PANDORA

Material Sourcing Natural Capital Assessment and Net benefit Analysis

S&P Dow Jones Indices
ESG Analysis

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CREDITS

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EXECUTIVE SUMMARY

PANDORA is an international jewellery company based in Denmark known for its customisable charm bracelets, designer rings and necklaces. As a part of its efforts to advance environmentally responsible sourcing practices, PANDORA commissioned Trucost to conduct a screening environmental cost assessment and net benefit analysis. The objective was to understand the environmental cost associated with important materials used in jewellery manufacturing and to assess the impact of sourcing materials from different geographies. The analysis focused on three material comparisons and a series of environmental Key Performance Indicators (KPI) as shown in Table 1.

Table 1 Material choices and their impacts selected for net benefit analysis

Material Choice	Life Cycle Coverage	Key Performance Indicators (KPI)
Mined Gold vs Recycled Gold	Cradle to pure gold ingots	• Greenhouse gases • Air Pollution • Land Occupation • Water Depletion • Land & water pollution
Mined Silver vs Recycled Silver	Cradle to pure silver ingots	
Diamond vs Cubic Zirconia	Cradle to unrefined stones (excluding cutting and polishing)	• Greenhouse gases • Air pollution

Trucost quantified the important environmental impacts associated with the production of each material and valued the resulting environmental costs in monetary terms. Trucost developed a methodology to account for impacts associated with each material, accounting for all upstream activities, drawing on published life cycle inventory data, corporate disclosures and other data sources.

While diamonds and cubic zirconia are not typically comparable, with one being a precious natural stone and the other being a simulant, PANDORA uses both materials to produce jewellery that appeals to its customers while also targeting an affordable price point. In this context, PANDORA sought to understand the environmental impacts of both types of stones used in its jewellery to help inform future strategies to grow the business while reducing its environmental impacts. The analysis of diamond and cubic zirconia was limited to energy use impacts across two KPIs (climate change and air pollution), due to a lack of robust data on the environmental impact of producing these materials. While recycled gold and silver can be recovered from high-value sources such as coins and jewellery items, this analysis focused on the recycling of gold and silver from waste electronics, which is likely to have a greater environmental impact due to the need for additional processing and refining. Table 2 presents the environmental cost per kilogram of each material assessed in this study.

Table 2 Comparison of the environmental cost of alternative material choices1

KPI	Mined Gold (€/Kg)	Recycled Gold (€/Kg)	Mined Silver (€/Kg)	Recycled Silver (€/Kg)	Diamond (€/Kg)	Cubic Zirconia (€/Kg)
Climate Change	€ 1,747	€ 94	€ 51	€ 1.62	€ 6,112	€ 0.10
Land Use	€ 417	€ 1	€ 7	€ 0.02	NA	NA
Air Pollutants	€ 1,636	€ 15	€ 51	€ 0.26	€ 312	€ 0.06
Water Consumption	€ 7	€ 0	€ 0	€ 0.00	NA	NA
Land and Water Pollutants	€ 93,879	€ 21	€ 788	€ 0.28	NA	NA
Total	**€97,686 (€28,538 ; €226,410)**	**€132 (€110 ; €169)**	**€897 (€289 ; €2,013)**	**€2.2 (€1.8 ; €3)**	**€6,424 (€6,203 ; €6,920)**	**€0.16 (€0.11 ; €0.22)**

The results of this analysis suggest that the environmental costs of producing cubic zirconia and recycled gold and silver are less than 1% of the cost of producing natural diamond and mined gold and silver, respectively. In the case of mined gold and silver, land and water pollutants represent the most important driver of environmental costs and are associated primarily with the disposal of mine tailings. In contrast for recycled gold and silver, greenhouse gases were found to be the most important environmental cost driver and are linked to energy use in the metal recovery and refining process. The environmental costs of producing cubic zirconia from mined zirconium are significantly lower than the production of natural mined diamonds, due primarily to the scarcity of natural diamonds and the energy intensity of diamond mining operations.

To understand the potential impact of alternative material sourcing locations on the overall environmental cost, Trucost undertook a limited sensitivity analysis focusing on key gold and silver producing countries for which robust data was available. This analysis revealed that the environmental costs of producing mined gold could vary by a factor of 14 times between the highest and lowest environmental cost countries assessed. For mined silver, environmental costs varied by a factor of four between the countries assessed.

This variation may be explained by the variable quality of gold and silver ore deposits in each location, which is linked to both the energy required and the quantity of waste produced per kilogram of production. Trucost also investigated the impact of utilizing renewable energy in natural diamond mines and in cubic zirconia manufacturing. The environmental cost of producing natural diamonds using renewable energy (approximately 85% hydroelectricity) was ten times less than those using a country average mix of primarily fossil energy sources. In the case of cubic zirconia, use of hydro and wind energy reduced the environmental cost considerably when compared to a country average mix of electricity sources.

[1] Figures in brackets represent the results of a sensitivity analysis in which the maximum and minimum environmental cost values were applied for all KPIs except climate change and land occupation. Further details of the sensitivity analysis are presented in the Sensitivity Analysis section.

The following key conclusions can be drawn from this screening assessment:

- The environmental costs of recycled gold and silver are likely to be lower than mined gold and silver, and increased sourcing of recycled gold and silver could contribute to reducing PANDORA's environmental footprint.
- The environmental cost of producing mined gold and silver may vary significantly between producing countries and mine sites. This suggests that PANDORA may be able to reduce its environmental footprint by strategically sourcing mined gold and silver from comparatively low environmental cost producing countries.
- While natural diamonds and cubic zirconia are not strictly comparable due to their diverse chemical composition, both materials are used by PANDORA to produce jewellery that that is appealing to PANDORA customers. In this context, it is likely that the increased use of cubic zirconia will significantly reduce the environmental cost per item of jewellery produced by PANDORA.
- The use of renewable energy in the production of all materials studied will reduce the overall environmental cost of production.

While these conclusions are supported by the screening analysis conducted by Trucost, further research based on data from PANDORA suppliers is recommended to confirm the results and inform future strategic decisions taken by PANDORA to reduce its environmental impact.

INTRODUCTION

PANDORA is an international jewellery company based in Denmark that manufactures silver, gold and precious stone jewellery. PANDORA commissioned Trucost to undertake a screening natural capital assessment and net benefit analysis of three alternative sourcing choices for key materials used in jewellery production. This study compared the costs to society of the environmental impact of producing the following material alternatives:

I. Mined Gold vs Recycled Gold

II. Mined Silver vs Recycled Silver

III. Natural Diamond vs Cubic Zirconia

This net benefit analysis study utilises industry average life cycle assessment data and other secondary data to represent materials used by PANDORA and does not constitute a complete life cycle assessment of PANDORA's processes that is consistent with the relevant ISO standards (ISO 14040 and ISO 14044). This screening assessment is therefore not as robust as a full life cycle assessment, but instead gives a useful snapshot of the natural capital impacts associated with each material. Furthermore, the underlying data is modelled and includes some simplifying assumptions, so it is therefore not suitable for a detailed comparison. Screening studies can be a useful first step to understand the material impacts and prioritise the focus of future analyses.

OBJECTIVE

The objective of this project was to:

1. Estimate the environmental costs associated with the production of key materials used by PANDORA in jewellery manufacture.
2. Investigate the potential environmental costs and net benefits of alternative material sourcing strategies, such as sourcing from different geographies and increasing the use of renewable energy in material production.

METHODOLOGY

Scope of Analysis

Key Performance Indicators

The environmental impacts were quantified and valued for each material based on the key performance indicators given in Table 3. For recycled and mined gold and silver, the five most material environmental impacts were considered, drawing on previously published life cycle assessments from the Ecoinvent database (Wernet et al, 2016).

A study from the University of Vermont describes the paucity of life cycle assessment data on the environmental impacts of diamond production (Ali, 2011). As such, the natural capital assessment presented in this report is limited to the indicators for which adequate disclosed data from diamond producers was available. This was limited to greenhouse gas emissions and air pollution associated with energy use in diamond production only. While more extensive data was available for cubic zirconia, the assessment was limited to these two indicators for comparability with natural diamond.

Table 3 Impact metric selected for precious metal (gold & silver) and precious stone (cubic zirconia & diamond)

Impact Metric	Description	KPI	Gold & Silver	Diamond & Cubic Zirconia
Climate Change	Greenhouse gas that contributes to climate change expressed as CO_2e (Global Value)	CO_2 equivalent (kg)	✓	✓
Air Pollution	Classical air pollutants (region specific)	Ammonia (kg)	✓	✓
		Nitrogen oxides (kg)		
		Sulphur dioxide (kg)		
		Particulate matter (kg PM_{10} eq)		
		Non-methane volatile Organic compounds (kg)		
Land and Water Pollution	Human and ecosystem toxic metals; organic and inorganic chemicals emitted to land and water (region specific)	Freshwater eutrophication (kg P eq)	✓	×
		Terrestrial eco-toxicity (kg 1,4-DB eq)		
		Freshwater eco-toxicity (kg 1,4-DB eq)		
		Marine eco-toxicity (kg 1,4-DB eq)		
		Human toxicity (kg 1,4-DB eq)		
Land Occupation	Occupation of land (region specific)	Natural land (m^2)	✓	×
		Agricultural land (m^2)		
		Urban land (m^2)		
Water Depletion	Consumption of freshwater (region specific)	Water depletion (m^3)	✓	×

Materials Selected for Comparison

This section describes the material alternatives considered for this study and scope of the processes involved in their manufacture.

Gold and Silver Mining vs Recovery from Electronics Waste

The scope of analysis for gold and silver production extends from cradle (extraction of raw materials) to the production of refined gold and silver ready for use in jewellery manufacturing, incorporating all resources consumed and emissions created directly and indirectly in this process. In the case of recycled gold and silver, the scope of analysis extends from the arrival of waste electronics scrap at the recycling facility through the production of refined gold and silver ready for use in jewellery manufacturing. Recycled gold and silver can also be recovered from high-value sources such as coins and jewellery items. However, this was not considered in this study in order to follow a more conservative approach, representing a higher-end estimate of the environmental cost of gold and silver recycling. The scope of the analysis is shown in Figure 1 and key exclusions are described in Table 4, and expanded upon in the Key Assumptions section.

Figure 1 Recycled and mined precious metal (gold & silver) production flow diagram

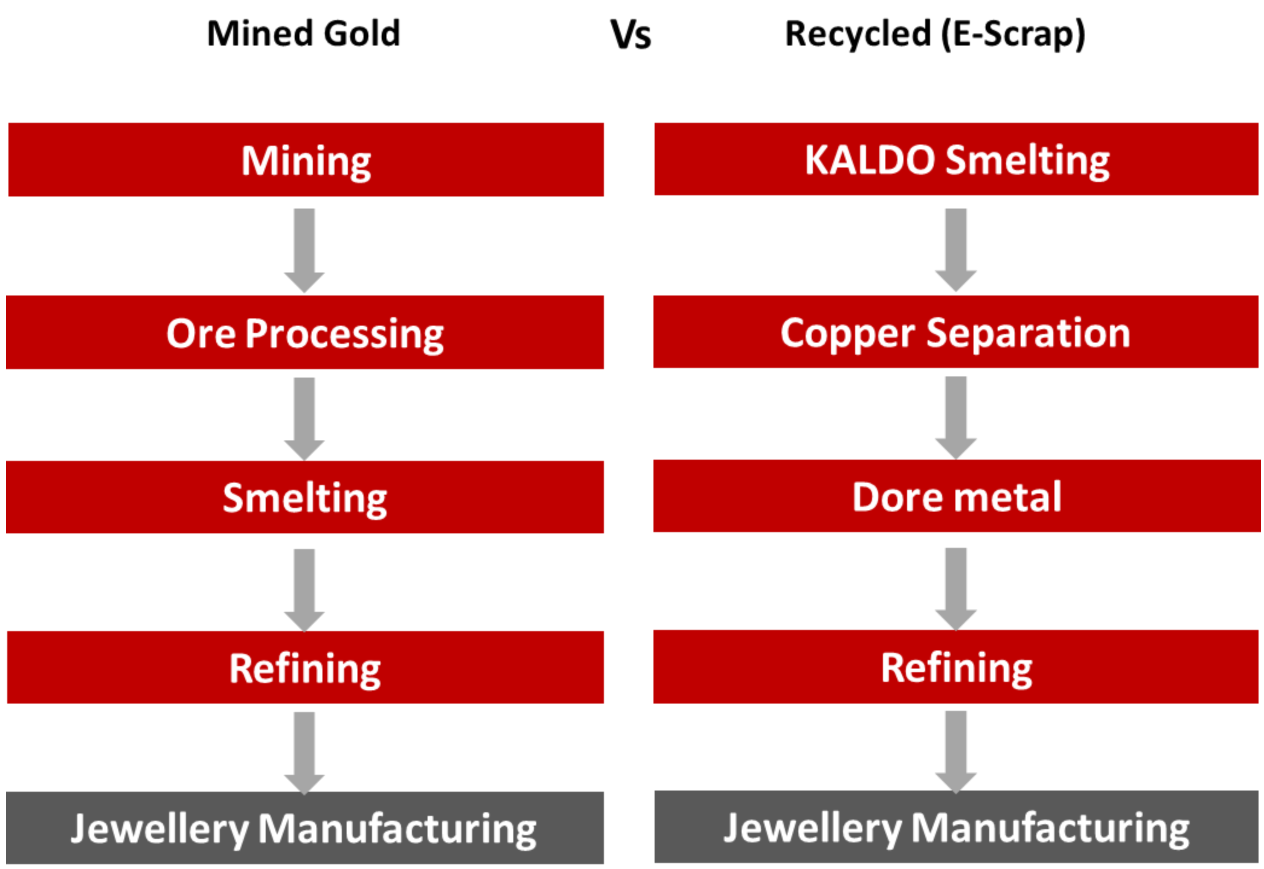


Table 4 Precious metal net benefit analysis – scope exclusions

Excluded Activity	Rationale
Jewellery Manufacturing	This stage was expected to be similar for both mined and recycled gold and silver, and thus in the absence of robust data, it was decided that this stage should be excluded. Analysis of this stage could be undertaken by PANDORA with data specific to jewellery manufacturing processes used by PANDORA.
High Value Recycling	LCA data on gold and silver recycling from high value sources was not available. Moreover, impacts from high value gold and silver recycling were expected to create less environmental impact. Trucost elected to take a conservative approach and hence focused on e-waste metal recycling as a higher-end estimate of the environmental cost.

