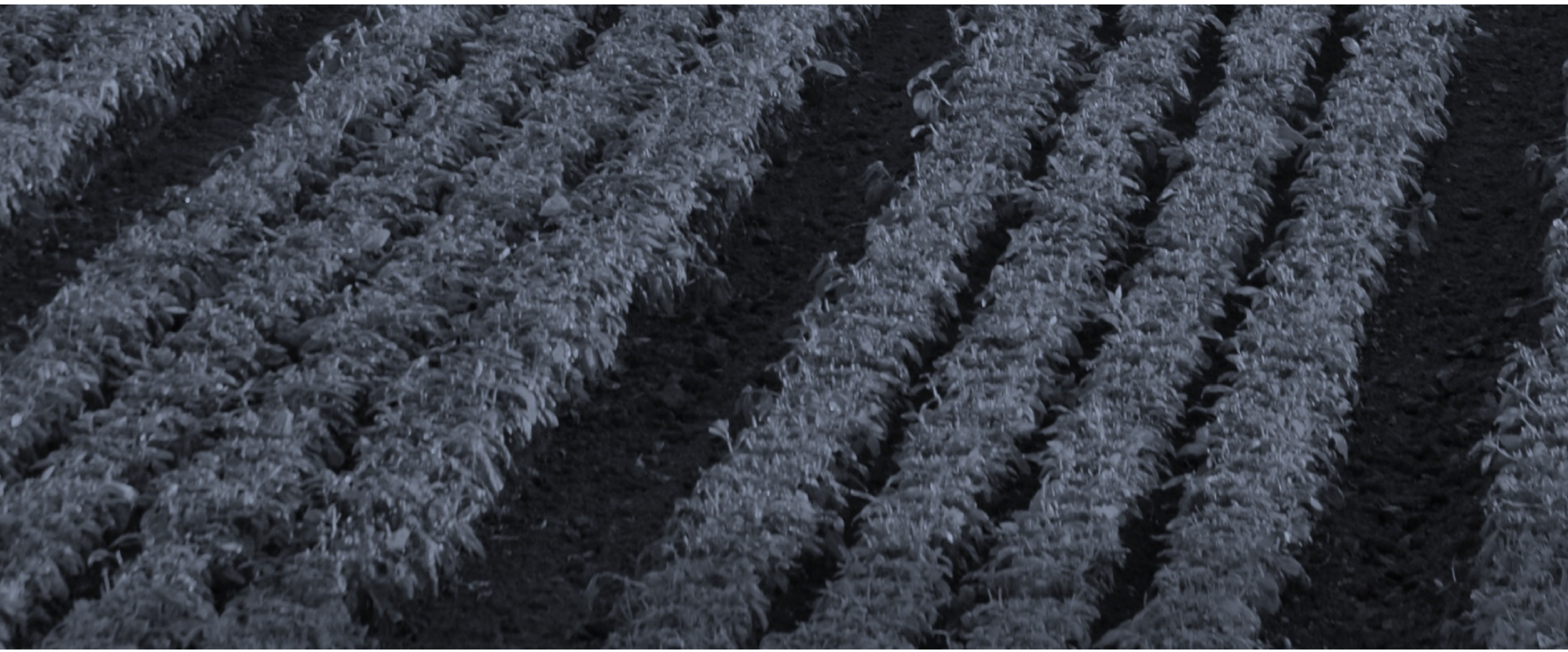
Food and Agriculture Organization
of the United Nations

# Natural Capital Impacts in Agriculture

## SUPPORTING BETTER BUSINESS DECISION-MAKING



**About this document**

This project is led by Nadia El-Hage Scialabba, Climate, Energy and Tenure Division, with the generous financial support of the Federal Republic of Germany. It builds on knowledge gained through the Food Wastage Footprint: Full-Cost Accounting (FAO, 2014). With this study, FAO aims to establish the basis for the development of the Food and Beverage Sector Guide of the Natural Capital Protocol currently in preparation.

**Acknowledgements**

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This project products are available at: http://www.fao.org/nr/sustainability/natural-capital

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# EXECUTIVE SUMMARY

Global food production faces a challenging landscape of rising input costs, climate change, health concerns, social inequality, resource competition and ecosystem degradation. With a global population set to reach 9 billion by 2050, do we fully understand the true costs and benefits associated with crop and livestock production, their different management practices, or the options for increasing productivity?

In many countries, there is a worrying disconnect between the retail price of food and the true cost of its production. As a consequence, food produced at great environmental cost in the form of greenhouse gas emissions, water pollution, air pollution, and habitat destruction, can appear to be cheaper than more sustainably produced alternatives.

With decisions to expand and intensify farming operations, stakeholders require better information on the relationship between their activities, the subsequent natural capital impacts, as well as their dependencies on natural capital. This study provides stakeholders with better information to inform strategic decision-making, which reduces impacts on natural capital that is crucial to long-term food provisioning and improving human well-being.

To enhance the understanding of natural capital impacts and dependencies of businesses, natural capital accounting and monetisation is increasingly being used by the business community. This enables technical environmental analysis to be translated into the language of economics and policy, so it can be better integrated into strategic business decision-making.

This study provides stakeholders with an indication of the true magnitude of the economic and natural capital costs associated with commodity production, and present a framework that can be used to measure the net environmental benefits associated with different agricultural management practices. This study builds on previous analysis from Trucost's study for TEEB on *Natural Capital at Risk: The Top 100 Externalities of Business*, and FAO's *Food Wastage Footprint: Full Cost Accounting*.

To achieve this objective, Trucost has worked with FAO on two different types of analysis, utilising both Trucost data and models, as well as FAO data, to deliver:

- A global, commodity-based "materiality" approach to assess the natural capital impacts caused by the production of four crops – maize, rice, soybean and wheat – and four livestock commodities – beef (from cattle), milk (from cattle), pork and poultry.
- A set of four case studies focusing on different agri-commodities, exploring the trade-offs that exist between adopting different farming practices. These studies include:
    - *Beef*: Holistic grazing management vs. conventional cattle grazing in Brazil
    - *Rice*: System of rice intensification (SRI) vs. conventional rice farming in India
    - *Soy*: Organic farming vs. conventional soybean farming in the USA
    - *Wheat*: Organic farming vs. conventional wheat farming in Germany

It is hoped that the outputs of this analysis will further accelerate business uptake of a monetary approach that supports the integration of natural capital costs into mainstream business decision-making and operations. Furthermore, the practical case studies aim to demonstrate an approach that assesses the natural capital cost of different management options, and how this can be used to support better policy and optimise production.

Within both parts of the analysis, the commodity production and environmental impact data has been primarily sourced from FAO, with other relevant datasets coming from lifecycle analysis databases such as Agri-footprint. The monetisation of biophysical data has followed Trucost's published methodologies (see Appendices for details), and values the externality costs associated with different drivers of environmental impact. This approach applies a cost to the impacts on human health as well as ecosystems.

## MATERIALITY ASSESSMENT FINDINGS

The materiality assessment assesses impacts from the farm gate back along the upstream supply chain, which includes the production of agricultural inputs such as energy and feed. Downstream phases are excluded. The main findings from this phase of work are:

- The operational natural capital costs associated with crop production in this study represent nearly USD 1.15 trillion, over 170 percent of its production value, whereas livestock production in this study produces natural capital costs of over USD 1.81 trillion, 134 percent of its production value.
- Farming practices have been analyzed in over 40 countries, which contribute to about 80% of global production for each commodity, and 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).
- On average, 68 percent of the impacts of livestock production can be attributed to operational activities taking place on the farm. For example, the conversion of natural ecosystems to pastureland for beef production in Brazil, which results in a natural capital cost of over USD 473 million, is the largest single impact in the study.
- Supply chain impacts can represent a significant source of the costs of agricultural production, as is the case for pork production in China, which generates air emissions, uses water, and converts land that have a natural capital cost of over USD 118 million. This is due in part to the production of animal feed.
- On average, 77 percent of the natural capital costs of crop production occur on the farm. The highest natural capital costs of crop production in this study can be attributed to maize farming in China, followed by rice farming in China and India.

- India generates the greatest natural capital costs associated with rice farming. The operational costs total over USD 80 million and are due to the impact of water pollution, land use change and water consumption.
- In extreme cases, the overuse of fertilizers can be the source of significant natural capital impacts, as is the case for wheat farming in Germany. The natural capital cost of fertilizer leaching into waterways is responsible for 95 percent of its total impact, or USD 55 million.

## CASE STUDY FINDINGS

Across all four studies, a number of significant benefits associated with alternative management practices could not be monetised. These included both on-site and off-site benefits to biodiversity, soil fertility, and improved livestock welfare. The main findings from the case studies are:

*Cattle Farming in Brazil*

i. The use of holistic grazing management can result in the regeneration of grassland ecosystems, which can reduce the cost of natural capital impacts by 11 percent.
ii. Greenhouse gas emissions offer the most significant natural capital cost reductions through the use of holistic grazing management (USD 1 232 per tonne of beef produced). This is due to the increased carbon sequestration of rehabilitated grassland ecosystem on which the cattle graze.
iii. Studies are inconclusive on the economic benefits of holistic grazing management, though one study calculates the direct financial benefits to the farmer are around USD 68 per cow.

*Rice Farming in India*

i. Significant reductions in soil, air and water pollutants can be achieved by adopting the system of rice intensification (SRI), with a reduction in natural capital impact of up to 97 percent, 78 percent and 16 percent respectively.
ii. The greatest natural capital cost reductions are associated with reduced land use change (USD 48 per tonne) and water consumption (USD 41 per tonne). This is due to the increase in yields and the use of intermittent flooding in SRI production systems.
iii. Studies show that gross margins for SRI farms on average increase by 18 percent per hectare, whilst operating costs decrease by 13 percent. This assumes yields of 6.5 tonnes per hectare for SRI farms, and 3.8 tonnes for non-SRI.

*Soybean Farming in the US*

i. Farmers that adopt organic farming practices, which utilise crop rotations and the use of cover crops, can achieve significant reductions in water pollution, air pollution and water consumption. The natural capital cost saving associated with these impacts can be as great as USD 27, USD 19, and USD 16 per tonne of soybeans produced.
ii. Decreasing natural capital impact is achieved through the elimination of pesticides and the application of organic manure such as slurry.
iii. Studies show that gross margins and operating costs for farms employing these practices increase up to 219 percent and 12 percent per hectare. Along with the price premium paid for

organic produce, this assumes yields of 2.9 tonnes per hectare for organic farms, and 3.2 tonnes for conventional farms.

*Wheat Farming in Germany*

i. Farmers that adopt organic farming practices, which utilise crop rotations and the use of cover crops, can achieve significant reductions in water pollution and greenhouse gas emissions. The natural capital cost saving associated with these impacts can be as great as USD 1 122 and USD 43 per tonne of wheat produced.
ii. Decreasing natural capital impact is achieved through the elimination of pesticide use, and the application of organic manure. Fertilizer run-off is also reduced through the use of cover crops instead of leaving fields fallow.
iii. Studies show that gross margins for farms employing these practices on average increase by 111 percent per hectare, whilst operating costs decrease by 32 percent. Along with the price premium paid for organic produce, this assumes yields of 3.5 tonnes per hectare for organic farms and 6.9 tonnes for conventional farms.

The total environmental costs calculated in this study represent an informed estimate and should be treated with a degree of caution. This is because the calculation of non-market natural capital costs, on a global scale, requires a number of assumptions. For example, more than 100 estimates of the social cost of carbon are available. They run from USD -10 to USD +350 per tonne of carbon. Peer-reviewed estimates have a mean value of USD 43 per tonne of carbon with a standard deviation of USD 83 per tonne. For this study and in alignment with previous FAO reports, we have inflated and used the 2006 Stern cost of carbon, which equates to USD 115 per tonne.

*The analysis in this report, undertaken in partnership between Trucost and FAO, will contribute to the Natural Capital Protocol's Food and Beverage sector guide by introducing practical examples of natural capital valuation analysis that business can utilise.*

# KEY TERMS

| Term | Definition |
|---|---|
| Direct impacts | This refers to the operational emissions or impacts that occur due to the farming activity. For example, the use of farm machinery that runs on diesel will cause the emission of greenhouse gases. Also, the use of fertilizers will also cause impacts, as nutrients will enter surrounding waterways through the process of leaching, resulting in eutrophication. Although some impacts occur away from the farm, the impacts occur directly due to activities that take place on the farm. |
| Indirect impacts | These are emissions that refer to the impacts caused by companies in the supply chains of the farms, or those companies that subsequently use the outputs from the farm. Indirect impacts refer to the environmental impacts that occur due to others outside the boundary of the farm. In the context of this study, this means that all of the impacts from the production of inputs to the farm are encompassed in the term 'indirect impacts'. |
| Natural capital | Using a common definition of natural capital in the business arena, natural capital is "the stock of natural ecosystems on Earth including air, land, soil, biodiversity and geological resources. This stock underpins our economy and society by producing value for people, both directly and indirectly." (NCC, 2014a) |
| Natural capital intensity | This refers to the monetary value of the natural capital impacts caused by each agri-sector, per tonne of production. For example, cattle farming in South America may cause natural capital impacts valued at USD 30 per tonne of beef produced. |
| Poultry | Poultry production is the term used for the production of eggs and meat. The term poultry in this report refer to meat production only and has been used instead of the term 'broiler' which is "applied to chicks that have especially been bred for rapid growth." (LEAD Initiative, 2015) |
| Supply chain (downstream) | This refers to entities or users of the commodity that either directly use or process the commodity after it has left the farm. |
| Supply chain (upstream) | This refers to entities that supply the farm. This encompasses fertilizer and pesticide production, and in terms of livestock production, this also includes the production of crops as feed. The entities encompassed in this definition do not necessarily have to directly supply the farm, but rather can be the supplier to suppliers.<br><br>In the charts of this document, where supply chain impacts have been included, if they have not been separated into '1st tier supply chain' and 'Rest of supply chain', then the chart refers to the sum of these categories. This is what is known as the 'upstream supply chain'. |
| Value chain | This term encompasses both upstream and downstream parts of the supply chain. Please see above for a definition of both of these terms. |
| 1st tier supply chain | This refers to the direct suppliers to the farm. This will include companies and entities that the farm has direct expenditure with. |
| Rest of supply chain | On some charts, the term 'rest of supply chain' has been used to denote all businesses that do not directly supply the farm. These will be companies that provide inputs into the 1st tier supply chain. |

# BACKGROUND

Businesses have a significant impact and dependency on natural capital. Impacts are caused by emitted greenhouse gas emissions from the combustion of fossil fuels, unsustainable water abstraction in water scarce areas, deforestation and land use change amongst others. Worryingly, business is increasingly reliant on the very natural capital that is being degraded in order to meet the needs of a growing global population and changing consumption patterns.

The natural capital available to business is being degraded at an ever increasing rate (UNEP 2007; UNEP 2010). Numerous international and national bodies, such as the Natural Capital Coalition[1] (NCC) in the private sector, the Wealth Accounting and the Valuation of Ecosystem Services (WAVES)[2] partnership in the public sector, and the Natural Capital Declaration[3] (NCD) in the finance sector, have been formed specifically to address the increased risk posed by the deteriorating supply-demand balance for natural capital flows. These recent efforts have focussed on placing monetary values on natural capital in order to factor in the effect caused by businesses and to better inform their strategic decision-making. One such initiative that is gaining traction within the private sector, and being developed by the NCC with support from the International Finance Corporation (IFC), the International Union for the Conservation of Nature (IUCN) and The World Bank, is the Natural Capital Protocol.[4] The objective is to create a harmonised accounting framework, providing businesses with robust tools and metrics to identify their impact and reliance on natural capital.

The Natural Capital Protocol consists of three main parts; the Protocol, and two sector guides; one to cover businesses in the Food and Beverage sector, and a second for those businesses in the Apparel value chain. The analysis in this report, undertaken in partnership between  and FAO, will contribute to the Food and Beverage sector guide by introducing practical examples of natural capital valuation analysis that business can utilise. The report focuses on 8 agricultural commodities and explores:

i. How natural capital impacts are distributed in different countries for 8 commodities
ii. Operational versus supply chain impacts
iii. The monetary value of natural capital impacts
iv. The drivers of natural capital impacts

Many responsible businesses are already utilising academic research, environmental impact analysis and datasets from organisations such as the FAO, assisting them in making more sustainable business decisions. It is however also recognised that environmental analysis often fails to drive boardroom decision-making, due in part to the technical language used. The Protocol and this work as part of the Sector Guide hopes to demonstrate, the value of monetising, where possible, these natural capital impacts and dependencies to ensure their value is understood and utilised by non-technical, senior business decision makers. The following section provides more information on the Natural Capital Protocol. Additional information can be found in Appendix I.

[1] http://www.naturalcapitalcoalition.org/
[2] http://www.wavespartnership.org/en
[3] http://www.naturalcapitaldeclaration.org/
[4] http://www.naturalcapitalcoalition.org/natural-capital-protocol.html

# NATURAL CAPITAL PROTOCOL

## What is the NCP?

At present there are a growing number of fragmented activities underway regarding the valuation of natural capital in business applications. As stated by the Natural Capital Coalition 'one of the challenges in scaling uptake in business is the lack of a harmonised approach to enable natural capital valuation to be practically used in these applications for example, internal management, reporting and disclosure' (NCC, 2014b). The Natural Capital Protocol (NCP) project is a response to this challenge – with its overall vision to transform the way business operates through understanding and incorporating their impacts and dependencies on natural capital.

The broad aim of the NCP is to enable businesses to assess and better manage their direct and indirect interactions with natural capital. In particular, through increasing knowledge, equipping users to effectively link and embed outputs directly into business, for example in its operations, supply chain management, and accounting, thereby stimulating action. Table 1 provides an overview of the scope of this study - commodities, value chain, geographies and impacts that have been included - to help various business functions identify the relevance to their organisations. The NCP will provide clear guidance on how businesses can assess their impacts and dependencies on natural capital as well as take the user through the purpose and value-add of carrying out such an assessment within their business.

The NCP development is being managed by a consortium led by the World Business Council for Sustainable Development (WBCSD). The current target date for the publication of the NCP is June 2016 while public consultation on a draft version is expected in the autumn of 2015. A rough outline of the NCP sector guide is provided in Appendix I.

## What are the Sector Guides?

In addition to the development of the Protocol, the project includes the creation of two accompanying Sector Guides that will provide additional guidance and complementary information on implementing the NCP in sector-specific-contexts. Initially, the Sector Guides are focussing on the Food and Beverage and Apparel sectors due to the complexities of the natural capital impacts and dependencies across their respective value chains. The main aim of the Sector Guides is to ensure that the NCP adequately addresses these complexities and provides additional guidance on how a business would conduct a natural capital assessment. Moreover, the Sector Guides will help demonstrate the business case for natural capital measurement by coherently articulating the business value and benefits that can be achieved by companies operating at different stages of the value chain.

The development of the Sector Guides for Food and Beverage and Apparel sectors is being led by the International Union for Conservation of Nature (IUCN), and includes consortium members Cambridge Institute for Sustainability Leadership (CISL),[5] EY (formerly Ernst and Young),[6] FAO, Trucost,[7] and True

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[5] http://www.cisl.cam.ac.uk/
[6] http://www.ey.com/
[7] http://www.trucost.com/

Price.[8] In addition, numerous sector organisations are being engaged during their formulation including the FAO. As above, the current target date for the publication of the Sector Guides is March 2016 while public consultation on draft versions is expected in the autumn of 2015.

It is envisaged that the results of this study will be incorporated into two key areas of the Food and Beverage Sector Guide – the Materiality Matrix and Practical Case Studies. The first phase of this study, the materiality analysis across eight commodities, will help inform the Materiality Matrix. The second part of this study will test approaches to analysing farm-level practice/management trade-offs, and will be utilised in the Practical Case Studies section within the Sector Guide.

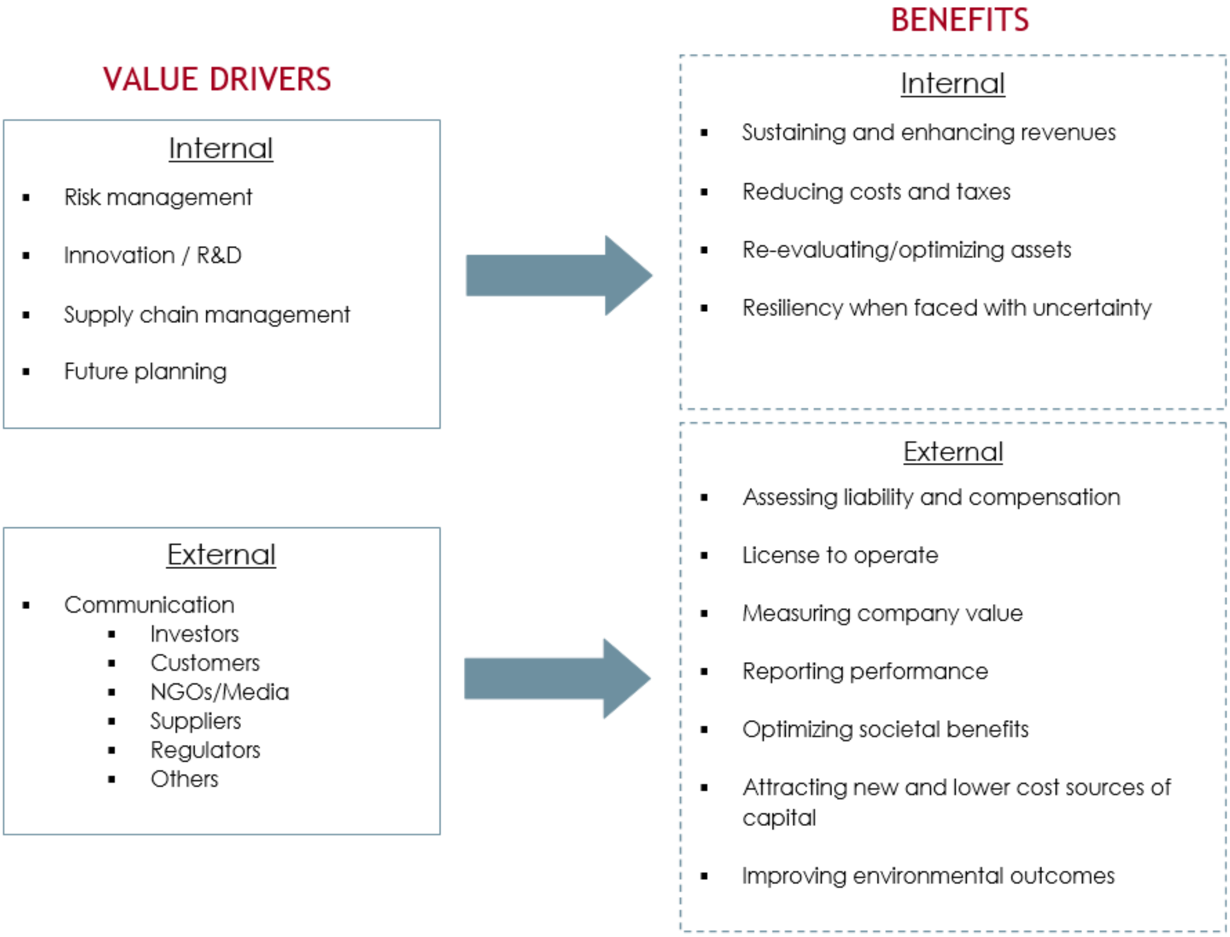


FIGURE 1: VALUE DRIVERS AND THE EXPECTED BENEFITS OF USING THE NATURAL CAPITAL PROTOCOL

[8] http://trueprice.org/

## Business Engagement

There will also be several rounds of engagement with companies to ensure that the NCP and Sector Guides are 'fit for purpose'. Around 200 companies are being invited to become Business Engagement Partners (BEPs) to help develop and pilot the NCP and Sector Guides. It is expected that these companies will provide practical case studies that can be used in the main NCP and the accompanying Sector Guides. First drafts of both publications are expected to be publically released for feedback early in 2016.

# NATURAL CAPITAL IMPACTS IN AGRICULTURE

This study, undertaken in partnership between Trucost and FAO, focuses on the natural capital impacts caused by the production of four crop, and four livestock agri-commodities. Given the timeframes and funding available, it was agreed to focus on the production of commodities in forty countries, with the countries chosen based on the production in calories per day of each commodity, as well as their contribution to global production. The crop commodities that are included in the analysis are *maize; rice; soybean and; wheat*; whereas the livestock commodities that have been included are *cattle (beef); cattle (dairy); hog and pig and; poultry*.

The study aimed to address a number of objectives, both as a standalone piece of analysis and as a contributor to the Food and Beverage Sector Guide as part of the Natural Capital Protocol. The study also has the following objectives:

- Improve the integration of natural capital accounting by businesses with significant operational and agricultural supply chain impacts
- Demonstrate to businesses, using practical case studies, how natural capital impacts can be reduced with more sustainable farm management practices

To achieve these outcomes, the analysis was completed in two phases, utilising Trucost data and models, as well as FAO data and expert knowledge.

## Phase 1: Materiality Assessment

A materiality study is a top-down approach that analyzes a broad set of impacts, across a broad study area. The level of granularity and accuracy that this entails, enables the identification of a wide range of material impacts, providing valuable insight to a wider audience. Materiality studies are often used as an initial step to provide focus on where to undertake more robust, bottom-up analysis, relating to production of a specific commodity in a specific location or environment.

The first phase of the study achieves this materiality approach by utilising a mix of FAO data and Trucost's models to assess the natural capital impacts in monetary terms at a national level, hereafter referred to as 'natural capital costs'. This phase was developed to meet the first objective, by identifying material impacts, and presenting these impacts in a business metric, US Dollars.

Business extraction and production activities can damage natural capital with long term economic and social consequences, which are more often paid by those affected rather than those responsible. These risks are sufficiently large that the Word Economic Forum's Global Risk Report (2013) cites water supply crisis, food crises, biodiversity loss and ecosystem collapse, extreme weather events and rising greenhouse gas emissions, within the top risks to the global economy over the next 10 years from a likelihood and magnitude perspective. In an agricultural context, agroecological production has been identified as one of the ways in which to regenerate agroecosystems, and reverse the damage caused by extractive production activities. Agroecology refers to the application of ecological principles in the design and management of agricultural land, and the idea of a systems-based approach viewing the various social, technological and natural conditions that are present. It is a way of identifying the links and interdependencies of various aspects of agricultural ecosystems so that more sustainable production activities can be identified and implemented (Agroecology, 2015; InterDev, 2015).

This materiality study uses a top-down approach, utilising Trucost's environmentally extended input-output (EEIO) model, hybridised with FAO data and Trucost's valuation coefficients. This allows for both the breadth and scope required for different agricultural-reliant businesses, and ensures all relevant and material natural capital impacts are identified, and presented to the business user as natural capital costs in US Dollars. Once material impacts have been identified by an agri-reliant business, they can start to understand the scale of the risk, and refine the analysis to integrate it into better internal management practices.

An example of a similar approach taken by Trucost, covering an even broader scope, was commissioned in 2013 by the TEEB for Business Coalition, now the Natural Capital Coalition, to quantify the impact on natural capital caused by primary production and primary processing sectors in the global economy. For each sector in each region (sector-region), the natural capital cost broken down by six key environmental indicators – GHGs, air pollutants, water use, waste, emissions to land and water, and land use change. The 20 sector-regions with the highest combined impacts across all environmental indicators were also estimated. Coal power generation in Eastern Asia and North America ranked 1$^{st}$ and 3$^{rd}$ respectively, whereas the agricultural sectors with the greatest impacts are cattle ranching and farming in South America (2$^{nd}$), followed by wheat and rice farming in Southern Asia, which are placed 4$^{th}$ and 5$^{th}$ respectively (TEEB for Business Coalition, 2013).

The application of these materiality results resonates with a wider audience than just large private business. For example, commodity traders and others within the finance sector can use the outputs to engage with key commodity producers and allocate capital accordingly. The information in this analysis will be useful in order to assess the feasibility of the long-term production of commodities, and the potential to be exposed to an increase in costs, resulting from increasing regulation or scarcity. Regulation could take the form of making companies internalise the costs of the natural capital impacts that they are responsible for, which can be attributed to fertilizer or pesticide use for example. NGOs, food retailers, and consumers also stand to benefit from this analysis, as environmental impacts that couldn't previously be reconciled, now have a common metric with which to be compared and aggregated. It provides all stakeholders with a baseline to further investigate the natural capital costs and geographies that are most material to them. It also provides a solid foundation in which to refine the analysis in Phase 2.

## Phase 2: Trade-offs of Different Farming Systems

Once a business or organisation has identified the material natural capital impacts and risks, one of the next steps is to understand how they can start to reduce those impacts, thus optimising performance. A practical approach is to explore the impacts of more sustainable management practices of that particular commodity, and to then support a change through investments in technology, knowledge sharing, infrastructure and learning.

For this phase of the study, four case studies analyzed various farm-level management practices. The analysis explored the trade-offs that exist between adopting different farming practices of selected commodities in different countries. The analysis has considered the change in yields of each crop as well as natural capital costs of the impacts associated with each practice. Each study is to serve as an example to businesses of how, taking steer from the materiality study, they can refine the accuracy and relevance at a more granular scale, gaining an understanding of the natural capital impacts, costs, and trade-offs that exist at a farm-level, for the most material and strategically important commodities. The agri-commodities that have been identified for this phase of the work, based on the Materiality Assessment are shown below:

- Cattle (beef): Holistic grazing management vs. conventional cattle grazing in Brazil
- Rice: System of rice intensification vs. conventional rice farming in India
- Soy: Organic farming vs. conventional soybean farming in USA
- Wheat: Organic farming vs. conventional wheat farming in Germany

The core objective of the analysis is to demonstrate to agri-businesses that by measuring its impact, and indirectly its dependency on natural capital, this can inform more sustainable farming decisions, increase profitability, and ensure a more resilient and stable supply of each commodity. It is envisaged that the outputs from these examples can be used by many different businesses within the food/beverage value chain.

# PHASE 1: MATERIALITY ASSESSMENT

## METHODOLOGY

### Scope

FAOSTAT identifies more than two hundred agricultural commodities produced in the world (FAOSTAT, 2014a). The selection of commodities to include in the materiality assessment was based on combining an environmental impact approach and a functional unit approach.

*Environmental Impact*

On the environmental side, a high-level literature review was conducted to identify the categories of agricultural commodities that most frequently feature at the top of impact rankings. In its 'Food Wastage Footprint Summary Report' (FAO, 2013), FAO ranks the agricultural commodities with the highest contribution to global carbon, water and land use footprints according to the food wasted. Those with the highest carbon impacts include cereals, meat and vegetables whereas those with the highest water and land use impacts are cereals, fruits and milk, and then meat, milk, and cereals respectively.

The results of this study, as well as the wider impact of these commodities, are substantiated by their inclusion in WWF's The 2050 Criteria (2012). This report addresses 10 global commodities that are identified as high priority due to the depth, and significance of their current, and potential cumulative impacts on biodiversity, greenhouse gas emissions and water use. The sectors identified include beef, dairy and soybean alongside others such as aquaculture, cotton, palm oil, sugar and timber.

In a separate study focusing on water, WWF identified a list of 25 key crop-industry combinations highly exposed to both water risks and of high economic importance; these include wheat production in India and China, and rice production in Bangladesh and India (PRI, 2014).

*Functional Unit*

The selection criteria for commodities in this study combines the commodity relevance to people, which includes its role in promoting food security, and the economy, which takes into account trade value. The datapoints were taken from FAOSTAT and include daily food supply, in calories per capita per year, and the global production value generated by crops and livestock over the course of a year (FAO, 2014b). Interestingly, these two functional unit approaches overlapped in terms of results. Thus, the most globally important commodities in terms of food security and the economy are the following:

- ***Crop Commodities***: maize, rice, wheat and soybean[9]
- ***Livestock Commodities***: pork, poultry, cattle (beef) and cattle (dairy)

[9] This study took into account that soybean is an important input as feed in some livestock sectors, and therefore chose this commodity over the likes of sugarcane.

The following materiality assessment assesses impacts from the farm gate back along the upstream supply chain, which includes the production of agricultural inputs such as energy and feed. Downstream phases are excluded.

Table 1 below describes the scope of the materiality assessment.

