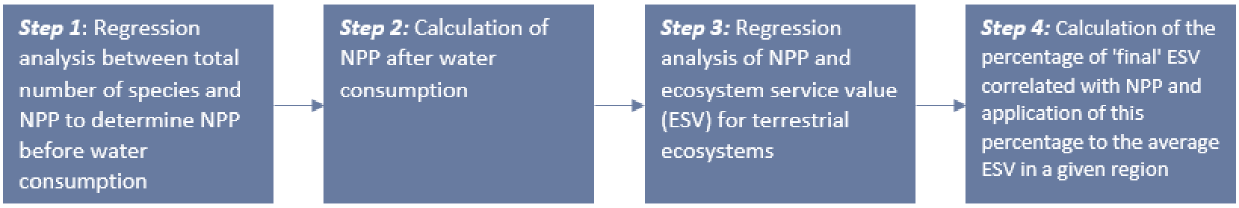
The objective of biophysical modelling is to determine the fraction of NPP which is limited only by water availability, and thus captures the vulnerability of an ecosystem to water deficiencies. However, as the effects of water consumption on ecosystems depend on local water availability, NPP is adjusted to take into account the prevailing water scarcity. Thus, the metric is expressed as the percentage of one square meter that will be affected by the consumption of one cubic meter of water in a year.

2.2.2. Economic Modelling

VALUING THE IMPACT ON ECOSYSTEMS IN THIS STUDY

Trucost's approach to valuing a change in NPP due to water abstraction follows a four-step process, as displayed in figure 6 below. The underlying approach calculates NPP before and after water consumption, and links those to the ecosystem service value (ESV) before and after water consumption. This allowed for quantifying the loss of ESV due to water abstraction.

FIGURE 6: STEPS FOR CALCULATING THE VALUE OF ECOSYSTEM SERVICES LINKED DIRECTLY TO BIODIVERSITY



Trucost first calculated the average NPP for each country in its database, based on the average NPP per ecosystem type (Costanza et al., 2007) and the ecosystem split per country (Olson et al., 2004). Species richness is based on the International Union for Conservation of Nature (IUCN) Red List, which provides at a country-level, the number of fauna and flora species, as well as their conservation status (IUCN, 2015).

Trucost then tested the strength of the relationship between NPP and species richness to assess whether a significant correlation exists. Trucost used this relationship to calculate the pre- and post-change in average NPP for each country in its dataset based on species richness

In order to calculate the post-change NPP, Trucost used the NPP limited by water availability to estimate the change in NPP that is attributable to water consumption. By using the percentage of NPP affected by water availability, the NPP remaining after water consumption was determined.

A monetary value for the provisioning, regulating and cultural services by terrestrial ecosystem type was first calculated based on the analysis of De Groot et al. (2012). De Groot et al calculate the minimum, maximum, median, average and standard deviation for each service provided by key terrestrial ecosystems.

Finally, Trucost calculated the percentage difference between pre- and post-water consumption ESV at a country level. Trucost applied this percentage to the average value of one square meter of natural ecosystem in a given region to align with the results of the biophysical modelling.