Natural Diamond vs Cubic Zirconia

The scope of analysis for diamond and cubic zirconia extended from the cradle to the production of unrefined diamonds or cubic zirconia, prior to cut and polishing processes. The scope of the analysis is shown in Figure 2, and key exclusions are described in Table 5 and expanded upon in the Key Assumptions section.

Figure 2 Diamond and cubic zirconia production flow diagram

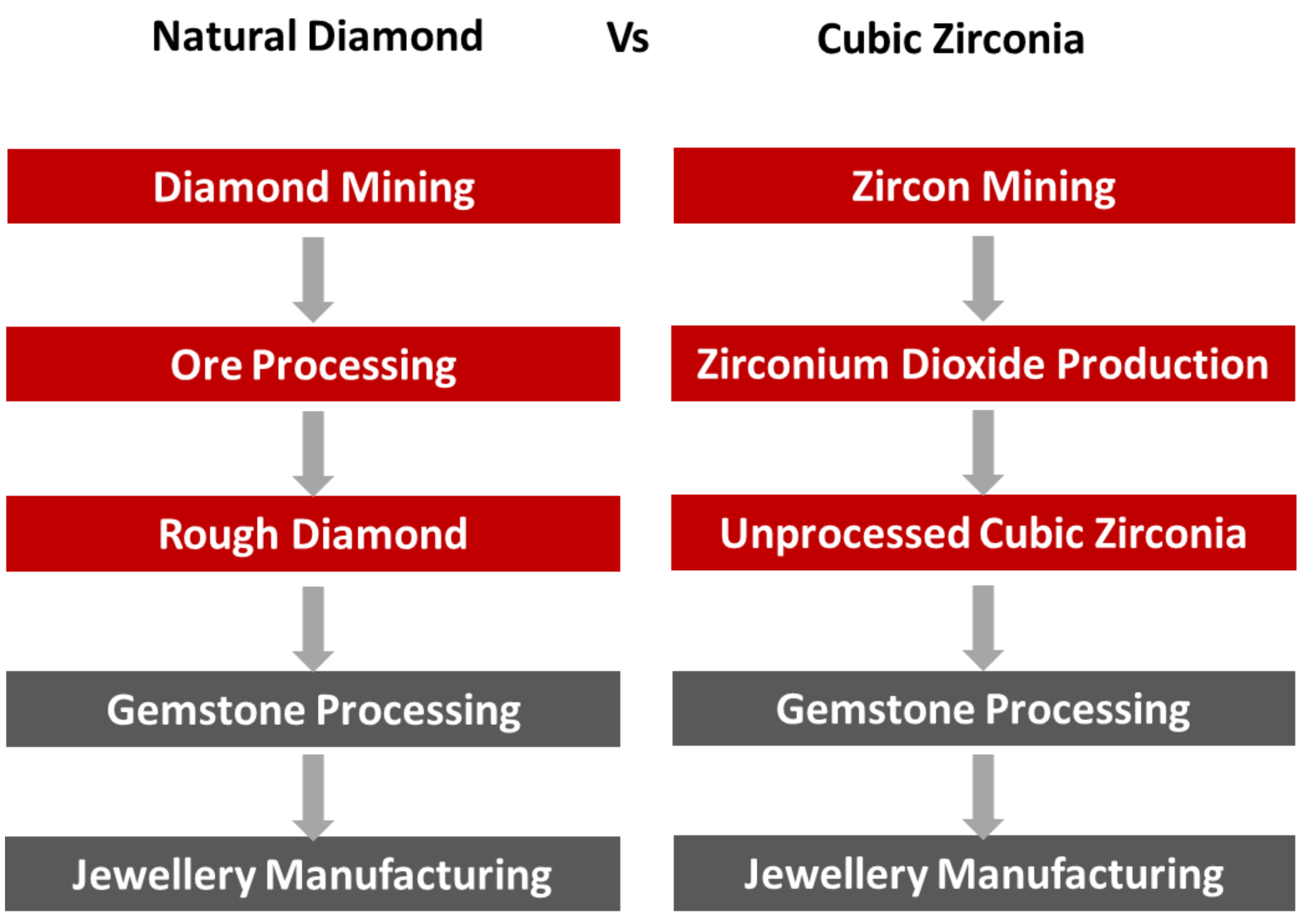


Table 5 Precious stone net benefit analysis – scope exclusions

Excluded Activity	Rationale
Gem Stone Processing and Jewellery Manufacturing	Inadequate data was available for this project on gemstone processing and jewellery manufacturing. As such, the authors chose to limit the scope to the gemstone production phases of the life cycle.
Non-Energy-Related Environmental Impacts	The objective of this study was to compare the environmental impacts of natural diamond with that of cubic zirconia. Life cycle assessment data on natural diamond is not currently available, and thus the analysis was limited to those KPIs from which reliable data could be sourced. Reliable disclosed data from diamond producers was limited to energy use and thus this determined the scope of the environmental assessment. To enable a comparison of natural diamond and cubic zirconia, the scope of KPIs was kept consistent for both materials.
Other Environmental Impacts of Energy Use	GHG and air pollutants are the most material impacts of fossil energy consumption and thus formed the focus of the analysis.

Functional Unit

The following functional units were used for this net benefit analysis:

- Gold (mined and recycled): One kilogram (kg) of pure gold.
- Silver (mined and recycled): One kilogram (kg) of pure silver.
- Cubic Zirconia: One kilogram (kg) of unpolished cubic zirconia.
- Diamond: One kilogram (kg) of unpolished diamond.

Geographic Coverage

To understand the environmental cost impact of sourcing materials from different regions, a series of comparisons were made as described in table 6. The selection of comparator geographies was dictated by the limited availability of reliable data. Country-specific environmental valuation coefficients were used to monetise environmental impacts occurring in each location. As such, the results reflect differences in both the environmental impacts of production practices and the economic costs of those impacts, given the specific practices and characteristics in each geography.

Table 6 Details of materials selected and geography of impact

Material	Geography of Impact Data	Region-Specific Valuation Factor
Mined Gold	Global Average	Global Average
	Australia	Australia
	Canada	Canada
Recycled Gold	Sweden	Global Average
Mined Silver	Global Average	Global Average
	Canada	Canada
	Papua New Guinea	Papua New Guinea
Recycled Silver	Sweden	Global Average
Diamond	Argyle Mine (Australia)	Australia
	Diavik Mine (Canada)	Canada
	Debeers Global	Canada, South Africa, Namibia & Botswana
Cubic Zirconia	Global Average	Global Average

Data Collection Procedures

Trucost used secondary data from existing databases and scientific and technical literature. The following key sources were used:

- Corporate-disclosed data on energy consumption in diamond production from Debeers (all mines); Rio Tinto (Argyle mine, Australia), and Diavik mine (Canada).
- Life cycle inventory data for gold production, silver production and the recycling of gold and silver from electronics scrap, sourced from the Ecoinvent database v3.3 (Wernet et al, 2016) and Ecoinvent v2.2 database (Frischknecht et al, 2005).
- Other published literature where relevant.

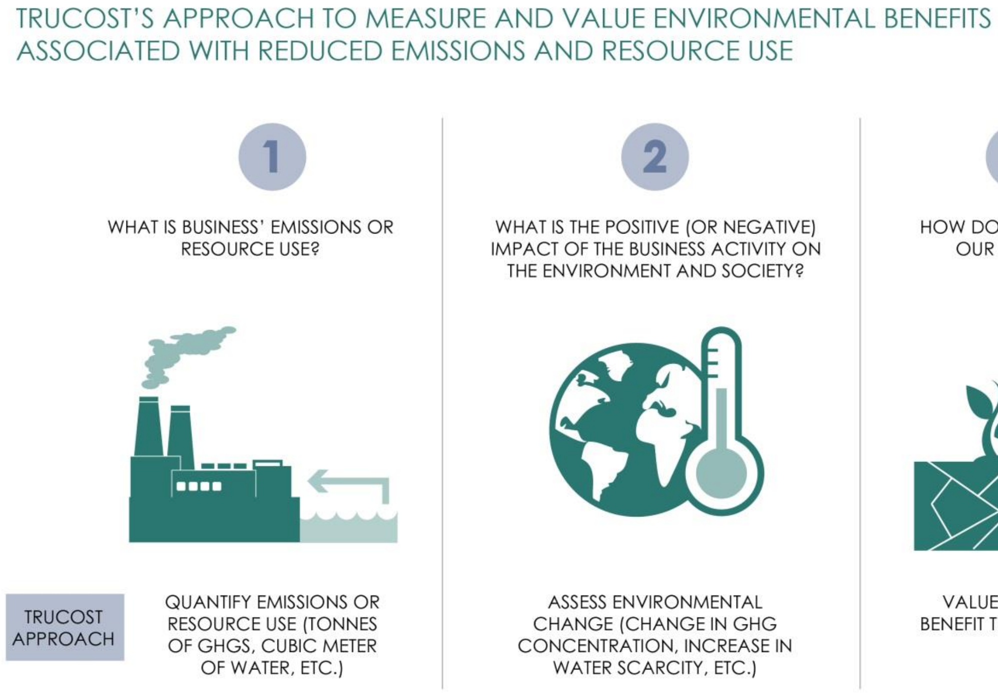
Analysis Framework

This section describes the high-level approach adopted by Trucost to model and value the environmental costs of the material alternatives. Figure 3 illustrates the valuation framework used in this analysis, which comprises three key stages:

1. Quantifying the emissions and resource use associated with production of materials selected for this study.
2. Quantifying the impacts or environmental changes linked to emissions and resource use.
3. Valuing the costs and benefits of these changes to society.

Each of these stages is described below.

Figure 3 Trucost's approach to measuring and valuing environmental costs and benefits associated with emissions and resource use



Step 1: Quantifying Emissions and Resource Use

The first step is to quantify the emissions and resource use associated with all of the activities that fall within the scope of the study. This includes direct emissions by the processing facilities or logistics vehicles, and the cradle-to-gate emissions and resources used to produce the inputs to these activities (such as electricity or raw materials). Emissions and resource use can be quantified via primary and secondary data collection. Primary data collection refers to the use of actual, measured data collected on site at a facility. Secondary data can include LCA studies, academic research and input-output modelling, all of which can be used to represent activities occurring at the facility. The choice of methodology is primarily driven by the aim of the study and data availability.

This study relies primarily on secondary data on the inputs to the various stages of the gold, silver, diamond and cubic zirconia production processes from the following sources:

- Published literature in scientific journals, reports from authoritative organizations and external databases. In particular, disclosures by Debeers mines (global, 2009); Rio Tinto (Argyle mine, Australia, 2014) and Diavik Mine (Canada, 2014).
- Life cycle inventory databases, including primarily Ecoinvent v3.3 database (Wernet et al, 2016) and Ecoinvent v2.2 database (Frischknecht et al, 2005), applying the ReCiPe life cycle impact assessment methodology (Goedkoop et al, 2009).

The following hierarchy was applied for the selection of data sources for use in this study (in descending order of preference):

1. Secondary data from Life Cycle Analysis study with the same, or a comparable, scope and boundary to this study.
2. Secondary data collected from research journals with the same, or a comparable, scope and boundary to this study.
3. Secondary data collected from company disclosures with the same, or a comparable, scope and boundary to this study.
4. Global average or regional datasets.