TABLE 1: SCOPE OF THE MATERIALITY ASSESSMENT

| Dimension | Scope | Justification |
| --- | --- | --- |
| *Commodities* | ***Crops***: maize, rice, wheat and soybean<br>***Livestock***: pork, poultry, cattle (beef) and cattle (dairy) | Agricultural commodities with the highest contribution to global calories produced for human consumption (FAO, 2014b) and global production value. |
| *Value chain* | From production inputs to the farm gate. | Paucity of data on the rest of the value chain considering the geographical coverage and level of granularity expected. |
| *Geographies* | For each commodity, the assessment covered countries representing 80% of global production | Considering that environmental impacts vary amongst countries, the assessment should include several countries and should be based on country-specific factors where possible.<br><br>The countries contributing to the top 80% of global production is applied due to a disproportionately large number of countries contributing to the remaining 20% |
| *Environmental impacts* | Greenhouse gases (GHGs)<br>Air pollutants<br>Water abstraction<br>Water pollutants<br>Soil pollutants<br>Land use change[10] | The range of impacts should be broad as one of the purposes of the assessment is to identify significant environmental impacts so that an investigation in to what practices drive these impacts can be conducted. |

## Approach

The methodology used has developed an approach that quantifies environmental impacts in physical terms (cubic metres of water use, tonnes of emissions, hectares of land converted), as well as monetary terms (US Dollars). The analysis of direct impacts refers to the quantification of environmental impacts resulting from onsite farming activities, whereas indirect impacts refer to the quantification of environmental impacts resulting from upstream supply chain activities (i.e. production of agricultural inputs).

### *Quantification*

The main body of this assessment utilises Trucost's Environmentally Extended Input-Output model (EEIO model). This model quantifies environmental impacts at the farm level (direct model) and through its entire supply chain (indirect model). Assessment of direct environmental impacts were as country

[10] Land use change considers the value of ecosystem services lost from converting the land from its natural ecosystem, to the current livestock production system. It currently considers the complete loss of provisioning, regulating and cultural ecosystem services.

specific as possible, and the assessment of the supply chain was based on global average factors. Appendix III provides a more detailed description of Trucost's EEIO model.

Environmental impacts include greenhouse emissions and air pollutants from energy and non-energy sources, water abstraction, water pollution from fertilizer application and soil pollution from pesticide application, as well as land use change and greenhouse gas emissions from land clearing. Table 2 summarises the scope of the environmental impacts taken into account.

TABLE 2: ENVIRONMENTAL IMPACTS THAT HAVE BEEN QUANTIFIED IN THIS ANALYSIS

| Environmental impact | Crops | | Livestock | |
|---|---|---|---|---|
| | Farming | Supply chain | Farming | Supply chain |
| GHGs (from energy and non-energy sources) | Yes | Yes | Yes | Yes |
| GHGs (from land clearing) | Yes | Yes | Yes | Yes |
| Air pollutants | Yes | Yes | Yes | Yes |
| Water pollutants (from manure and fertilizers) | Yes | Yes | No[11] | Yes |
| Soil pollutants (from pesticides application) | Yes | Yes | N/A[12] | Yes |
| Water consumption | Yes | Yes | Yes | Yes |
| Land use change | Yes | Yes | Yes | Yes |

*Valuation*

Valuation consists of transforming physical quantities into monetary values using environmental valuation techniques. This step enables the quantification in monetary terms of the damage caused by pollution or natural resource extraction. In order to derive valuation coefficients, a literature review was conducted in order to understand the magnitude of each environmental impact on receptors such as

[11] The emissions from animal manure are not given in the Agri-Footprint library used to calculate emissions factors for livestock production. This is because "animal manure is considered to be a residual product of the animal production systems so it does not receive part of the emissions of the animal production system when animal manure is applied… Emissions due to the management of manure on the farm are included within the system boundaries, but the emissions due to application of manure are attributed to the crop cultivation stage." (SimaPro, 2014a) As such, manure is treated as managed waste in the direct impact of livestock production. It is also important to note that heavy metals are often found in livestock manure but data availability is limited.
[12] Pesticides are not used directly in livestock production so have not been included in the analysis of the impacts caused by operations of livestock production systems.

crops, ecosystems, human health and materials. Secondary literature was used to estimate the social cost of these impacts – natural capital valuation. These valuations reflect the impact on ecosystems and the damage to human health. Value transfer techniques were applied to make the valuations country-specific. The Appendices provide an overview on each valuation methodology, as well as more information on value transfer.

Table 3 and Table 4 below outline what is included in the valuation scope of each environmental impact.

TABLE 3: ENVIRONMENTAL IMPACTS THAT HAVE BEEN GIVEN A MONETARY VALUE IN THIS ANALYSIS

| Environmental impact | Scope |
|---|---|
| GHGs (from energy and non-energy sources) | Multitude of impacts, including but not limited to, changes in net agricultural productivity, human health and property damages from increased flood risk. The GHGs considered in this analysis include carbon dioxide, methane and nitrous oxide. The social cost of carbon, in 2013 USD, used in this study is just under USD 115 per tonne $CO_2$ (Stern, 2006). |
| GHGs (from land clearing) | The carbon stock lost due to land conversion is included in this valuation. The Direct Land Use Change Assessment Tool developed by Blonk Consultants (2014) has been used in this study, and the carbon stock calculations are based on IPCC rules, which has been developed to meet PAS 2050 standards as well as be consistent with the GHG Protocol Product and Scope 3 Accounting and Reporting Standards. The carbon stock lost due to land clearing relates to the loss of biomass and soil organic carbon. The values are crop and country-specific and rely on a number of data sources which include FAO and UNFCCC.<br><br>The same carbon price has been applied to GHG emissions described above. Land conversion has been attributed to crop and livestock expansion. Therefore GHGs from land clearing is calculated as a direct impact of crop production only, whereas for livestock production it has been calculated as a direct impact, from livestock expansion, and a supply chain impact, from cropland expansion used as feed. |
| Air Pollutants | The impacts on crop yields, water quality, timber production, human health and corrosion of building material is calculated in this valuation. Country-specific values are used in this study and includes impacts from the emission of SOx, NOx, PM10, VOCs and ammonia from fuel use, fertilizer application, pesticide application, enteric fermentation and other sources. For instance, the values used for SOx emissions range between USD 600 and USD 4 000 per tonne, whereas values for VOCs range between USD 350 and USD 2 600 per tonne. |
| Water pollutants (from fertilizer application) | Eutrophication impacts on ecosystems, through decreased occurrence of species. This valuation includes the impacts on species from the emission of nitrogen, nitrates, phosphates, and phosphorus. Values are country-specific and can range between USD 0 and USD 82 000 per tonne for nitrates, and between USD 0 and USD 818 000 per tonne for phosphates. |
| Soil pollutants (from pesticides application) | Land pollutants have toxicity impacts on human health and ecosystems. This valuation includes the impacts of over 80 pollutants, which consists of pesticides such as atrazine, herbicides such as Diuron and fungicides such as Folpet. Values are country-specific and can range between USD 44 000 and USD 825 000 per tonne for Atrazine, and between USD 38 000 and USD 721 000 per tonne for Folpet. |

| Environmental impact | Scope |
| --- | --- |
| Water consumption | This includes the impacts on human health and ecosystems. The unit of measurement for human health is disability adjusted life years (DALYs) and the potentially disappeared fraction of species (PDF) for ecosystem damage. Water scarcity is a factor in the water valuation, so countries with a higher water scarcity will have a higher cost attributed to water consumption. Values are country-specific and can range between USD 0.14 and USD 3 per $m^3$. |
| Land use change | This values the ecosystem services lost from the conversion of natural ecosystems to agricultural land, including country-specific distribution of 23 global ecosystems with a meta-analysis and valuation of 17 different ecosystem services. The natural ecosystems that are covered in this study include; deserts; semi-deserts; savannah; temperate natural grasslands; tropical natural grasslands; other grasslands; floodplains; peat wetlands; swamps and marshes; other wetlands; Mediterranean woodlands; tropical woodlands; other woodlands; mangroves; tidal marsh; salt water wetlands; boreal/coniferous forests; temperate deciduous forests; temperate forest general; tropical dry forests; tropical rainforests; tropical forest general and; other forests.<br><br>GHG emissions from land clearing is included in the section above. |

TABLE 4: SUMMARY OF LIMITATIONS

| Limitation | Explanation |
| --- | --- |
| Aggregation of data | In some cases, components of valuations which represent impacts on different receptors, such as human populations, are aggregated and use different valuation techniques. The individual components of valuations may or may not be directly comparable, but the methodology applied is consistent across the different impact categories and to each unique receptor. |
| Exclusions | Some impact categories have been excluded on the basis of materiality or data availability. Please see the relevant methodology sections in the Appendices for further information. |
| Overlap | In some instances, where global averages have been used, or if there is a lack of data, some aspects of the valuations may overlap in scope. If this has occurred, this is stated in the relevant methodology section in the Appendices of this document. |
| Static | Valuations are adjusted using inflation rates and apply at a specific point in time. |
| Value transfer | Value transfer has been used at points to derive valuation coefficients that have been applied during this study. Transferring values from study sites to the policy sites can contain a number of errors, for example, the value at the policy site can only be as accurate as the original calculation. Also, all of the limitations surrounding the original study are equally valid for the value at the policy site. See Brander (2013) for a comprehensive assessment of value transfer techniques. |

# KEY FINDINGS

## Total Natural Capital Costs

This section describes the impacts on natural capital in terms of the total costs caused by the annual production of each commodity in each study country. Intensities are used in conjunction with annual production quantities in order to calculate the total natural capital costs per country. Please refer to the Appendix III for more information on how intensities and costs of natural capital impacts have been calculated in Trucost's environmentally-extended input-output (EEIO) model.

The results are broken down by direct operations (on-site farming activities), the first tier of the supply chain (businesses who directly supply the farms), and by the rest of the supply chain (the suppliers of the suppliers). In the case of crop farming, first tier suppliers include, but are not limited to, energy providers, as well as pesticide and fertilizer manufacturers. For livestock sectors, in this instance, first tier suppliers include feed producers, such as those in maize and soybean farming, as well as energy providers.

As described in the Approach section, the quantification of impacts was based on country-specific factors where possible, or global average factors if not. Valuation factors are country-specific, apart from greenhouse emissions where the impact on natural capital is global. However, country-specific valuations have limitations, such as the fact that they rely on national averages, or that the dispersion models used are not country-specific. The analysis that is contained hereafter should be used to highlight where there are opportunities to improve farming practices, and not to directly compare impacts in different countries without further analysis. This is because of the detailed nuances that exist between farming practices, as presented in Phase 2.

*Crops*

Figure 2 shows each of the four crops, in order of the highest combined operational and supply chain natural capital costs per unit of production, across the globe.

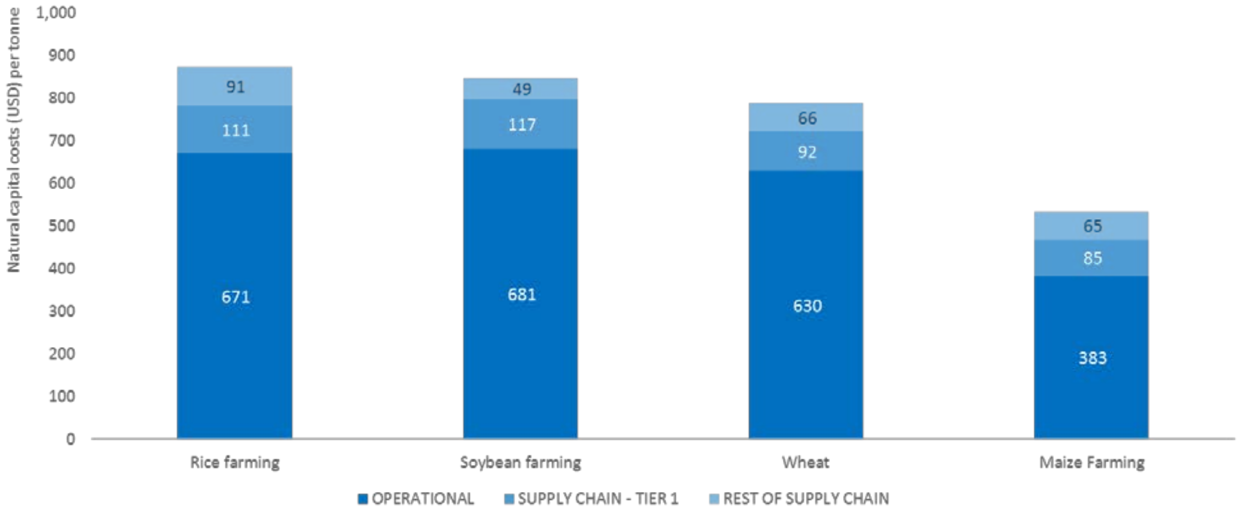


FIGURE 2: GLOBAL OPERATIONAL AND SUPPLY CHAIN NATURAL CAPITAL COSTS PER TONNE OF ***CROP*** PRODUCTION

Figure 2 shows the costs of the impacts of conventional crop production globally. It shows that on average, rice production causes the highest natural capital costs of all the crops analyzed in this study. The main driver of the natural capital costs in rice production comes from the operational impacts that occur on the farm, which account for 77 percent of the total impacts. The average contribution of operational natural capital costs to the impacts across all crop sectors is also 77 percent.

This provides business with an understanding of where the impacts of each type of crop production are situated within the value chain. It also provides a guide of what potential, more sustainable alternatives should address. Operational impacts are discussed in more detail in the sections below, and impacts are broken into the seven key performance indicators (KPIs) listed in Table 3. The following sections can show businesses what impacts are most significant in the operations of farms in different regions, which can aid in the selection of alternative farming systems and mitigation strategies.

Figure 3 shows the costs of the top 10 crop production impacts with the highest natural capital costs by country.

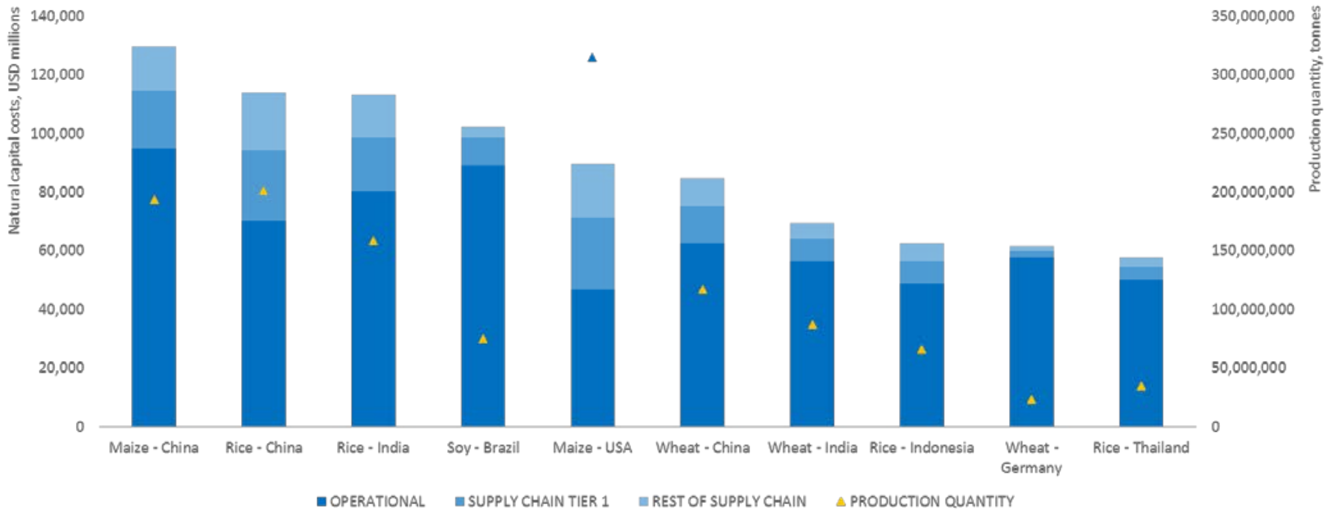


FIGURE 3: TOP 10 OPERATIONAL AND SUPPLY CHAIN NATURAL CAPITAL COSTS OF *CROP* PRODUCTION BY COUNTRY

Figure 3 shows that the total impact associated with the production of maize and rice in China have the greatest natural capital impact. China is the largest producer of rice, and is the second largest producer of maize behind the United States of America, which produces almost 40 percent more maize than China. China's rice production inflicts greater natural capital costs than rice production in India despite China's natural capital cost per tonne of rice production being 21 percent lower than India's. This is driven by the greater production volume of rice in China. Brazil is the only producer of soybeans to feature in the list and this is mainly due to the impacts of land use change that occur as a result of its operations. Operational impacts account for 85 percent of Brazil's soybean farming total impacts. In total, the top 10 countries and sectors listed in Figure 3, account for 59 percent of the total crop production natural capital costs in this study.

Figure 3 builds on the information presented above to highlight to business the specific sectors and countries with the largest cost of environmental impacts during crop production. It highlights significant global issues and provides an indication of the sustainability of conventional farming systems. Businesses can use this as a starting point to investigate what impacts are most material in these sectors and countries, then qualitatively assess whether the external costs of the impacts are likely to be internalised, and over what timescales. Businesses can use this information to either identify what impacts alternative farming systems should address, so as to reduce these impacts, or can use this information to assess to what degree they are dependent on the natural capital that they are impacting.

Table 5 outlines the top 3 contributors to the natural capital costs in each crop production sector in the study. The natural capital costs include both operational and supply chain impacts.

TABLE 5: TOP CONTRIBUTORS TO THE NATURAL CAPITAL COSTS IN EACH *CROP* SECTOR (OPERATIONAL AND SUPPLY CHAIN IMPACTS)

| Crop | Top contributors to the natural capital costs (USD million) | | | Total costs (USD million) |
|---|---|---|---|---|
| | 1st | 2nd | 3rd | |
| Maize | *China* 129 607 (35%) | *USA* 89 687 (24%) | *Brazil* 57 344 (16%) | 369 243 |
| Rice | *China* 113 681 (22%) | *India* 113 315 (22%) | *Indonesia* 62 580 (12%) | 507 308 |
| Soybean | *Brazil* 102 268 (58%) | *USA* 52 051 (30%) | *Argentina* 21 724 (12%) | 176 044 |
| Wheat | *China* 84 602 (19%) | *India* 69 387 (16%) | *Germany* 61 560 (14%) | 439 188 |

The breakdown of these results, for all countries in the study, can be seen from Figure 4 to Figure 7, and in Table 6 below. The figures show the natural capital costs associated with the production of each of the crops in this study, in conjunction with the total production of each crop.

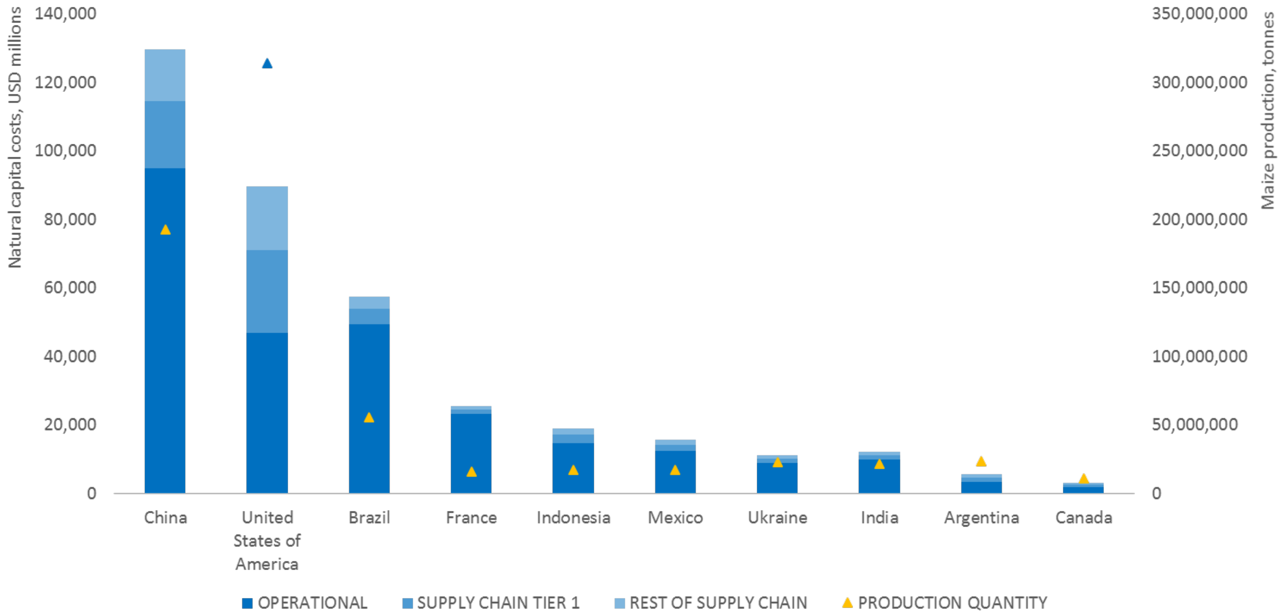


FIGURE 4: OPERATIONAL AND SUPPLY CHAIN NATURAL CAPITAL COSTS OF ***MAIZE*** PRODUCTION BY COUNTRY

***Findings***

China and the USA have the highest impact on natural capital due to maize production. Together, they are responsible for 59 percent of the total natural capital costs in this sector for the countries analyzed.

***Land use change*** *and the emission of* ***water pollutants*** *cause the greatest natural capital impact in this sector. Land use change means that ecosystem services are lost, which provide benefits directly to people and businesses. Fertilizers are a common cause of water pollution and a major source of natural capital impact in this study.*

*This highlights to business that capacity of ecosystem services to support agricultural ecosystems are decreasing. A high conversion rate from naturally occurring land to man-made ecosystems indicate that the base of natural capital that they rely on is being degraded. The degree of a business' dependency on those ecosystem services will dictate the costs of degradation to that business, as well as the rate of internalisation of those costs.*

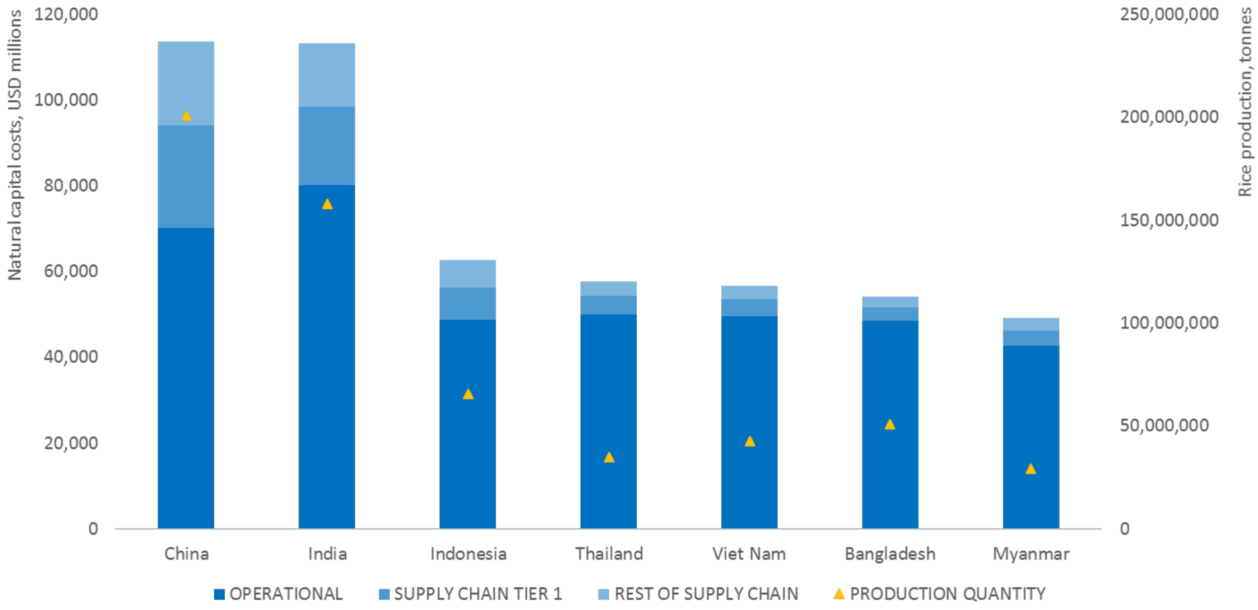


FIGURE 5: OPERATIONAL AND SUPPLY CHAIN NATURAL CAPITAL COSTS OF ***RICE*** PRODUCTION BY COUNTRY

***Findings***

China and India have the highest impact on natural capital due to rice production in this study. Each country is responsible for 22 percent of the natural capital costs caused due to rice production. China and India are also responsible for 62 percent of the production of rice of countries in this study.

*The cost of natural capital impacts in the study countries are driven by a combination of* ***land use change****, the emissions of* ***water pollutants****, and* ***water consumption****. In each country, the combination of these impacts are responsible for over 93 percent of the impacts.*

*These results show businesses that the capacity of ecosystem services and functions to support the environment, and agricultural production, are decreasing. It also highlights that water pollution, from the application of fertilizers, also has a significant impact on species that provide a supporting service to ecosystem service provision. For businesses to reduce their impact on ecosystems, and hence increase their resilience, addressing the negative effects of fertilizers and the conversion of land should be a priority.*

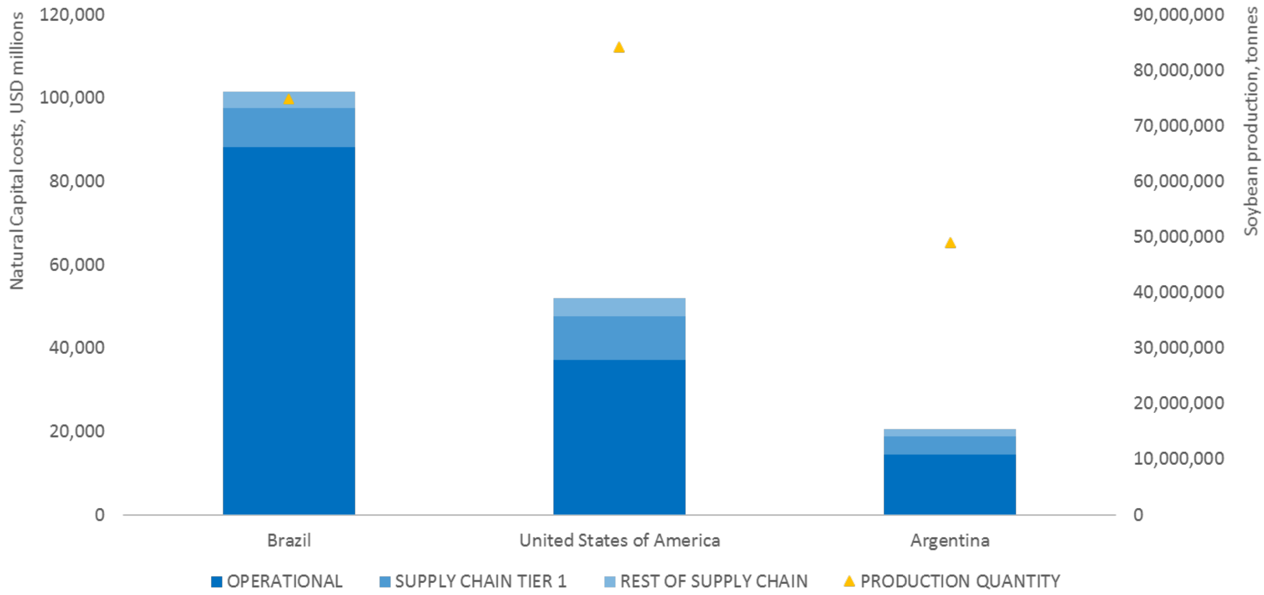


FIGURE 6: OPERATIONAL AND SUPPLY CHAIN NATURAL CAPITAL COSTS OF ***SOYBEAN*** PRODUCTION BY COUNTRY

***Findings***

Brazil is responsible for 58 percent of the natural capital impacts in the soybean farming sector in this study. The USA, on the other hand, produces 11 percent more soybeans, but with almost half the impact of Brazilian producer. This is despite the fact that less land is required to produce a tonne of soybean in the USA.

*The majority of the natural capital impacts occurring due to the production of soybeans in Brazil is because of **land use change** (63 percent) and **water pollution** (23 percent). This is a significant impact as ecosystem services are lost when areas, such as the Amazon Rainforest and Cerrado, are cleared to make way for soybean plantations.*

*Businesses should be aware that the impacts due to land use change and water pollution decrease the capacity of ecosystems to support agricultural production in these regions. The cost of these impacts could be realised through an increased variability in yield due to a change in local environmental conditions, such as the availability of good quality irrigation water. The identification of the type and magnitude of impacts allows businesses to select mitigation strategies that directly address the most material environmental issues.*

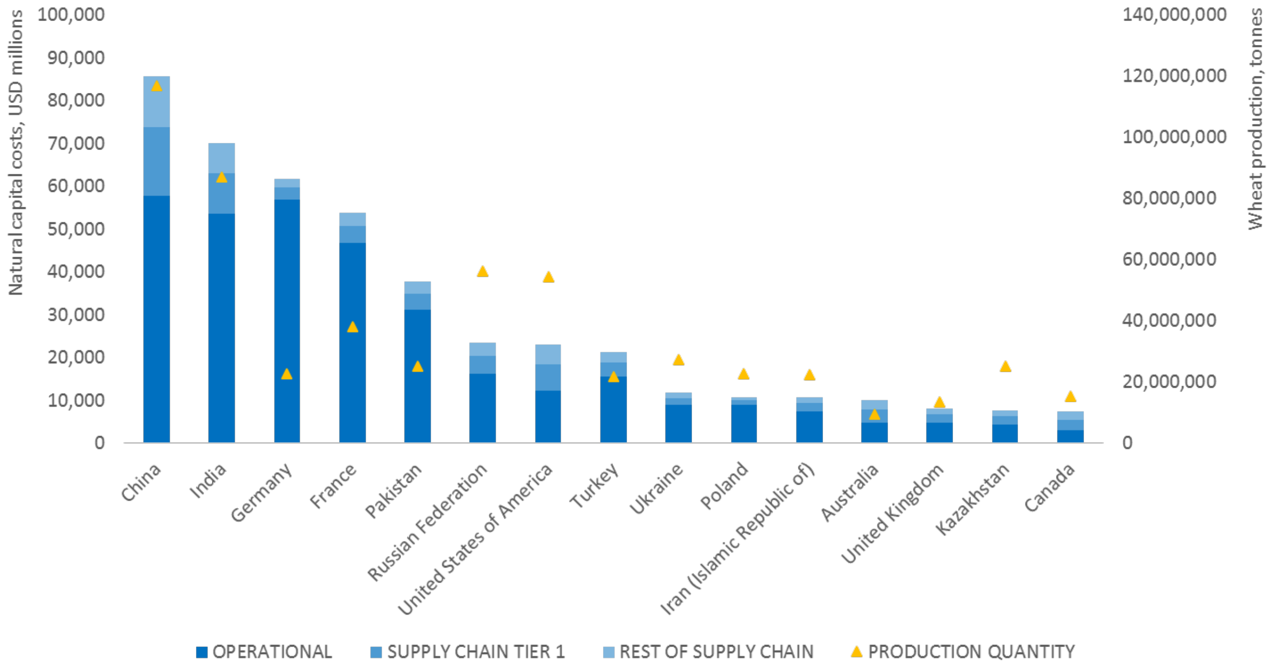


FIGURE 7: OPERATIONAL AND SUPPLY CHAIN NATURAL CAPITAL COSTS OF ***WHEAT*** PRODUCTION BY COUNTRY

***Findings***

The top three countries in this study, China, India and Germany, are responsible for almost 50 percent of the cost of the impacts on natural capital. China and India are the two largest producers of wheat, and are therefore expected to have higher impact on natural capital. However, Germany is ranked 9th in terms of total wheat production, and generates a disproportionately high impact on natural capital.