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LAND USE CHANGE

1. OVERVIEW

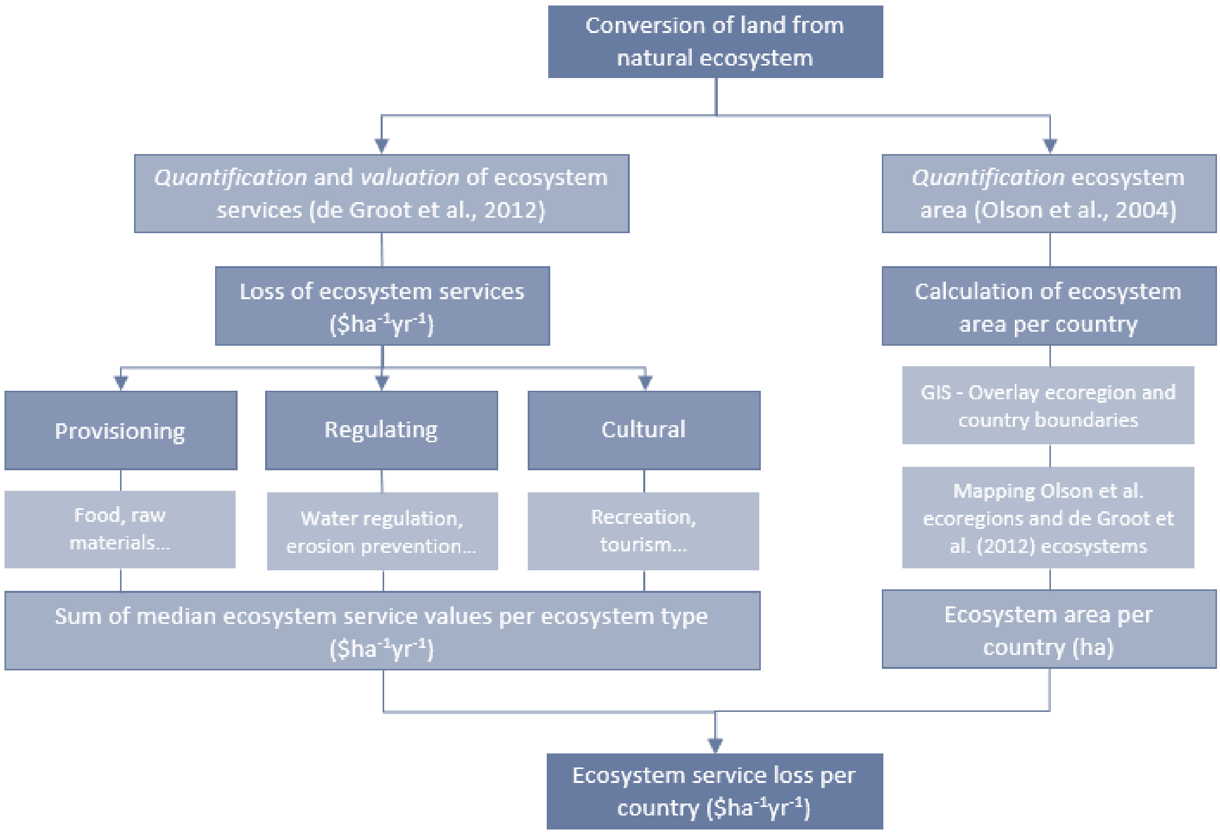
1.1. GENERAL PROCESS

Trucost's land use change methodology is used to value the ecosystem services loss when naturally occurring ecosystems have been converted to manmade ecosystems. For example, if rainforest has been converted to pastureland for cattle farming, this is considered as land use change and covered by Trucost's valuation. However, if another part of this rainforest has been degraded by removing vegetation, but is still considered as essentially the original rainforest, then this is not covered by Trucost's land use change valuation. The methodology takes the view that the time of land conversion is unknown, and therefore an average, not marginal, ecosystem value is used.

The value of the ecosystem services provided by the new land type may be quantified and assigned a monetary value depending on the scope of the work. The monetary valuation covered in this methodology represents the value of ecosystem services lost due to land use change only.

The valuation methodology is split into two parts: the quantification and valuation of ecosystem services, and the quantification of ecosystem area, per country or region. These are outlined in figure 7 below.

FIGURE 7: GENERAL OVERVIEW OF TRUCOST VALUATION PROCESS FOR LAND USE CHANGE



2. VALUATION METHODOLOGY SUMMARY

Trucost's methodology is split into two components – biophysical modelling and economic modelling. Biophysical modelling describes how Trucost calculates the ecosystem services that are lost by converting each ecosystem, as well as the land area converted from its natural state. Economic modelling describes how Trucost calculates the value of the ecosystem services that have been lost. Each section is described in more detail below. This methodology is limited to ecosystem services that are provided by terrestrial ecosystems.

2.1. IMPACT ON ECOSYSTEMS

2.1.1. Biophysical Modelling

DE GROOT ET AL. (2012)

For the purposes of this study, Trucost has used de Groot et al. (2012) as a basis for mapping material ecosystem services to ecosystems. De Groot et al. (2012) was preferred, as the study presents ecosystem service values in 'international dollars' suitable for global application. This also aligns with Trucost's other valuation methodologies, and means that the step of mapping ecosystem services between different studies does not have to be attempted. This step would involve the loss of some granularity in the final results. Table 6 outlines the ecosystems and the ecosystem services that have been considered in this study. The cells in red indicate where values were provided, but Trucost chose not to include them. The green cells indicate where an additional value was calculated. Both cases will be described in more detail later.
It is important to note that some ecosystem services, such as nutrient cycling, have been mapped to different ecosystem service categories. In this instance, nutrient cycling has been classified as a regulating service rather than a supporting service. Furthermore, the de Groot et al. (2012) study was based on a subset of 665 value estimates included in the Ecosystem Service Valuation Database (from a total of 1,300), selected on the basis of the following criteria:

i. The value was derived from an original case study (benefit transfer studies were excluded);
ii. The value can be assigned to a specific biome or ecosystem, and a specific time period;
iii. The value can be converted to a per hectare value;
iv. Information is provided on the valuation method used and
v. Information is provided on the location, surface area and scale of the study used to derive the value estimate.

TABLE 6: ECOSYSTEM SERVICES ASSESSED IN TRUCOST'S METHODOLOGY BASED ON DE GROOT ET AL. (2012)