The outcome of Step 1 is an inventory of all resources used and emissions released by the activities included within the scope of the study. This data is then organized in terms of a series of environmental Key Performance Indicators (KPIs) that represent the most important consequences of the emissions and resource use. The following KPIs were considered for this study:

- Climate change: CO_2 equivalent (kg)
- Ammonia (kg NH_3)
- Nitrogen oxides (kg NO_x)
- Sulphur dioxide (kg SO_2)
- Particulate matter formation (kg PM_{10} eq)
- Non-methane volatile organic compounds (kg NMVOC)
- Freshwater eutrophication (kg P eq)
- Terrestrial eco-toxicity (kg 1,4-DB eq)
- Freshwater eco-toxicity (kg 1,4-DB eq)
- Marine eco-toxicity (kg 1,4-DB eq)
- Human toxicity (kg 1,4-DB eq)
- Natural land transformation (m^2)
- Agricultural land occupation (m^2)
- Urban land occupation(m^2)
- Water depletion (m^3)

Step 2: Understanding and Quantifying the Impacts

The second step is to understand and quantify the consequences of emissions and resource use in terms of their impact on a specific end-point, such as humans or ecosystems. Each impact can have several end-points. For example, water depletion (a negative impact) can affect society (end point 1) through lack of drinking water and decreased food supply, and can affect the environment (end point 2) through decreased water availability to sustain plants and animals.

Impacts are quantified in biophysical terms as "valued attributes". Examples of valued attributes include changes in life expectancy or changes in species richness (a measure of biodiversity) due to the emission of pollutants. Biophysical models are used to estimate changes in valued attributes, based on a thorough literature review, and adapted to reflect local conditions. For example, the extent to which water pollution affects society through decreased life expectancy depends on local social and environmental factors, such as access to drinking water and pollutant dispersion based on hydrological patterns.

The biophysical modelling approaches applied to quantify these impacts are described in the appendix.

Step 3: Valuing the Impacts in Monetary Terms

The third step involves the conversion of impacts measured in biophysical terms into monetary terms that reflect the costs and benefits to specific end-points affected by the change in valued attribute. The output of this step is a valuation coefficient that reflects the cost or benefit to natural and social capital associated with specific practices.

One key consideration here is that regardless of the end point (see Step 2), value is in the eye of the beholder. Costs and benefits are human-centric, even in cases where the end-point is the environment. For example, the costs and benefits of a change in biodiversity are valued based on the services that biodiversity provides to society.

Several techniques exist to quantify a change in valued attribute and calculate the costs and benefits in monetary terms of a specific action. Techniques span from observing behaviour in already-existing markets as a proxy (for example, how much is spent on aquatic recreational activities) to creating artificial markets by asking a population for their willingness to pay for the existence of wildlife habitat. Table 7 summarizes the different techniques that can be used.

Table 7 Examples of monetary valuation techniques

Valuation Technique	Description
Abatement Cost	The cost of removing a 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 (King, Mazzotta & Markowitz, 2000).
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 (King, Mazzotta & Markowitz, 2000).
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 affect 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 (King, Mazzotta & Markowitz, 2000).
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.

All of the approaches above are equally valid, and Trucost chose valuation techniques based on data availability and suitability. Trucost has been consistent in its application of valuation techniques across all end points. For example, the change in life expectancy has been valued the same, regardless of whether it is caused by malnutrition due to water depletion or the ingestion of contaminated food due to water pollutants. **Value is highly contingent on local conditions**. In order to estimate costs or benefits at a location where valuation data does not exist and it is not possible to readily obtain data within the scope of the project, Trucost relies on the value transfer method. In this method, the economic value of ecosystem services or impacts is estimated by transferring available information from completed studies to another location or context by adjusting for certain variables. Examples of these variables include population density, income levels, average size of ecosystems etc.

Best practice guidelines for value transfers have been set out by the United Nations Environment Program in its Guidance Manual on Value Transfer Methods for Ecosystem Services (Brander, 2004). When possible, Trucost follows these guidelines in all of its value transfer calculations. In some instances, studies from different ecosystems and geographies have had to be applied due to data availability and data quality.

Further detail on Trucost's environmental valuation methods is provided in the Appendix.

In this analysis, all impacts have been valued based on location specific valuation coefficients as described in Table 6.

RESULTS AND DISCUSSION

The following section describes the results of the analysis and highlights key conclusions and insights of relevance to PANDORA.

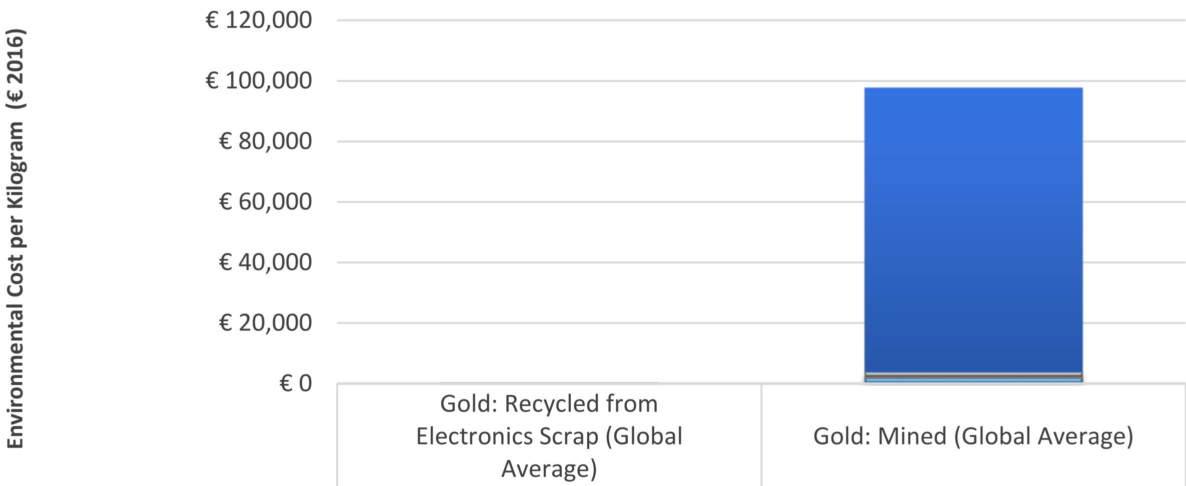
Gold Mined vs Recycled Gold

The environmental cost comparison between mined and recycled gold is shown in Figure 4. The environmental cost per kilogram of mined gold is estimated at €97,686[2] due to high costs associated with land and water pollution, greenhouse gases and air pollutant emissions. In comparison, the environmental cost of recycled gold is 740 times less, at €132 per kilogram. Over 96% of the environmental cost of mined gold production is associated with land and water pollution. This high cost is primarily due to the disposal of sulphide tailings from the mine, which contain a range of chemicals and metals that are toxic to human health. A study conducted in Oman found that water wells and surface water bodies near gold mines contained heavy metals at higher concentrations than recommended under World Health Organization safety standards (Abdul-Wahab & Marikar, 2012). While the degree to which heavy metals are leached from mine tailings may vary between countries due to different practices and regulations, mine tailings are likely to represent an important potential source of toxic emissions to land and water. In the case of recycled gold, the environmental cost is primarily driven by greenhouse gases associated with energy use in the mechanical separation of the electronics waste and the melting of recovered metals in a furnace.

Figure 4 compares the environmental cost of mined and recycled gold across each individual KPI. This chart reveals the major KPIs contributing to the total environmental cost and the differences between mined and recycled gold.

[2] Note: All the results were calculated by Trucost in U.S. dollars, which were later converted to EUR using the 2016 average exchange rate of €0.904 per USD.

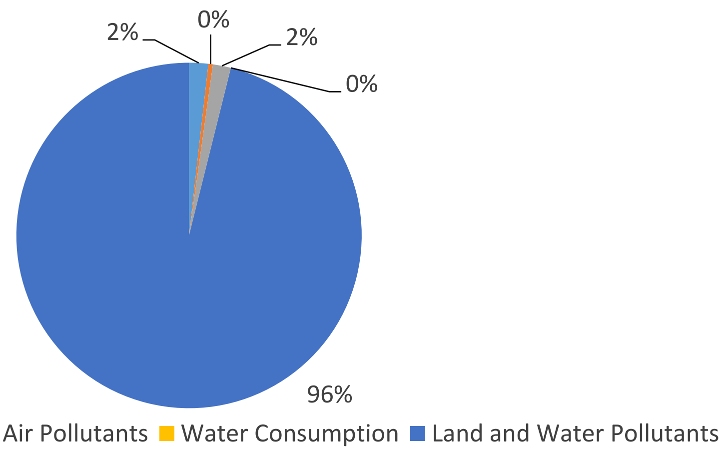
Figure 4 Environmental cost comparison between mined and recycled gold



	Gold: Recycled from Electronics Scrap (Global Average)	Gold: Mined (Global Average)
Land and Water Pollutants	€ 21	€ 93,879
Water Consumption	€ 0.2	€ 7
Air Pollutants	€ 15	€ 1,636
Land Use	€ 1	€ 417
Climate Change	€ 94	€ 1,747

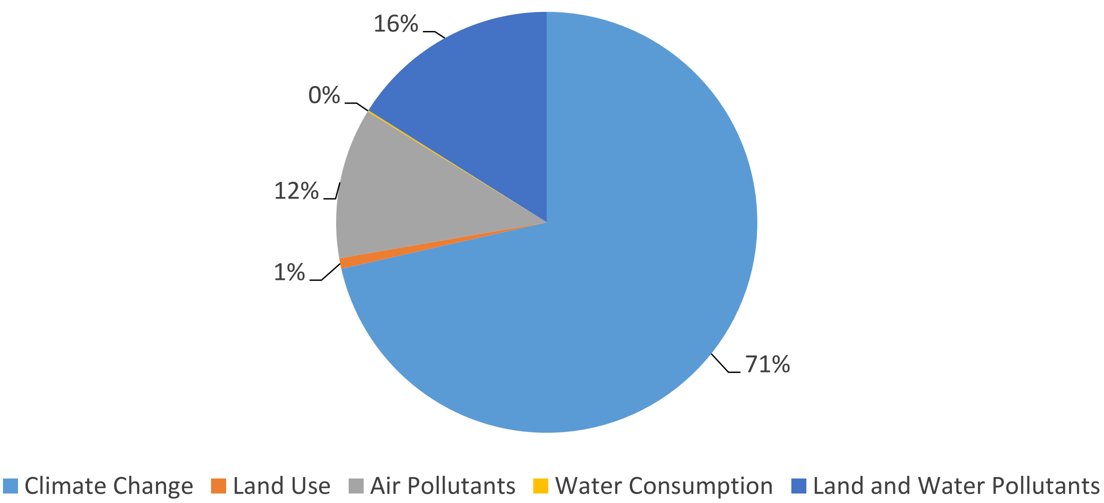
As shown in Figure 5, land and water pollution associated with sulphide tailings dominate the environmental cost of mined gold production, at over 96% of the total cost.

Figure 5 Mined gold: Contribution of key KPIs to the total environmental cost



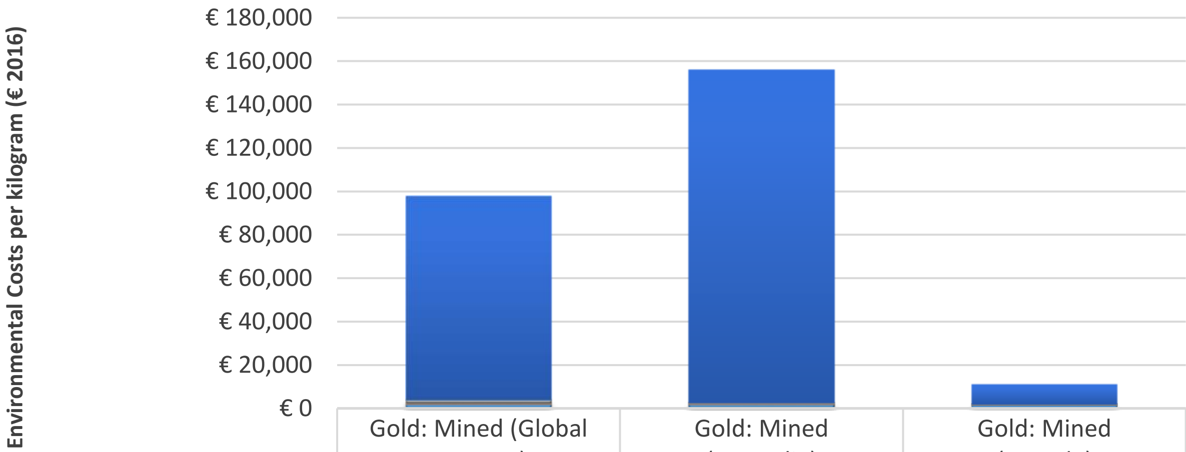
Greenhouse gas emissions dominate the environmental cost of recycled gold at 71%, or €94.5 per kilogram of gold. Air pollution emissions associated primarily with energy used in the refining process and land and water pollution associated with the refining chemicals contribute to the environmental cost of recycled gold.