*The high natural capital costs associated with growing wheat in Germany are due to the **water pollution** caused by fertilizer application on the farm – 95 percent of its total impact. The European Environmental Agency (EEA) identifies Germany one of the countries in Europe with the greatest exceedance of critical nutrient loads (EEA, 2014). Conversely, the impacts caused by wheat production in China and India, are due to **land use change** and **water consumption** respectively.*

*These geo-specific impacts outline to businesses that the dependency on water availability in China and India is a key factor when considering more sustainable farming systems. Whereas the use of fertilizers, and their impact on water quality and ecosystems, should be a focus for businesses in Germany.*

TABLE 6: TOTAL NATURAL CAPITAL COSTS OF *CROP* PRODUCTION (USD PER COUNTRY)

| Rank | Country | Operational | | Supply chain (tier 1) | | Rest of supply chain | | Production quantity | |
|---|---|---|---|---|---|---|---|---|---|
| | | Cost (USD million) | % | Cost (USD million) | % | Cost (USD million) | % | tonnes | % |
| Maize production | | | | | | | | | |
| 1 | China | 94 880 | 36% | 19 674 | 33% | 15 053 | 33% | 193 000 000 | 28% |
| 2 | USA | 46 806 | 18% | 24 294 | 41% | 18 587 | 41% | 314 000 000 | 45% |
| 3 | Brazil | 49 352 | 19% | 4 528 | 8% | 3 464 | 8% | 55 700 000 | 8% |
| 4 | France | 23 228 | 9% | 1 309 | 2% | 1 002 | 2% | 15 900 000 | 2% |
| 5 | Indonesia | 14 754 | 6% | 2 387 | 4% | 1 826 | 4% | 17 600 000 | 3% |
| 6 | Mexico | 12 361 | 5% | 1 842 | 3% | 1 410 | 3% | 17 600 000 | 3% |
| 7 | India | 9 959 | 4% | 1 335 | 2% | 1 022 | 2% | 21 800 000 | 3% |
| 8 | Ukraine | 8 952 | 3% | 1 241 | 2% | 950 | 2% | 22 800 000 | 3% |
| 9 | Argentina | 3 428 | 1% | 1 331 | 2% | 1 018 | 2% | 23 800 000 | 3% |
| 10 | Canada | 1 822 | 1% | 810 | 1% | 620 | 1% | 10 700 000 | 2% |
| - | *Total* | *265 541* | *100%* | *58 751* | *100%* | *44 951* | *100%* | *692 900 000* | *100%* |
| Rice production | | | | | | | | | |
| 1 | China | 70 218 | 18% | 23 905 | 37% | 19 558 | 37% | 201 000 000 | 35% |
| 2 | India | 80 245 | 21% | 18 188 | 28% | 14 881 | 28% | 158 000 000 | 27% |
| 3 | Indonesia | 48 647 | 13% | 7 664 | 12% | 6 270 | 12% | 65 700 000 | 11% |
| 4 | Thailand | 49 999 | 13% | 4 275 | 7% | 3 498 | 7% | 34 600 000 | 6% |
| 5 | Viet Nam | 49 496 | 13% | 3 945 | 6% | 3 228 | 6% | 42 400 000 | 7% |
| 6 | Bangladesh | 48 591 | 13% | 3 056 | 5% | 2 500 | 5% | 50 600 000 | 9% |
| 7 | Myanmar | 38 740 | 10% | 3 523 | 5% | 2 882 | 5% | 29 000 000 | 5% |
| - | *Total* | *389 936* | *100%* | *64 555* | *100%* | *52 817* | *100%* | *581 300 000* | *100%* |
| Soybean production | | | | | | | | | |
| 1 | Brazil | 89 035 | 63% | 9 335 | 38% | 3 898 | 38% | 74 800 000 | 36% |
| 2 | USA | 37 027 | 26% | 10 599 | 44% | 4 425 | 44% | 84 200 000 | 41% |
| 3 | Argentina | 15 460 | 11% | 4 419 | 18% | 1 845 | 18% | 48 900 000 | 24% |
| - | *Total* | *141 523* | *100%* | *24 353* | *100%* | *10 168* | *100%* | *207 900 000* | *100%* |
| Wheat production | | | | | | | | | |
| 1 | China | 62 504 | 18% | 12 870 | 25% | 9 228 | 25% | 117 000 000 | 21% |

| Rank | Country | Operational | | Supply chain (tier 1) | | Rest of supply chain | | Production quantity | |
|---|---|---|---|---|---|---|---|---|---|
| | | Cost (USD million) | % | Cost (USD million) | % | Cost (USD million) | % | tonnes | % |
| 2 | India | 56 312 | 16% | 7 615 | 15% | 5 460 | 15% | 86 900 000 | 16% |
| 3 | Germany | 57 723 | 16% | 2 235 | 4% | 1 603 | 4% | 22 800 000 | 4% |
| 4 | France | 47 869 | 14% | 3 307 | 6% | 2 371 | 6% | 38 000 000 | 7% |
| 5 | Pakistan | 32 269 | 9% | 3 005 | 6% | 2 155 | 6% | 25 200 000 | 5% |
| 6 | Russia | 17 538 | 5% | 3 340 | 7% | 2 395 | 7% | 56 200 000 | 10% |
| 7 | USA | 14 103 | 4% | 4 935 | 10% | 3 538 | 10% | 54 400 000 | 10% |
| 8 | Turkey | 16 604 | 5% | 2 617 | 5% | 1 877 | 5% | 21 800 000 | 4% |
| 9 | Ukraine | 9 455 | 3% | 1 273 | 2% | 913 | 2% | 22 300 000 | 4% |
| 10 | Poland | 9 213 | 3% | 886 | 2% | 635 | 2% | 9 339 200 | 2% |
| 11 | Iran | 8 044 | 2% | 1 454 | 3% | 1 043 | 3% | 13 500 000 | 2% |
| 12 | Australia | 5 741 | 2% | 2 476 | 5% | 1 775 | 5% | 27 400 000 | 5% |
| 13 | United Kingdom | 5 355 | 2% | 1 527 | 3% | 1 095 | 3% | 15 300 000 | 3% |
| 14 | Kazakhstan | 4 958 | 1% | 1 533 | 3% | 1 099 | 3% | 22 700 000 | 4% |
| 15 | Canada | 3 737 | 1% | 2 040 | 4% | 1 463 | 4% | 25 300 000 | 5% |
| - | *Total* | *351 425* | *100%* | *51 113* | *100%* | *36 651* | *100%* | *558 139 200* | *100%* |

*Livestock*

Figure 8 shows each of the four types of livestock, in order of the highest combined operational and supply chain natural capital costs per unit of production globally. It is important to note that *operational impacts due to water pollution and soil pollution have not been included in the analysis below.* However, emissions due to the management of manure on the farm are included, but the emissions due to application of manure are attributed to the crop cultivation stage. As such, manure is treated as managed waste in the direct impact of livestock production. It is also important to note that heavy metals are often found in livestock manure but data availability is limited. The integration of these impacts would increase the natural capital costs of livestock production.

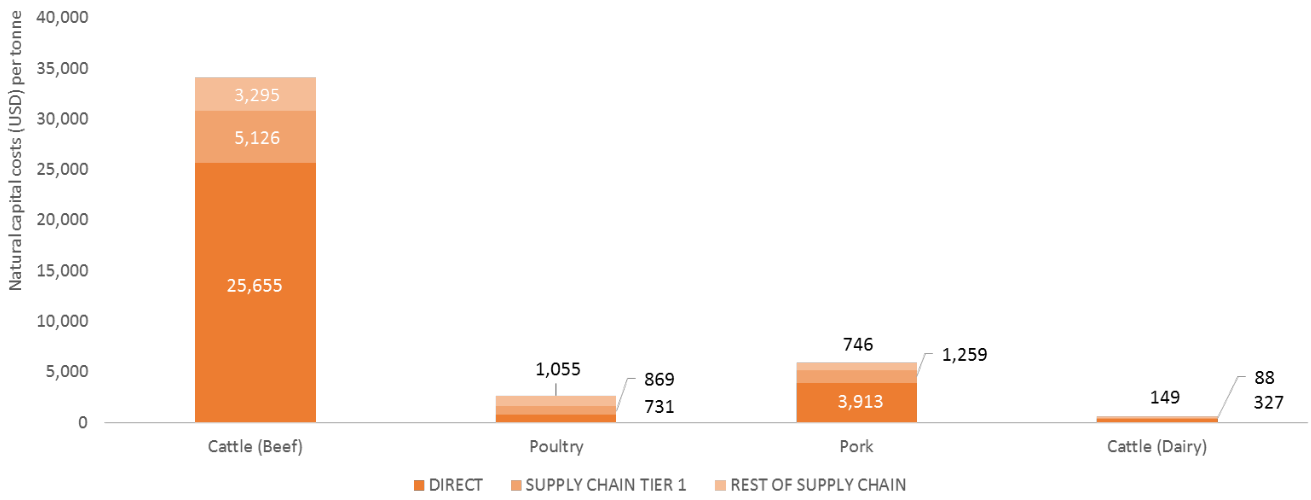


FIGURE 8: OPERATIONAL AND SUPPLY CHAIN NATURAL CAPITAL COSTS OF ***LIVESTOCK*** PRODUCTION[13]

Figure 8 shows that on average, the production of beef causes the highest natural capital costs of all the livestock sectors analyzed in this study. The main driver of the natural capital costs in beef production comes from the operational impacts, which account for 75 percent of the total impacts. Conversely, the majority of the impacts of poultry production occur in the supply chain, which are responsible for 73 percent of the impacts. Overall, the average contribution of the operational impacts to the total natural capital costs, across all sectors, is 71 percent, meaning that the cost of supply chain impacts, account for 29 percent.

Figure 8 shows the costs of the impacts of conventional livestock production globally. This provides business with an understanding of where the impacts of each type of livestock are situated within the value chain. It also provides a guide of what potential, more sustainable alternatives, should address. Operational impacts are discussed in more detail in the sections below. The following sections can show businesses what impacts are most significant in the operations of farms in different regions, which can aid in the selection of alternative farming systems and mitigation strategies.

Figure 9 shows the top 10 livestock production impacts with the highest natural capital costs by country.

[13] It is important to remember that the operational natural capital costs associated with livestock production do not include the water pollution impacts occurring due to manure.

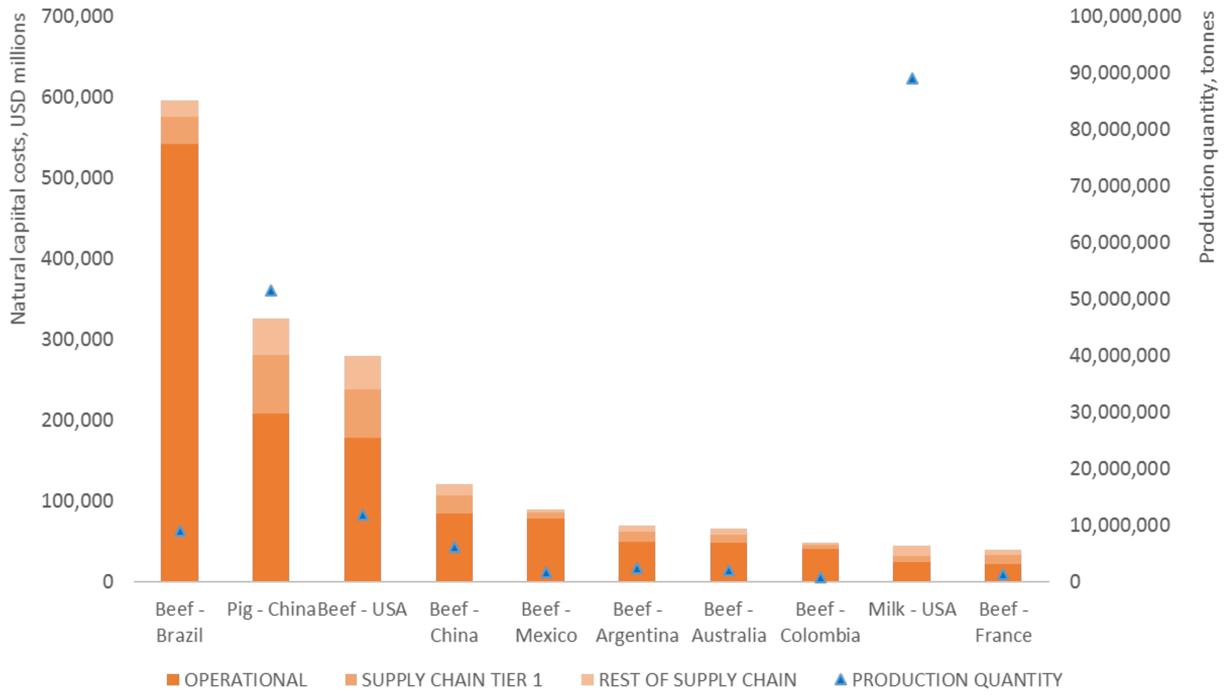


FIGURE 9: TOP 10 OPERATIONAL AND SUPPLY CHAIN NATURAL CAPITAL COSTS OF ***LIVESTOCK*** PRODUCTION BY COUNTRY

Figure 9 shows that the impacts associated with beef production in Brazil has the greatest environmental impact. Brazil is the second largest producer of beef behind the USA, and accounts for 9 million tonnes of beef production annually, approximately 18 percent of the total. The USA, the largest beef producer, accounts for 25 percent of production. Pork production in China also has a significant impact due to the vast quantities produced; over 51 million tonnes. The Netherlands and Denmark are the second and third largest contributors to the natural capital costs of pork production, and combine to account for 13 percent of the total impacts. In total, the top 10 countries and sectors listed in Figure 9 account for 63 percent of the total costs of the impacts of livestock production in this study.

Figure 9 allows businesses to begin analyzing the type and magnitude of the impacts associated with either their operations, or the products they purchase. It highlights significant global issues and provides an indication to business of the sustainability of conventional livestock farming systems. Businesses can use this as a starting point to investigate what impacts and practices are most material in these sectors and countries, and then qualitatively assess whether the external costs of the impacts are likely to be internalized, and over what timescales. Businesses can use this information to either identify what impacts alternative livestock farming systems should address, so as to reduce the cost of these impacts and therefore the likelihood that the costs will be internalized. Businesses can also use this information to begin to assess to what degree they are dependent on the natural capital that they are impacting, and how the change of these costs can materially affect the business. Table 7 shows the top 3 three countries, in each livestock sector, that impact most on natural capital.

TABLE 7: TOP CONTRIBUTORS TO THE NATURAL CAPITAL COSTS IN EACH *LIVESTOCK* SECTOR (OPERATIONAL AND SUPPLY CHAIN IMPACTS)

| Livestock | Top contributors to the natural capital costs (USD million) | | | Total costs (USD million) |
|---|---|---|---|---|
| | 1st | 2nd | 3rd | |
| Cattle (beef) | *Brazil*<br>595 987 (36%) | *USA*<br>279 758 (17%) | *China*<br>120 961 (7%) | 1 668 618 |
| Cattle (dairy) | *USA*<br>44 948 (16%) | *Brazil*<br>31 969 (12%) | *India*<br>27 317 (10%) | 274 560 |
| Pork | *China*<br>326 677 (62%) | *Netherlands*<br>35 326 (7%) | *Denmark*<br>29 689 (6%) | 523 470 |
| Poultry | *USA*<br>36 518 (19%) | *Brazil*<br>27 904 (15%) | *China*<br>27 060 (14%) | 188 704 |

Operational and supply chain impacts for these livestock sectors are discussed in more detail in the sections below.

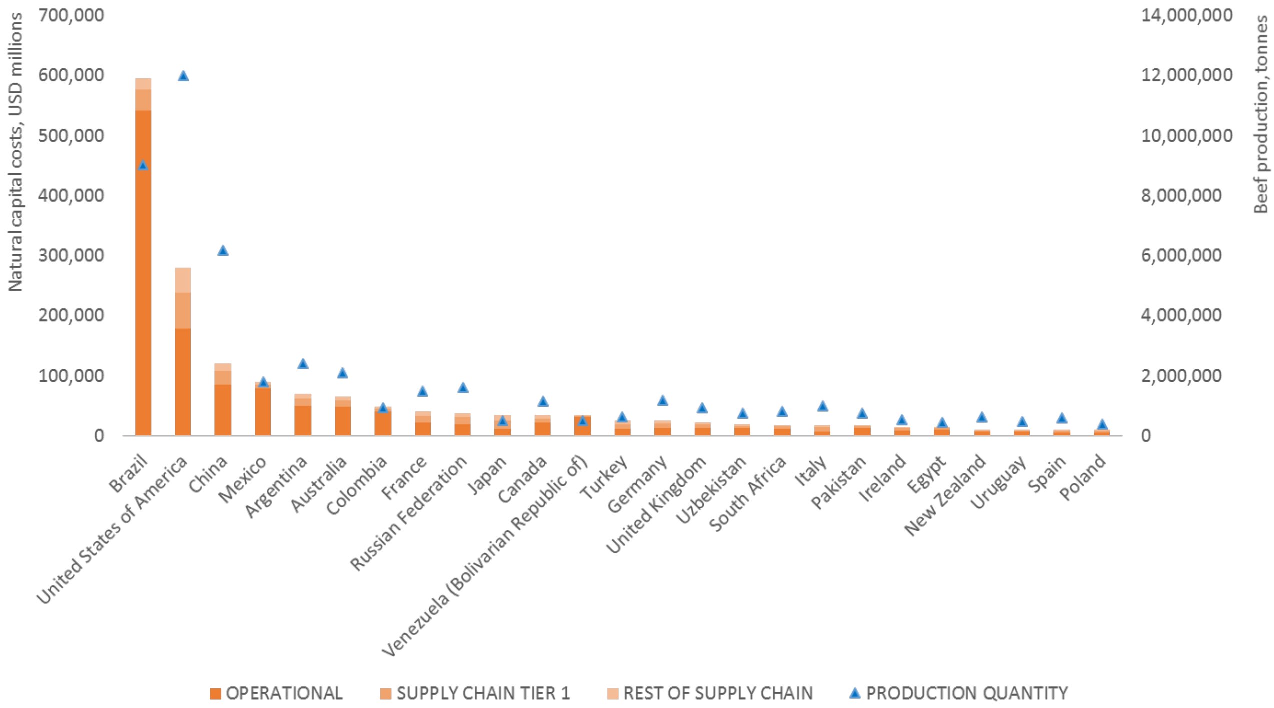


FIGURE 10: OPERATIONAL AND SUPPLY CHAIN NATURAL CAPITAL COSTS OF ***CATTLE (BEEF)*** PRODUCTION BY COUNTRY

***Findings***

Brazil has the greatest impact on natural capital due to beef production. The impacts are mainly due to ***land use change*** and the impact of ***greenhouse gas*** emissions. Combined, these impacts represent 99 percent of the costs of the impacts for Brazilian beef production. The USA also has a significant impact on natural capital due to beef production, and the combined costs due to land use change and greenhouse gas emissions represent 92 percent of the impacts.

*This demonstrates to businesses that the expansion of livestock on naturally occurring ecosystems can significantly degrade their capacity to deliver ecosystem services. This could directly impact cattle farmers, or these effects could indirectly affect other farming practices in the region by changing water availability and rates of soil erosion. Businesses can use this information as a starting point to analyze which type of impacts they are directly and indirectly exposed to. This can be performed in terms of analysing the extent to which the farm is dependent on the natural capital being degraded, and how the business may have to adapt to these changes.*

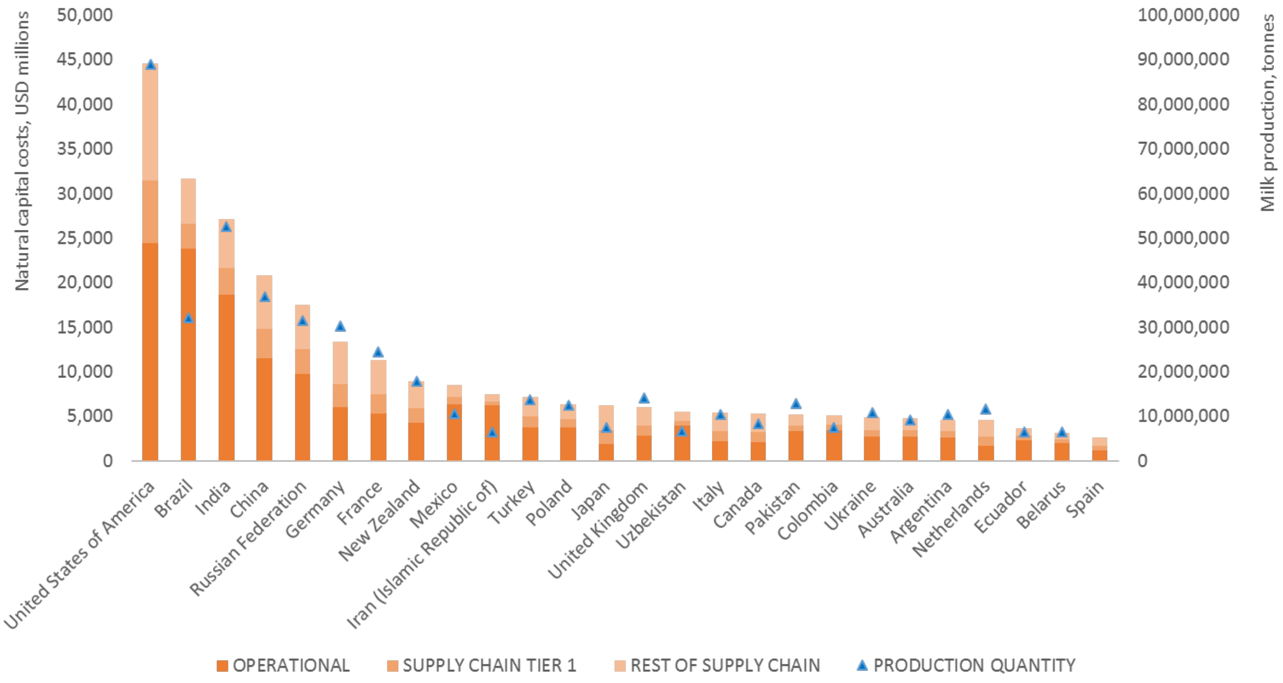


FIGURE 11: OPERATIONAL AND SUPPLY CHAIN NATURAL CAPITAL COSTS OF ***CATTLE (DAIRY)*** PRODUCTION BY COUNTRY

***Findings***

The USA, Brazil and India account for 38 percent of the costs of the impacts due to milk production in this study. Typically around 70 percent of these impacts are due to ***land use change*** by converting naturally occurring ecosystems, such as rainforest, to pastureland. The top 10 countries in Figure 11 account for 70 percent of the milk production and natural capital costs in this study.

*This highlights to business that capacity of ecosystem services to support agricultural ecosystems are decreasing. A high conversion rate from naturally occurring land to man-made ecosystems indicates that the base of natural capital that they rely on is being degraded. The degree of a business' dependency on those ecosystem services will dictate the costs of degradation to that business, as well as the rate of internalisation of those costs. Businesses should also be aware that 25 percent of the costs of milk production are due to **greenhouse gas** emissions. The internalisation of the costs of carbon emissions could begin to impact as regulatory bodies look to curtail GHG emissions coming from agriculture.*

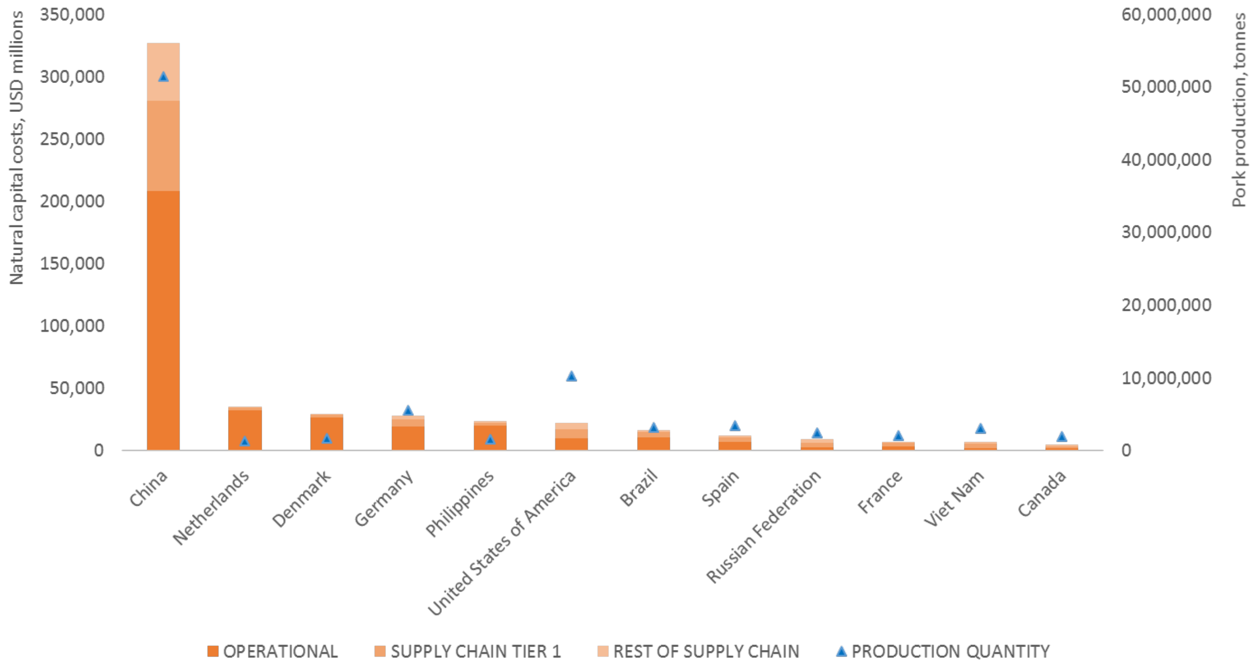


FIGURE 12: OPERATIONAL AND SUPPLY CHAIN NATURAL CAPITAL COSTS OF ***PORK*** PRODUCTION BY COUNTRY

***Findings***

China is responsible for 60 percent of the natural capital costs of the pork production in this study and is responsible for 58 percent of the production. Other significant contributors to global natural capital costs include the Netherlands (9 percent) and Denmark (8 percent).

*The overwhelming majority of the operational impacts from pork production are due to* ***land use change****, which account for 88 percent of the total. However, supply chain impacts of pork production are also a significant source of natural capital costs. For example, in China, land use change, largely due to the production of feed, accounts for 30 percent of the supply chain impact, and greenhouse gas emissions account for an additional 28 percent.*

*This information gives businesses and other stakeholder's insight into the dependency of pork producers in China of purchasing concentrate feeds. This allows businesses to start assessing whether their operations, or their suppliers, could be affected by the natural capital impacts associated with the production of feed. It also enables businesses to start assessing whether pork production can continue to expand in China, or whether other farming systems would need to be adopted to increase supply.*

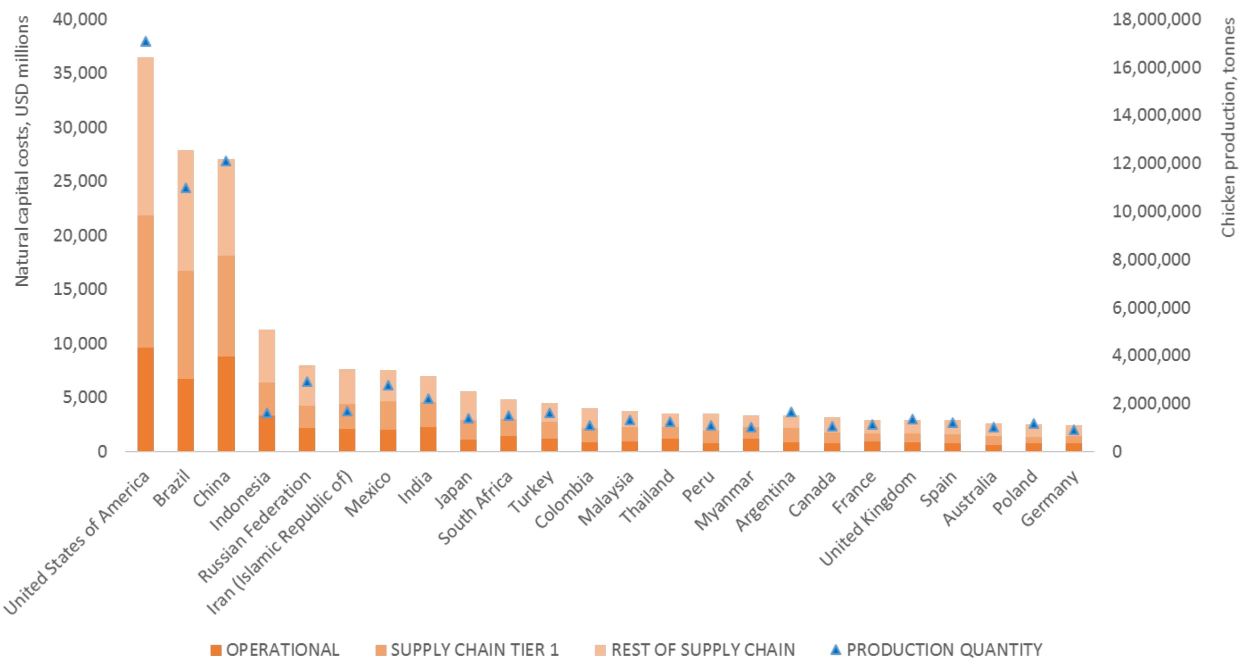


FIGURE 13: OPERATIONAL AND SUPPLY CHAIN NATURAL CAPITAL COSTS OF ***POULTRY*** PRODUCTION BY COUNTRY

***Findings***

The top three contributors to the natural capital costs in this study, the USA, Brazil, and China are responsible for 48 percent of the natural capital costs of poultry production. Together, they also represent 57 percent of poultry production analyzed. In general, 72 percent of the natural capital impacts occur in the supply chain.