Ecosystem	Provisioning services						Regulating services									Cultural services					Habitat or supporting services	
	Food	Water	Raw materials	Genetic resources	Medicinal resources	Ornamental resources	Air quality reg.	Climate reg.	Disturbance moderation	Water flow reg.	Waste treatment	Erosion prevention	Nutrient cycling	Pollination	Biological control	Aesthetic information	Recreation	Inspiration	Spiritual experience	Cognitive development	Nursery service	Genetic diversity
Coastal wetlands		Y	Y	Y	Y	-	-	Y	Y	-	Y	Y	Y	-	-	-	Y	-	-	-	-	-
Grasslands		Y	Y	-	Y	-	-	Y	-	-	Y	Y	-	-	-	-	Y	-	-	-	-	-
Inland wetlands		Y	Y	-	Y	Y	-	Y	Y	Y	Y	Y	Y	-	Y	Y	Y	Y	-	-	-	-
Temperate forest		Y	Y	-	-	-	-	Y	-	-	Y	Y	Y	-	-	-	Y	-	-	-	-	-
Tropical forest		Y	Y	Y	Y	-	Y	Y	Y	Y	Y	Y	Y	Y	Y	-	Y	-	-	-	-	-
Woodlands		-	Y	-	-	Y	-	Y	-	-	Y	Y	-	Y	-	-	Y	-	-	-	-	-

ECOSYSTEM AREA

The terrestrial area covered by each ecosystem in each country was calculated by mapping the ecosystem categories in table 6 to Geographic Information System (GIS) datasets representing country administrative boundaries and global ecoregions. Country boundaries, or administrative areas, were derived from the GADM v2.0 dataset (GADM, 2012). The data was downloaded as a shapefile and used in conjunction with ecoregion data derived from Olson et al. (2004), which showed the size and distribution of over 800 terrestrial ecoregions around the world. Once these datasets were spatially joined, Trucost was able to calculate the area of each ecoregion in each country.

2.1.2. Economic Modelling

Values of ecosystem services were also sourced from de Groot et al. (2012) as shown in table 7TABLE 7. However, de Groot et al. (2012) supplemented the information in this database with variables derived from GIS datasets that represent context specific characteristics of each study. This information was used to estimate a meta-regression value function for each ecosystem type. An example provided in the paper details the calculation of a value function for inland waterway ecosystems. This meta-regression value function is as follows:

$$\textbf{(1)}\ \ln(yi) = a + b_w X_{wi} + b_c X_{ci} + b_s X_{si} + u_i$$

y: wetland value standardized to 2007 US$ $ha^{-1}yr^{-1}$ (dependent variable)
$_i$: the number of value observations
a: constant
b_w, b_c, b_s: coefficients of the explanatory variable
X_{wi}: explanatory variable of the valued wetland (site area, wetland type…)
X_c: socio-economic and geographical context (GDP per capita, population within 50km…)
X_s: valuation study method
u: residuals

Table 7 details the ecosystem service values presented in de Groot et al. (2012), calculated using the method detailed above.

TABLE 7: UNIT VALUES OF ECOSYSTEM SERVICES, 2007 INTERNATIONAL DOLLARS $HA^{-1}YR^{-1}$ (DE GROOT ET AL., 2012)

Ecosystem	Provisioning services		Regulating services		Cultural services		Habitat or supporting services		Average unit value (2007 Int.$ $ha^{-1}yr^{-1}$)
	Ecosystem services	Values	Ecosystem services	Values	Ecosystem services	Values	Ecosystem services	Values	
Coastal systems	2	*15*	2	*2*	3	*7*	2	*4*	***28,917***
Coastal wetlands	5	*59*	5	*35*	1	*19*	2	*26*	***193,845***
Coral reefs	4	*30*	4	*16*	4	*39*	2	*9*	***352,915***
Fresh water (rivers/lakes)	2	*10*	1	*2*	1	*3*	-	-	***4,267***
Grasslands	4	*12*	3	*9*	2	*9*	1	*2*	***2,871***

Ecosystem	Provisioning services		Regulating services		Cultural services		Habitat or supporting services		Average unit value (2007 Int.$ $ha^{-1}yr^{-1}$)
	Ecosystem services	Values	Ecosystem services	Values	Ecosystem services	Values	Ecosystem services	Values	
Inland wetlands	5	*94*	6	*40*	3	*17*	2	*17*	***25,862***
Marine[2]	2	*7*	1	*1*	1	*4*	1	*2*	***491***
Temperate forest	3	*9*	5	*13*	2	*26*	1	*10*	***3,013***
Tropical forest	5	*38*	9	*31*	1	*20*	2	*7*	***5,264***
Woodlands	3	*13*	3	*3*	1	*1*	2	*4*	***1,588***

Trucost chose to use the ecosystem service values detailed in de Groot et al. (2012) on the basis that the values had been adjusted to account for Purchasing Power Parity (PPP) and because the meta-regression methodology applied was considered more robust than the Constanza et al. (2014) method. Costanza et al. (2014) was constrained by the need to follow the same methodology as in the 1997 study to ensure comparability. Costanza study also included the valuation of supporting services which may be partially or completely captured within the valuation of other ecosystem services.

Finally, Trucost considers land use change as any occupation of land that exists in place of natural ecosystems, which means the average value of ecosystem services is used instead of the marginal value. This takes into account the fact that the timing of land conversion is unknown with respect to the timespan from when there was zero ecosystem service scarcity to present day levels of scarcity.

[2] The term for the "Open Ocean" ecosystem has been used interchangeably with the "Marine" ecosystem. The data above represents the data available for the Open Ocean ecosystem in the de Groot (2012) Appendices.

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