Figure 6 Recycled gold - Contribution of key KPIs to the total environmental cost



To understand the role of sourcing location choices in the environmental cost of gold, a scenario analysis was performed comparing the impacts of mined gold production in a comparatively high (Australia) and low (Canada) impact gold-producing country. The differences in environmental impact per tonne of production may be due to a range of factors, including ore quality, mining practices and technology and mining regulatory standards. Data in the Ecoinvent database was limited to just a few gold-producing countries and is thus not representative of the environmental impacts of gold production in all countries, but does highlight the variability in environmental performance across geographies.

Figure 7 Gold mining impacts: Geography-specific material sourcing analysis



	Gold: Mined (Global Average)	Gold: Mined (Australia)	Gold: Mined (Canada)
Land and Water Pollutants	€ 93,879	€ 153,305	€ 9,149
Water Consumption	€ 7	€ 7	€ 2
Air Pollutants	€ 1,636	€ 29	€ 11
Land Use	€ 417	€ 556	€ 438
Climate Change	€ 1,747	€ 1,883	€ 1,473

From Figure 7, it is evident that the region from which the mined gold is sourced has an impact on total environmental cost. Environmental costs vary widely between mine locations, with mined gold from Canada creating 14 times less environmental costs than gold from Australia. This difference may be due to the superior ore grade of mines in Canada—the Canadian mine studied produces 94% less sulphide tailings per kilogram of gold—but also due to the different values of environmental impacts in each country. In the case of Australia, it was observed that the gold grade (grams of gold per tonne mined material (g/t)) has been gradually declining. Gold grade fell from 50 g/t during the 1850s to around 1 g/t during 2000; this means that for every tonne of ore milled, a large quantity of waste will be generated (Mudd, 2007). There may also be differences in the regulation of mining operations and emissions between countries however a detailed study of mining regulations and mining practices was beyond the scope of this project. This could be considered in a future study.

Silver Mined vs Recycled Silver

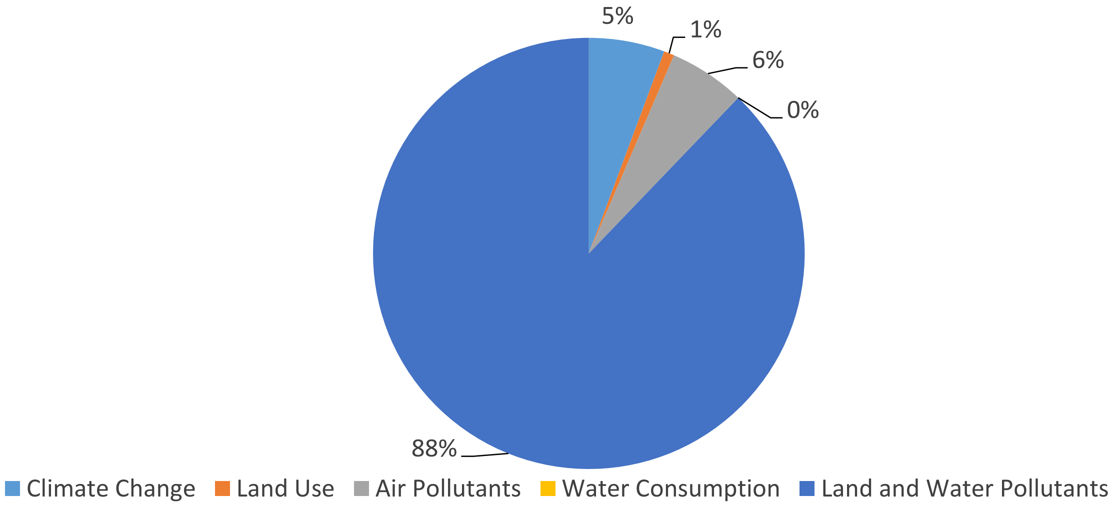
The environmental cost comparison between mined and recycled silver is shown in Figure 9. The environmental cost per kilogram of mined silver is estimated at €897, due to high costs associated with land and water pollution, greenhouse gases and air pollutant emissions. In comparison, the environmental costs of recycled silver are 410 times less, at €2 per kilogram. Over 88% of the environmental cost of mined silver production is associated with land and water pollution. Land and water pollution associated with sulphide tailings from the mine are the most material environmental cost of mined silver production, accounting for 88% of the total environmental cost. This is because of the sulphide tailings, or mine waste disposal, which results in high human toxicity, one of the KPIs selected for our study. In the case of recycled silver, environmental cost is mainly driven by greenhouse gases from energy use in separating and refining the recycled silver.

Figure 8 Environmental cost comparison: Mined and recycled silver

	Silver: Recycled from Electronics Scrap (Global Average)	Silver: Mined (Global Average)
Land and Water Pollutants	€ 0.3	€ 788
Water Consumption	€ 0.003	€ 0.09
Air Pollutants	€ 0.3	€ 51
Land Use	€ 0.02	€ 7
Climate Change	€ 2	€ 51

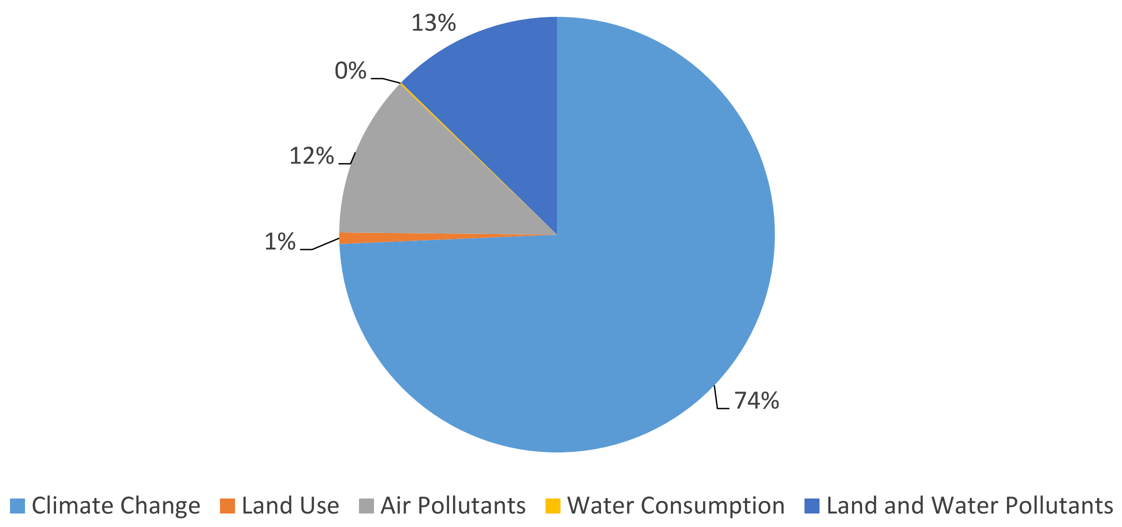
The contribution of each KPI to the total environmental cost of mined silver can be seen in Figure 10. The major contributor is land and water pollutants, followed by greenhouse gases and air pollution. The contributions from land use and water consumption are negligible.

Figure 9 Mined silver- KPI contribution to total environmental cost



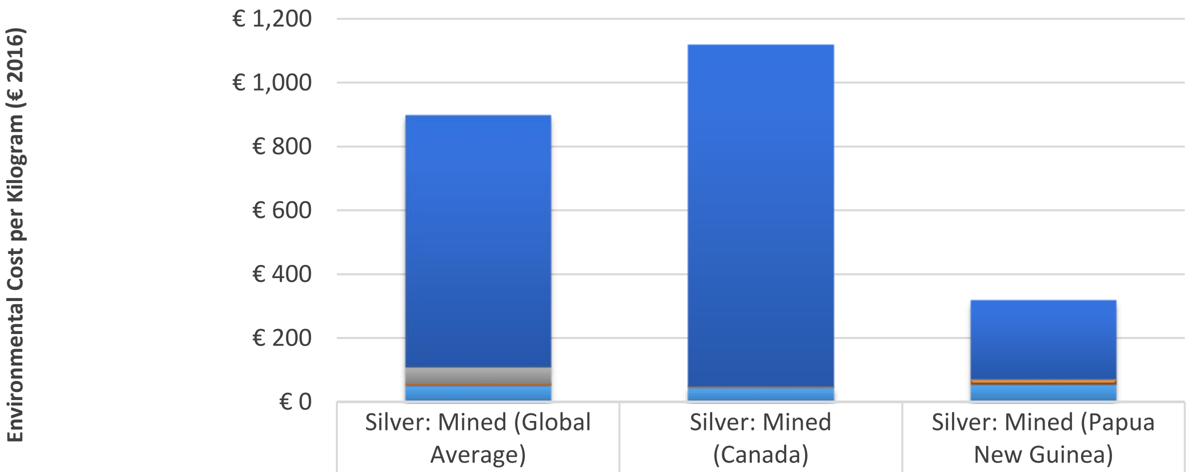
Similarly, the contribution of each KPI to the total environmental cost for recycled silver can be seen in Figure 11. Here, the major impact comes from greenhouse gases, followed by land and water pollution and air pollution.

Figure 10 Recycled silver- KPI contribution to total environmental cost



To understand the role of sourcing location choices in the environmental cost of silver, a scenario analysis was performed comparing the impacts of mined silver production in a comparatively high (Canada) and low (Papua New Guinea) impact silver-producing country. Data in the Ecoinvent database was limited to just a few gold-producing countries and is thus not representative of the environmental impacts of gold production in all countries, but does highlight the variability in environmental performance across geographies.

Figure 11 Silver mining impacts: Geography-specific material sourcing analysis



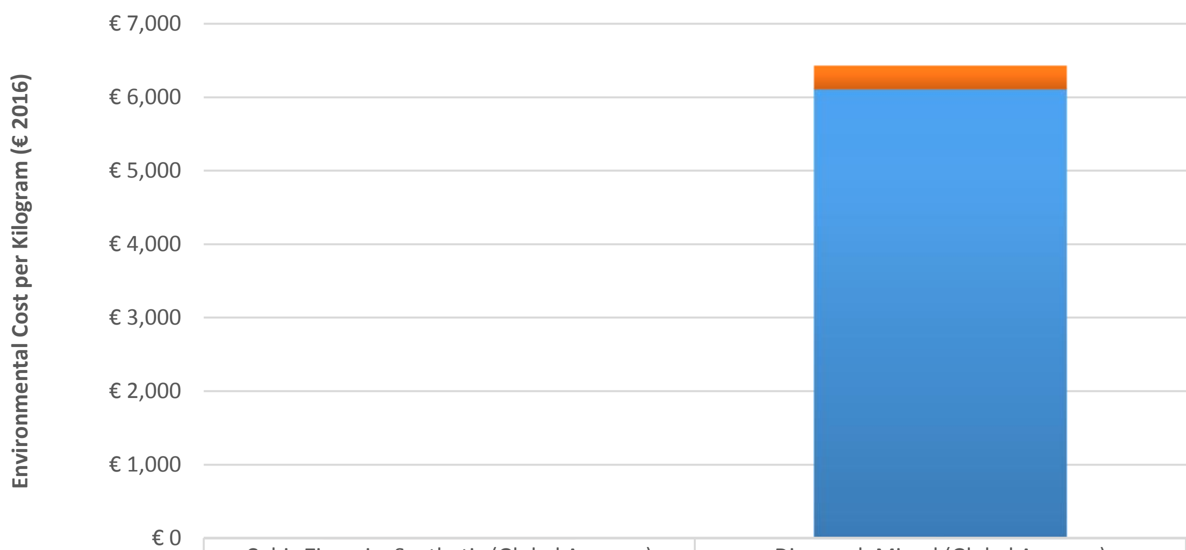
	Silver: Mined (Global Average)	Silver: Mined (Canada)	Silver: Mined (Papua New Guinea)
Land and Water Pollutants	€ 788	€ 1,070	€ 245
Water Consumption	€ 0.09	€ 0.08	€ 0.13
Air Pollutants	€ 51	€ 1	€ 3
Land Use	€ 7	€ 4	€ 14
Climate Change	€ 51	€ 44	€ 54

From the results, it is evident that the region from which the mined silver is sourced has an impact on total environmental cost. Environmental costs vary widely between mine locations, with mined silver from Papua New Guinea creating 3.5 times less environmental costs than silver from Canada. This difference may be explained by the smaller quantities of waste produced at the mine studied in Papua New Guinea, which produces 59% less sulphide tailings per kilogram of silver compared to mines in Canada.