*Typically, the supply chain impacts of poultry production are mainly due to the emissions of **land use change, greenhouse gas emissions,** and **air pollution**, which combine to contribute over 83 percent of the supply chain natural capital costs.*

*The USA creates natural capital impacts that are 23 percent greater than those in Brazil. The operational natural capital costs is driven by the emission of **greenhouse gases** and **air pollutants**. The greenhouse gas impacts in the supply chain are mainly driven by the manufacture of feed. Interestingly, Indonesia inflicts high natural impacts proportional to its production. The natural capital cost of its impacts are USD 7 000 per tonne, which is over three-times higher than USA and China. In part, this is due to the operational GHG emissions in Indonesia, which are nearly four-times higher than the USA.*

TABLE 8: TOTAL NATURAL CAPITAL COSTS OF *LIVESTOCK* PRODUCTION (USD PER COUNTRY)

| Rank | Country | Operational | | Supply chain (tier 1) | | Rest of supply chain | | Production quantity | |
|---|---|---|---|---|---|---|---|---|---|
| | | Cost (USD million) | % | Cost (USD million) | % | Cost (USD million) | % | tonnes | % |
| Cattle (beef) production | | | | | | | | | |
| 1 | Brazil | 542 363 | 43% | 34 107 | 14% | 19 517 | 12% | 9 030 000 | 18% |
| 2 | USA | 178 918 | 14% | 59 474 | 24% | 41 365 | 26% | 12 000 000 | 25% |
| 3 | China | 84 648 | 7% | 22 701 | 9% | 13 612 | 8% | 6 182 155 | 13% |
| 4 | Mexico | 78 242 | 6% | 7 507 | 3% | 4 350 | 3% | 1 803 930 | 4% |
| 5 | Argentina | 49 841 | 4% | 12 674 | 5% | 7 912 | 5% | 2 419 700 | 5% |
| 6 | Australia | 49 112 | 4% | 10 028 | 4% | 6 416 | 4% | 2 109 860 | 4% |
| 7 | Colombia | 41 071 | 3% | 4 579 | 2% | 2 813 | 2% | 940 000 | 2% |
| 8 | France | 22 796 | 2% | 10 745 | 4% | 6 694 | 4% | 1 501 610 | 3% |
| 9 | Russian Federation | 19 876 | 2% | 11 465 | 5% | 7 000 | 4% | 1 625 470 | 3% |
| 10 | Japan | 11 175 | 1% | 13 651 | 5% | 10 005 | 6% | 500 440 | 1% |
| 11 | Canada | 21 913 | 2% | 7 091 | 3% | 4 934 | 3% | 1 154 240 | 2% |
| 12 | Venezuela | 30 906 | 2% | 1 760 | 1% | 1 057 | 1% | 494 500 | 1% |
| 13 | Turkey | 11 716 | 1% | 7 787 | 3% | 5 680 | 4% | 644 906 | 1% |
| 14 | Germany | 12 914 | 1% | 7 876 | 3% | 4 846 | 3% | 1 170 380 | 2% |
| 15 | United Kingdom | 12 507 | 1% | 6 254 | 2% | 3 899 | 2% | 936 000 | 2% |
| 16 | Uzbekistan | 12 511 | 1% | 3 624 | 1% | 2 503 | 2% | 763 000 | 2% |
| 17 | South Africa | 12 165 | 1% | 3 662 | 1% | 2 536 | 2% | 828 609 | 2% |
| 18 | Italy | 7 511 | 1% | 6 643 | 3% | 4 246 | 3% | 1 000 370 | 2% |
| 19 | Pakistan | 12 652 | 1% | 3 143 | 1% | 1 958 | 1% | 761 000 | 2% |
| 20 | Ireland | 9 128 | 1% | 3 768 | 2% | 2 325 | 1% | 545 942 | 1% |
| 21 | Egypt | 9 454 | 1% | 3 012 | 1% | 2 138 | 1% | 454 484 | 1% |
| 22 | New Zealand | 6 581 | 1% | 2 496 | 1% | 1 561 | 1% | 622 676 | 1% |
| 23 | Uruguay | 6 701 | 1% | 2 366 | 1% | 1 448 | 1% | 479 000 | 1% |
| 24 | Spain | 5 910 | 0% | 2 303 | 1% | 1 269 | 1% | 604 113 | 1% |
| 25 | Poland | 5 661 | 0% | 2 270 | 1% | 1 276 | 1% | 394 900 | 1% |
| - | *Total* | *1 256 273* | *100%* | *250 988* | *100%* | *161 358* | *100%* | *48 967 285* | *100%* |

| Rank | Country | Operational | | Supply chain (tier 1) | | Rest of supply chain | | Production quantity | |
|---|---|---|---|---|---|---|---|---|---|
| | | Cost (USD million) | % | Cost (USD million) | % | Cost (USD million) | % | tonnes | % |
| Cattle (dairy) production | | | | | | | | | |
| 1 | USA | 24 463 | 15% | 7 451 | 17% | 13 034 | 18% | 89 000 000 | 18% |
| 2 | Brazil | 23 892 | 15% | 3 003 | 7% | 5 074 | 7% | 32 100 000 | 7% |
| 3 | India | 18 622 | 12% | 3 189 | 7% | 5 507 | 8% | 52 500 000 | 11% |
| 4 | China | 11 590 | 7% | 3 530 | 8% | 5 987 | 8% | 36 900 000 | 8% |
| 5 | Russian Federation | 9 766 | 6% | 2 984 | 7% | 4 968 | 7% | 31 400 000 | 6% |
| 6 | Germany | 6 038 | 4% | 2 679 | 6% | 4 753 | 7% | 30 300 000 | 6% |
| 7 | France | 5 317 | 3% | 2 402 | 6% | 3 859 | 5% | 24 400 000 | 5% |
| 8 | New Zealand | 4 242 | 3% | 1 736 | 4% | 3 021 | 4% | 17 900 000 | 4% |
| 9 | Mexico | 6 334 | 4% | 849 | 2% | 1 405 | 2% | 10 700 000 | 2% |
| 10 | Iran | 6 224 | 4% | 454 | 1% | 830 | 1% | 6 391 400 | 1% |
| 11 | Turkey | 3 790 | 2% | 1 181 | 3% | 2 169 | 3% | 13 800 000 | 3% |
| 12 | Poland | 3 728 | 2% | 1 049 | 2% | 1 674 | 2% | 12 400 000 | 3% |
| 13 | Japan | 1 930 | 1% | 1 545 | 4% | 2 779 | 4% | 7 474 310 | 2% |
| 14 | United Kingdom | 2 850 | 2% | 1 267 | 3% | 1 999 | 3% | 14 200 000 | 3% |
| 15 | Uzbekistan | 3 939 | 2% | 557 | 1% | 1 023 | 1% | 6 712 200 | 1% |
| 16 | Italy | 2 218 | 1% | 1 252 | 3% | 2 073 | 3% | 10 500 000 | 2% |
| 17 | Canada | 2 133 | 1% | 1 157 | 3% | 2 086 | 3% | 8 400 000 | 2% |
| 18 | Pakistan | 3 316 | 2% | 705 | 2% | 1 204 | 2% | 12 900 000 | 3% |
| 19 | Colombia | 3 497 | 2% | 616 | 1% | 1 023 | 1% | 7 500 000 | 2% |
| 20 | Ukraine | 2 721 | 2% | 858 | 2% | 1 354 | 2% | 10 800 000 | 2% |
| 21 | Australia | 2 748 | 2% | 753 | 2% | 1 291 | 2% | 9 101 000 | 2% |
| 22 | Argentina | 2 596 | 2% | 773 | 2% | 1 265 | 2% | 10 500 000 | 2% |
| 23 | Netherlands | 1 711 | 1% | 1 133 | 3% | 1 817 | 2% | 11 600 000 | 2% |
| 24 | Ecuador | 2 357 | 1% | 509 | 1% | 843 | 1% | 6 375 320 | 1% |
| 25 | Belarus | 1 971 | 1% | 479 | 1% | 744 | 1% | 6 489 300 | 1% |
| 26 | Spain | 1 176 | 1% | 582 | 1% | 918 | 1% | 6 522 000 | 1% |
| - | *Total* | *159 169* | *100%* | *42 691* | *100%* | *72 700* | *100%* | *486 865 530* | *100%* |

| Rank | Country | Operational | | Supply chain (tier 1) | | Rest of supply chain | | Production quantity | |
|---|---|---|---|---|---|---|---|---|---|
| | | Cost (USD million) | % | Cost (USD million) | % | Cost (USD million) | % | tonnes | % |
| Pork production | | | | | | | | | |
| 1 | China | 208 328 | 60% | 72 334 | 65% | 46 014 | 70% | 51 500 000 | 58% |
| 2 | Netherlands | 32 357 | 9% | 2 046 | 2% | 923 | 1% | 1 347 170 | 2% |
| 3 | Denmark | 26 734 | 8% | 2 018 | 2% | 937 | 1% | 1 720 200 | 2% |
| 4 | Germany | 19 670 | 6% | 5 731 | 5% | 2 507 | 4% | 5 616 070 | 6% |
| 5 | Philippines | 19 979 | 6% | 2 592 | 2% | 1 222 | 2% | 1 649 300 | 2% |
| 6 | USA | 10 202 | 3% | 7 316 | 7% | 4 910 | 7% | 10 300 000 | 12% |
| 7 | Brazil | 11 072 | 3% | 4 204 | 4% | 1 350 | 2% | 3 227 000 | 4% |
| 8 | Spain | 6 944 | 2% | 3 806 | 3% | 1 526 | 2% | 3 469 350 | 4% |
| 9 | Russian Federation | 3 003 | 1% | 3 481 | 3% | 2 572 | 4% | 2 427 640 | 3% |
| 10 | France | 3 750 | 1% | 2 347 | 2% | 1 011 | 2% | 2 157 410 | 2% |
| 11 | Viet Nam | 2 015 | 1% | 3 708 | 3% | 1 760 | 3% | 3 098 900 | 4% |
| 12 | Canada | 2 076 | 1% | 1 770 | 2% | 1 258 | 2% | 1 953 550 | 2% |
| - | *Total* | *346 130* | *100%* | *111 352* | *100%* | *65 988* | *100%* | *88 466 590* | *100%* |
| Poultry production | | | | | | | | | |
| 1 | USA | 9 632 | 19% | 12 250 | 24% | 14 636 | 20% | 17 100 000 | 24% |
| 2 | Brazil | 6 689 | 13% | 10 074 | 19% | 11 141 | 15% | 11 000 000 | 15% |
| 3 | China | 8 785 | 17% | 9 349 | 18% | 8 925 | 12% | 12 100 000 | 17% |
| 4 | Indonesia | 3 349 | 6% | 3 010 | 6% | 4 942 | 7% | 1 613 600 | 2% |
| 5 | Russian Federation | 2 152 | 4% | 2 059 | 4% | 3 728 | 5% | 2 909 430 | 4% |
| 6 | Iran | 2 110 | 4% | 2 287 | 4% | 3 205 | 4% | 1 686 000 | 2% |
| 7 | Mexico | 2 013 | 4% | 2 608 | 5% | 2 961 | 4% | 2 765 020 | 4% |
| 8 | India | 2 282 | 4% | 2 333 | 4% | 2 372 | 3% | 2 206 000 | 3% |
| 9 | Japan | 1 134 | 2% | 1 809 | 3% | 2 598 | 3% | 1 382 000 | 2% |
| 10 | South Africa | 1 455 | 3% | 1 560 | 3% | 1 828 | 2% | 1 485 610 | 2% |
| 11 | Turkey | 1 195 | 2% | 1 576 | 3% | 1 762 | 2% | 1 613 310 | 2% |
| 12 | Colombia | 845 | 2% | 1 336 | 3% | 1 826 | 2% | 1 086 000 | 2% |
| 13 | Malaysia | 956 | 2% | 1 269 | 2% | 1 509 | 2% | 1 315 000 | 2% |
| 14 | Thailand | 1 163 | 2% | 1 121 | 2% | 1 246 | 2% | 1 257 600 | 2% |

| Rank | Country | Operational | | Supply chain (tier 1) | | Rest of supply chain | | Production quantity | |
|---|---|---|---|---|---|---|---|---|---|
| | | Cost (USD million) | % | Cost (USD million) | % | Cost (USD million) | % | tonnes | % |
| 15 | Peru | 762 | 1% | 1 187 | 2% | 1 511 | 2% | 1 084 820 | 2% |
| 16 | Myanmar | 1 172 | 2% | 1 082 | 2% | 1 109 | 1% | 1 015 860 | 1% |
| 17 | Argentina | 854 | 2% | 1 291 | 2% | 1 203 | 2% | 1 649 000 | 2% |
| 18 | Canada | 750 | 1% | 1 008 | 2% | 1 440 | 2% | 1 053 220 | 1% |
| 19 | France | 922 | 2% | 782 | 2% | 1 241 | 2% | 1 112 140 | 2% |
| 20 | United Kingdom | 869 | 2% | 821 | 2% | 1 234 | 2% | 1 354 000 | 2% |
| 21 | Spain | 734 | 1% | 840 | 2% | 1 329 | 2% | 1 205 750 | 2% |
| 22 | Australia | 643 | 1% | 805 | 2% | 1 106 | 1% | 1 017 090 | 1% |
| 23 | Poland | 755 | 1% | 635 | 1% | 1 082 | 1% | 1 150 000 | 2% |
| 24 | Germany | 733 | 1% | 659 | 1% | 1 063 | 1% | 895 880 | 1% |
| - | *Total* | *51 955* | *100%* | *61 749* | *100%* | *75 000* | *100%* | *71 057 330* | *100%* |

# Natural Capital Intensities

The natural capital intensity represents the average impact on natural capital caused by the production of one tonne of each commodity, each year. The average intensity is shown first at a global level, and then at a continental level. The intensities are representative of all countries in this study (80 percent of global production for each commodity), and they are weighted by the production quantity in each country. The information in the following sections has been broken out so that the operational impacts of the farm, and the impacts of those supplying the farm, are presented separately. These are each referred to as operational and supply chain impacts.

*Crops*

Figure 14 and Figure 15 show the breakdown of natural capital impacts, per tonne of production, for operational and supply chain impacts globally. The figures show that on average, for all crops, operational impacts are greater than supply chain impacts per tonne of crop produced. In general, the natural capital costs are driven by the emissions of water pollutants and the effects of land use change on ecosystem service loss.

The information shows businesses that, when analysing the impacts of conventional crop farming systems, and how these impacts can be reduced, focus should be on the farm's operational impacts. In particular, the effect of water pollution from fertilizer application, and the loss of ecosystem services from land use change should be addressed. For instance, it was shown earlier that maize production in Germany has a particularly high operational impact due to the leaching and subsequent eutrophication of fertilizers in water bodies. Businesses and other stakeholders can begin to look at the application rates of fertilizers, the method of application, and the drivers for this. This can include analyzing the effects of subsidies provided by the Common Agricultural Policy (CAP) on fertilizer application, or the cost and sourcing of fertilizers.

Table 9 highlights the breakdown of operational and supply chain intensities for each of the crop sectors in this study. Figure 14 and Figure 15 look at these impacts more in detail.

TABLE 9: BREAKDOWN OF NATURAL CAPITAL INTENSITIES FOR *CROP* PRODUCTION

| Crop | Operational | | Supply chain | | Total (USD per tonne) |
|---|---|---|---|---|---|
| | USD per tonne | % | USD per tonne | % | |
| Maize | 383 | 72% | 150 | 28% | 533 |
| Rice | 671 | 77% | 202 | 23% | 873 |
| Soybean | 681 | 80% | 166 | 20% | 847 |
| Wheat | 630 | 80% | 157 | 20% | 787 |

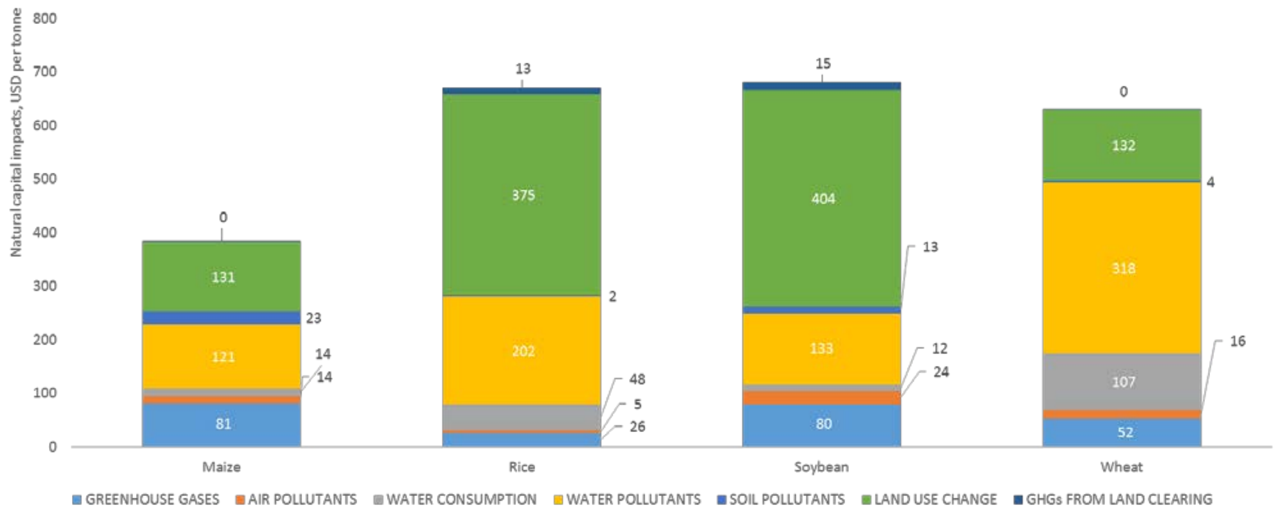


FIGURE 14: OPERATIONAL NATURAL CAPITAL INTENSITY OF *CROP* COMMODITIES (USD OF IMPACTS PER TONNE OF PRODUCTION)

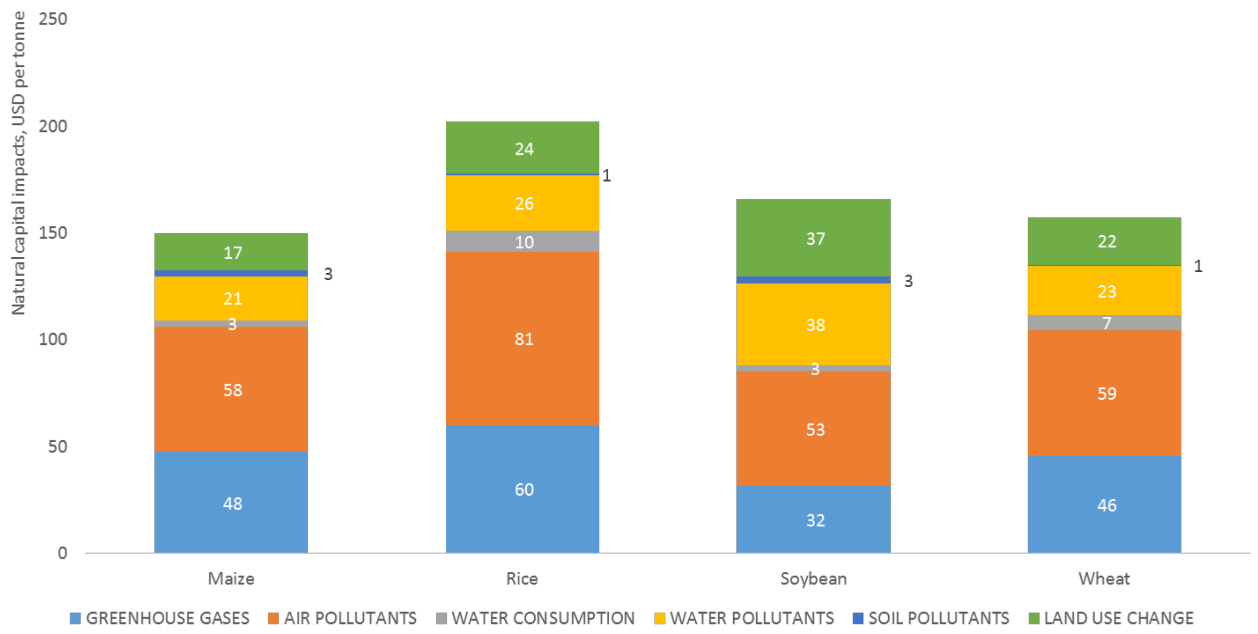


FIGURE 15: SUPPLY CHAIN NATURAL CAPITAL INTENSITY OF ***CROP*** COMMODITIES (USD OF IMPACTS PER TONNE OF PRODUCTION)

*Livestock*

As presented for crops, Figure 16 and Figure 17 show the breakdown of livestock impact on natural capital, per tonne of production, for operational and supply chain impacts globally. Table 10 that accompanies these figures shows that on average, the operational impacts are greatest, per tonne produced. The contribution of operational impacts associated with the farming practices in all sectors is 64 percent.

The information shows businesses that, when analyzing the impacts of conventional livestock farming systems, and how these impacts can be reduced, focus should be on the farm's operational impacts. In particular, the effect of greenhouse emissions and the loss of ecosystem services from land use change. For instance, it was shown earlier that beef production in Brazil has a particularly high operational impact due to the loss of ecosystem services from the conversion of rainforest. Businesses and other stakeholders could begin to analyze the feasibility of restoring the ecosystem services lost due to land conversion, and assessing which services would provide the greatest benefit. Alternatively, businesses that wish to mitigate the impacts of beef production in Brazil, instead of maintaining conventional grazing methods, they can alter production by beginning to introduce rotational grazing practices. This could allow pastureland to regenerate more consistently but may require capital expenditure in order to install the required infrastructure (FAO, 2015a).

Table 10 highlights the breakdown of operational and supply chain intensities for each of the livestock sectors in the study. Figure 16 and Figure 17 look at these impacts more in detail.

TABLE 10: BREAKDOWN OF NATURAL CAPITAL INTENSITIES FOR *LIVESTOCK* PRODUCTION

| Livestock | Operational | | Supply chain | | Total USD per tonne |
|---|---|---|---|---|---|
| | USD per tonne | % | USD per tonne | % | |
| Cattle (beef) | 25 655 | 75% | 8 421 | 25% | 34 076 |
| Cattle (dairy) | 327 | 58% | 238 | 42% | 564 |
| Pork | 3 913 | 66% | 2 005 | 34% | 5 917 |
| Poultry | 731 | 28% | 1 924 | 72% | 2 656 |

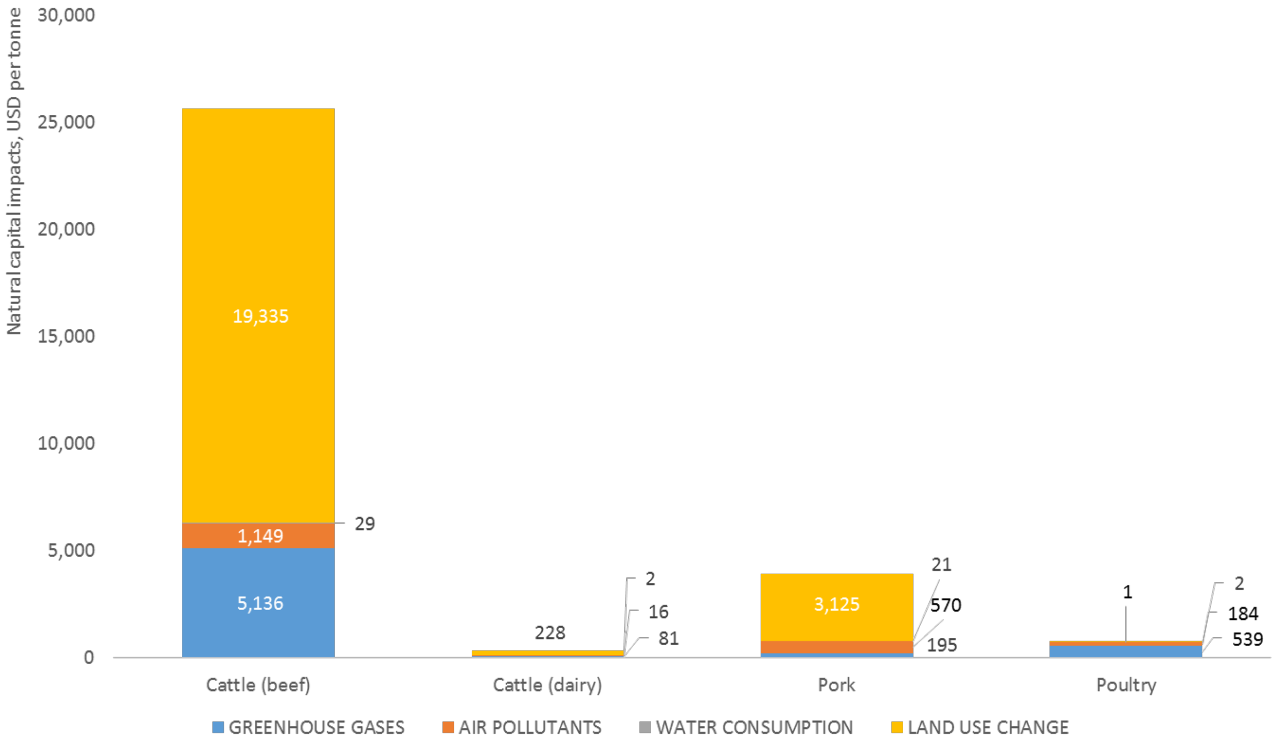


FIGURE 16: OPERATIONAL NATURAL CAPITAL INTENSITY OF *LIVESTOCK* COMMODITIES (USD OF IMPACTS PER TONNE OF PRODUCTION)

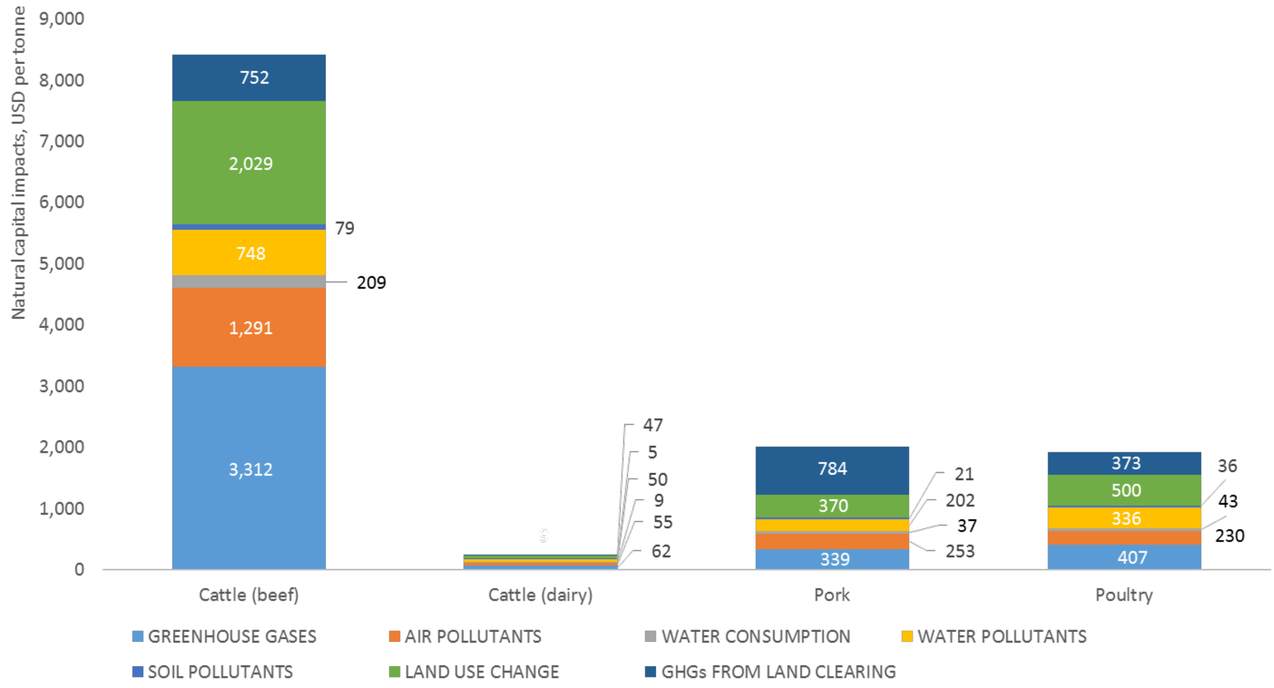


FIGURE 17: SUPPLY CHAIN NATURAL CAPITAL INTENSITY OF ***LIVESTOCK*** COMMODITIES (USD OF IMPACTS PER TONNE OF PRODUCTION)

*Regional natural capital intensities*

The costs of the operational and supply chain natural capital impacts vary between countries for each commodity. This section aims to highlight the impacts of each commodity at a continental level, including both farming operations and supply chain impacts. This approach was taken to highlight regional trends and issues that are material to each sector in each region.

As described in the Approach section, the quantification of impacts was based on country-specific factors in the majority of cases, or global average factors if the data was not available. Valuation factors are country-specific, apart from greenhouse emissions where the impact on natural capital is global. However, country-specific valuations have limitations, such as the fact that they rely on national averages, or that the dispersion models used are not country-specific. Another limitation, for example, is that for the production of the livestock commodities in this study, it was not possible to ascertain in which country feed was being produced, so in this instance, global average impact factors were used.

The analysis that is contained hereafter should be used to highlight where there are opportunities to improve farming practices, and highlight where the most material impacts exist. This is so that a company can begin to reduce its impact, and enable the identification of alternative farming systems that enable a reduction in these impacts, whilst maintaining or even increasing production. The identification of more sustainable farming systems should also include an assessment of the degree to which a company is dependent on the natural capital that is impacted.

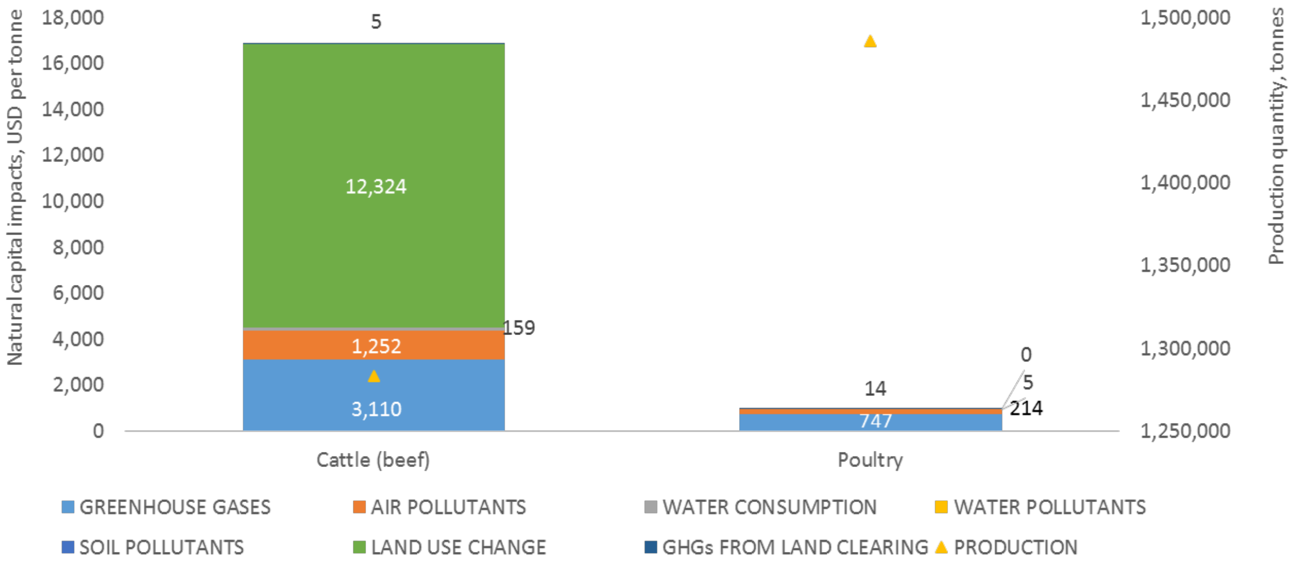


FIGURE 18: OPERATIONAL NATURAL CAPITAL INTENSITIES OF ASSOCIATED WITH CROP AND LIVESTOCK PRODUCTION IN AFRICA (PARTIAL)

*Findings*

For beef production in Africa, the contribution of ***greenhouse gases*** and ***land use change*** are the most significant impacts. The operational impacts of poultry production are mainly due to ***greenhouse gas emissions***. The countries that are included in Figure 18 above include South Africa and Egypt for beef production, and only South Africa for poultry production.

Cattle farming in some regions of Africa places pressure on ecosystems as they can be overgrazed during dry seasons. This can affect the long-term viability of grazing on such lands as the broken ecological cycle means that ecosystems cannot regenerate and repair the damage caused. This behaviour can be increased due to the pressures placed on farmers due to expanding population centres as well as the expansion of arable farms (FAO, 2015b). Businesses should be aware of the drivers and pressures that cause these impacts. Companies that are reliant on agricultural produce from Africa may be impacted by farmers competing for land use. Regulation could also be introduced to control the expansion of certain types of agricultural activity that can affect the supply to businesses. These impacts will vary due to the nature of the dependency that the business has on that commodity coming from these regions.

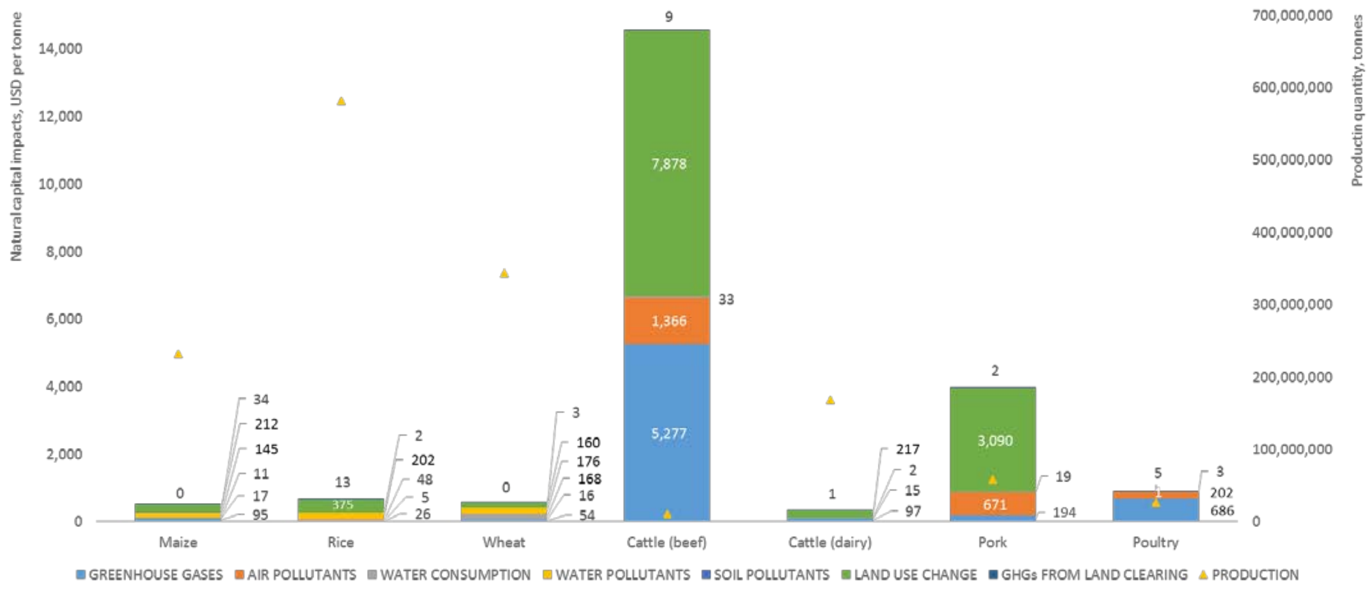


FIGURE 19: OPERATIONAL NATURAL CAPITAL INTENSITIES OF ASSOCIATED WITH CROP AND LIVESTOCK PRODUCTION IN *ASIA*

***Findings***

Due to the materiality threshold applied, the only activity that has not been included in this study for Asia is maize production. In crop production sectors, the most material impacts, per tonne of crop produced, are ***land use change*** and ***water pollution***, which account for 42 percent and 30 percent of the natural capital costs respectively. For livestock sectors in Asia, the most material impacts, per tonne of production, are ***land use change*** and ***greenhouse gas emissions***, which account for 57 percent and 32 percent of the costs respectively. The countries that are included in Figure 19 above include China, India, and Indonesia. Please see Table 6 and Table 8 for a complete list of countries included in this analysis.