Natural Diamond vs Cubic Zirconia

The environmental cost comparison between diamond and cubic zirconia is depicted in Figure 13. The environmental cost of energy use per kilogram of unpolished diamond is estimated at €6,424, due to high costs associated with greenhouse gases and air pollutant emissions. In comparison, the environmental cost of unpolished cubic zirconia is just 0.001% of that of mined diamond, at €0.16 per kilogram, due to the vastly smaller quantity of energy required to produce cubic zirconia. Diamond mining is energy intensive because of the physical nature and density of its source material. According to a report by the United States Geological Survey (USGS), the primary sources of diamonds are Kimberlite and Lamproite, which are volcanic rock forms (Chirico & Malpeli, 2014). In contrast, zircon is a by-product of mining and processing heavy mineral sands and it is processed to produce gemstones (Hedrick, 2001). Hence, it is simpler to extract zircon compared to diamond, which involves energy-intensive methods such as rock blasting and drilling. Another important factor to consider is the difference in ore grade between diamond and zircon. The Zircon Industry Association suggests that zircon is mined from mineral sand deposits, and heavy mineral content of sand deposits range from 0.5% to >20%, out of which zircon content varies from 1% to 50%, based on deposit (Zircon_Industry_Association, 2016). In the case of diamonds, the ore grade decreases with increasing diamond size, ranging from 10 to 70 carats per hundred tons (Oosterveld, 2016).

Figure 12 Environmental cost comparison and KPI contribution: Diamond and cubic zirconia

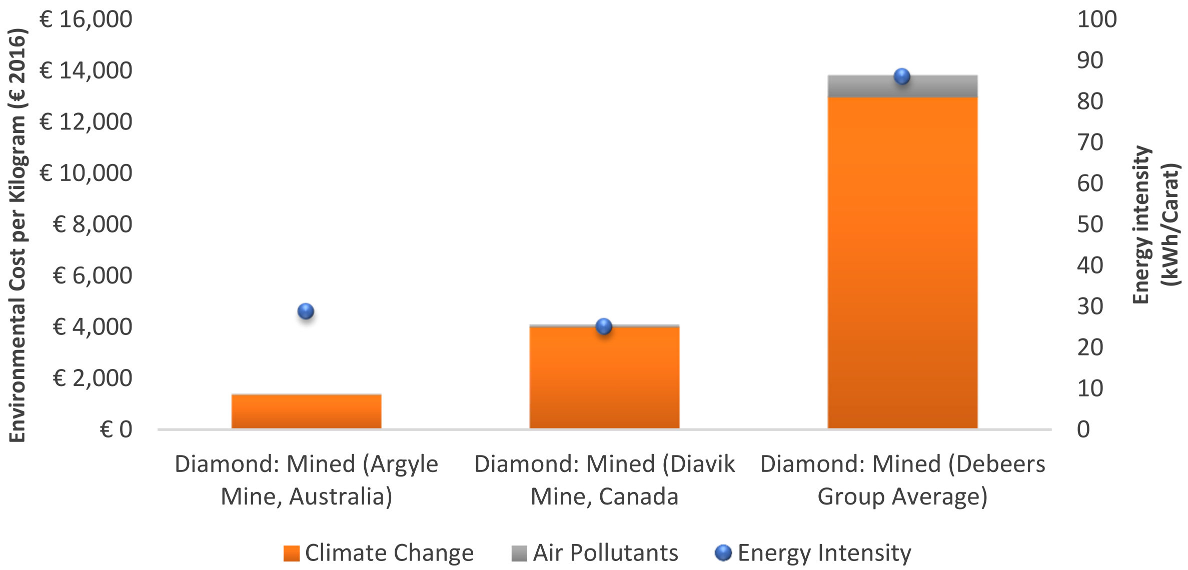


	Cubic Zirconia: Synthetic (Global Average)	Diamond: Mined (Global Average)
Air Pollutants	€ 0.06	€ 312
Climate Change	€ 0.10	€ 6,112

The contribution of each KPI to the total environmental cost of diamond and cubic zirconia is shown in Figure 13. The major contributor is GHG for both the materials, followed by air pollution.

To understand the importance of the diamond sourcing location to the total environmental costs, corporate energy use disclosures were obtained from a literature review for three large diamond producers. The Argyle mine in Australia exhibits a lower estimated environmental cost (€ 1,373/kg) when compared to the Diavik mine in Canada and global mines operated by Debeers (€ 4,093/kg and € 13,807/kg, respectively). This difference is due to the energy intensity of each mine (or group of mines) and the mix of energy sources used at each mine. The respective energy intensity of the mines and their environmental cost are depicted in Figure 14.

Figure 13 Diamond production energy intensity and associated environmental cost for selected mines



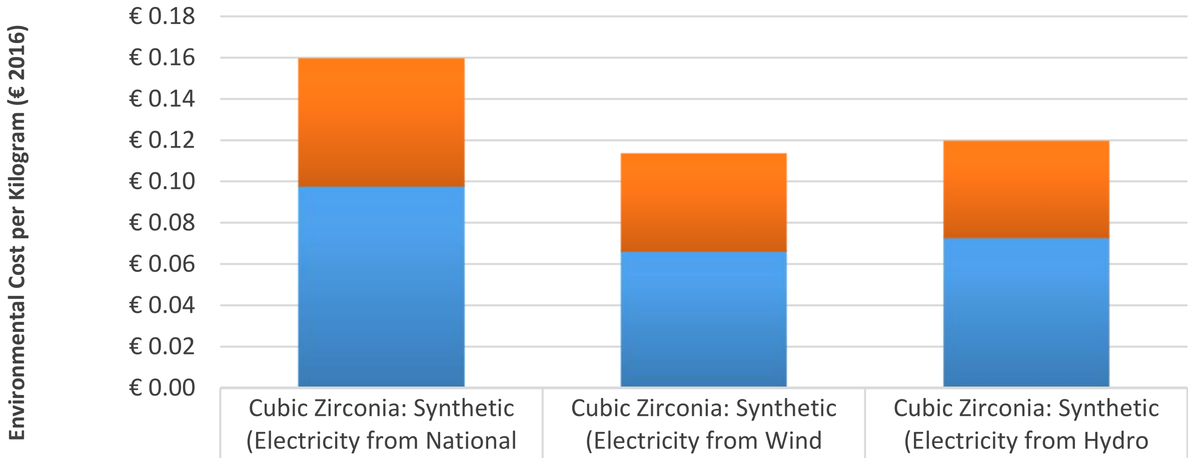
The environmental costs per carat of diamond vary widely between mines, with the cost of diamonds from the Argyle mine in Australia creating three times less environmental cost than that of the Diavik mine in Canada. This is due to the use of hydroelectricity to supply approximately 85% of the energy needs of the Argyle mine. In contrast, the Diavik mine sources approximately 11% of its energy from wind power, while Debeers does not report any renewable energy use at its mines. The energy mix composition for each mine is shown in Table 8 below.

Table 8 Energy mix composition of diamond mines considered for the study (Debeers, 2010; RioTinto, 2015; RioTinto, 2014)

Mine	Grid Electricity	Diesel	Wind	Hydro
Rio Tinto, Argyle Mine (Australia)	0%	15%	0%	85%
Rio Tinto, Diavik Mine (Canada)	0%	89%	11%	0%
Debeers (Group Average)	39%	61%	0%	0%

To understand the importance of sources of energy used in production of cubic zirconia, three scenarios were considered, with electricity used in the manufacturing process sourced from the local electricity grid, hydropower or wind power. The environmental cost was found to be lowest for wind energy, slightly higher for hydropower and greatest for the local electricity grid.

Figure 14 Environmental cost of cubic zirconia production using grid electricity, wind energy and hydro energy



	Cubic Zirconia: Synthetic (Electricity from National Grid)	Cubic Zirconia: Synthetic (Electricity from Wind Power)	Cubic Zirconia: Synthetic (Electricity from Hydro Power)
Air Pollutants	€ 0.06	€ 0.047	€ 0.047
Climate Change	€ 0.10	€ 0.066	€ 0.073

KEY CONCLUSIONS AND RECOMMENDATIONS

The following key conclusions can be drawn from this screening assessment:

- The environmental costs of recycled gold and silver are likely to be lower than mined gold and silver, and increased sourcing of recycled materials could contribute to reducing PANDORA's environmental footprint.
- The environmental cost of producing mined gold and silver may vary significantly between producing countries. This suggests that PANDORA may be able to reduce its environmental footprint by strategically sourcing mined gold and silver from comparatively low-environmental-cost countries.
- While natural diamonds and cubic zirconia are not strictly comparable due to their diverse chemical composition, both materials are used by PANDORA to produce jewellery that that is appealing to PANDORA customers. In this context, it is likely that the increased use of cubic zirconia will significantly reduce the cost per item of jewellery produced by PANDORA.
- The use of renewable energy in the production of all materials studied will reduce the overall environmental cost of production.

While these conclusions are supported by the screening analysis conducted by Trucost, further research based on data from PANDORA suppliers is recommended to confirm the results and inform future strategic actions taken by PANDORA to reduce its environmental impact. As such, Trucost recommends that PANDORA consider further investigation in the following areas:

- Engage with major suppliers of gold and silver to better understand the mix of recycled and mined material supplied to PANDORA, the locations from which the metals are sourced, and any programs or initiatives implemented by suppliers to manage and reduce their environmental cost.
- Expand the analysis of diamond and cubic zirconia to cover all material environmental KPIs through strategic data collection from key suppliers.
- Extend the environmental cost analysis to cover the full cradle to gate supply chain to gain a better understanding of the contribution of PANDORA's own jewellery manufacturing activities to the total environmental cost of each jewellery item.

Expand the environmental cost analysis to include other materials used in the manufacture of jewellery, such as copper, and consideration of dependency risks associated with competition for scarce natural resources in the future.

SENSITIVITY ANALYSIS

A limited sensitivity analysis was conducted to apply the maximum and minimum Trucost natural capital cost valuations to all KPIs except climate change and land use. The maximum and minimum values were calculated by Trucost by selecting the highest and lowest values respectively for key parameters (such as water scarcity) used in the valuation methodologies described in the appendix. Thus the sensitivity analysis illustrates the variability in the environmental cost of environmental impacts associated with each material, but does not consider variation in the magnitude of these impacts. Land use and climate change were excluded from the sensitivity analysis as the underlying valuation methodologies are not amenable to the calculation of robust upper and lower bound estimates. Table 9 below depicts in detail the variation in KPI costs between low and high ranges, and the resulting change in the total environmental cost of materials.

Table 9 Sensitivity Analysis and resulting low and high environmental cost interval

KPI	Environmental Cost (€/Kg)											
	Mined Gold		Recycled Gold		Mined Silver		Recycled Silver		Diamond		Cubic Zirconia	
	Low	High	Low	High	Low	High	Low	High	Low	High	Low	High
Climate Change	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Land Use	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Air Pollutants	€ 363	€ 3,223	€ 3	€ 30	€ 11	€ 101	€ 0.06	€ 0.52	€ 91	€ 807	€ 0.01	€ 0.12
Water Consumption	€ 2	€ 118	€ 0	€ 3	€ 0	€ 1	€ 0.00	€ 0.04	NA	NA	NA	NA
Land and Water Pollutants	€ 26,009	€ 220,905	€ 11	€ 41	€ 219	€ 1,852	€ 0.09	€ 0.62	NA	NA	NA	NA
Total	**€ 28,538**	**€ 226,410**	**€ 110**	**€ 169**	**€ 289**	**€ 2,013**	**€ 1.79**	**€ 2.82**	**€ 6,203**	**€ 6,920**	**€ 0.11**	**€ 0.22**

KEY ASSUMPTIONS

Table 10 below describes the key assumptions and datasets used in the calculation of environmental cost associated with materials selected by PANDORA.

Table 10 PANDORA net benefit analysis: Scope, assumptions and limitations

Material	Functional Unit	Scope of Analysis	Environmental KPIs	Methodology	Data Sources	Limitations
Diamond	1kg Rough Diamond	Cradle to Gate (Emissions from Energy Only)	• Greenhouse Gases • Air Pollutants ○ PM_{10} ○ NH_3 ○ NO_x ○ SO_2 ○ NMVOC	Estimation of energy consumption in diamond mining based on corporate disclosures of energy use and diamond production	• Corporate disclosures from Debeers mines (Debeers, 2010); Argyle mine, Australia (RioTinto, 2015); and Diavik mine, Canada (RioTinto, 2014) • Ecoinvent database (Wernet et al, 2016)	• Due to limited data availability, the analysis is limited to impacts from disclosed energy consumption and does not consider other environmental impacts of diamond mining, such as land use, water use and land and water pollution. • The analysis is based on data from a limited number of mines and may not be representative of diamond mines globally. • Disclosed energy consumption at each mine is assumed to be solely attributable to diamond production and no co-products are produced from the mine. • The analysis is intended to produce an approximation of the environmental cost of impacts arising from energy use in diamond mining but does not constitute a complete ISO standard life cycle assessment (LCA).
Cubic Zirconia	1kg Zirconium Oxide	Cradle to Gate (Emissions from Energy Only)	• Greenhouse Gases • Air Pollutants ○ PM_{10} ○ NH_3 ○ NO_x ○ SO_2 ○ NMVOC	Energy consumption associated with zircon mining and zirconium oxide production estimated based on data from the Ecoinvent database	• Ecoinvent database (Wernet et al, 2016)	• The analysis is limited to impacts from estimated energy consumption zircon mining and zirconium oxide production and does not consider other environmental impacts of zircon mining, such as land use, water use and land and water pollution. • Zirconium oxide is assumed to be equivalent to unprocessed cubic zirconia. This may lead to an underestimate of the environmental impacts of cubic zirconium production.

						• The analysis is intended to produce an approximation of the environmental cost of impacts arising from energy use in cubic zirconia production but does not constitute a complete ISO standard LCA.
Mined Gold	1kg Gold	Cradle to Gate	• Greenhouse Gases • Air Pollutants • Land and Water Pollutants • Water Depletion • Land Occupation	Screening LCA based on data for gold mining in Australia, Canada, and a global average calculated by Ecoinvent.	• Ecoinvent database (Wernet et al, 2016)	• No primary data was collected in this study and the results are based on secondary life cycle inventory data published on the Ecoinvent database. • Case study production countries were selected based on data availability and may not be representative of the actual source countries for gold used by Pandora. • This analysis represents a screening LCA for gold mining but does not constitute a complete ISO standard LCA.
Recycled Gold	1kg Gold Recycled from Electronics Scrap	Cradle to Gate	• Greenhouse Gases • Air Pollutants • Land and Water Pollutants • Water Depletion • Land Occupation	Screening LCA based on data for global average gold recycling calculated by Ecoinvent.	Ecoinvent database (Frischknecht et al, 2005)	• No primary data was collected in this study and the results are based on secondary life cycle inventory data published in the Ecoinvent database. • Ecoinvent data for precious metal recovery from electronic scrap was extrapolated from data for copper recycling by Ecoinvent. • Gold recycling from high value sources (such as coins and jewellery) was not considered due to data limitations. High value gold recycling is a significant source of recycled gold in global markets and is expected to be associated with less environmental impacts than recycling from scrap due to the reduced need for mechanical separation and processing. Thus, the results presented herein may represent an overestimate of the environmental cost of the average recycled gold available in the market. • This analysis represents a screening LCA for gold recycling and does not constitute a complete ISO standard LCA.

Mined Silver	1kg Silver	Cradle to Gate	• Greenhouse Gases • Air Pollutants • Land and Water Pollutants • Water Depletion • Land Occupation	Screening LCA based on data for silver mining in Papua New Guinea, Canada and a global average, calculated by Ecoinvent	Ecoinvent database (Wernet et al, 2016)	• No primary data was collected in this study, and the results are based on secondary life cycle inventory data published in the Ecoinvent database. • Case study production countries were selected based on data availability and may not be representative of the actual source countries for silver used by Pandora. • This analysis represents a screening LCA for silver mining and does not constitute a complete ISO standard LCA.
Recycled Silver	1kg Silver Recycled from Electronics Scrap	Cradle to Gate	• Greenhouse Gases • Air Pollutants • Land and Water Pollutants • Water Depletion • Land Occupation	Screening LCA based on data for global average silver recycling calculated by Ecoinvent.	Ecoinvent database (Frischknecht et al, 2005)	• No primary data was collected in this study and the results are based on secondary life cycle inventory data published in the Ecoinvent database. • Ecoinvent data for precious metal recovery from electronic scrap was extrapolated from data for copper recycling by Ecoinvent. • Silver recycling from high value sources (such as coins and jewellery) was not considered due to data limitations. High value silver recycling is a significant source of recycled silver on global markets and is expected to be associated with less environmental impacts than recycling from scrap due to the reduced need for mechanical separation and processing. Thus, the results presented herein may represent an overestimate of the environmental cost of the average recycled silver available in the market. • This analysis represents a screening LCA for silver recycling and does not constitute a complete ISO standard LCA.

APPENDIX.

TRUCOST NATURAL CAPITAL VALUATION METHODOLOGIES

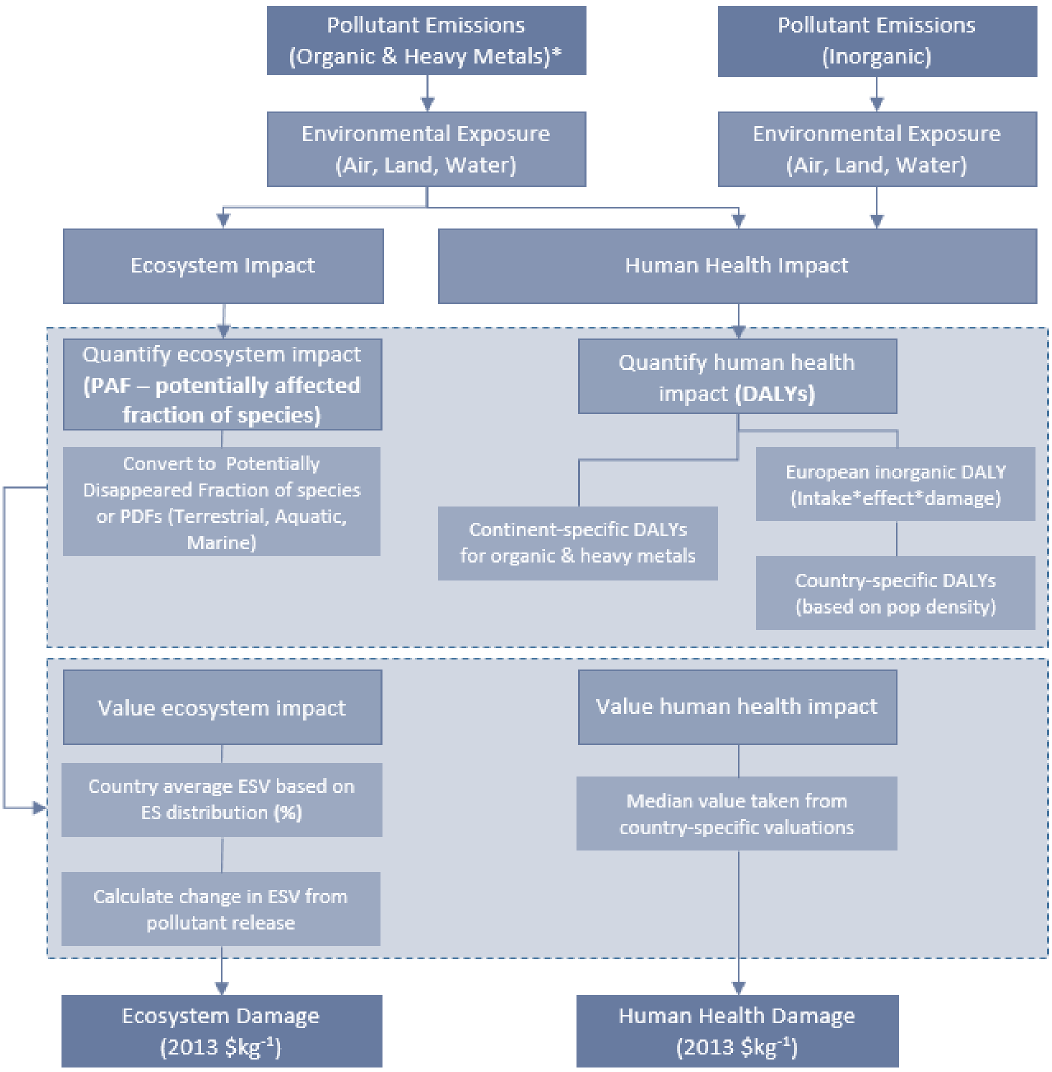
The following is an extract of Trucost's natural capital valuation methodology describing the methods underpinning the valuation of environmental costs and benefits in this study.

For more information on the methodologies summarized below, as well as sensitivity analysis for selected parameters, please refer to the full Trucost valuation methodology. This is available on request by emailing info@trucost.com.

Air, Land and Water Pollutants

Figure 15 summarizes the overall approach used to value the emission of air, land and water pollutants.

Figure 15: General overview of Trucost valuation process for air, land and water pollutants



ESV: Ecosystem Services Value

DALY: Disability-Adjusted Life Year

ES: Ecosystem Services

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

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

IMPACT ON HUMAN HEALTH

BIOPHYSICAL MODELLING

ORGANIC SUBSTANCES AND HEAVY METALS

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

The output of this analysis step is the number of DALYs lost due to the emission of each pollutant, to a specific media, at the continental level.

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

SULPHUR DIOXIDE, NITROGEN OXIDE AND PARTICULATE MATTER (PM10)

USES-LCA2.0 does not estimate DALY impacts for common inorganic air pollutants such as sulphur dioxide, nitrogen oxide and PM_{10}. Adaptation of USES-LCA2.0 to model these substances would result in higher-than-acceptable uncertainty, due to the different characteristics of organic and inorganic substances. Trucost conducted a literature review to find an alternative method to quantify the DALY impact of emission of these pollutants.

ECONOMIC MODELLING

Trucost values DALYs lost due to environmental impacts based on a global median estimate of the value of a life year adapted from a willingness-to-pay study conducted for the New Energy Externalities Development for Sustainability (NEEDS) project (Desaigues et al., 2006; 2011). This is a proactive cost estimate, which takes into account the perceived effects of morbidity and mortality. The value of a life year was adapted for each country based on national income per capita and an income elasticity of 0.5 (Desaigues et al, 2006, 2011), and a global median was calculated and used in all study countries. This approach avoids the ethical challenges associated with assigning a higher value to human health impacts in high income countries compared to low income countries.

IMPACT ON ECOSYSTEMS

BIOPHYSICAL MODELLING

ORGANIC SUBSTANCES AND HEAVY METALS

USES-LCA2.0 models the impact of polluting substances emitted to air, land and water on terrestrial, freshwater and marine ecosystems. This model was adopted by Trucost for assessing the ecosystem damage caused by organic substances and heavy metals. It follows the same modelling steps as for human toxicity, namely exposure assessment, effect assessment and risk characterization. USES-LCA2.0 has also been adapted to generate results at a continental level.

USES-LCA2.0 estimates the potentially affected fraction of species (PAF) per unit emission of pollutant to air, land and water. Trucost adjusted the PAF results to reflect the proportion of species disappeared (PDF), using assumptions from the Eco-Indicator 99 model (Goedkoop & Spriensma, 2000). This adjustment was necessary to link pollutant-related impacts on species to the value of ecosystem services provided by the species in an ecosystem.

OZONE, SULPHUR DIOXIDE, NITROGEN OXIDE AND PARTICULATE MATTER

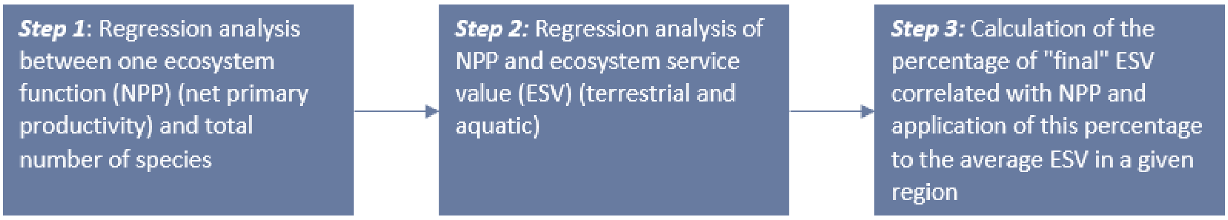
Impact on ecosystems has not been included for ozone, sulphur dioxide, nitrogen oxides and PM10.

ECONOMIC MODELLING

VALUING THE IMPACT ON ECOSYSTEMS IN THIS STUDY

Trucost's approach to valuing a change in the PDF of species follows a three-step process, as shown in Figure 15.

Figure 16: Steps for calculating the value of ecosystem services linked directly to biodiversity



In this methodology, Trucost estimated the link between biodiversity, measured species richness (IUCN, 2015), net primary productivity (NPP) (Costanza et al., 2007) and ecosystem service value (ESV). NPP was chosen over other ecosystem processes, such as nutrient cycling, due to data availability and its direct link with key ecosystem services. A monetary value for the provisioning, regulating and cultural services generated for each terrestrial ecosystem type was first calculated based on the analysis of De Groot et al. (2012). This was combined with the country-specific ecosystem distributions (Olson et al., 2004) to estimate an ecosystem service value per hectare in each country. De Groot et al. calculate the minimum, maximum, median, average and standard deviation for each service provided by key terrestrial and aquatic ecosystems. Finally, Trucost calculated the percentage change in ESV per unit emission of pollutant at the country and substance level and applied this percentage to the average value of one square meter of natural ecosystem in each region globally.