Beef, pork and chicken production are the greatest sources of natural capital impacts in Asia. Traditionally, pork and chicken producers have been in competition for concentrate feeds, which could mean that farming systems need to change to improve the security of its feed supply, and to maintain or increase the supply of either pork or poultry (D'Souza, 2007). Alternatively this could drive the search for new sources of food, such as the use of agricultural by-products which could change farming systems so that they work more synergistically. For instance, livestock and crop production systems could be combined so that manure could be used to fertilise land, improve soil structure and water filtration. This would also reduce the need for farmers to purchase synthetic fertilizers and hence reduce input costs.

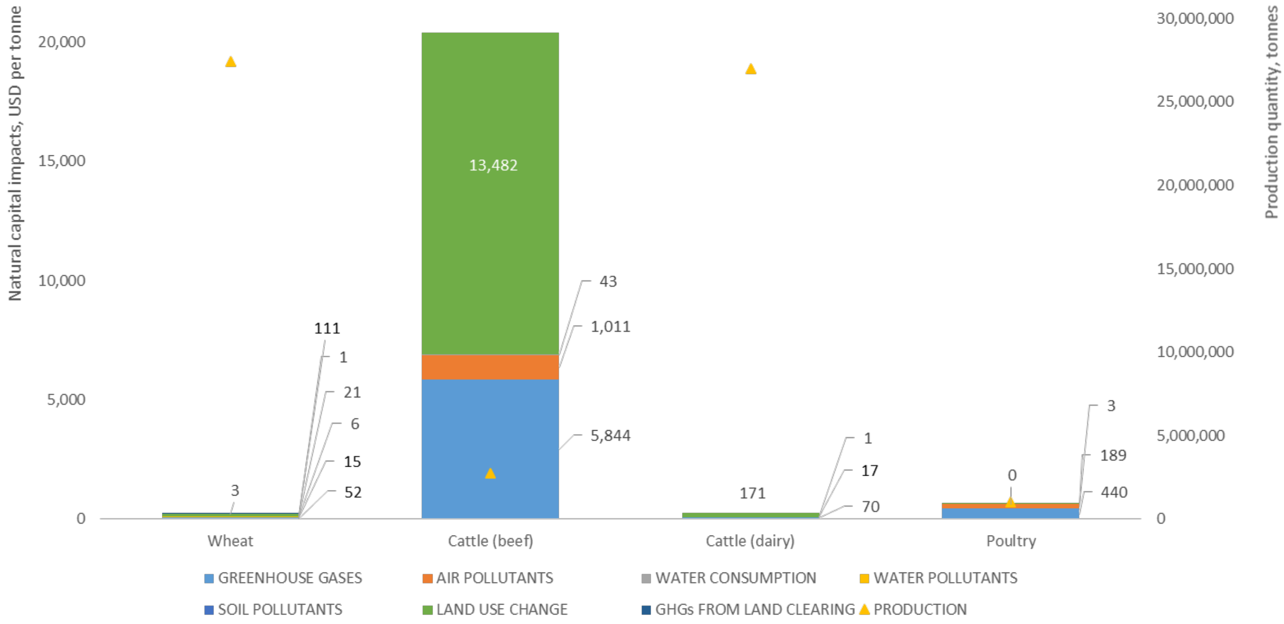


FIGURE 20: OPERATIONAL NATURAL CAPITAL INTENSITIES OF ASSOCIATED WITH CROP AND LIVESTOCK PRODUCTION IN *OCEANIA*

*Findings*

Due to the materiality threshold applied, the activities that have not been included in this study for Oceania are maize, rice, soybean, and pork production. In livestock sectors, the most material impacts, per tonne of meat produced, are ***land use change*** and ***greenhouse gas emissions***, which account for 64 percent and 30 percent of the costs respectively. The countries that are included include Australia and New Zealand.

The beef industry in Australia occupies over half of its land mass so it has a huge potential to deliver environmental benefits as well as impact the environment. Improved management of herds and pasture can deliver benefits, for example, rotational grazing can mean that ecosystems regenerate quicker and deliver a greater flow of ecosystem services back to cattle farmers and other stakeholders (NLWRA, 2008). This can have the knock-on effect of increasing the capacity of land to maintain greater numbers of cattle, which can deliver greater economic benefits.

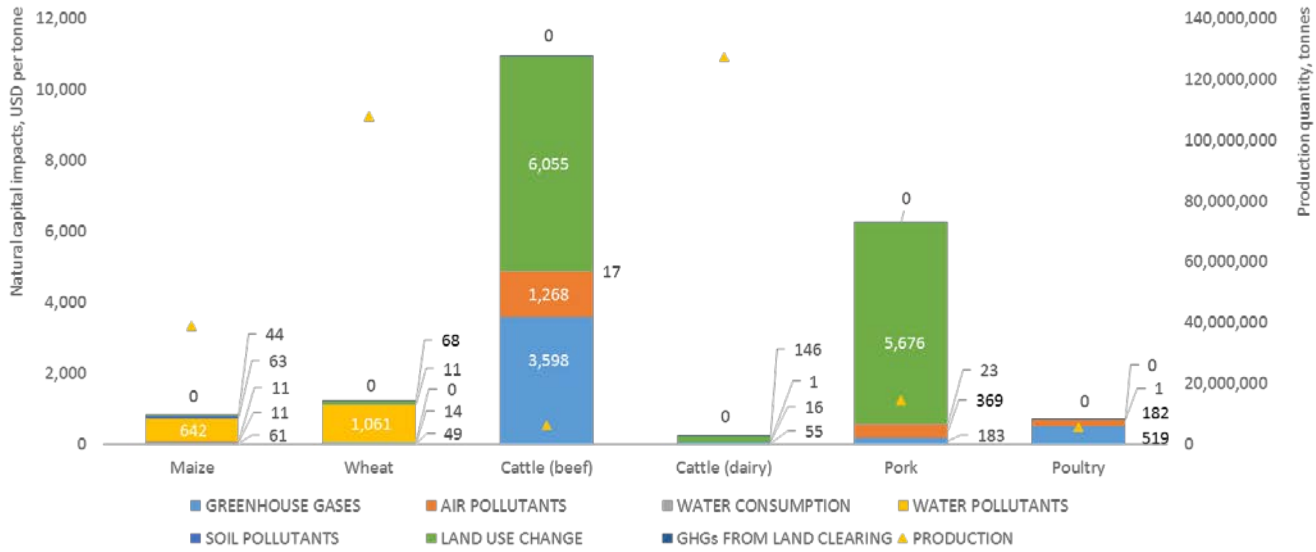


FIGURE 21: OPERATIONAL NATURAL CAPITAL INTENSITIES OF ASSOCIATED WITH CROP AND LIVESTOCK PRODUCTION IN *EUROPE*

*Findings*

Due to the materiality threshold applied, the activities that are not included in this study for Europe are rice and soybean production. In crop production sectors, the most material impacts for European countries, per tonne of crop produced, are due to ***water pollution*** and ***land use change***, which account for 84 percent and 5 percent of the natural capital costs respectively. In livestock sectors in Europe, the most material impacts, per tonne of meat produced, are ***land use change*** and ***greenhouse gas*** emissions, which account for 66 percent and 24 percent of the costs respectively. The countries that are included in Figure 21 above include the France, Germany and the United Kingdom. Please see Table 6 and Table 8 for a complete list of countries included in this analysis.

The agricultural landscape in the EU has been changing, which is resulting in fewer smallholder farmers and more large-scale industrial farms. This has been coupled with the change in land cover and increasing farmland abandonment. These are important drivers in declining biodiversity which enable successful farming. This presents farmers and agri-businesses with the opportunity to improve the biological diversity on farmland, which will help to maintain crop productivity and reduce the dependence on synthetic inputs such as fertilizers and pesticides (Walls, 2006).

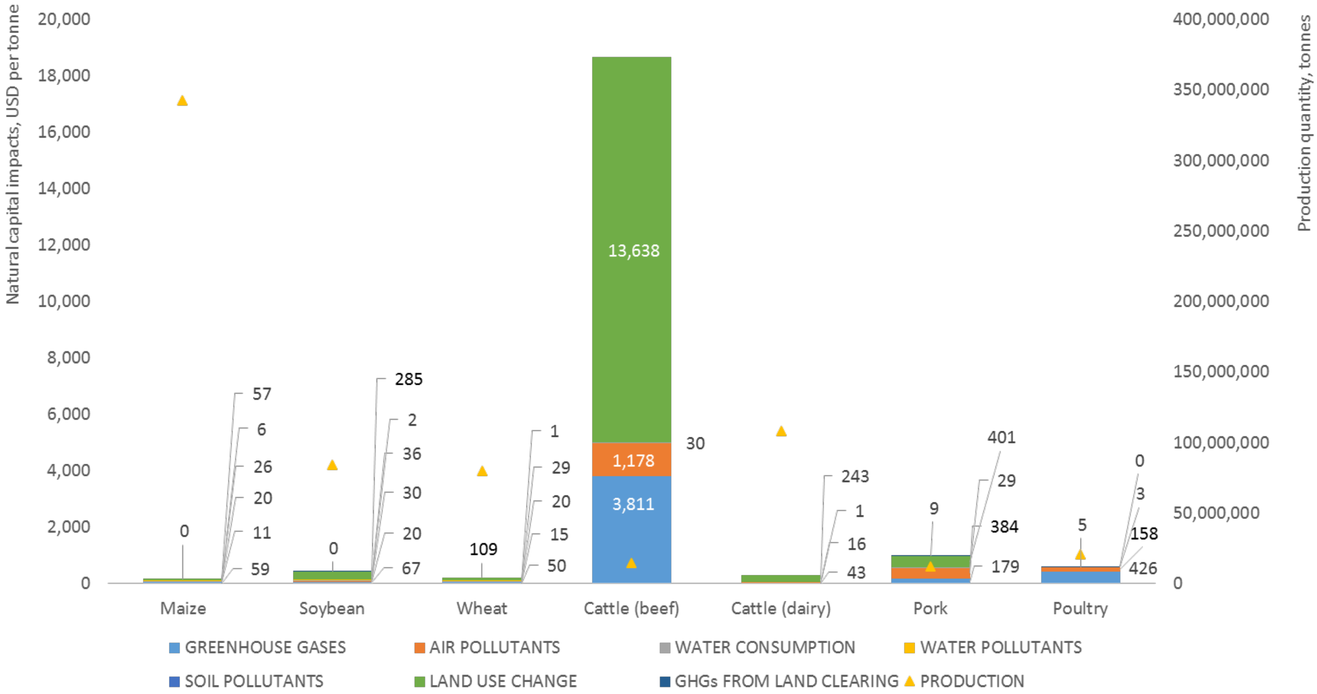


FIGURE 22: OPERATIONAL NATURAL CAPITAL INTENSITIES OF ASSOCIATED WITH CROP AND LIVESTOCK PRODUCTION IN *NORTH AMERICA*

***Findings***

Due to the materiality threshold applied, the only activity not included in this study for North America is rice production. In crop production sectors, the most material impacts for North American countries, per tonne of crop produced, are due to ***land use change*** and ***greenhouse gas emissions***, which account for 54 percent and 21 percent of the natural capital costs respectively. The same is true for livestock sectors as the most material impacts, per tonne of meat produced, as ***land use change*** and ***greenhouse gas*** emissions account for 68 percent and 22 percent of the costs respectively. The countries that are included in Figure 22 above include the Canada, Mexico and the USA.

Water pollution in crop farming sectors are the third most significant contributor to natural capital impacts in North American agricultural production systems. To combat the effects of this, the United States Department of Agriculture (USDA) launched the National Water Quality Initiative (NWQI) in order to “reduce non-point sources of nutrients, sediment, and pathogens related to agriculture in small high-priority watersheds in each state.” (EPA, 2014) This is used a means to facilitate private conservation initiatives which reduce these impacts by identifying polluting farms. Through farmers and companies identifying the impacts of water pollutants from agricultural land, financial assistance is available to avoid, trap and control run-off which will reduce the cost of natural capital impacts on society, as well as the financial costs of the farmer.

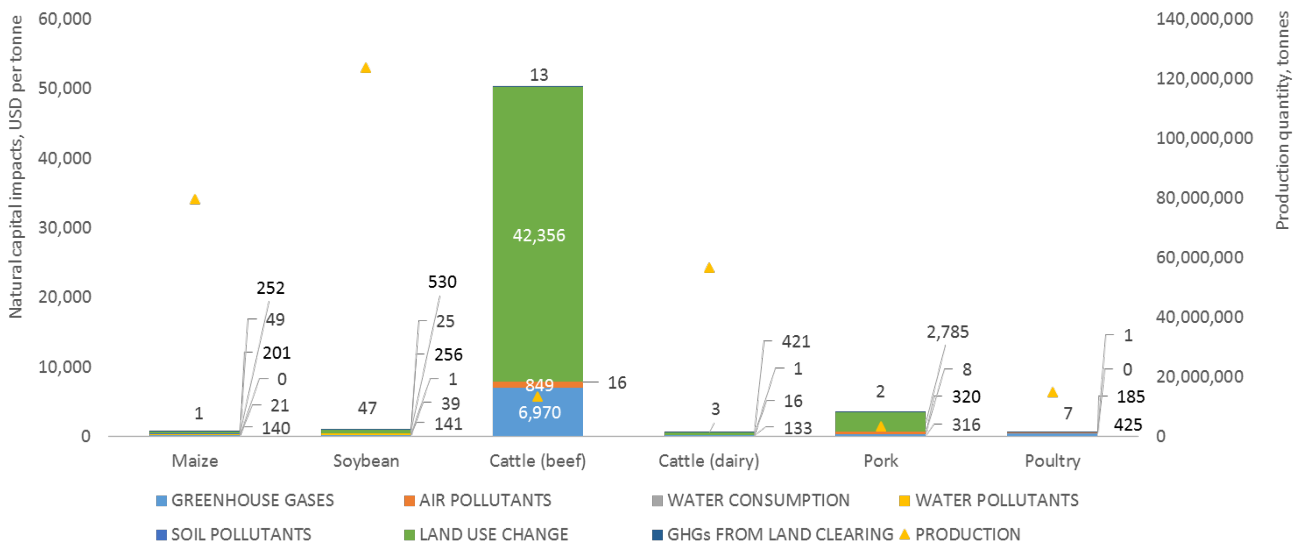


FIGURE 23: OPERATIONAL NATURAL CAPITAL COSTS OF ASSOCIATED WITH CROP AND LIVESTOCK PRODUCTION IN ***SOUTH AMERICA***

***Findings***

Due to the materiality threshold applied, the activities that are not included in this study for South America are rice and wheat production. In crop production sectors, the most material impacts for South American countries, per tonne of crop produced, are due to ***land use change*** and ***water pollution***, which account for 46 percent and 27 percent of the natural capital costs respectively. In livestock sectors in South America, the most material impacts, per tonne of meat produced, are ***land use change*** and ***greenhouse gases***, which account for 83 percent and 14 percent of the costs respectively. The countries that are included in Figure 23 above include the Argentina, Brazil and Uruguay. Please see Table 6 and Table 8 for a complete list of countries included in this analysis.

Beef production in Brazil emerged as having the highest costs of impacts on natural capital in the study. Fertile land that provides valuable ecosystem services is converted in order to expand agricultural land. The effects of land use change can be regional, in terms of the forest fragmentation, the loss of water provisioning and soil erosion services, and the other is global, in terms of climate change. These impacts have led to the emergence of mechanisms such as payments for ecosystem services (PES) as well as the Reducing Emissions from Deforestation and Forest Degradation (REDD+) scheme. These initiatives can provide opportunities for businesses to reduce its impact on the environment whilst ensuring its long-term viability in operating in areas such as Brazil (Ometto et al, 2013).

# PHASE 2: TRADE-OFFS OF DIFFERENT FARMING SYSTEMS

The second phase of the study analyzed different farming practices that are used in the production of four commodities. The analysis focused on the trade-offs that exist between adopting different farming practices. The following trade-offs have been analyzed:

- *Cattle* – conventional farming versus holistic grazing management in Brazil
- *Rice* – conventional farming versus the system of rice intensification in India
- *Soybean* – conventional farming versus organic farming in USA
- *Wheat* – conventional farming versus organic farming in Germany

Each study is to serve as an example to businesses of how the impacts identified in the materiality assessment in Phase 1 can be compared to more sustainable farming practices. The core objective of the analysis is to demonstrate to agri-businesses that by measuring its impact, and indirectly its dependency on natural capital, this can inform more sustainable farming decisions, increase profitability, and ensure a more resilient and stable supply of each commodity.

*Value Drivers*

There are many reasons why businesses would seek to undertake an assessment of the impacts and dependencies that exist within their operations and/or value chain. Specific value drivers that a company might have for switching from conventional to more sustainable management practices include mitigating risk, managing supply chains and strategically proofing its future activities. The typical benefits that a company may derive include ensuring a longer term crop supply, diversifying revenue streams, reducing input costs and maintaining its licence to operate.

*Production costs*

The following case studies include an overview of the change in revenues that farmers are likely to expect as a result of switching to more sustainable farming practices. This is an important, and often under-reported, aspect of switching to more sustainable farming systems.

A literature review was conducted and studies found that assesses the profitability of organic and non-organic farming systems and finds that despite a drop in yield, the majority of cases show organic farms to be more economically profitable, and yields are higher in cases of biophysical stress such as droughts (Nemes, 2009). Pimentel *et al.* (2005) studied corn and soybean farming in the USA and indicates that the total input costs for conventional farming is USD 354 per hectare, whereas for organic agriculture the cost is around USD 281 per hectare, a 21 percent decrease, a result supported by Hanson *et al.* (1997). In two studies comparing organic and conventional wheat production in Australia, input costs were 40 percent and 74 percent lower than conventional farming practices (Wynen, 2001; Dumaresq, 2001). Similarly, rice farming in the Philippines revealed that the total operating costs of organic versus non-organic farming systems decreased by 21 percent, despite a higher labour (13 percent) and seed costs (35 percent) (Rubinos *et al.*, 2007). Despite this, the study also showed that certain aspects of organic farming had higher costs, such as seeding and machinery use, and the annual net return on conventional farming was USD 184 per hectare and USD 176 per hectare for organic farming.

In the case of dairy farming, a study conducted in the USA calculated that the total input cost for organic farmers in Minnesota was 23 percent less than for non-organic farmers. This was due to the fact that organic herds have lower feeding costs than non-organic dairy cows as they rely on purchased concentrate feed, protein, vitamins and minerals (Heins, 2011). Similarly, a study in Northern Ireland, UK, shows that the decreasing availability of forage could mean that farmers have to pay between GBP 110 and GBP 140 per tonne (approximately USD 178 and USD 227) for concentrate feed for beef and dairy cattle respectively (DARD, 2003).

*Overview of Case Studies*

A literature review assessed the benefits of the country-specific farming systems listed above. As the studies used do not analyze all trade-offs from the two production systems, datapoints were combined from a number of different studies. The studies that have been selected analyze the same production practices as closely as possible, but in some instances the practices studied between studies do not exactly mirror one another. As a result, specific practices vary slightly between the studies so there may be some over- or underestimation of the natural capital impacts of alternative farming practices. To analyze the impact of land use change for more sustainable farming systems, it was assumed that farmers would want to maintain the same yields compared to conventional farming systems. Therefore, if the alternative farming practice yields more tonnes per hectare, then the land use impact will decrease, and vice versa.

The following case studies show that in the vast majority of cases, the cost of the natural capital impacts of the more sustainable farming systems will decrease. They also show the benefits from switching to these systems that cannot currently be monetised. For example, the benefits of increasing biodiversity on and around farmland. Where data is available, there is also a discussion of the economic benefits that farmers would achieve by farming more sustainably, which show in general, that gross margins and operating costs for sustainable farming systems would increase with decreasing natural capital impacts.

# CATTLE FARMING - BRAZIL

## HOLISTIC GRAZING MANAGEMENT VS. CONVENTIONAL

## 1. Background

### 1.1 Overview

Conventional cattle farming relates to extensive grazing systems that predominate in Latin American countries such as Brazil and Argentina (Deblitz and Ostrowski, 2004). The main production system of beef in Brazil is extensive pastoralism; approximately 82% of beef cattle were raised under this system in 2008 and the remainder were raised under feedlotting (Ferraz and de Felocio, 2010). Nevertheless, in the past ten years production efficiency per hectare has improved by 25% (Brazilian Beef, n.d.). Extensive cattle ranching is identified as the primary driver of deforestation in the Amazonian region, and in Northern Brazil, cattle ranching has expanded at a rate of 9% per annum accounting for 70-80% of total deforestation in the region over the period 1998-2008 (Kaimowitz et al, 2014; Nepstad et al, 2006).

Holistic grazing management involves mimicking grazing herds to reduce overgrazing and improve the natural ecosystem that is being grazed (Savory Institute, 2013). Livestock are penned on sub-plots of pasture to deposit manure, disturb land with their hooves, and feed on all available pasture as no feed from external sources is required. Holistic grazing management involves grazing livestock in high densities, on sectioned areas of pasture land called paddocks, which will be revisited by cattle after specified regeneration periods have been observed. The pasture land is divided into small paddocks which the livestock will graze over a standard period of time according to farming strategy. Although holistic grazing management has widely reported benefits, such as improved biodiversity, there is a lack of scientific evidence about herd impact on ecosystem responses, for example defoliation and recovery of individual plants, due to greatly complicated inter-relationships between human management and nature.

Brazil has been chosen as the case study country as it is one of the largest global producers of beef, and is the largest contributor to global natural capital costs. These are largely due to the ecosystem services lost due to land change use and the emissions from greenhouse gases (GHGs). Holistic grazing management helps restore degraded pasture land and mitigates GHGs, and Brazilian cattle farming has the greatest potential to mitigate its natural capital impact by switching farming practices, as almost all of its impacts are due to land use change (87 percent) and greenhouse gas emissions (11 percent).

### 1.2 Managing natural capital in cattle farming

The beef industry is coming under increasing pressure to operate more sustainably, due to public awareness of the high natural capital impacts. For example, one global company has committed to only purchasing beef in Brazil from suppliers who are not associated with deforestation of the Amazon (Cheeseman, 2015). Other value drivers that beef producers and agri-businesses might have for switching from conventional cattle farming to holistic grazing management practices include; reducing the potential impact of future regulations; better management of supply chains; reducing input costs and; strategically future proofing its activities by ensuring a longer term feed supply from quality pasture land (Savory Institute, 2013).

One of the key benefits of holistic grazing management is that it aids the restoration of the pasture land, and in Brazilian cattle farming regions, farmers have experienced the degradation of pastures due to overgrazing and selective grazing practices (Costa and Rehman, 1999). This leads to farmers needing to fertilise land or expanding into frontier areas through deforestation to maintain productivity (de Campos Bernardi *et al.*, 2011; WWF, 2012). These practices increase natural capital costs whereas holistic grazing management helps farmers better manage the land so that its existing natural capital can be preserved (Teague *et al.*, 2011).

Assigning a monetary valuation to ecosystem services helps to demonstrate the economic benefits of maintaining good quality pasture land. The impact of losing these ecosystem services can be internalized and transformed into financial costs when, for example, the use of fertilizers become necessary, or the quality of the beef is compromised by a poorer diet from degraded pasture lands (de Campos Bernardi *et al.,* 2011). Calculating the cost of natural capital impacts helps farmers to evaluate the potential risks they are exposing themselves to, the costs that they impose on society, and provide an evidence base to change practices before those risks materially affect their profitability.

# 2. Methodology

## 2.1 Scope

Land use change and GHG emissions were assessed for both conventional farming and holistic grazing management. Soil and water pollutants were not assessed in the baseline scenario so could not be included in the case study, and no datapoints were found on the water consumption of holistic grazing management. Table 11 below outlines the impacts that have been analyzed.

TABLE 11: SCOPE OF THE ASSESSMENT OF ORGANIC AND CONVENTIONAL CATTLE PRODUCTION

| Category | Holistic grazing comparison | Reason for change | Explanation | References |
|---|---|---|---|---|
| GHGs | 18% less GHG emissions | Pasture quality improvement, improved animal health and intensive grazing management | An FAO study estimated the reduction in GHG emissions for better pasture quality, animal health and husbandry improvements, and intensive grazing management in Brazil to be 18-29%. As this analysis focusses only on the improvements from intensive grazing management, the conservative estimate of 18% reduction is selected. | ***Gerber et al, 2013*** Study conducted in Brazil. |
| Land Use Change | USD 166 $ha^{-1}$ | Natural ecosystem of the pasture land is maintained as grassland. | Improvements in land management will lead to the ecosystem changing from degraded pasture land to grassland. The relative improvement in ecosystem service value compared to conventional cattle is USD 166 $ha^{-1}$. | ***Savory Institute, 2013*** Study conducted in various locations globally. |
| Economic Costs | USD 68 per adult cow | Greater weight gain of cows, improved reproductive success | Estimated benefit based on increased weight gain from cows under rotational grazing compared to continuous grazing of pastures. | ***Eaton et al, 2011*** Study conducted in Brazil. |

## 2.2 Quantification and Valuation Approach

Table 12 provides an overview of the costs of the natural capital impacts by continuous grazing of conventional cattle farming.

TABLE 12: NATURAL CAPITAL IMPACTS FROM BASELINE ANALYSIS

| Category | Impact Type | Natural capital costs (USD per tonne of production) |
|---|---|---|
| Natural capital impacts | GHGs | 6 845 |
| | Land use change | 52 440 |

The biophysical data underling these baseline monetary valuations were adjusted to reflect the benefits that are derived from holistic grazing management. The operational GHG emissions for holistic grazing management were calculated by applying the estimated reduction of 18 percent found by a previous FAO study (Gerber *et al*, 2013), and adjusting the baseline figure accordingly. For land change use, the baseline calculations were recalculated using the assumption that the quality of the land had improved and provided a higher value of ecosystem services as opposed to the degraded pasture land. Further detail can be found in Appendix XII.

# 3. Findings

## 3.1 Overview

Figure 24 compares the natural capital impacts of conventional farming and holistic grazing management. The reduction in natural capital impacts due to holistic grazing management in Brazil are USD 6 838 per tonne of beef - a reduction of 11 percent.

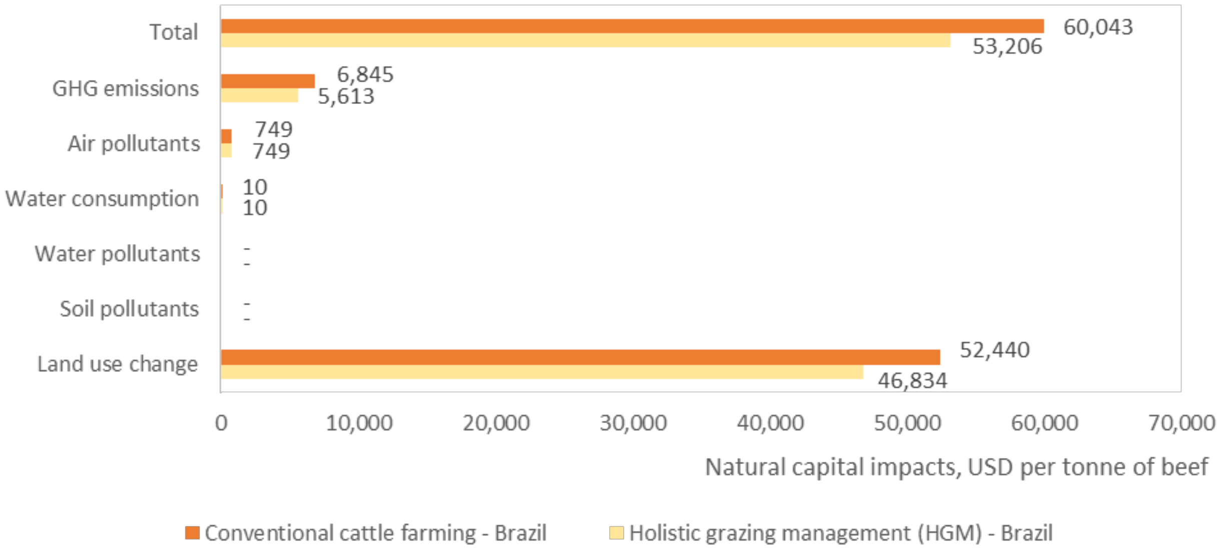


FIGURE 24: MONETARY VALUE OF THE OPERATIONAL IMPACTS CAUSED BY PRODUCING ONE TONNE OF BEEF IN BRAZIL

The natural capital impacts of restoring the pasture lands through better grazing management practices results in a gain of ecosystem services that are valued at around USD 166 per hectare of land, or USD 5 606 per tonne of beef produced. The improved ecosystem service value reflects the increasing quality of the pasture land which includes important services such as climate regulation and erosion prevention. GHG emissions were estimated to reduce by 18 percent for each tonne of beef produced, resulting in a natural capital saving of USD 1 232 per tonne. These savings come about from better pasture quality, improved animal health and husbandry, and intensive grazing management, which will provide additional benefits to the farmer that are not captured in this valuation.

The change in farming practices can also improve biodiversity on the pasture land, and in surrounding ecosystems. These potential benefits haven't been valued in this study but are discussed qualitatively in Section 3.3.

### 3.2 Economic costs

Limited datapoints were found on the economic costs and benefits of each farming practice. Of the data that was found, the academic research was split on whether there are increased profits with holistic grazing management or not. Some studies reported beneficial returns (Bryan *et al.*, 1986; Undersander *et al.,* 2002) where others reported no difference (Bransby, 1991). However one study, conducted in Mexico, did report greater net profit under holistic grazing management (Ferguson *et al,* 2013). Although these results were not statistically significant, improvements in livestock nutrition, soil fertility, animal health and welfare were reported. Another study based in Brazil in 2009, stated that the economic gain from holistic grazing management was approximately USD 68 per adult animal (Eaton *et al,* 2011).

### 3.3 Other impacts

Biodiversity has not been directly valued in this case study, but is nonetheless an important factor to successful cattle farming. In degraded soil, if holistic grazing management is followed for a span of three years, insects that were previously forced out of the ecosystem, such as the dung beetle, return to the ecosystem (Savory Institute, 2013). The fauna that return to restored ecosystems, such as moles and prairie dogs, churn the soil and encourage deep rooted perennial grasses to regrow (*Ibid*). As a result of a wider availability of higher quality grasses, plants are grazed more evenly and there is better distribution of manure (Fears, 2013). Over time, the manure degrades into the soil and provides organic matter which provides a better environment for microorganisms to flourish. This in turn, improves the quality of the pasture and provides increasing amounts of grass for cattle to feed on, which reduces the farmer's reliance on purchased concentrate feeds (Eaton *et al*, 2011).

During grazing, cattle consume fresh plant material, which is rich in nitrogen and released back into soil in the form of manure. When poorer quality grasses are not grazed, it dries and subsequently gets oxidized by microorganisms which releases carbon dioxide into the atmosphere. The optimal carbon to nitrogen ratio in the soil is 25-30:1 (Illinois University, 2015). As the carbon content of the soil increases, organisms use more nitrogen to decompose the material and oxidise the carbon. The increased uptake of nitrogen causes a reduction in soil fertility, which is combated by holistic grazing management as it discourages the cattle from selectively grazing higher quality grasses only (Byck, 2013).

Finally, holistic grazing management delivers other benefits such as reducing incidents of livestock morbidity, due to the absence of pesticides use, as well as the increasing diversity of flora on pasture land that improves the dietary composition and health of cattle (Eaton *et al.*, 2011; Fears, 2013).

### 3.4 Limitations

Owing to restrictions in data availability and the nature of holistic grazing management, the following limitations were imposed on the analysis:

- No direct data would be found on holistic grazing management studies in Brazil. This may be due to the fact that it has various names in the literature including management-intensive grazing, multiple-pasture grazing, short-duration grazing, cell grazing, and controlled grazing (Beetz and Rinehart, 2010).
- No data could be sourced which detailed the impacts of water consumption by holistic grazing management.
- The impact on soil and water pollution were out of the scope of this study, meaning that any potential costs or benefits provided by holistic grazing management could not be evaluated.

## 4. Conclusions

After analyzing available data sources, holistic grazing management shows a reduction in natural capital impact compared to conventional cattle farming. However, there are benefits outside the scope of this study that cannot be monetised which include improving soil and plant biodiversity. The analysis shows that natural capital impacts can be reduced by up to 12 percent by switching to holistic grazing management practices, and this change is largely driven by the improvement in the quantity and quality of ecosystem services. Due to a paucity of data points, the study was unable to quantify with much certainty the economic benefits provided to the farmer by holistic grazing management practices.