Greenhouse Gases

Trucost values greenhouse gas (GHG) emissions using an estimate of the social cost of carbon (SCC). The SCC represents a best estimate of the marginal externality cost of greenhouse gas emissions as it reflects the full global cost of the damages caused by GHG emissions over their lifetime in the atmosphere. This is in contrast with the market prices observed in emissions trading schemes (ETS), or estimates of the marginal abatement cost (MAC) of GHG reductions.

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

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

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

BIOPHYSICAL & ECONOMIC MODELLING

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

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

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

LIMITATIONS

SCC valuations are contingent on assumptions, and in particular assumptions relating to the discount rate, emission scenarios and equity weighting. Estimates of the SCC are most sensitive to the following key categories of assumptions:

- **Emissions scenarios:** The assumptions made on future emissions, the extent and pattern of warming and other possible impacts of climate change, then deriving how these factors translate into economic impacts.
- **Equity weighting:** This refers to the spatial and temporal dimensions of climate change impacts. Some studies take account of equity weightings which adjust SCC estimates for differences in climate change impacts depending on the development and wealth of nations (Stern, 2006; Tol, 2011).

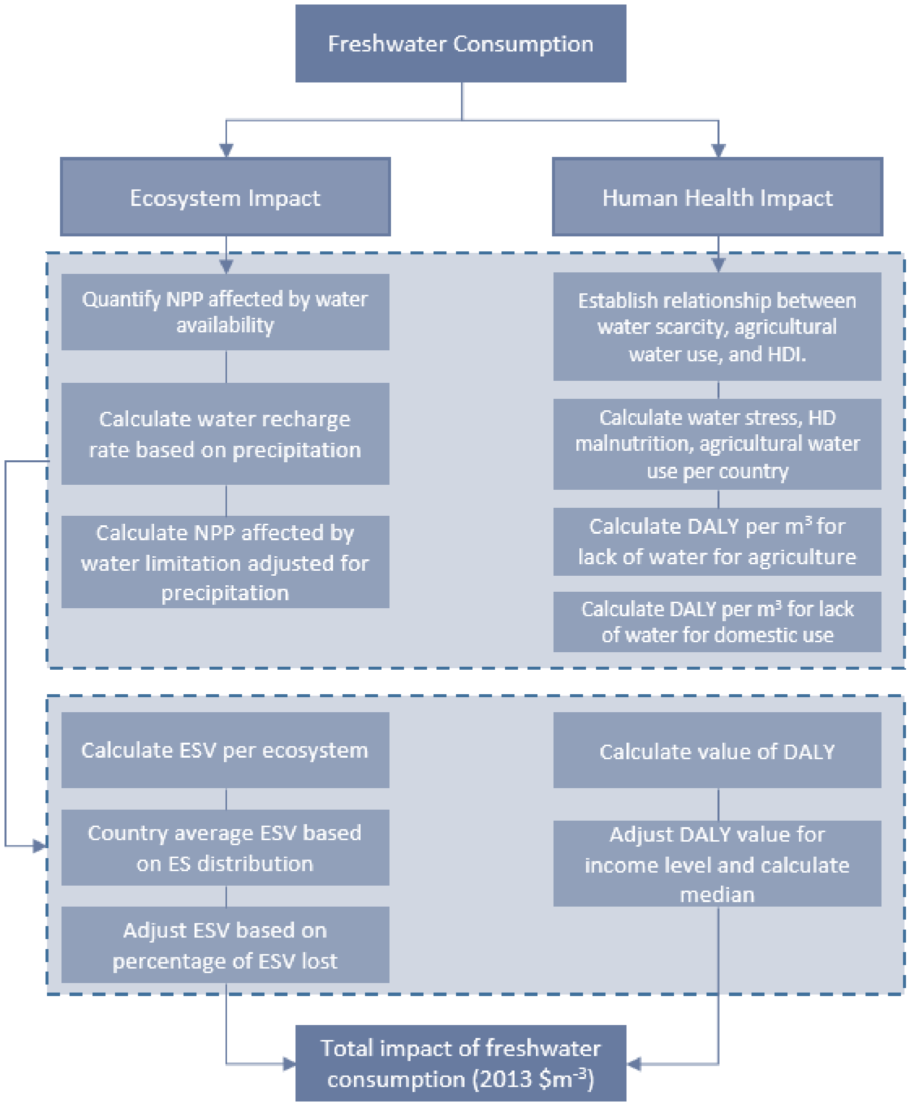
- **Uncertainties:** The variation in SCC valuations is influenced by uncertainties surrounding estimates of climate change damages and related costs.
- **Discount rate:** Higher discount rates result in lower present day values for the future damage costs of climate change. The long time horizon of climate change impacts makes the choice discount rate crucial as well as controversial (IPCC, 2014). For example, Stern (2006) uses a discount rate of 1.4%, compared to a range of between 2.5% and 5% used by the U.S. EPA (2013).

The SCC used in this analysis was US$128 per tonne of CO_{2e} in 2015 prices.

Water Consumption

Figure 17 summarises the approach used to value water consumption.

Figure 17: General overview of Trucost valuation process for water consumption



LEGEND

NPP: Net Primary Productivity

ESV: Ecosystem Services Value

HDI: Human Development Index

DALY: Disability-Adjusted Life Year

IMPACT ON HUMAN HEALTH

BIOPHYSICAL MODELLING

The quantification methodology for human health impacts due to water consumption was developed based on estimates of the disability-adjusted life years lost per unit of water consumed as modelled in Eco-indicator 99 (Goedkoop & Spriensma, 2000). This approach quantifies the human health impacts resulting from a lack of water for irrigation and lack of domestic water in terms of DALYs lost per cubic meter of water abstracted.

LACK OF WATER FOR IRRIGATION

In order to quantify human health impacts associated with malnutrition as a result of lack of water for irrigation, Trucost used the methodology developed by Pfister (2011). This methodology estimates the human health impact of water-scarcity-related malnutrition based on a series of variables including local water stress, share of total water withdrawals used for agricultural purposes, country human development index and per-capita water requirements. The outcome of this modelling is an estimate of the number of DALYs lost per cubic meter of water abstracted in each country.

LACK OF DOMESTIC WATER

Lack of access to domestic water for sanitation can lead to the spread of disease. This impact on health was estimated based on country-specific factors derived from Motoshita et al. (2010). This model, which is based on a multiple regression analysis, estimates the human health impacts associated with the water-deprivation-related incidence of diarrhoea and three intestinal nematode infections: ascariasis, trichuriasis and hookworm disease. The outcome of this modelling is an estimate of the number of DALYs lost per cubic meter of water abstracted in each country.

ECONOMIC MODELLING

Trucost values DALYs lost due to environmental impacts based on a global median estimate of the value of a life year adapted from a willingness-to-pay study conducted for the New Energy Externalities Development for Sustainability (NEEDS) project (Desaigues et al., 2006; 2011). This is a proactive cost estimate, which takes into account the perceived effects of morbidity and mortality. The value of a life year was adapted for each country based on national income per capita and an income elasticity of 0.5 (Desaigues et al, 2006, 2011), and a global median was calculated and used in all study countries. This approach avoids the ethical challenges associated with assigning a higher value to human health impacts in high income countries compared to low income countries.

IMPACT ON ECOSYSTEMS

BIOPHYSICAL MODELLING

Restricted access to water can impact the net primary productivity of ecosystems. Net primary productivity is the rate of new biomass production by plants in an ecosystem and is used by Trucost as an indicator of ecosystem functioning. Net primary productivity was considered here as a proxy measure of ecosystem health, as it is closely linked with the function of vascular plant species (Pfister, 2011) that form a critical primary element of the food chain, and are thus essential for the healthy functioning of an ecosystem (Ibid). It is thus assumed that damage to vascular plants is representative of damage to all fauna and flora species in an ecosystem (Delft, 2010).

NPP can be affected by a range of parameters, including temperature, radiation and water availability (Nemani et al., 2003). The objective of the biophysical modelling is to determine the fraction of NPP which is limited only by water availability, and thus captures the vulnerability of an ecosystem to water deficiencies. Trucost used country-specific estimates of NPP limitation due to water availability (*NPP wat lim*) derived from Pfister (2011).

However, as the effects of water consumption on ecosystems depend on local water availability, *NPP wat lim* is adjusted to take into account the prevailing water scarcity. To achieve this, precipitation was used as a proxy for water scarcity, with country-specific precipitation data sourced from Aquastat (FAO, 2014b). In that sense, countries with the same *NPP wat lim* but higher water scarcity (lower precipitation) will be affected by ecosystem damage to a greater extent. Thus, the parameter *NPP wat lim* adjusted reflects the percentage of 1 m^2 that will be affected by the consumption of 1 m^3 of water in a year (units are m^2 year per m^3).

ECONOMIC MODELLING

Trucost valued the impact on ecosystems due to water consumption based on the following three steps:

- Mathematically link ecosystem functioning to ecosystem service provision
- Quantify the effect on ecosystems due to water consumption
- Calculate the monetary value of the effect on ecosystem services

Trucost first calculated the average baseline NPP for each country in its database, based on the average NPP per ecosystem type and the ecosystem split per country. Average NPP per ecosystem type is based on the values reported by Costanza et al. (2007). Ecosystem split is based on a calculation of the area of each ecoregion in each country (Olson et al., 2004), and then mapping these ecoregions to the ecosystems in the Ecosystem Valuation Database or ESVD (de Groot et al, 2012).

Trucost then calculated the change in NPP per unit of water consumption based on the biophysical modelling described in the previous section. Trucost then estimated the link between NPP and ESV using regression analysis and used this to quantify the change in ESV per 1 m^2 in each country per cubic meter of water consumption. A GDP-weighted average valuation was calculated for each region considered in this study and was used to value the ecosystem impacts of water consumption.

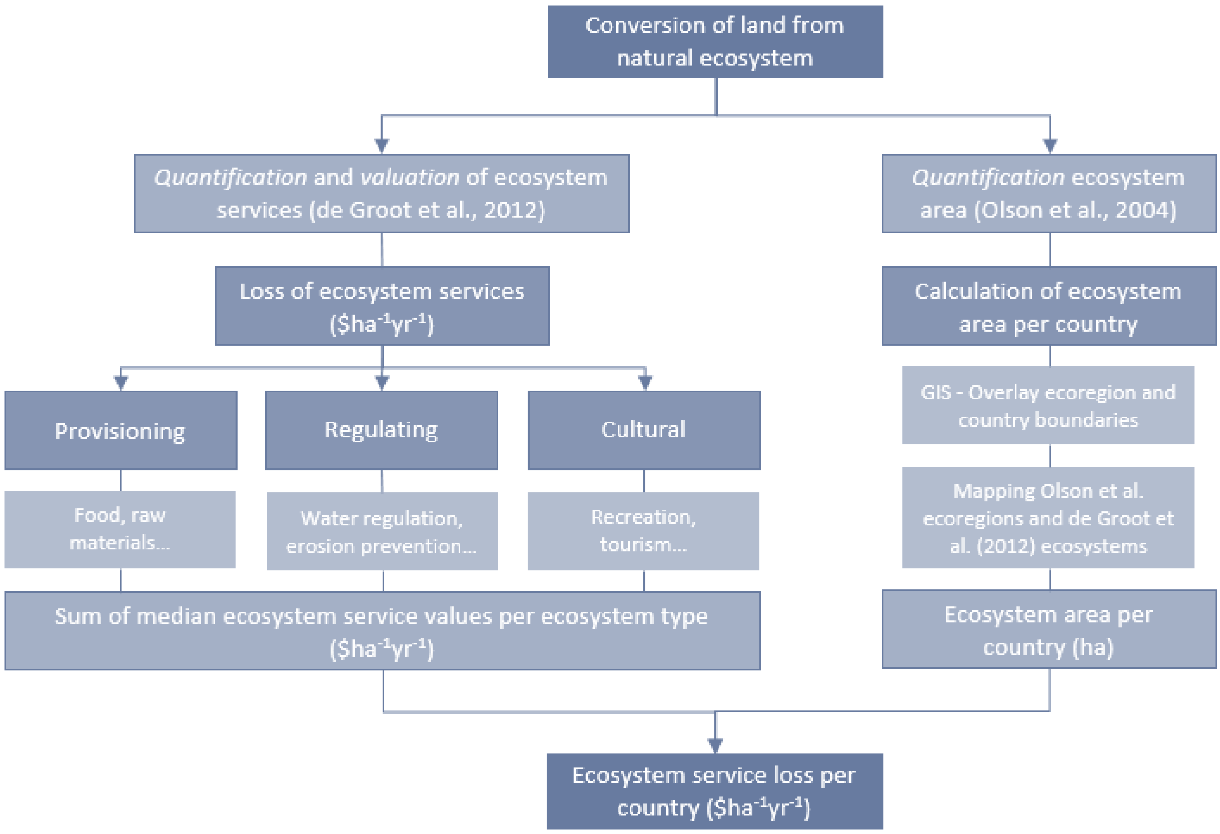
Land Occupation

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

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

The valuation methodology is split into two parts: the quantification and valuation of ecosystem services and the quantification of ecosystem area per country or region. These are outlined in Figure 18 below.