Holistic grazing management is seen in some academic circles as controversial because of the extent and scalability of its benefits (McWilliams, 2013).  The rebuttal from Allan Savory points to the fact that this is due to the holistic nature of the management practice, which requires the development of new skills and training to implement successfully. He also cites that holistic grazing management is opposed because it behaves contrary to the reductionist approach of academic research (Savory, 2013). As a result, much of the evidence for its success is anecdotal (Byck, 2013) and not in peer-reviewed journals.

# RICE FARMING - INDIA

## SYSTEM OF RICE INTENSIFICATION vs. CONVENTIONAL

## 1. Background

### 1.1 Overview

Conventional production in India refers to rice produced in paddies and involves the use of continuous flooding (Kawasaki and Herath, 2011). Rice paddy production in India covered 42 million hectares and produced nearly 158 million tonnes of rice in 2011 (FAOSTAT, 2014b). The system of rice intensification (SRI) is a farming method developed in 1980s in Madagascar and is now used worldwide (De Laulanié, 2011). It increases rice yields through the better management of plants, soils, water and nutrients. Some of the techniques involve:

- Early, quick and healthy plant establishment.
- Reduced planting density leading to less competition for soil nutrients.
- Improved soil conditions through enrichment with organic matter.
- The paddies are flooded intermittently, not continuously.

India is the second largest producer of rice after China, and despite this, it has greater natural capital impacts from the on-site operations of its farming practices. Hence, India was selected as the case study site, as its farmers and enterprises potentially have most to gain from changes to their management practices.

### 1.2 Managing natural capital in rice farming

Specific value drivers that a farm might have for switching from conventional to SRI practices include mitigating their exposure to water shortages through improved water efficiency, reducing input costs through less pesticide use, and increasing profitability by improving rice yields (De Laulanié, 2011). The typical benefits that a business may derive from switching to more sustainable agricultural practices include ensuring longer term crop yields, minimising input costs and maintaining its licence to operate (Palanshami *et al.,* 2012; Jayapalreddy and Shenoy, 2013).

Water pollutants are a significant impact in the operational natural capital intensity of rice. Not only can water pollutants directly impact the quality of water used for irrigation on the farm, and subsequently affect the quality of the rice produced that may harm trade, but they can also affect downstream water users, such as the health of the local labour force (Katakey and Chaudhary, 2013). Likewise, during periods of drought, rice farmers could be affected by the availability of water, as governments may restrict agricultural water use in favour of public water consumers, as was the case in Thailand in early 2015 (Jikkham and Wongyala, 2015). Assigning a natural capital cost to the impacts of water consumption and water pollution from SRI and conventional farming practices, helps to demonstrate the risks and mitigation potential of switching to more sustainable farming practices.

One of the key benefits of SRI is its diminished use of water. Traditional rice practices involve the continuous flooding of paddies and thus yields can be affected severely during times of drought (Kawasaki and Herath, 2011). Flooded rice fields are also significant sources of methane emissions, and paddy rice generates approximately 500 million tonnes of carbon dioxide equivalent ($CO_2e$) annually (WRI, 2014). Finally, SRI increases yields whilst using less input, and thus creates a more profitable farming practice that is both resilient to external stressors, and places less dependence on natural capital (Chowdhury *et al.*, 2014). For example, SRI can reduce pesticide spend by 96 percent, from 49 to 2 USD per hectare, reducing the natural capital impacts of soil pollution whilst maintaining adequate pest control (Jayapalreddy and Shenoy, 2013). Using SRI methods, fertilizer spend can also be reduced in instances by up to a third, which subsequently reduces the impacts of water pollution (Rajendran et al., 2007).

# 2. Methodology

## 2.1 Scope

Greenhouse gas (GHG) emissions, water pollutants, water consumption, air pollutants, soil pollutants, land use change and economic costs were assessed for both conventional and SRI practices. Table 13 below outlines impacts that have been analyzed. All information relates to operational impacts of rice farming in India.

TABLE 13: SCOPE OF THE ASSESSMENT OF SRI AND CONVENTIONAL RICE PRODUCTION

| Category | SRI comparison | Reason for change | Explanation | References |
|---|---|---|---|---|
| GHGs | 23% (combined) less methane and nitrous oxide emissions | Attributed to planting, water and fertilizer management practices | Fluctuations in methane and nitrous oxide emissions due to intermittent drying and wetting. | *(Jain et al., 2014)* Study conducted in India. |
| Air Pollutants | 72% less ammonia emissions | Reduced fertilizer expenditure | Assumed linear relationship between reduced fertilizer spend in SRI and ammonia emissions. | *(Zhao et al, 2010a)* Study conducted in China *(Rajendran et al, 2007)* Study conducted in India. |
| Water Consumption | 64% less water usage | Fields are flooded intermittently and not continuously | Reduced water consumption due to changes in irrigation practices. | *(Chowdhury et al, 2014)* Study conducted in India. |
| Water Pollutants | 2.9% and 4.5% reduction in nitrogen and phosphorus load | Fields are flooded intermittently and not continuously | Total nitrogen and total phosphorus loads reduced after applying recommended ponding depth management practices. | *(Jung et al, 2014)* Study conducted in South Korea. |
| Soil Pollutants | 2.9% reduction | Reduced pesticides expenditure | Assumed linear relationship between reduced pesticides spend in SRI and soil pollutants. | *(Jayapalreddy and Shenoy, 2013)* Study conducted in India. |

| Category | SRI comparison | Reason for change | Explanation | References |
|---|---|---|---|---|
| Land Use Change | 26% reduction in land use | To maintain conventional yields, less land is required | Rice yields are found to be higher India-wide for SRI rice farms | *(Palanshami et al., 2012)* Study conducted in India. |
| Economic | 18% increase in gross margin per hectare | Higher yields and lower operating costs in SRI practices | SRI uses less inputs, has lower operating costs, has higher yields, and thus is a more profitable farming system. | *(Palanshami et al., 2012)* Study conducted in India |

### 2.2 Quantification and Valuation Approach

Table 14 provides an overview of the costs of the natural capital impacts of conventional rice farming.

TABLE 14: NATURAL CAPITAL IMPACTS FROM BASELINE ANALYSIS

| Category | Impact Type | Natural capital costs (USD per tonne of production) |
|---|---|---|
| Natural capital impacts | GHGs | 24 |
| | Air pollutants | 4.5 |
| | Water consumption | 114 |
| | Water pollutants | 181 |
| | Soil pollutants | 1.7 |
| | Land use change | 182 |

The biophysical data underling these baseline monetary valuations were adjusted to reflect the benefits that are derived from the system of rice intensification. The methane and nitrous oxide emissions were modified to obtain total GHG emissions for SRI practices. For air pollution, ammonia emissions were calculated by adjusting values according to the reduced expenditure on fertilizer (per tonne of rice produced) by SRI farmers. Similarly, the quantity of total nitrogen and total phosphorus loads in water were adjusted to reflect the reduced impacts from water pollution, and water consumption by SRI farmers was reduced to reflect the efficiency gains by intermittently flooding rice fields. Finally, due to the reduced expenditure on pesticides (per tonne of rice produced), the impact of soil pollution was adjusted to calculate the total impact of SRI farmers. Further details regarding the methodology can be found in Appendix XII.

# 3. Findings

### 3.1 Overview

Figure 25 shows the operational natural capital impacts of conventional and SRI farming systems. The total costs of the natural capital impacts of SRI production versus conventional practices in India reduces by USD 129 per tonne - a 25 percent reduction. Switching practices also reduces the supply chain natural capital costs by about USD 9 per tonne produced, due to the reduced use of fertilizers and pesticides.

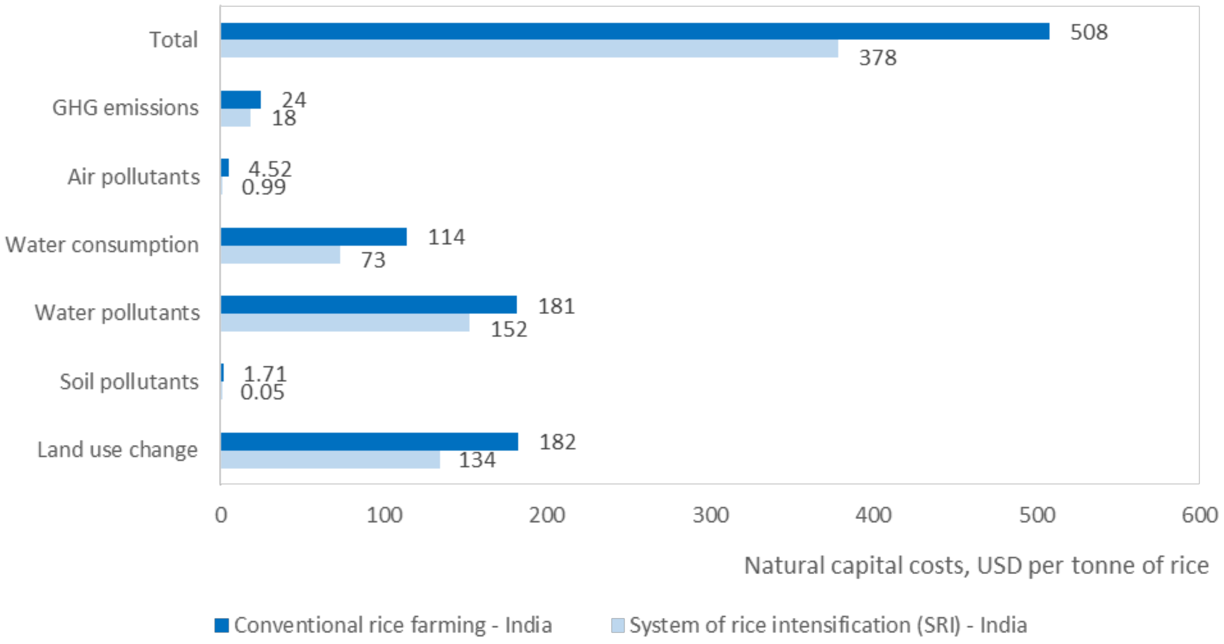


FIGURE 25: MONETARY VALUE OF THE OPERATIONAL IMPACTS CAUSED BY PRODUCING ONE TONNE OF RICE IN INDIA

The largest contributors to the reduction in the cost of the natural capital impacts in SRI practices are land use change, water consumption and water pollution. The cost of each of these natural capital impacts in SRI practices reduced by USD 48 (26 percent), USD 41 (36 percent), and USD 29 (16 percent) per tonne of rice produced. SRI practices also significantly reduce the costs of soil pollution and air pollution as each of these impacts decrease by 97 percent and 78 percent respectively.

There are additional benefits outside the scope of this project that could increase the value delivered by SRI farming practices, such as improving biodiversity. These benefits have been discussed qualitatively in Section 3.3.

## 3.2 Economic analysis

A survey, based on 2011 data from 2 234 SRI and conventional farms across India, reported yields of 3.79 tonnes per hectare for conventional and 4.64 tonnes per hectare for SRI (Palanshami *et al.,* 2012). Prices varied slightly, and rice produced via the SRI method fetched a price 38 percent higher than conventional practices (USD 74 per tonne for conventional and USD 103 for SRI).[14] The gross margin for SRI farmers was USD 190 per tonne, whereas conventional rice in India had a gross margin of USD 196 per tonne in the same growing season - a 3 percent decrease. Gross margins were 18 percent higher per hectare for SRI farmers whereas operating costs were 13 percent lower. However, when comparing the

[14] Prices were reported in Rupees and have been adjusted for inflation and converted to 2013 USD.

operating costs per tonne of rice production, the cost reduction for SRI farmers compared to conventional production was 29 percent.

### 3.3 Other impacts

Increasing biodiversity on rice fields helps to maintain soil fertility and reduce pests without the use of artificial pesticides (Zhao et al., 2010b; Way and Heong, 1994). Soil biota are the key drivers of fertility and a strong relationship exists between soil biodiversity and its productivity. Thiyagarajan and Gujja (2013) demonstrated that SRI plants had higher uptake of nitrogen, which suggests greater activity of nitrogen fixing bacteria, which could explain the reduction in water pollution from SRI practices. Furthermore, increasing concentrations of biota, such as earthworms, aided an increase in water infiltration, whereas other organisms such as termites and ants form an important part of soil food web which helps to store and release soil nutrients (Thiyagarajan and Gujja, 2013).

### 3.4 Limitations

- No data could be found specific to water pollution in India, hence a study based in South Korea was used. The reduction of water pollutants was also assumed to be linear because of limited data availability, which might not be the case. Until a greater number of quantitative and qualitative data points studying this effect have been published, it is not possible to test this hypothesis.
- No data could be found specific to ammonia emissions from fertilizer application under SRI and conventional rice farming in India, hence a study based in China was used. However, information on the reduced fertilizer spend was taken from a study in India.
- A linear relationship between pesticide use and soil pollution was assumed because of limited data availability, which might not be the case. Until a greater number of quantitative and qualitative data points studying this effect have been published, it is not possible to test this hypothesis.

## 4. Conclusions

The system of rice intensification offers clear environmental benefits compared to conventionally flooded rice farming systems in India. The analysis shows that the cost of natural capital impacts can be reduced by 25 percent largely due to the reduced impacts of land use change, water consumption and water pollution. There is also a case for switching farming practices based on economic performance of SRI systems. The increase in yields and decrease in input costs allowed the gross margin per hectare to increase by 18 percent for SRI. It is important to note that these results will vary across locations in India, and that the impacts could increase or decrease based on specific local environmental conditions. The analysis shows that the system of rice intensification, at a national level, offers an opportunity to reduce the environmental impacts of rice production whilst increasing income for local farmers.

# SOYBEAN FARMING - UNITED STATES OF AMERICA

## ORGANIC VS. CONVENTIONAL

## 1. Background

### 1.1 Overview

Conventional soybean farming has evolved to incorporate crop rotations whereas organic practices have gone a step further and avoid the use of synthetic inputs. Organic soybean farming has also evolved over the years to incorporate the use of cover crops, organic fertilizers, the implementation of best management practices of soils, as well as the elimination of pesticides (Pimentel, 2005). In this case study, farming that incorporates the use of these practices is referred to as organic farming systems.

This study shows that the USA is the largest producer of soybeans, ahead of Brazil and Argentina, in second and third place respectively, and the annual natural capital costs of its soybean production are 37 percent higher than the total revenue that the sector generates each year. To combat these impacts, the USA has started to collect data on its sustainable practices over the last few decades. For instance, the Soybean Sustainability Assurance Protocol (SSAP) is reporting an estimated 47 percent reduction of greenhouse gases (GHGs), 65 percent decrease in soil erosion, and 46 percent less energy used per tonne of soybean produced since 1980 on their certified farms (SSAP, 2013). As a result, the USA was selected as the country for this case study.

### 1.2 Managing natural capital in soybean farming

Specific value drivers that a farm might have for switching from conventional to organic practices include mitigating the impacts of climate change, reducing the natural capital impacts on the farm, and strategically future proofing its activities. The typical benefits that a business may derive from switching to more sustainable agricultural practices include ensuring longer term crop yields, minimizing input costs, and ensuring long-term demand from its farm (Pimentel, 2005; Delate *et al.,* 2003).

A 22 year-long study comparing organic legume-based, and organic animal-based farming, incorporating corn crop rotations, and conventional soybean farming, based on synthetic fertilizer and herbicide use as well as a simple five year crop rotation, found there to be similar yields (Pimentel, 2005), whereas other studies estimate organic yields at 92 percent of conventional farms (de Ponti *et al.*, 2012). In the study by Pimentel (2005), the annual net return for the conventional system was USD 184 per hectare versus USD 176 for the organic legume-based system. When the costs of the biological transition for the organics system was considered, over a three year period, net returns reduced to USD 162 per hectare. The organic farms had more consistent financial results year-on-year, as the standard deviation for net returns over a ten year period were USD 127 for the conventional system versus USD 109 for the organic rotation. This suggests that conventional farming practices are more likely to be affected by environmental stress such as droughts and increases in pest populations.

One of the key benefits of organic soybean farming is the reduced input costs that are achieved by eliminating pesticide use in addition to the price premium received for organic produce. For example, one study predicts that the profit per hectare is 368 percent higher than conventional soybean (Delate *et al.,* 2003). The elimination of pesticide use also avoids soil pollution, and promotes natural pest regulation, an ecosystem service that reduces the dependency of farmers on synthetic inputs.

Around 85 percent of the world's soybean crop is processed into meal and vegetable oil, and almost all of that oil is used as animal feed (Soyatech, 2015). Soybeans are an important source of feed for pork production, but can also be used for biofuels and for human consumption (NCSPA, 2014; WWF, 2012). There are significant natural capital impacts in livestock supply chains and, as pressure mounts for livestock farmers to reduce their natural capital impact, this pressure could also be felt financially by soybean farmers (Opio *et al.,* 2013).

# 2. Methodology

## 2.1 Scope

Greenhouse gas (GHG) emissions, air pollutants, water consumption, water pollutants, soil pollutants and economic costs were assessed for both conventional and organic soybean farming. Land use change was not compared as it was assumed that yields between organic and conventional farming remain relatively equal, so an expansion of land to maintain production is not required (Pimentel, 2006). Table 15 below outlines impacts that have been analyzed.

TABLE 15: SCOPE OF THE ASSESSMENT OF SUSTAINABLE AND CONVENTIONAL SOYBEAN PRODUCTION

| Category | Organic soybean comparison | Reason for change | Explanation | References |
|---|---|---|---|---|
| GHGs | 12% reduction | Change in management practices | Energy reduction due to a change in management practices. Data taken from LCA database Ecoinvent v2.2. | *(Meier, 2015)* Global study. |
| Air Pollution | 88% reduction in ammonia emissions | Use of organic fertilizer | Use of slurry and manure instead of synthetic fertilizers emits less ammonia emissions to the air. | Based on LCA modelling *(Meier et al., 2014)* Global study. |
| Water Consumption | 54% reduction | Change in management practice | Water reduction due to a change in management practices. Data taken from LCA database Ecoinvent v2.2. | *(Meier, 2015)* Global study. |
| Water Pollution | 36% reduction in phosphorus use; zero nitrogen use | Changes in fertilizer practices | Organic practices do not need to add nitrogen-based fertilizers and use less phosphorus-based fertilizers. Assumed that this directly results in less leaching. | *(Pimentel, 2006)* Study conducted in the USA. |
| Soil Pollution | Zero pesticide use | No synthetic pesticides applied | Pesticides are used in conventional but not organic farming practices. | *(Pimentel, 2006)* Study conducted in the USA. |

| Category | Organic soybean comparison | Reason for change | Explanation | References |
|---|---|---|---|---|
| Economic | 220% increase in gross margin per tonne | Price premium and lower operating costs per hectare for organic | Organic soybean attain a higher market price that is 167% higher than conventional soybeans. | *(McBride and Green, 2009)* Study conducted in the USA. |

### 2.2 Quantification and Valuation Approach

Table 16 provides an overview of the costs of the natural capital impacts of conventional soybean farming.

TABLE 16: NATURAL CAPITAL IMPACTS FROM BASELINE ANALYSIS

| Category | Impact Type | Natural capital costs (USD per tonne of production) |
|---|---|---|
| Natural capital impacts | GHGs | 67 |
| | Air pollutants | 20 |
| | Water consumption | 30 |
| | Water pollutants | 36 |
| | Soil pollutants | 1.7 |

The biophysical data underling these baseline monetary valuations was adjusted to reflect the benefits that are derived from organic soybean farming. The GHG reduction, described in Table 15, was used to calculate the new GHG emissions and to calculate the impacts of air pollution, the ammonia emissions were adjusted by the yield to give an emissions factor for ammonia in kilogrammes per tonne of soybean. Similarly, the quantity of total phosphorus leaching was adjusted to reflect the reduced phosphorus use, and the total impacts from nitrogen leaching were removed. Finally, due to the lack of pesticides used in organic soybean, the impact of soil pollution was assumed to be zero. Further detail regarding the methodology can be found in Appendix XII.

## 3. Findings

### 3.1 Overview

The total natural capital impact savings from organic soybean production in the USA is USD 72 per tonne - a 16 percent reduction. Figure 26 shows the overall results from the natural capital impacts of conventional and organic farming systems.

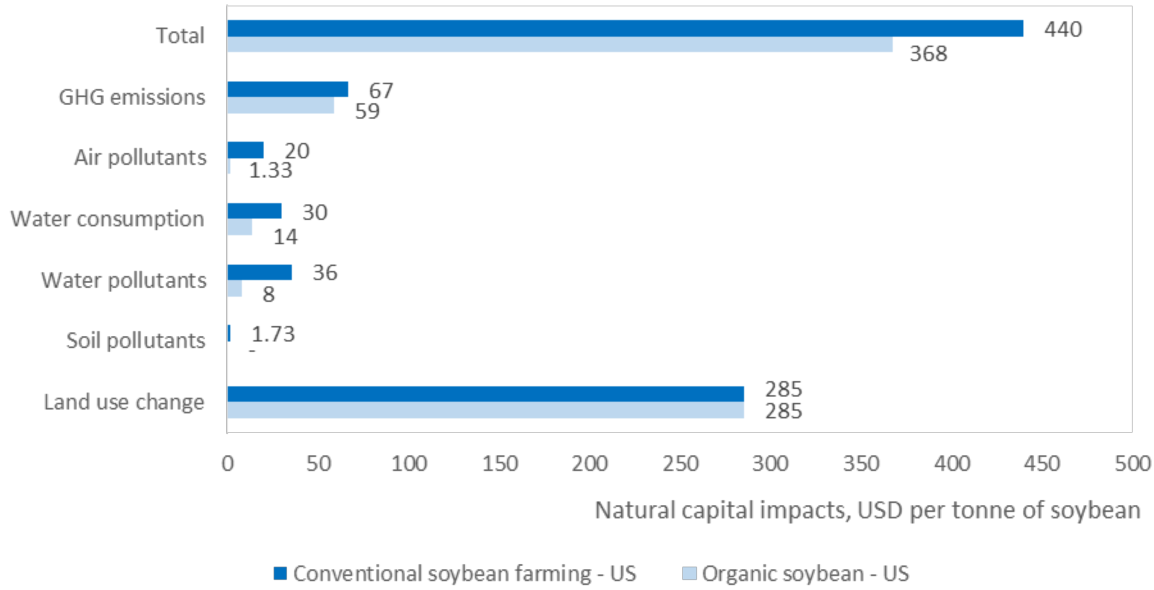


FIGURE 26: MONETARY VALUE OF THE OPERATIONAL IMPACTS CAUSED BY PRODUCING ONE TONNE OF SOYBEAN IN THE UNITED STATES OF AMERICA

The use of sustainable practices reduces the natural capital impacts of water pollution by USD 27, air pollution by USD 19, and water consumption by USD 16 per tonne of soybeans. The cost of the natural capital impacts of soil pollution, while not as significant, reduced by USD 1.7 per tonne, or 100 percent. The impact of GHG emissions decreased by USD 8 per tonne, approximately 12 percent. The total natural capital impacts that are avoided due to organic soybean farming are USD 72 per tonne, a reduction of 16 percent.

There are ecosystem services outside the scope of this project that could increase the difference in the value delivered by conventional and organic systems, such as improving biodiversity. However, these benefits have been included qualitatively in Section 3.3.

## 3.2 Economic analysis

A survey, based on 2006 data from 237 organic farms and 1 425 conventional farms, reported yields of 3.16 tonnes per hectare for conventional and 2.09 tonnes per hectare for organic farming – a 34 percent decrease (McBride and Green, 2009). Organic soybean fetched a price of USD 622 per tonne, a 167 percent increase over conventional which fetched USD 233.[15] The gross margin for organic soybeans was USD 481 per tonne, whereas conventional soybean in the USA had a gross margin of USD 150 per tonne in the same growing season (a 220 percent increase). Operating costs for organic soybeans were 70 percent higher per tonne, or 12 percent higher per hectare due to the decrease in yield, however the price premium for organic soybeans increased its overall returns.

Yields of organic soybeans have improved in more recent times, which has been demonstrated by a meta-analysis study that shows yields in the USA were on average only 8 percent lower than conventional farming systems (de Ponti et al, 2012). If the 2006 yields from the McBride and Green

[15] Prices were reported in 2006 USD and have been adjusted for inflation so now represent 2013 USD.

study had been comparable to current trends, operating costs per tonne of soybeans would have been 22 percent higher for organic systems, a 48 percent decrease from the previous value calculated from McBride and Green. The operating costs for organic systems would have been USD 101 per tonne versus USD 83 for conventional farms, making organic farms even more profitable as gross margins would increase to USD 622 per tonne.

### 3.3 Other impacts

After harvest and before the next planting of annual cash crops like soy, cover crops can be planted in the same field to provide additional benefits to farmers (Pimentel, 2005). Cover crops are planted for their benefits to soil, such as erosion prevention, which can subsequently be harvested for sale or used to increase organic matter in the soil (SARE, 2012). The use of cover crops can also increase plant diversity around the farm over a number of years (Larsen, 2013).

Cover crops trap residual nitrogen and prevent it from leaching to water sources and can also protect the soil from getting eroded due to wind and rain (Corn Soybean Digest, 2014). In Iowa, rye cover crops are used in no-tillage soybean production, which reduced interrill erosion by 54 percent and rill erosion by 90 percent when compared to no-tillage without cover crops (Singer, 1999). The residue left over from cover crops gets decomposed in the soil and provides organic matter for building soil structure, which enriches the biota (SARE, 2012). Finally, cover crops aid water infiltration and nutrient recycling through the deposition of phosphorous, the trapping of nitrates and sequestration of carbon, encourages the improvement of biodiversity which reduces the need for pesticide use, which all provide benefits directly or indirectly to the farmer (Salon, 2012).

Organic farms tend to grow a wider range of crops per farm than conventional farms (de Ponti et al 2012). Under organic practices, the soil exhibits undisturbed decomposition of humus and provides habitat for active biotic community (Mäder et al, 2002). For example, the colonisation of root length by mycorrhizae fungi was 2.5-10 times greater on low-input organic soybean farming, which is important for the natural transfer of nutrients from the soil to the plants (Douds et al, 1993; Royal Horticultural Society, 2015). Mycorrhizae fungi have added benefits as they also sequester carbon, encourage biodiversity and ecosystem restoration, maintain long term soil fertility, and can even reduce drought stress in soybean (Wilson et al., 2009; Leake et al, 2004; Jefferies et al, 2003; Bethlenfalvay et al, 1988).

The production of genetically modified (GM) soybeans create unique, and until now, mostly unquantifiable impacts on biodiversity. Soybean is currently harvested on over 110 million hectares of land globally and nearly 80% of this is due to the production of GM soybean (FAOSTAT, 2014b; GMO Compass, 2014). GM crops can impact ecosystem service provision (Lovei, 2001), farm biodiversity (Firbank, 2003), weed abundance and diversity (Heard *et al.*, 2003), and the development of toxin resistant insect strains (Cerda and Wright, 2002; Garcia and Altieri, 2005). These impacts are currently not captured in monetary valuations conducted in this study, but should carry considerable weight when assessing the costs of benefits of GM farming practices.

### 3.4 Limitations

- The decline of water pollution due to the reduction in phosphorus use was assumed to be linear because there of limited data availability. Until a greater number of quantitative and qualitative datapoints studying this effect have been published, it is not possible to test this hypothesis.

- A very limited amount of data on the blue water consumption in organic soybean farming could be found, so a general percentage reduction in water use had to be applied. Water use in conventional soybean farming relates to blue water use only.
- It was assumed that because no nitrogen-based fertilizers are used in organic farming, there would be no nitrogen leaching that contributed towards water pollution.
- Not all studies used to calculate the different natural capital impacts of organic soybean farming analyze the same management practices.

# 4. Conclusions

Organic soybean farming has both economic and natural capital advantages over conventional soybean farming in the USA. The analysis shows that natural capital impacts can be reduced by 16 percent largely due to the reduction in water pollution, air pollution, and water consumption. The reduction of the natural capital impacts from these three categories result in savings of USD 27, USD 19 and USD 16 per tonne of soybean production. The gross margin for organic soybean can be increased by up to 220 percent, which can mainly be attributed to the price premium paid for organic produce. Finally, organic soybean farming delivers additional benefits such as improving soil structure, water filtration and reduced soil erosion, which helps to maintain long-term yields and farm profitability.

# WHEAT FARMING - GERMANY

## ORGANIC VS. CONVENTIONAL

## 1. Background

### 1.1 Overview

Conventional wheat farming involves the application of synthetic fertilizers and pesticides whereas organic wheat farming practices have evolved to include the use crop rotation, cover crops, organic fertilizers, elimination of pesticides, changing irrigation practices and the deployment of new soil management practices (McCoy, 2005).

Germany, ranked 9th in terms of total wheat production compared to China and India, respectively the two largest producers of wheat, generates a disproportionately high impact on natural capital, the majority of which are realised in its operations. The operational impacts of Germany's wheat production on natural capital are only 8 percent lower than those found in China despite the latter producing over 5 times more wheat. For these reasons, Germany was selected as the case study location, as small changes in farm practices can significantly reduce the cost of natural capital impacts.

Organic agriculture can minimise the impacts caused by pesticide and fertilizer application in conventional wheat farming, but it is widely argued that the removal of fertilizers and pesticides negatively affects yields (Biello, 2012). More than external inputs, it is rotations and associations that build-up fertility in organic systems, so the timeframe is crucial in comparing outcomes. Studies have found that yields of organic wheat can equal conventionally farmed wheat and this case study aims to assess the environmental impacts and yields of both of these practices (Ponisio *et al.,* 2014).

### 1.2 Managing natural capital in wheat farming

Specific value drivers that an enterprise might have for switching from conventional to organic practices include mitigating the impacts of climate change and reducing the potential impact from droughts. The typical benefits that a company may derive from switching to more sustainable agricultural practices include protecting and maintaining yields against environmental pressures such as droughts, minimising input costs, diversifying revenue streams (through crop rotation), and maintaining its licence to operate (Al-Karaki et al., 2004; Nieberg and Rahmann, 2005).

In Germany, farmers have the greatest exceedance of critical nutrient loads (EEA, 2014), which means that nitrogen is emitted beyond EU 'safe' limits, which is a major explanatory factor why water pollution represents 95 percent of wheat's operational natural capital impacts. Water pollution has a direct impact on the water treatment costs of a watershed, can directly impact land and property prices thus, devaluing the asset of the farmland itself, and can have a negative impact on human health (McDonald and Shemie, 2014; Dodds et al., 2009; Townsend et al., 2003; WHO, 2002).

One of the key benefits of organic wheat farming is that it helps to preserve soil nutrients by reducing fertilizer use and by using nitrogen-fixing cover crops, which studies have shown can increase crop yields (Kumar and Goh, 2002). Therefore organic farming can significantly reduce nitrate leaching, which provides cleaner water and reduces the negative impact on ecosystems caused by eutrophication (Hörtenhuber et al., 2014).

# 2. Methodology

## 2.1 Scope

Greenhouse gas (GHG) emissions, air pollutants, water pollutants, soil pollutants, land use change, and economic costs were assessed for both conventional and organic wheat farming. Table 17 below outlines the impacts that have been analyzed. All information relates to of the operational impacts of wheat farming in Germany.

TABLE 17: SCOPE OF THE ASSESSMENT OF ORGANIC WHEAT PRODUCTION

| Category | Organic wheat comparison | Reason for change | Explanation | References |
|---|---|---|---|---|
| GHGs | 73% reduction in GHG emissions | Converting to organic fertilizer | Reduction is attributed to reduced emissions from changes in synthetic fertilizer use, crop rotation and reduced waterlogging during heavy rain (which releases $N_2O$). | An LCA study *(Hirschfeld et al., 2008)* Study conducted in Germany. |
| Air Pollutants | 65% reduction in ammonia emissions | Converting to organic fertilizer | Emissions from slurry and solid manure based on figures from 2011. | An LCA study *(Meier et al, 2014)* Study conducted in Switzerland. |
| Water Pollutants | 38% reduction in nitrate leaching | Converting to organic fertilizer | Reduction in nitrate leaching into local water bodies from wheat producers. | *(Hörtenhuber et al., 2014)* Study conducted in Austria. |
| Soil Pollutants | Zero pesticide use | No synthetic pesticides used | Elimination of pesticides and introduction of natural predators | *(Weber et al., 2002)* Study conducted in Germany. |
| Land Use Change | 27% yield reduction | Converting to organic fertilizer; No synthetic pesticides used | Organic wheat has slightly reduced yields compared to conventional farming practices | *(de Ponti et al, 2012)* |
| Economic | 315% increase in gross margin | Price premium and lower operating costs per hectare for organic | Organic wheat fetches higher market prices and achieves lower operating costs due to reduced fertilizer and pesticide use. | *(Nieberg and Rahmann, 2005)* for organic; *(European Commission, 2013)* for conventional |

### 2.2 Quantification and Valuation Approach

Table 18 provides an overview of the costs of the natural capital impacts of conventional wheat farming.

TABLE 18: NATURAL CAPITAL IMPACTS FROM BASELINE ANALYSIS

| Category | Impact Type | Natural capital costs (USD per tonne of production) |
|---|---|---|
| Natural capital impacts | GHGs | 59 |
| | Air pollutants | 18 |
| | Water pollutants | 2 396 |
| | Soil pollutants | 2.5 |
| | Land use change | 56 |

The biophysical data underling the baseline monetary valuations was adjusted to reflect the benefits that are derived from organic wheat farming. The operational GHG emissions for organic wheat farming were calculated in an LCA by Hirschfeld et al. (2008) and used to replace baseline factors. For air pollution, ammonia emissions from Meier et al. (2014) were adjusted by the change in wheat yields to give ammonia emissions in kilogrammes per tonne of wheat. Similarly, the impact of water pollution was calculated by adjusting the amount of nitrate leaching that was coming from organic fertilizer. Finally, as no pesticides are used in organic wheat production in this case study, the natural capital impact associated with soil pollution is zero. Further details regarding the methodology can be found in Appendix XII.

## 3. Findings

### 3.1 Overview

The reduction in natural capital impacts due to organic wheat farming in Germany are approximately USD 1 166 per tonne - a 46 percent reduction. Figure 27 compares the natural capital impacts of conventional and organic wheat farming systems.

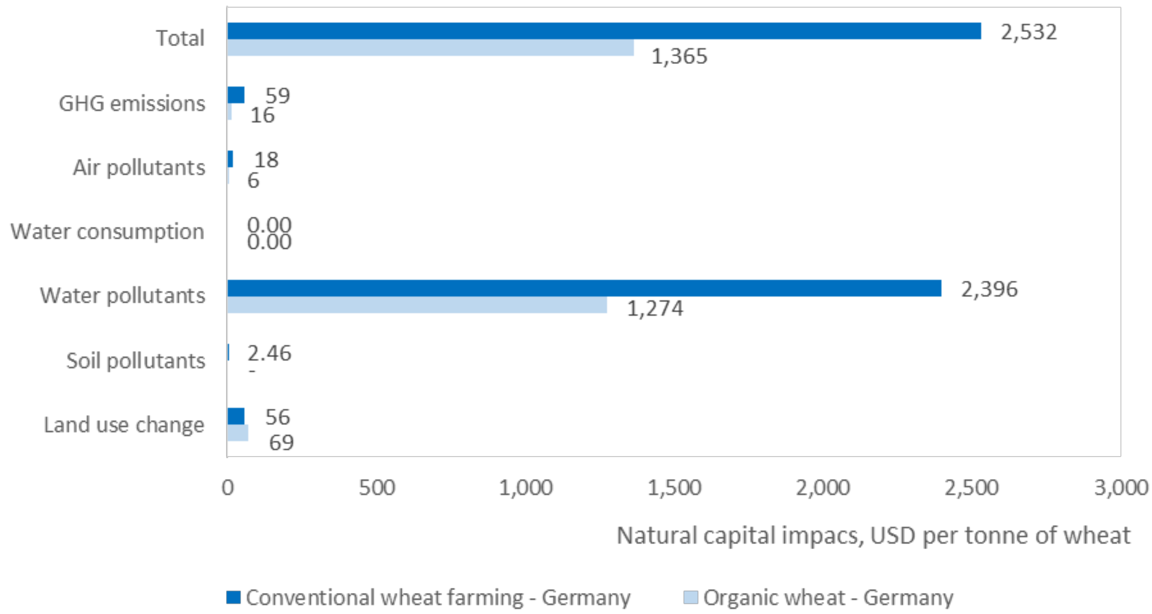


FIGURE 27: MONETARY VALUE OF THE OPERATIONAL IMPACTS CAUSED BY PRODUCING ONE TONNE OF WHEAT IN GERMANY

The impact of using organic fertilizers reduces the natural capital cost of water pollution by USD 1 122 per tonne of wheat produced, a 47 percent reduction. GHG emissions were estimated to be reduced by 73 percent per tonne of wheat produced, resulting in the costs of natural capital impacts reducing by USD 43 per tonne. The impacts associated with land use change increase by 23 percent, or USD 13 per tonne, as more land is required to maintain total production volumes resulting from organic yield reductions.

There are ecosystem services outside the scope of this project that could increase the difference in the value delivered by organic systems, such improving biodiversity. However, these benefits have been included qualitatively in Section 3.3 below.

## 3.2 Economic analysis

A survey, based on 217 organic farms in Germany highlights the motivations for moving away from conventional farming practices, which are broken down into environmental (38 percent), economic (29 percent) and political considerations (20 percent) (Nieberg and Rahmann, 2005). The study shows there has been an increase in economically-driven switches, with only 15 percent of organic farmers thinking about reconverting to conventional farming. In this survey, farmers reportedly had yields of 3.5 tonnes per hectare with an average price of USD 509 per tonne. The gross margin was USD 478 per tonne, whereas conventional wheat in Germany had a gross margin of USD 115 per tonne in the same growing season (European Commission, 2013).[16] Operating costs were 34 percent higher per tonne of organic wheat due to the decrease in yield, whereas they were 32 percent lower per hectare compared to

[16] Figures were reported in 2002 Euros and have been adjusted to 2013 USD. The wheat in this study refers exclusively to the growing of winter wheat.

conventional farms. The revenue generated by organic farms was 157 percent greater per tonne of wheat than for conventional farms.

However, yields have improved in organic farming as demonstrated by a meta-analysis study by de Ponti et al. (2012). If the yields from the 2002 study had been comparable to current trends, operating cost would have been 7 percent lower per tonne of wheat produced, making it even more profitable.

Another factor in the profitability of organic wheat farmers is the price premium which is received for organic produce. In 2002, the price for conventional wheat in Germany averaged at USD 176 per tonne (European Commission, 2013), and even if the price premium of organic wheat was removed so that it equalled the national average, then the gross margin per tonne of organic wheat would drop to USD 145 per tonne, which is still higher than the gross margin for conventional farmers (USD 115 per tonne).

### 3.3 Other impacts

Organic wheat farming has other impacts that are not captured in the above valuation. For example, through organic farming, it is possible to re-introduce traditional crop varieties that better adapt to local climatic conditions and promote agricultural biodiversity (FAO, 2003). A study on wheat in Germany illustrates that, where sandy soils are common, soil nitrogen gets easily washed away due to spring rain. This impact was tackled by using a native variety of wheat, which has a vegetative cycle that fixates more of the available nitrogen in the soil (*Ibid*), therefore limiting the natural capital impacts of water pollution which affects human health and ecosystems (WHO, 2002; WHO, 1999).

Organic farms tend to grow a wider range of crops per farm than conventional farms (de Ponti et al., 2012). Under organic practices, the soil exhibits undisturbed decomposition of humus and provides habitat for an active biotic community (Mäder et al., 2002). For example, the colonisation of root length by mycorrhizae fungi was 40 percent higher on organic farming (*Ibid*). This is important for the natural transfer of nutrients from the soil to the plants, which synthetic fertilizers replace (Royal Horticultural Society, 2015). Mycorrhizae fungi have added benefits as they also sequester carbon, encourage biodiversity and ecosystem restoration, maintain long term soil fertility, and can even reduce drought stress in soybean (Wilson et al., 2009; Leake et al, 2004; Jefferies et al, 2003; Bethlenfalvay et al, 1988). Finally, mycorrhizae fungi can even reduce drought stress in wheat (Al-Karaki et al, 2004).

### 3.4 Limitations

- Studies have been collected from peer-reviewed and, where possible, papers that have conducted meta-analyses. However, there are limited numbers of such studies to draw from.
- For two of the impacts, air and water pollution, data could not be found for Germany specifically. Instead, data was used from studies conducted in Switzerland and Austria.
- The economic analysis was taken from two different sources and hence there may have been discrepancies in types of costs included.
- Not all studies used to calculate the different natural capital impacts of organic wheat farming compared to conventional practices analyze the exact same management practices between studies.

# 4. Conclusions

Organic wheat farming has both economic and natural capital advantages over conventional wheat farming in Germany. The analysis shows that the cost of natural capital impacts can be reduced by 46 percent largely due to the reduction in water pollutants. There are also reductions in the emission of GHGs, air, land and water pollutants. However, the impacts from land use change would be expected to increase as more land would be required to maintain yields. The impacts from water consumption are assumed to be the same across both farming practices. This is because only groundwater is included in the scope of this analysis and wheat production in Germany is predominantly irrigated with rainwater. The gross margin for organic wheat can be increased by 315 percent, due to the price premium and reduced operating costs when compared with conventional.

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# APPENDIX I: NATURAL CAPITAL PROTOCOL

The Food and Beverage Sector Guide, in conjunction with the main Natural Capital Protocol, are currently in an early drafting phase but are expected to contain the following sections (or a variation thereof):

## SECTOR SPECIFIC CONTEXT

i. Background on why natural capital is relevant to the Food and Beverage sector and how the sector benefits from it
ii. The business case for natural capital measurement in the sector which will include:
   a. Engagement with key stakeholders
   b. Overview of the key business value drivers and benefits of conducting a natural capital assessment
iii. Sector Materiality Matrix
   a. This will define the material natural capital impacts and dependencies at each stage of the value chain for different sectors and subsectors

## PRACTICAL GUIDANCE FOR APPLYING THE NCP AND FOOD AND BEVERAGE GUIDES

i. This will follow the principles outlined in the NCP but provide any sector-specific considerations where relevant

## PRACTICAL CASE STUDIES

i. Demonstrate how the NCP has been applied within the food and beverages sector
ii. Demonstrate how the NCP has addressed specific business value drivers and delivered business benefits
iii. Demonstrate how businesses can embed the NCP on an ongoing basis

# APPENDIX II: NATURAL CAPITAL INTENSITIES PER MILLION USD REVENUE

The tables below outline the natural capital intensities of the commodities included in this study. They show the total cost of natural capital impacts, per million USD revenue generated by each sector in the countries shown. This is to supplement the information presented throughout this study which presents natural capital intensities in terms of USD per tonne of production. The table also shows the natural capital impacts as a percentage of the revenue in each sector and country. The cost of natural capital impacts as a percentage of revenue range between 111 percent and 893% for crop farming, and between 42% and 1 237% for livestock farming. The sectors with the highest median natural capital cost as a percentage of revenue is rice farming (378 percent) for crops, and beef production (280 percent) for livestock.

### TABLE 1: NATURAL CAPITAL INTENSITIES OF CROP PRODUCTION

| Rank | Country | Cost of natural capital impacts per USD million revenue (USD per USD million) | Cost of natural capital impacts as a percentage of revenue |
|---|---|---|---|
| Maize production | | | |
| 1 | France | 5 881 824 | 588% |
| 2 | Brazil | 3 818 542 | 382% |
| 3 | India | 2 780 742 | 278% |
| 4 | Ukraine | 2 706 300 | 271% |
| 5 | Mexico | 2 555 130 | 256% |
| 6 | Indonesia | 2 395 964 | 240% |
| 7 | China | 1 986 186 | 199% |
| 8 | Argentina | 1 308 860 | 131% |
| 9 | Canada | 1 210 528 | 121% |
| 10 | USA | 1 113 071 | 111% |
| Rice production | | | |
| 1 | Bangladesh | 4 959 970 | 496% |
| 2 | Viet Nam | 4 021 171 | 402% |
| 3 | Myanmar | 3 905 496 | 391% |
| 4 | Thailand | 3 782 572 | 378% |
| 5 | Indonesia | 2 285 902 | 229% |
| 6 | India | 1 744 003 | 174% |
| 7 | China | 1 331 242 | 133% |

| Rank | Country | Cost of natural capital impacts per USD million revenue (USD per USD million) | Cost of natural capital impacts as a percentage of revenue |
|---|---|---|---|
| Soybean production | | | |
| 1 | Brazil | 3 049 129 | 305% |
| 2 | Argentina | 1 368 336 | 137% |
| 3 | USA | 1 366 897 | 137% |
| Wheat production | | | |
| 1 | Germany | 8 928 308 | 893% |
| 2 | France | 5 248 600 | 525% |
| 3 | Pakistan | 4 036 821 | 404% |
| 4 | Poland | 3 926 399 | 393% |
| 5 | Ukraine | 2 963 392 | 296% |
| 6 | India | 2 953 460 | 295% |
| 7 | Turkey | 2 613 092 | 261% |
| 8 | Iran | 2 349 207 | 235% |
| 9 | Russian Federation | 2 258 441 | 226% |
| 10 | China | 2 130 770 | 213% |
| 11 | United Kingdom | 1 693 386 | 169% |
| 12 | Kazakhstan | 1 604 919 | 160% |
| 13 | USA | 1 482 865 | 148% |
| 14 | Australia | 1 308 201 | 131% |
| 15 | Canada | 1 150 272 | 115% |

## TABLE 2: NATURAL CAPITAL INTENSITIES OF LIVESTOCK PRODUCTION

| Rank | Country | Cost of natural capital impacts per USD million revenue (USD per USD million) | Cost of natural capital impacts as a percentage of revenue |
|---|---|---|---|
| Cattle (beef) production | | | |
| 1 | Venezuela | 12 367 482 | 1237% |
| 2 | Brazil | 11 834 766 | 1183% |
| 3 | Mexico | 8 027 546 | 803% |
| 4 | Colombia | 6 677 780 | 668% |
| 5 | Australia | 3 959 908 | 396% |

| Rank | Country | Cost of natural capital impacts per USD million revenue (USD per USD million) | Cost of natural capital impacts as a percentage of revenue |
|---|---|---|---|
| 6 | Pakistan | 3 513 580 | 351% |
| 7 | Argentina | 3 449 738 | 345% |
| 8 | China | 3 443 982 | 344% |
| 9 | Spain | 2 896 132 | 290% |
| 10 | Uzbekistan | 2 886 315 | 289% |
| 11 | Uruguay | 2 814 861 | 281% |
| 12 | South Africa | 2 805 845 | 281% |
| 13 | Poland | 2 797 216 | 280% |
| 14 | Canada | 2 665 919 | 267% |
| 15 | Egypt | 2 647 451 | 265% |
| 16 | New Zealand | 2 640 853 | 264% |
| 17 | USA | 2 621 086 | 262% |
| 18 | Ireland | 2 537 506 | 254% |
| 19 | France | 2 329 415 | 233% |
| 20 | United Kingdom | 2 252 338 | 225% |
| 21 | Russian Federation | 2 122 764 | 212% |
| 22 | Germany | 2 050 332 | 205% |
| 23 | Turkey | 1 718 306 | 172% |
| 24 | Italy | 1 679 379 | 168% |
| 25 | Japan | 1 349 206 | 135% |
| Cattle (dairy) production | | | |
| 1 | Iran | 2 823 922 | 282% |
| 2 | Brazil | 1 966 547 | 197% |
| 3 | Mexico | 1 908 054 | 191% |
| 4 | Uzbekistan | 1 684 474 | 168% |
| 5 | Colombia | 1 566 449 | 157% |
| 6 | India | 1 548 286 | 155% |
| 7 | Ecuador | 1 373 288 | 137% |
| 8 | Pakistan | 1 354 228 | 135% |
| 9 | Belarus | 1 340 241 | 134% |

| Rank | Country | Cost of natural capital impacts per USD million revenue (USD per USD million) | Cost of natural capital impacts as a percentage of revenue |
|---|---|---|---|
| 10 | Poland | 1 202 680 | 120% |
| 11 | Australia | 1 158 632 | 116% |
| 12 | Argentina | 1 143 108 | 114% |
| 13 | Ukraine | 1 137 245 | 114% |
| 14 | Russian Federation | 1 113 216 | 111% |
| 15 | China | 1 100 400 | 110% |
| 16 | USA | 1 076 352 | 108% |
| 17 | Turkey | 1 027 387 | 103% |
| 18 | United Kingdom | 955 007 | 96% |
| 19 | France | 936 465 | 94% |
| 20 | New Zealand | 929 681 | 93% |
| 21 | Spain | 909 797 | 91% |
| 22 | Germany | 884 526 | 88% |
| 23 | Italy | 834 692 | 83% |
| 24 | Canada | 804 286 | 80% |
| 25 | Netherlands | 800 538 | 80% |
| 26 | Japan | 702 434 | 70% |
| Pork production | | | |
| 1 | Netherlands | 4 585 539 | 459% |
| 2 | Denmark | 3 797 541 | 380% |
| 3 | Philippines | 2 333 527 | 233% |
| 4 | Brazil | 1 476 549 | 148% |
| 5 | Germany | 1 334 506 | 133% |
| 6 | Spain | 964 392 | 96% |
| 7 | China | 850 945 | 85% |
| 8 | France | 842 811 | 84% |
| 9 | USA | 547 525 | 55% |
| 10 | Viet Nam | 509 593 | 51% |
| 11 | Canada | 486 422 | 49% |
| 12 | Russian Federation | 422 072 | 42% |

| Rank | Country | Cost of natural capital impacts per USD million revenue (USD per USD million) | Cost of natural capital impacts as a percentage of revenue |
|---|---|---|---|
| Poultry production | | | |
| 1 | Myanmar | 1 488 302 | 149% |
| 2 | China | 1 488 153 | 149% |
| 3 | India | 1 445 707 | 145% |
| 4 | Thailand | 1 390 634 | 139% |
| 5 | Argentina | 1 365 990 | 137% |
| 6 | South Africa | 1 300 396 | 130% |
| 7 | Turkey | 1 262 818 | 126% |
| 8 | Mexico | 1 256 759 | 126% |
| 9 | Brazil | 1 229 378 | 123% |
| 10 | USA | 1 224 734 | 122% |
| 11 | Malaysia | 1 214 700 | 121% |
| 12 | France | 1 164 566 | 116% |
| 13 | Iran | 1 164 418 | 116% |
| 14 | United Kingdom | 1 163 522 | 116% |
| 15 | Germany | 1 133 607 | 113% |
| 16 | Australia | 1 133 323 | 113% |
| 17 | Peru | 1 123 916 | 112% |
| 18 | Indonesia | 1 122 426 | 112% |
| 19 | Poland | 1 121 568 | 112% |
| 20 | Canada | 1 089 826 | 109% |
| 21 | Colombia | 1 077 150 | 108% |
| 22 | Spain | 1 071 814 | 107% |
| 23 | Japan | 1 046 979 | 105% |
| 24 | Russian Federation | 1 045 271 | 105% |

# APPENDIX III: TRUCOST'S ENVIRONMENTALLY EXTENDED INPUT-OUTPUT (EEIO) MODEL

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 531 sectors within and beyond agriculture. 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 15 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 fertilizers. 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 fertilizers, 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

| Component | Justification |
|---|---|
| Indirect Model | ***Input-Output (IO) Factors***<br>IO factors for the flow of goods and services between sectors are created from United States Bureau of Economic Analysis (BEA) benchmark supply and use tables.[17] These are produced to enable government and business decision-makers, researchers, and the general public to track and understand the performance of the US economy. |
| Direct Model | ***Environmental Matrix***<br>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*

Indirect or supply chain impacts are calculated from supply and use tables published by the United States Department of Commerce, Bureau of Economic Analysis (BEA)[18]. 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

[17] http://www.bea.gov/industry/io_benchmark.htm
[18] http://www.bea.gov/industry/io_annual.htm

collated and homogenized so that each industry's inputs reflect, as far as possible, a unique set of inputs for around 426 industries.

Input-output 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 USA 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 major commodities can be included.

However, some sectors which are important from an environmental perspective, such as power generation, are highly aggregated, and BEA data have insufficient detail on many sectors within the agricultural industry. In these cases, Trucost has disaggregated the input-output 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 programme.

*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 has been sourced from FAOSTAT Emissions Database on a country-by-country basis, 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 (which produced similar results to the blue water footprints that can be found on AQUASTAT). Land use for ruminants was estimated using the SOL-model (FAO, 2013). 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). Land use for crops was calculated using harvested area per country, taken from FAOSTAT (2011a). Fertilizer use factors were determined using FertiStat (2007) and IFA (2009). Pesticide use factors were determined using NCFAP (2008) and FAO (2009). Production quantities and price of commodities per country were sourced from FAOSTAT (2011a; 2011b).

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

*Outputs and Externalities*

Trucost's EEIO outputs cover over 100 environmental impacts which can be condensed into 6 high-level environmental key performance indicators covering the major categories of unpriced natural capital impact categories: water use, greenhouse gas emissions (GHGs), waste, air pollution, land and water pollution, and land use change.

*Strengths and Weaknesses*

Input-Output (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 for this project.

Multi-regional IO modelling adjusts for trade between regions to estimate embedded impacts in products more accurately. Trucost recommends adopting a hybridized 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 531 sectors whereas multi-regional IO models usually include 80 sectors.

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# APPENDIX IV: KEY CONCEPTS RELATED TO NATURAL CAPITAL VALUATIONS

This section describes the three fundamental concepts involved in placing monetary values on environmental impacts or natural resource use; (i) valuation techniques; (ii) impact pathway analysis and; (iii) value transfer.

*Valuation Techniques*

The table below summarizes the different techniques that can be used to value environmental impacts, including comments on which was applied for valuing specific receptors. All of the approaches below are equally valid, and this study chose valuation techniques best suited to calculating the social impact of environmental emissions, taking data availability and suitability into account. The study is consistent in its application of valuation techniques for receptors across all impact categories, for example, the impact on crops was valued in the same manner for acidification potential and photochemical ozone creation potential. The valuation technique selected for each environmental impact category is provided in the valuation methodology sections that follow.

*TABLE 1*: VALUATION TECHNIQUES

| Valuation Technique | Description |
|---|---|
| Abatement cost | The cost of removing a negative by-product for example, by reducing the emissions or limiting their impacts. |
| Avoided cost / Replacement cost / Substitute cost | Estimates the economic value of ecosystem services based on either the costs of avoiding damages due to lost services, the cost of replacing ecosystem services, or the cost of providing substitute services. Most appropriate in cases where damage avoidance or replacement expenditures have or will be made (Ecosystem valuation, 2000a). |
| Contingent valuation | A survey-based technique for valuing non-market resources. This is a stated preference/willingness-to-pay model in that the survey determines how much people will pay to maintain an environmental feature. |
| Direct market pricing | Estimates the economic value of ecosystem products or services that are bought and sold in commercial markets. This method uses standard economic techniques for measuring the economic benefits from marketed goods based on the quantity purchased and supplied at different prices. This technique can be used to value changes in the quantity or quality of a good or service (Ecosystem valuation, 2000b). |
| Hedonic pricing | Estimates the economic value of ecosystem services that directly affect the market price of another good or service. For example proximity to open space may affects the price of a house. |
| Production function | Estimates the economic value of ecosystem products or services that contribute to the production of commercially marketed goods. Most appropriate in cases where the products or services of an ecosystem are used alongside other inputs to produce a marketed good (Ecosystem valuation, 2000c). |
| Site choice / Travel cost method | A revealed preference/willingness-to-pay model which assumes people make trade-offs between the expected benefit of visiting a site and the cost incurred to get there. The cost incurred is the person's willingness to pay to access a site. Often used to calculate the recreational value of a site. |

*Impact Pathway Approach (IPA)*

IPA was used to value Eutrophication Potential, Acidification Potential and Photochemical Ozone Creation Potential.

The Impact Pathway Approach (IPA) is a bottom-up-approach in which environmental benefits and costs are estimated by following the pathway from the source of an environmental pressure (i.e. emission of pollutants), via changes in the quality of air, soil and water, to the physical impact (i.e. health risks) of such changes expressed in monetary terms.

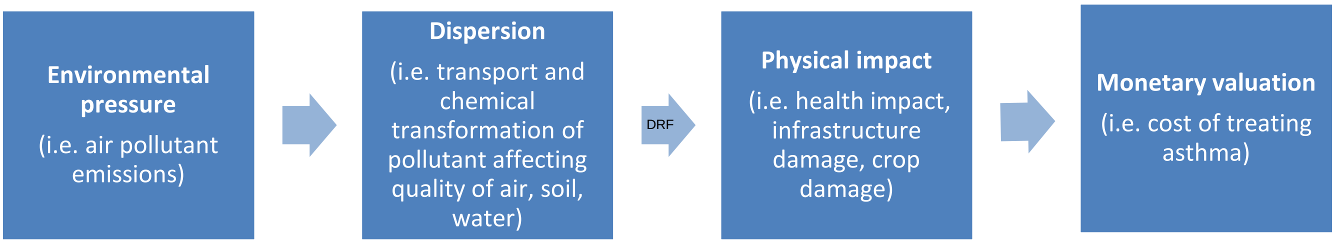


*FIGURE 1*: IMPACT PATHWAY APPROACH

Environmental pressures are translated into physical impacts using dose-response functions (DRFs). DRFs use scientific data to measure the relationship between a concentration of a pollutant (the dose) and its impact on things like human health, building materials, crops (the receptor). The receptor density (i.e. population density and crop density) drives the quantity of physical impact.

The study uses existing dispersion models from Life Cycle Analysis characterization models such as SimaPro's EcoIndicator99 (2014d) or ReCiPe (2014e), with DRF functions built-in. To account for the variability in receptor density when building its valuation methodologies, valuations are adjusted according to regional receptor densities, such as background population structure or air pollutant concentration.

*Value Transfer*

In order to estimate environmental costs or benefits in a context when no study exists, value transfer is used. In this method, the goal is to estimate the economic value of ecosystem services, or environmental impacts, by transferring available information from completed studies, to another location or context by adjusting for certain variables. Examples include population density, income levels, and average size of ecosystems to name just a few.

Best practice guidelines for value transfers have been set-out by UNEP in a document entitled Guidance Manual on Value Transfer Methods for Ecosystem Services (Brander, 2013). Where possible, this study endeavoured to follow these guidelines in all of its value transfer calculations. It is important to note however, that value transfers can only be as accurate as the initial study (Ecosystem valuation, 2000d), and due to data availability and data quality, in some instances, studies from different ecosystems and geographies have had to be ubiquitously used throughout a valuation methodology. For more information on the methods and limitations used in each methodology, please refer to the following references.

# Appendix IV References

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# APPENDIX V: GREENHOUSE GAS EMISSIONS VALUATION OVERVIEW

The steps below describe the methodology adopted to value the natural capital impact of greenhouse gas (GHG) emissions. For the purposes of this study, the social cost of carbon is used, as calculated by Stern (2006), which has been inflated from 2000 USD 85 per tonne $CO_2$ to 2013 USD 115 per tonne, using World Bank consumer price index (CPI) inflation rates.

## SCOPE

The social cost of carbon (SCC) is used to value the natural capital impact of GHG emissions. The advantages and disadvantages of this approach, as compared to marginal abatement costs and market price approaches are summarised below.

*Social cost of carbon*

*Definition*: The global direct cost of damages resulting from GHG emission-induced temperature rise, direct market costs and future risks. The value is based on the present value of each tonne of carbon dioxide equivalent ($CO_2e$) emitted now, taking into account the full global cost of the damage that it imposes during its 100 year lifetime in the atmosphere.

*Advantages*: The SCC signals what society should be willing to pay now to avoid the future damage caused by carbon emissions, and therefore best reflects the total damage caused by emitting one tonne of $CO_2e$. In theory, climate policy would set emissions reduction targets that result in a marginal abatement cost (MAC) equal to the SCC and, in perfect markets the price of carbon should equal the SCC. SCC is therefore the most complete measure of the damage generated by the emission of GHGs and is the method used by this study.

*Disadvantages*: SCC valuations are highly contingent on assumptions, in particular the discount rate chosen, emission scenarios and equity weighting. Please see the next section on calculating a valuation coefficient for a discussion of each.

*Marginal abatement cost*

*Definition*: The marginal abatement cost uses the known costs to reduce carbon to achieve an emissions reduction target, for example through energy efficiency improvements, renewable energy, materials substitution and/or carbon capture and storage technology.

*Advantages*: Based on the known actual costs of existing reduction efforts.

*Disadvantages*: Costs of reduction will fluctuate over time, by sector and by geography as technology matures. Different reduction targets will translate into different MACs for each country. Estimates of the costs or benefits of increasing energy efficiency, or switching to renewable energy, are influenced by fossil fuel prices, carbon prices and other policy measures. The policies and technologies used to support carbon abatement will therefore influence pricing. The local variability in carbon price under this approach means that it has not been selected by this study.

*Market price*

*Definition*: The value of traded carbon emission rights, under policies which constrain the supply of emissions through the use of permits, credits or allowances. The market price should be equal to the MAC for a given target, if the carbon market covers all emissions sources and is competitive. In the absence of a comprehensive international emissions trading scheme, a cap consistent with the optimal stabilization goal would result in a market price of carbon equal to both the MAC and SCC (Department of Energy and Climate Change, 2011).

*Advantage*: Market prices are easily accessible.

*Disadvantages*: Market-based mechanisms have been slow and fragmented so companies are unlikely to pay market prices for emissions across global operations. Traded market prices do not reflect non-traded carbon costs, nor the impact of other market-based mechanisms such as carbon/fuel taxes, subsidies for removal of fossil fuels, or support for low carbon technologies (i.e. feed-in-tariffs for renewable energy supplies). As a result, and as stated by the IPCC (2007), "market forces… cannot work directly as a means to balance the costs and benefits of GHG emissions and climate change" and, "the failure to take into account external costs, in cases like climate change, may be due not only to the lack of property rights, but also the lack of full information and non-zero transaction costs related to policy implementation." For these reasons, the market price of carbon has not been chosen by this study.

## CALCULATING A VALUATION COEFFICIENT

Over 300 studies attempt to put a price on carbon, valuing the impact of climate change on agriculture, forestry, water resources, coastal zones, energy consumption, air quality, tropical and extra-tropical storms, and human health. Estimates across studies vary from below-zero to four-figure estimates, mainly due to four factors that have been outlined below.

*Emissions scenarios*: In order to derive the social cost of carbon, assumptions need to be made on future emissions, the extent and pattern of warming, and other possible impacts of climate change, to translate the impacts of climate change into economic consequences. Tol (2011) identified three methodological approaches undertaken by the literature – expert review, enumerative method, and statistical method – and conducted a meta-analysis of the results. The studies agree that the negative effects of climate change outweigh the short-run benefits of inaction. This consensus was, in part, reached from nine studies that calculated the total economic cost of climate change, which in turn yielded more than 200 estimates of the marginal cost of carbon.

*Discount rate*: The discount rate used to calculate the present value of future economic damages resulting from carbon emitted today can be the most significant source of variation in estimates of the social cost of carbon (Tol, 2011). Higher discount rates result in lower present day values for the future damage costs of climate change. Variations in discount rates can be due to differences in assumptions about factors such as the rate of pure time preference, the growth rate of per capita consumption and the elasticity of marginal utility of consumption. The rate of time preference is the percentage of income that someone can be compensated as a result of forgoing consumption today. For example, Stern (2006) uses a rate of 0.1 percent. As a reference point, discount rates used by the US EPA (2013) range between 2.5 percent and 5 percent.

*Equity weighting*: A global SCC can take into account variations in the timing and locations at which the costs of climate change impacts will be internalized, which may differ from the locations where the GHGs are emitted. Some studies including Stern (2006) and Tol (2011) take account of equity weightings – corrected for differences in the valuations of impacts in poor countries.

*Uncertainties*: Variations in valuations are influenced by uncertainties surrounding estimates of climate change damages and related costs. However, climate change studies since 1995 tend to take account of net gains as well as losses due to climate change (Tol, 2011). The mean estimate of the social cost of carbon, as well as the standard deviation, have declined since 2001, suggesting either a better understanding of the impacts of climate change, or the convergence of methodologies (*Ibid*). Further, GDP loss estimates in relation to climate change have declined over time, as later studies focus on the positive and negative effects of climate change whilst taking adaptation measures into account.

The US Environmental Protection Agency (EPA) calls upon three statistical models, known as integrated assessment models, to estimate the value of the social cost of carbon, defined as the economic damage that one ton of $CO_2$ emitted today will cause over the next 300 years (Interagency Working Group on Social Cost of Carbon, United States Government, 2013). The US EPA displays average social cost of carbon for discount rates of 5 percent, 3 percent and 2.5 percent. As noted in the 2010 technical support document (TSD), "the 3 percent discount rate is the central value, and so the central value that emerges is the average SCC across models at the 3 percent discount rate" (*Ibid*).

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# APPENDIX VI: AIR POLLUTANT VALUATION OVERVIEW

The main air pollutants include sulphur dioxide ($SO_2$), nitrogen oxides (NOx), particulate matter (PM), ammonia ($NH_3$), carbon monoxide (CO) and volatile organic compounds (VOCs). Each pollutant impacts one or more of the following categories in a unique way; human health; crop yields and; forest yields. The economic damage caused per unit of pollutant depends on the specific location, and is driven by population and crop and forest density. The valuations for each of the pollutants vary for each country depending on certain factors, such as population density, and range from USD 350 per tonne for VOCs to nearly USD 51,000 per tonne for PM emissions.

Each pollutant is associated with different but overlapping types of external costs. Some effects are caused directly by the primary pollutant emitted (e.g. health impacts of particulates) and some are caused by secondary pollutants formed in the atmosphere from pollutants that acts as precursors (e.g. sulphur dioxide forming sulphuric acid as well as sulphate compounds which contribute to smog). As each pollutant has a unique set of effects, each pollutant is valued using an individual methodology (although there is overlap between methodologies).

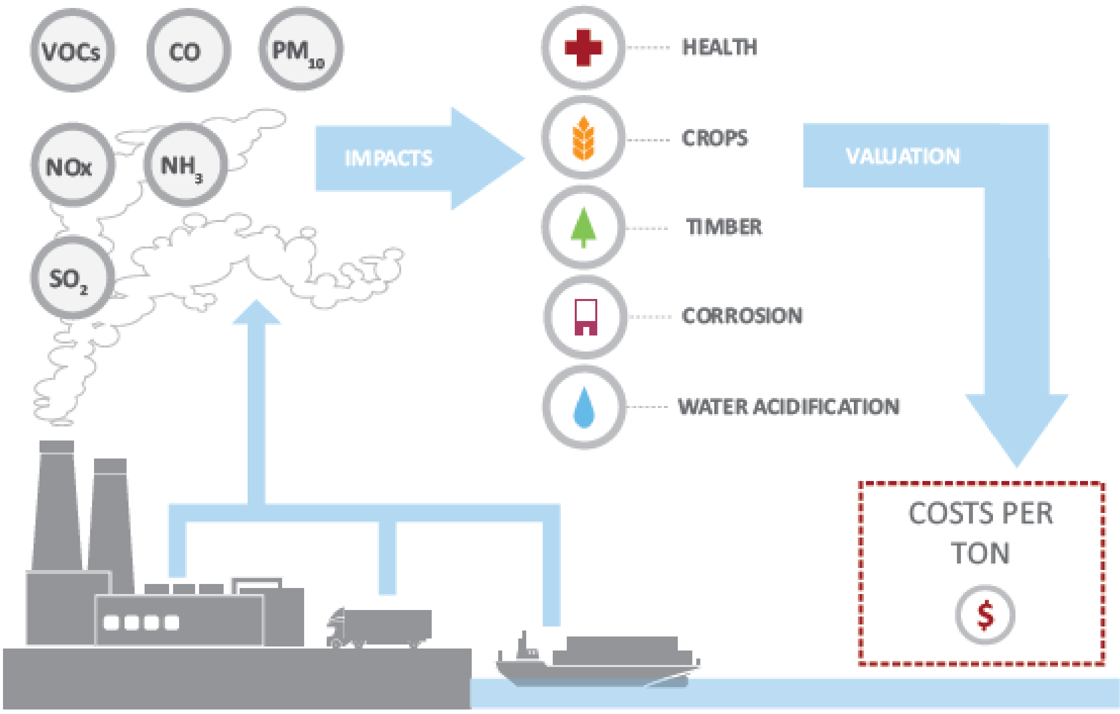


*FIGURE 1*: SCOPE OF AIR POLLUTION VALUATION

Studies of the costs of damages from air pollution use the Impact Pathway Approach (IPA) to identify burdens (e.g. emissions), assess their impacts and value them in monetary terms, for example ExternE (2003). ExternE is a result of more than 20 research projects conducted in the past 10-years, financed by DG Research and the European Commission. In this approach, emissions are translated into physical impacts using dose–response functions (DRFs) which use peer-reviewed scientific data to measure the relationship between a concentration of a pollutant (the dose) and its impact on human health, building materials, and crops (the receptor). A financial value is then assigned to each impact.

*Identifying the main impacts*

This study identified which environmental impacts to consider for each air pollutant using the Impact Pathway Approach. Where impacts are excluded, such as the impact of Particulate Matter on crops and forestry, it was due to immateriality relative other effects. The table below summarizes which impacts are included for each air pollutant.

*TABLE 1*: ENVIRONMENTAL IMPACTS CONSIDERED

| Air pollutant | Environmental impacts |
|---|---|
| Particulate matter (PM) | Human health |
| Ammonia ($NH_3$) | Human health, forestry productivity |
| Nitrous oxides (NOx) | Human health, forestry productivity, crop productivity |
| Volatile organic compounds (VOCs) | Human health, forestry productivity, crop productivity |
| Sulphur dioxide ($SO_2$) | Human health, forestry productivity, freshwater ecosystem damage, damage to building materials |

## Country specific valuations

*Air pollutant impacts on human health*

Health costs include: the cost of mortality; chronic bronchitis; hospital admission; asthma attacks; restricted activity days; respiratory symptom days; congestive heart failure; chronic cough; cough and wheeze; and bronchodilator use. This study looks at these particular health effects, as this is what is included in the ExternE IPA model described above. A meta-analysis is then conducted to calculate a global average value of the willingness-to-pay to avoid the impacts listed above. An overview of the steps involved in calculating these costs is provided below:

*Calculation of number of end points*

Data is compiled on the number of end points (number of health impacts) generated by the emission of one tonne of each air pollutant. In the context of health impacts, the number of end points is driven by population density, which is country-specific.

*Development of global average health costs*

A literature review was conducted to identify country-specific studies calculating the willingness-to-pay to avoid the different health impacts listed above. Using these studies, a country specific model was built to calculate global average costs, weighted by population for each health impact. A global average was chosen to avoid the ethical considerations of applying different values of health and life across countries.

*Application of global average costs*

Natural capital valuation coefficients for each air pollutant are obtained by multiplying the number of end points by the global health costs.

*Other environmental impacts air pollutants*

Natural capital valuations of air pollutant impacts on crops, timber, water and building materials are considered in this approach and are country specific. The change in crop yield has been considered due to the deposition of pollutants in the soil, therefore increasing soil acidity. Water impacts are assessed through the acidification effects of $SO_2$ deposition in water bodies. The impacts on buildings materials only includes the material loss due to corrosion. Other impacts such as discolouration and structural failure have not been included as either the effects have been deemed immaterial, or that impacts are more dependent on building design. An overview of the steps involved in calculating these costs is provided below.

*Literature compilation*

Data was compiled from IPA studies on the cost of the damage caused by air pollutants on crops, timber, water and building materials. A meta-analysis was then conducted of available literature on the costs that each of these impacts inflict on society to derive country-specific valuation coefficients.

*Adjustment of the cost based on receptor densities factors*

Trucost adjusted the country-specific data obtained from the literature based on receptor densities, such as the percentage of crop or forest cover in a country. Impacts on building materials centre on using maintenance costs which have been adjusted using purchasing power parity (PPP). Impacts on water acidification, included in the valuation of $SO_2$, is a global average.

# Appendix V References

ExternE Project. (2003) *Method for Estimation of Physical Impacts and Monetary Valuation for Priority Impact Pathways*. Externalities of Energy. Oxfordshire, UK.

# APPENDIX VII: EUTROPHICATION VALUATION OVERVIEW

## Approach

In Leiden University's Institute of Environmental Sciences (CML) characterization model (2001), eutrophication is expressed in kilograms of phosphate equivalents (kg P-Equiv), which relates to the water eutrophication potential of a substance.

Eutrophication has mostly been studied in the context of fertilizer application and agriculture. The impact included in this valuation is impacts on freshwater and coastal ecosystems. A literature review was conducted to calculate country-specific values, and used the equivalency model built in CML to derive the monetary damage cost of one kg P-Equiv. The values for the impacts assessed in this study vary for each country as they depend on a number of factors, such as average ecosystem size, and vary from USD 1 to over USD 800,000 per tonne of nitrate or phosphate that has leached into waterways.

## Valuation

Impact on water ecosystems is the most material impact of eutrophication.  The methodology used is based on the ExternE (2003) and NEEDS (2006) project work to estimate the impact of eutrophication on freshwater and coastal ecosystems and derived a benefit transfer function for willingness-to-pay.

The EcoIndicator 99 characterization model (GoedKoop and Spriensma, 2001) estimates the impact of airborne NOx emissions on Potential Disappeared Fraction (PDF) in the Netherlands (9.52 PDF per kg NOx). As NOx generates both acidification and eutrophication impacts,  disaggregated the total figure using the equivalency model built in TRACI (US EPA, 2003) to arrive at the final figure of 8.15 PDF per kg for the eutrophication impact of NOx (De Bruyn et al., 2010).

To value biodiversity, a study must define biodiversity, quantify biodiversity losses due to emissions of pollutants through dispersion and deposition models, and then place a monetary value on these losses. Marginal quantities of pollutant are needed, rather than an absolute valuation of an ecosystem or species. Research projects which have attempted the latter (such as ExternE (2003) and the NEEDS project (2006)), revolve around calculating the damage cost of pollutants released by energy generation. The ExternE study is the result of more than 20 research projects conducted in the past 10 years, financed by DG Research and the European Commission. The NEEDS project (2006) was run by a consortium of organizations, including 66 partners from the academic, public and private sectors.

*NOx emissions*

The effect of NOx emissions is treated as a special case as its emission to air has two effects in the methodologies – acidification and eutrophication. The NEEDS (2006) approach developed a formula to estimate the monetary cost per kilogram of NOx deposited to the terrestrial and freshwater environment in each European country using the three steps outlined below.

*1. Estimate the impact of NOx on ecosystems*

The EcoIndicator 99 characterization model was used to estimate the impact of NOx on biodiversity (Goedkoop and Spriensma, 2001), expressed in Potentially Disappeared Fraction (PDF), which is a probability of plant species disappearing from the area as a result of eutrophication.

*2. Calculate the willingness-to-pay to restore an area of land*

A meta-analysis of 24 studies and 42 value observations across regions and ecosystems was conducted to calculate an ecosystem's Ecosystem Damage Potential (EDP). EDP is similar to PDF; the former is expressed per hectare and the latter per square metre, so a simple conversion between the two was made. The EDP value includes both use and non-use values.

*3. Derive of a function to adapt the value to different countries using benefit transfer*

Within the NEEDS project, a regression analysis between willingness-to-pay and several variables was performed. The EDP value is known to have a positive correlation with population – as more people live close to an area with high biodiversity, there will be more people that value that biodiversity. The EDP value is known to have a negative correlation with the ecosystem size – so if an ecosystem covers a larger area, the value per unit area will be less. Similarly, as biodiversity change increases, the value per unit of biodiversity diminishes.

The value of ecosystem damage is a function of the change in biodiversity due to eutrophication, the willingness to pay for biodiversity (adjusted for purchasing power parity), the share of natural land and background eutrophication pressure.

## Limitations

To value the impact of eutrophication on ecosystems, the ExternE approach which relies on several assumptions due to data limitations:

i. The conversion from emissions to PDFs was developed for the Netherlands, using a Dutch impact pathway model, Natuurplanner (Latour et al., 1997). Due to differences in local conditions, there are potential transferability considerations. However, the conversion coefficient is assumed to be the same for other countries as no other data is available. Other models have tried to adapt the PDF fraction change at a continental level, such as EUSES (European System for the Evaluation of Substances) (EC, 2004). However, this model is only applicable to organic substances and heavy metals.

ii. ReCiPe (SimaPro, 2014d) is a newer characterization model incorporating the EcoIndicator 99 model (Goedkoop and Spriensma, 2001). used EcoIndicator 99 to estimate the impact of NOx on ecosystems through eutrophication rather than ReCiPe because the valuation model, and best-fit benefit transfer function, derived in the NEEDS project, used EcoIndicator 99 factors.

iii. Average country-level ecosystem size is derived from average terrestrial fragmentation data and actual data from Germany due to lack of country-level data. Average freshwater ecosystem size is derived from the total area covered by freshwater divided by the numbers of lakes. Depending on the country, this may overestimate or underestimate the results. For countries where the average ecosystem size is smaller, the valuation is underestimated, and vice versa, due to diminishing returns to area.

iv. The run-off factors (transport coefficients) are assumed to be the same amongst countries. This may underestimate or overestimate the final results based on soil type and other background factors.

v. This study assumed that the impact of nitrous oxides on ecosystems can be disaggregated based on the relative eutrophication and acidification potential of this substance as highlighted in the TRACI characterization model (US EPA, 2003).

# Appendix VI References

CML (Centre of Environmental Science). (2001) *Scientific Background*. Life cycle assessment: An Operational Guide to the ISO Standards. Maastricht.

EC (2004) European Union System for the Evaluation of Substances 2.0 (EUSES 2.0). Prepared for the European Chemicals Bureau by the National Institute of Public Health and the Environment (RIVM), Bilthoven, The Netherlands (RIVM Report no. 601900005).

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# APPENDIX VIII: ECOSYSTEM AND HUMAN TOXICITY FROM PESTICIDES OVERVIEW

This section describes Trucost's natural capital valuation methodology, which places a monetary impact on the damage inflicted ecosystems and human health, from various chemicals found in pesticides. The steps outlined below produce country specific valuations expressed in 2014 US Dollars per tonne of active ingredient in the pesticide used. Trucost calculated valuations that vary per country as they depend on a number of factors, such as population density, and values have been calculated for over 80 chemicals. The CML characterization model (2001) was used to develop a factor for each pesticide quantified by Trucost's Environmentally Extended Input-Output (EEIO) model.

## Valuation

*Ecosystem Toxicity*

In order to estimate the impact of pesticides on terrestrial ecosystems, Trucost used the same methodology as for eutrophication, based on the ExternE (2003) and NEEDS (2006) projects. Instead of using NOx as the reference substance, various pesticides were chosen (80 different pesticides including chlorpyrifos or vinclozolin). The EUSES model, as described above, calculates the potentially disappeared fraction (PDF) of these substances at a continental level, due to the emission of 1 kg of a pollutant.

Trucost then applied the model as described in the Eutrophication methodology to estimate the impact of eutrophication on terrestrial ecosystems.

*Human Toxicity*

In order to value the health impacts of pesticides, the EUSES-LCA2.0 model was used (Van Zelm et al., 2009). EUSES calculates the human toxicological effect and damage factors per substance, in conjunction with information related to the intake route (inhalation or ingestion), and disease type (cancer and non-cancer) at a continental level.

Damage factors express the change in damage to the human population, expressed in disability adjusted life years (DALYs), as a result of exposure. They consist of a disease specific factor, and a chemical-specific potency factor. EUSES also includes cancer-specific and non-cancer-specific factors. The chemical-specific factors relate to the average toxicity of a chemical towards humans, separately implemented for carcinogenic effects and effects other than cancer.

The EUSES's risk assessment is conducted at a continental level as follows:

i. *Exposure assessment*: estimation of the concentration/doses that human populations or the environment are exposed to. This should be adjusted for variability between regions.

ii. *Effects assessment*, including:

   a. Hazard identification: identification of a substance's possible adverse effects and its inherent capacity to cause these effects and;

b. Dose-response assessment: estimation of the relationship between the level of exposure to a substance (dose and concentration), as well as the incidence and severity of the effect.

iii. *Risk characterization*: estimation of the incidence and severity of the adverse effects likely to occur in a human population or the environmental due to actual or predicted exposure to a substance. This estimation results in a quantitative comparison per substance of the outcome of the exposure assessment and the effects assessment.

In order to put a value on the years of life lost, the NEEDS (2006) project approach was taken. The results of this approach are based on a contingent valuation questionnaire (or willingness-to-pay), conducted in nine European countries: France, Spain, UK, Denmark, Germany, Switzerland, Czech Republic, Hungary and Poland. First, the value was adapted to every country based on country-specific income levels. This benefit transfer approach was applied to the valuation of disease incidence as found in the EXIOPOL report (2011). Second, to avoid ethical criticisms on the value of life and disease incidence in different countries, the global median value for each type of health impact was applied.

## Limitations

To value the impact of pesticides on *ecosystems*, the ExternE approach was used which relies on several assumptions due to data limitations. An overview of these limitations is provided below:

i. The conversion from emissions to PDFs was developed for the Netherlands, using a Dutch impact pathway model, Natuurplanner (Latour et al., 1997). Due to differences in local conditions, there are potential transferability considerations. However, the conversion coefficient is assumed to be the same for other countries as no other data is available. Other models have tried to adapt the PDF fraction change at a continental level, such as EUSES (European System for the Evaluation of Substances) (EC, 2004). However, this model is only applicable to organic substances and heavy metals.

ii. Limitations built in the EUSES model are valid for Trucost's valuation. The EUSES model regionalises the impact of substances on ecosystems at a continental level.

To value the impact of pesticides on *health*, the ExternE approach was used which relies on several assumptions due to data limitations. An overview of these limitations is provided below:

i. The valuation per year of life lost and incidence rate were adapted based on income levels using purchasing power parity. This is in line with the ExternE approach. For ethical reason, the median valuation was used for every country.

ii. Limitations built in the EUSES model are valid for Trucost's valuation. The EUSES model regionalises the impact of substances on health at a continental level.

# Appendix VIII References

CML (Centre of Environmental Science). (2001) *Scientific Background*. Life cycle assessment: An Operational Guide to the ISO Standards. Maastricht.

ExternE Project. (2003) *Method for Estimation of Physical Impacts and Monetary Valuation for Priority Impact Pathways*. Externalities of Energy. Oxfordshire, UK.

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New Energy Externalities Developments for Sustainability (NEEDS). (2006) *Assessment of Biodiversity Losses*. Sixth Framework Programme. Zurich: Econcept AG.

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# APPENDIX IX: WATER CONSUMPTION VALUATION OVERVIEW

’s natural capital valuation of water abstraction is based on Pfister’s characterization model (SimaPro, 2014c), which includes impacts on ecosystem and on human health. The steps outlined below result in a country-specific valuation expressed in 2014 US Dollars per cubic metre of water abstracted and range from USD 0.004 to USD 2.87 per $m^3$. Applying the valuation consists in multiplying the quantity of water abstracted by the valuation factor of the corresponding country.

## Valuation

*Ecosystems*

Ecosystem quality is obtained by modelling the cause-effect chain of freshwater consumption on terrestrial ecosystem quality, and assessed following the EcoIndicator 99 method (Goedkoop and Spriensma, 2001). The units which measure the effect on ecosystem is the potentially disappeared fraction of species (PDF). The fraction of net primary productivity (NPP), which is limited by water availability, represented the vulnerability to water-shortages of an ecosystem, and is used as a proxy for PDF.

The valuation of PDF in monetary terms is based on the same approach as the one described for ecotoxicity from pesticide use.

*Human Health*

The relationship that has been developed by Pfister (2009) highlights that the impact on human health is obtained by modelling the cause-effect chain of water deprivation for agricultural users. The relationship calculates the effect of water deprivation on malnutrition for local populations based on two factors – the percentage of agricultural water usage in a country and the Human Development Index (HDI). Two constants are also used in the relationship which are explained in point (iii) below. The relationships states that malnutrition is an effect of water scarcity in agricultural areas as it reduces food production, and therefore has a knock-on effect on the availability of food in that region. It builds on the midpoint scarcity indicator and models the cause-effect chain by multiplying it by:

i. The agricultural user’s share of water use;
ii. A human development factor for malnutrition, which relates the Human Development Index (HDI) and;
iii. Two values independent of location that are combined into an effect factor that describes the DALYs/$m^3$ caused by agricultural water deprivation. These are:
    a. the per-capita water requirements to prevent malnutrition and;
    b. a damage factor that denotes the damage caused by malnutrition.

The valuation of DALYs in monetary terms is based on the same approach as the one described for human toxicity from pesticide use. Please see the section above.

## Limitations

i. The limitations outlined in Pfister et al. (2009)

ii. The conversion from emissions to PDFs was developed for the Netherlands, using a Dutch impact pathway model, Natuurplanner (Latour et al., 1997). Due to differences in local conditions, there are potential transferability considerations. However, the conversion coefficient is assumed to be the same for other countries as no other data is available. Other models have tried to adapt the PDF fraction change at a continental level, such as EUSES (European System for the Evaluation of Substances) (EC, 2004). However, this model is only applicable to organic substances and heavy metals.

iii. Limitations built in the EUSES model are valid for Trucost's valuation. The EUSES model regionalises the impact of substances on ecosystems at a continental level.

iii. The valuation per year of life lost and incidence rate was adapted based on income levels using purchasing power parity. This is in line with the ExternE approach. For ethical reason, the median valuation was used for every country.

iv. Limitations built in the EUSES model are valid for Trucost's valuation. The EUSES model regionalises the impact of substances on health at a continental level.

# Appendix IX References

ExternE Project. (2003) *Method for Estimation of Physical Impacts and Monetary Valuation for Priority Impact Pathways*. Externalities of Energy. Oxfordshire, UK.

EC (2004) European Union System for the Evaluation of Substances 2.0 (EUSES 2.0). Prepared for the European Chemicals Bureau by the National Institute of Public Health and the Environment (RIVM), Bilthoven, The Netherlands (RIVM Report no. 601900005).

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# APPENDIX X: LAND USE CHANGE VALUATION OVERVIEW

The premise behind valuing ecosystem services is to put a monetary value on the services that ecosystems provide that positively affect human well-being. The Millennium Ecosystem Assessment (MA, 2005) has set out to identify changes in ecosystem conditions and link these to changes in ecosystem service provision. By valuing ecosystem services lost from land use change, this measures the change in human well-being and therefore, the marginal value of each hectare of an ecosystem converted.

The MA has identified four umbrella categories for ecosystem services which are; provisioning services, regulating services, cultural services and supporting services. The values of these services provide an indicator of human well-being for either the local, regional or global population.

*TABLE 1*: DEFINITIONS OF ECOSYSTEM SERVICES (MA, 2005)

| Ecosystem service | Definition |
|---|---|
| Provisioning services | The benefits that ecosystems provide in the form of “products ‟ o humans or used in the production of other goods. They include timber, water, fish and genetic resources. |
| Regulating services | The benefits obtained from an ecosystem’s control of natural processes such as climate, disease, erosion, water quality and flows, and pollination, as well as protection from natural hazards such as storm and wave damage. They are ecosystem “functions and “regulatory processes ‟ th vegetation storing carbon, wetlands slowing down water flows and cleansing water, and coral reefs and mangroves protecting coastal infrastructure from erosion and storm damage. |
| Cultural services | The non-material benefits people obtain from ecosystems such as recreation, spiritual values, and aesthetic enjoyment. |
| Supporting services | The natural processes such as nutrient cycling and primary production that maintain the other services. The value of supporting services is captured within the value of the above three services and so should NOT be valued separately. |

’s valuation only considers the land that has been completely converted from its natural state in its valuation. For example, if tropical forest has been cleared to make way for agriculture or industrial activity, then the ecosystem services lost associated with this conversion have been considered. However, if a tropical forest has been degraded, but the tropical forest ecosystem still exists in some capacity, then this has not been included in the analysis.

The valuation relied on using studies contained within de Groot et al. (2014) to derive a global median value for each of the ecosystem services. The valuations were converted to current prices using local inflation rate, and then to US Dollars using 2014 exchange rates. The median was identified to exclude outliers. Aggregated ecosystem values depend on the number and type of ecosystem services provided, as well as the demand for them in the primary valuation studies. For example, de Groot calculates values for 11 ecosystem services provided by coastal wetlands, whereas only 9 ecosystem services have values associated with grasslands. The disparity between the amount of ecosystem services covered between ecosystems can be explained in part due to limited data availability. Ecosystem services included in the study include the provisioning of raw materials, climate regulation and the moderation of extreme events as well as cultural services such as the opportunities for recreation.

*Crops*

The land use of crops in this study was calculated by using GIS datasets. Raster files of crop locations (Portmann et al., 2010) were used to in conjunction with ecosystem distribution polygon files (Olson et al., 2004), in order to calculate the number of hectares of cropland that had replaced natural ecosystems. The ecosystems in each country were then mapped to those in De Groot (2012) so that an average value of ecosystem service loss could be applied. The value here relates to the annual flow of ecosystem services lost from the conversion of land to agricultural ecosystems.

*Livestock*

The land use of dairy cattle and beef cattle was calculated using data produced from FAO's Sustainability and Organic Livestock Model (SOL-M) (FAO, 2013). The feeding rations per type of animal, per country, was provided in conjunction with the amount of dry matter consumed per animal per year. In addition with the grass yields per country, in tonnes of grass per hectare, enable the calculation of the area of land needed per year to support dairy cattle and beef cattle in each country.  This area was the apportioned to the ecosystems present in each country based on Olson et al. (2004) ecoregion distribution per country. For broilers and pig farming sectors, because they are not ruminants, the same approach could not be followed. In this instance, data from the U.S. on the number of animals and size of farms was collected from sources such as the Census of Agriculture (USDA, 2009). This intensities calculated from this data were then replicated for other countries in this study.

## Limitations

The principal limitations and possible errors that may arise through this approach to land use valuation are:

i. Methods and assumptions are not standardised across primary valuation studies used in the meta-analysis.
ii. Valuations for ecosystems do not contain a complete set of relevant ecosystem services in some cases. There is not a complete list of countries covered in the meta-analysis so preferences will be unevenly weighted in favour of countries where more studies have been conducted. This is limited by data availability.
iii. Ecosystem service functions and values are highly localised and transfer at the national level will increase the level of uncertainty present in underlying values.
iv. An assumption has been made that there is a linear relationship between ecosystem service values and the scarcity of those ecosystem services. Due to limited data availability, the rate of change in ecosystem service provision could not be calculated so a linear approach to this

change has taken. This means that due to the unknown time at which land was converted, the average value of the ecosystem services has been calculated.

v. All ecosystem services are considered to be lost when land is converted from its natural ecosystem, regardless of the type of activity that takes its place.

## Appendix X References

MA. (2005) Millennium Ecosystem Assessment. *Ecosystems and Human Well-being: Synthesis*. Island Press, Washington, DC.

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

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Portmann, F. T., Siebert, S., Döll, P. (2010) *MIRCA2000 – Global monthly irrigated and rainfed crop areas around the year 2000*. A new high-resolution data set for agricultural and hydrological modelling. Global Biogeochemical Cycles. 24, GB 1011, doi: 10.1029/2008GB003435.

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# APPENDIX XI: GREENHOUSE GAS EMISSIONS FROM LAND CLEARING OVERVIEW

## Introduction

The ‘Land use tool’ by Blonk Consultants (2014) is based PAS 2050 protocol. According to the protocol, the assessment of the impact of land use change shall include all direct land use occurring not more than 20 years ago, or over a single harvest period prior to undertaking the assessment, whichever is longer. The estimation of the changes in soil organic carbon (SOC) stock is a pivotal step in the calculation of land transformation values in the Blonk model. Stock changes in SOC do not occur instantaneously but over a period of years to decades. The IPCC (2006) guidance for GHG inventories assumes a period of 20 year for a new equilibrium in soil organic carbon stock after conversion. Thus, an amortization period of 20 years was considered for the study.

This tool can be used to calculate GHG emissions from land clearing for a specific country and crop combination and attribute them to specified cultivated crops. However, not in every case the previous land use is known, so this tool also provides a means of estimating the GHG emissions from land clearing based on an average land clearing in the specified country. This tool can be used to quantify land clearing emissions consistent with the GHG Protocol Product and Scope 3 Accounting and Reporting Standards, and therefore has earned the built on GHG Protocol mark. The tool has also been reviewed by the World Resources Institute.

As per the Blonk model, the weighted average emissions factors which “takes into account relative differences in crop expansion at the expense of forest, grassland, annual/perennial” have been used. The normal average is a simple average between these clearing options. The worst case scenario described in the Blonk tool takes the highest value of the two approaches, as recommended by the PAS2050-1. For this analysis, the weighted average factor has been used.

The Blonk model relies on a number of data points provided by external organisations. These include:

i. Global Forest Resources Assessment 2010
ii. Crop, forest and grassland areas from FAOSTAT
iii. Crop yields from FAOSTAT

Other data sources include above and belowground biomass from the European Commission (2009), soil organic carbon per type of ecosystem and stock change factors from the IPCC (2006), crop definitions from PAS 2050 and the climate and soil types of countries provided by the European Commission’s Joint Research Centre (JRC).

The Blonk model provides results that are consistent with the overall carbon figures estimated by FAOSTAT for land use change involving deforestation and afforestation, but it will likely miss significant additional emissions from processes critical in some countries, such as peatland drainage and degradation, and ecosystem fires. The Blonk model is a useful tool to derive some more detailed crop specific analyses, while FAOSTAT estimates for emissions from agriculture and land use change are the reference values to use in global analyses, as reported by IPCC and others such as WRI and GTAP.

FAOSTAT's GHG Emissions Database from land use change[19] was considered as an alternative however, the country-level estimates that were provided cannot be attributed directly to certain crops as in the Blonk model. It should be noted that the data provided by FAOSTAT includes carbon emissions coming from the clearance from forests and grasslands, and also includes the planned development of indicators which link GHG emissions to certain commodities. The Stern (2006) social cost of carbon was applied to the carbon emissions arising from land use change – 2013 USD 115 per tonne $CO_2$.

## GHG emissions from land clearing – direct

*Crops*

This study used a country-specific, weighted average emissions factor. This takes into account the type of land lost in each country due to each crop that has expanded over the last 20-years. For those crops and/or countries that were missing factors, we took an average of the emission factors for countries in the study producing the same crop. The expansion of land over 20-years from 1992 to 2011 from the Blonk model was used. Some sectors in some countries showed a contraction in agricultural land. These were subsequently excluded from the analysis. The total GHG emissions from land clearing were calculated and then equally apportioned to the production of crops over the same period of time. This assumes that each tonne of crop produced, in every year, was equally responsible for the GHG emissions resulting from land clearing. Production data was taken from FAOSTAT. The average GHG emissions released from land clearing (tonnes of $CO_2e$ per tonne of production) were then multiplied by the production of crops in 2011 to give the total GHG emissions attributable to the production of crops, on land that has been expanded on, that year.

*Livestock*

To calculate the greenhouse gas emissions due to land clearing, the pastureland that had expanded over a 20-year period was calculated, which was given in the Blonk model. This data came directly from FAOSTAT. , using FAOSTAT data, then calculated the average stock of animals over a three year period from 1992 – 1995, and then from 2009 – 2011. This study only included sectors and countries in its analysis that had shown both an increase in stock numbers, as well as an increase in pastureland. This was done as the assumption that livestock occupied the same area in 1992 and in 2011 had to be taken as data regarding livestock densities for the years and countries in the analysis was not available. The densities of animals on pastureland were calculated by using GIS data provided by FAO (2014). Due to the processing time required, data was only calculated for countries for South America and an average for all of these countries was calculated, and subsequently used for the other countries in the analysis. This data was then used to calculate the percentage of land expansion that could be attributes to each grazing animal. The livestock that was considered in this assessment include cattle, pigs, chickens, sheep, buffalo and goat. The average carbon content of ecosystems was calculated, on a continental level, using the Blonk model, to estimate the carbon stock lost due to the expansion of livestock in this study. The carbon emissions were distributed over 20-years so that the production of meat in 2011 was allocated one-twentieth of the emissions calculated.

[19] Please see: http://faostat3.fao.org/download/G2/*/E

## GHG emissions from land clearing – indirect

*Livestock*

Only the GHG emissions from land clearing for the production of livestock feed were included in this analysis.

The percentage breakdown of feed for each animal, and the subsequent amount of feed consumed by each animal, at a continental level, has been attained from life-cycle analysis data provided by FAO and Hoekstra (2010). The hectares of land needed to produce this feed was then calculated using global average yield data, in kilogrammes per hectare, from FAOSTAT. Once the total hectares required to produce the feed, per kilogramme of produce, were calculated, emissions factors from the Blonk model were used to calculate GHG emissions in each continent, per kilogramme of output. These continental specific factors were used in conjunction with the production quantities in each country to calculate the total GHG emissions from land clearing to produce feed for livestock.

Some feed types were excluded from the analysis because they were not specifically grown to feed livestock. For example, crop residues have not been assigned any emission factor because they are a by-product of producing crops. Similarly, feed such as fresh grass and hay have not been assigned an emissions factor, nor have feeds such as pulp and leaves. This is because they do not map to any crops within the Blonk model, and therefore it has subsequently been assumed that land converted is either not material enough to be included in the model, or that land is not converted to specifically grow these crops.

# Appendix XI References

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