Figure 18: General overview of Trucost valuation process for land use



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

IMPACT ON ECOSYSTEMS

BIOPHYSICAL MODELLING

For the purposes of this study, Trucost has used de Groot et al (2012) as a basis for mapping material ecosystem services to ecosystems. De Groot et al (2012) was preferred, as the study presents ecosystem service values in 'international dollars' suitable for global application. This also aligns with Trucost's other valuation methodologies and means that the step of mapping ecosystem services between different studies does not have to be attempted. This step would involve the loss of some granularity in the final result, table.11 outlines the ecosystems and the ecosystem services that have been considered in this study. The cells in red indicate where values were provided, but Trucost chose not to include them. The green cells indicate where an additional value was calculated. Both cases will be described in more detail later.

It is important to note that some ecosystem services, such as nutrient cycling, have been mapped to different ecosystem service categories. In this instance, nutrient cycling has been classified as a regulating service rather than a supporting service. Furthermore, the de Groot et al (2012) study was based on a subset of 665 value estimates included in the Ecosystem Service Valuation Database (ESVD) (from a total of 1,300), selected on the basis of the following criteria (van der Ploeg & de Groot, 2010):

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

Table 11 Ecosystem services assessed in Trucost's methodology based on de Groot et al. (2012)

Ecosystem	Provisioning Services						Regulating Services									Cultural Services					Habitat or Supporting Services	
	Food	Water	Raw Materials	Genetic Resources	Medicinal Resources	Ornamental Resources	Air Quality Reg.	Climate Reg.	Disturbance Moderation	Water Flow Reg.	Waste Treatment	Erosion Prevention	Nutrient Cycling	Pollination	Biological Control	Aesthetic Information	Recreation	Inspiration	Spiritual Experience	Cognitive Development	Nursery Service	Genetic Diversity
Coastal Wetlands		Y	Y	Y	Y	-	-	Y	Y	-	Y	Y	Y	-	-	-	Y	-	-	-	-	-
Grasslands		Y	Y	-	Y	-	-	Y	-	-	Y	Y	-	-	-	-	Y	-	-	-	-	-
Inland Wetlands		Y	Y	-	Y	Y	-	Y	Y	Y	Y	Y	Y	-	Y	Y	Y	Y	-	-	-	-
Temperate Forest		Y	Y	-	-	-	-	Y	-	-	Y	Y	Y	-	-	-	Y	-	-	-	-	-
Tropical Forest		Y	Y	Y	Y	-	Y	Y	Y	Y	Y	Y	Y	Y	Y	-	Y	-	-	-	-	-
Woodlands		-	Y	-	-	Y	-	Y	-	-	Y	Y	-	Y	-	-	Y	-	-	-	-	-

ECOSYSTEM AREA

The terrestrial area covered by each ecosystem in each country was calculated by mapping the ecosystem categories in table 11 to datasets used in geographic information systems (GIS) that represent country administrative boundaries and global ecoregions. Country boundaries, or administrative areas, were derived from the GADM v2.0 dataset (GADM, 2012). The data was downloaded as a shapefile and used in conjunction with ecoregion data derived from Olson et al. (2004), which showed the size and distribution of over 800 terrestrial ecoregions around the world. Once these datasets were spatially joined, Trucost was able to calculate the area of each ecoregion in each country.

ECONOMIC MODELLING

Values of ecosystem services were also sourced from de Groot et al (2012), as shown in table 12. However, de Groot et al. (2012) supplemented the information in this database with variables derived from GIS datasets that represent context-specific characteristics of each study. This information was used to estimate a meta-regression value function for each ecosystem type. An example provided in the paper details the calculation of a value function for inland waterway ecosystems. This meta-regression value function is as follows:

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

y: wetland value standardized to 2007 US$ ha⁻¹yr⁻¹ (dependent variable)

$_i$*: the number of value observations*

a: constant

b_w*,* b_c*,* b_s*: coefficients of the explanatory variable*

X_{wi}*: explanatory variable of the valued wetland (site area, wetland type…)*

X_c*: socio-economic and geographical context (GDP per capita, population within 50km…)*

X_s*: valuation study method*

u: residuals

Table 12 details the ecosystem service values presented in de Groot et al (2012), calculated using the method detailed above.

Table 12 Unit values of ecosystem services, 2007 international dollars ha-1yr-1 (de Groot, 2012)

Ecosystem	Provisioning Services		Regulating Services		Cultural Services		Habitat or Supporting Services		Average Unit Value (2007 Int.$ $ha^{-1}yr^{-1}$)
	Ecosystem Services	Values	Ecosystem Services	Values	Ecosystem Services	Values	Ecosystem Services	Values	
Coastal Systems	2	*15*	2	*2*	3	*7*	2	*4*	***28,917***
Coastal Wetlands	5	*59*	5	*35*	1	*19*	2	*26*	***193,845***
Coral Reefs	4	*30*	4	*16*	4	*39*	2	*9*	***352,915***
Freshwater (Rivers/Lakes)	2	*10*	1	*2*	1	*3*	-	-	***4,267***
Grasslands	4	*12*	3	*9*	2	*9*	1	*2*	***2,871***
Inland Wetlands	5	*94*	6	*40*	3	*17*	2	*17*	***25,862***
Marine[3]	2	*7*	1	*1*	1	*4*	1	*2*	***491***
Temperate Forest	3	*9*	5	*13*	2	*26*	1	*10*	***3,013***
Tropical Forest	5	*38*	9	*31*	1	*20*	2	*7*	***5,264***
Woodlands	3	*13*	3	*3*	1	*1*	2	*4*	***1,588***

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

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

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

REFERENCES

Abdul-Wahab, S., & Marikar, F. (2012). The environmental impact of gold mines: pollution by heavy metals. Central European Journal of Engineering. doi:10.2478/s13531-011-0052-3

Ali, S. (2011). Ecological Comparison of Synthetic versus Mined Diamonds. University of Vermont. Retrieved from http://www.uvm.edu/~shali/Synthetic_Diamonds_Mined_Diamonds.pdf

Brander, L. (2004). Guidance Manual on Value Transfer Methods for Ecosystem Services. UNEP.

Chirico, P., & Malpeli, K. (2014). A Methodological Toolkit for Field Assessments of Artisanally Mined Alluvial Diamond Deposits. Virginia: US Geological Survey.

Goedkoop, M., Heijungs, R., Huijbregts, M., Schryver, A., Struijs, J., & Zelm, R. (2009). ReCiPe Life Cycle Impact Assessment Method.

Hedrick, J. (2001). ZIRCONIUM AND HAFNIUM. USGS.

Mudd, G. (2007). The Sustainability of Mining in Australia. Department of Civil engineering. Monash University. Retrieved from http://nowandfutures.com/d2/SustMining-Aust-aReport-Master.pdf

Oosterveld, T. (2016). SRK News, Diamond Resource Estimation. UK: SRK Consulting. Retrieved from http://www.srk.co.uk/files/File/newsletters/SRKnews31-Diamonds_A4.pdf

Zircon_Industry_Association. (2016). Retrieved from Zircon industry Association: http://www.zircon-association.org/zircon-sand

Costanza, R., d'Arge, R., de Groot, R., Farber, S., Grasso, M., Hannon, B., Limburg, K., Naeem, S., O'Neill, R. V., Paruelo, J., Raskin, R. G., Sutton, P., van den Belt, M. (1997) The value of the world's ecosystem services and natural capital. Nature. 387, 253-260.

Costanza, R., de Groot, R. S., Sutton, P., van der Ploeg, S., Anderson, S. J., Kubiszewski, I., Farber, S., Turner, R. K. (2014) Changes in the global value of ecosystem services. Global Environmental Change. 26, 152-158.

Costanza, R., Fisher, B., Mulder, K., Liu, S., Christopher, T. (2007) Biodiversity and ecosystem services: A multi-scale empirical study of the relationship between species richness and net primary production. Ecological Economics. Vol. 61, pp. 478-491.

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, pp.50-61.

Delft. (2010) Shadow Prices Handbook - Valuation and Weighting of Emissions and Environmental Impacts. CE Delft.

Desaigues, B., Ami, D. & Hutchison, M. (2006) Final report on the monetary valuation of mortality and morbidity risks from air pollution. Paris: NEEDS.

Desaigues, B., Ami, D., Bartczak, A., Braun-Kohlová, M., Chilton, S., Czajkowski, M., Farreras, V., Hunt, A., Hutchison, M., Jeanrenaud, C., Kaderjak, P., Máca, V., Markiewicz, O., Markowska, A., Metcalf, H., Navrud, S., Nielsen, J. S., Ortiz, R., Pellegrini, S., Rabl, A., Riera, R., Scasny, M., Stoeckel, M. -., Szántó, R. & Urban, J. (2011) Economic valuation of air pollution mortality: A 9-country contingent valuation survey of value of a life year (VOLY). Ecological Indicators. 11 (3), pp.902-910.

Desaigues, B., Ami, D., Bartczak, A., Braun-Kohlová, M., Chilton, S., Farreras, V., Hunt, A., Hutchison, M., Jeanrenaud, C., Kaderjak, P., Máca, V., Markiewicz, O., Metcalf, H., Navrud, S., Nielsen, J.S., Ortiz, R., Pellegrini, S., Rabl, A., Riera, R., Scasny, M., Stoeckel, M.-E., Szántó, R., Urban, J. (2006) Final Report on the Monetary Valuation of Mortality and Morbidity Risks from Air Pollution. Deliverable RS1b of NEEDS Project.

EC. (2004) European Union System for the Evaluation of Substances 2.0 (USES 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). Available via the European Chemicals Bureau, http://ecb.jrc.it

EPA. (2013) The Social Cost of Carbon. United States Environmental Protection Agency. [Online] Available from: http://www.epa.gov/climatechange/EPAactivities/economics/scc.html [Accessed on: 22.07.15]

FAO. (2014) AQUASTAT database. Food and Agriculture Organization of the United Nations (FAO). [Online] Available from: http://www.fao.org/nr/water/aquastat/data/query/index.html?lang=en [Accessed on 06.06.15]

GADM. (2012) Global Administrative Areas. Available online: http://www.gadm.org/version2 [Accessed on: 01.11.14]

Goedkoop, M. Spriensma, R. (2000) The Ecoindicator 99 - A Damage oriented method for Life Cycle Impact Assessment. Netherlands. Product Ecology Consultants.

IPCC. (2014) IPCC Fifth Assessment Report. Intergovernmental Panel on Climate Change. Working Group III.

IUCN. (2015) Table 6a - Number of animal species in each IUCN Red List Category by country. Table 6b - Number of plant species in each IUCN Red List Category by country. [Online] Available from: http://www.iucnredlist.org/about/summary-statistics [Accessed on: 06.06.15]

IWGSCC. (2013) Technical Support Document: Technical Update of the Social Cost of Carbon for Regulatory Impact Analysis. Interagency Working Group on Social Cost of Carbon, United States Government.

Krukowska, E. (2014) Europe Carbon Permit Glut Poised to Double by 2020: Sandbag. Bloomberg Business News. [Online] Available from: http://www.bloomberg.com/news/articles/2014-10-14/europe-carbon-permit-glut-poised-to-double-by-2020-sandbag-says [Accessed on: 23.07.15]

Motoshita, M., Itsubo, N., Inaba, A. (2010) Development of impact factors on damage to health by infectious diseases caused by domestic water scarcity. International Journal of Life Cycle Assessment. Vol. 16, pp. 65-73.

National Institute of Public Health and the Environment. (2004) European Union System for the Evaluation of Substances 2.0 (USES 2.0). Bilthoven.

Nemani, R., Keeling, C., Hashimoto, H., Jolly, W., Piper, S., Tucker, C., Myneni, R., Running, S. (2003) Climate-driven increases in global terrestrial net primary production from 1982 to 1999. Science Vol. 300, no. 5625, pp. 1560-1563

Olson, D. M., Dinerstein, E., Wikramanayake, E. D., Burgess, N. D., Powell, G. V. N., Underwood, E. C., D'Amico, J. A., Itoua, I., Strand, H. E., Morrison, J. C., Loucks, C. J., Allnutt, T. F., Ricketts, T. H., Kura, Y., Lamoreux, J. F., Wettengel, W. W., Hedao, P., Kassem K. R. (2004) Terrestrial Ecoregions of the World: A New Map of Life on Earth. BioScience. Vol. 51, no. 11, pp. 933-938.

Pfister, S. 2011. Environmental evaluation of freshwater consumption within the framework of life cycle assessment. DISS. ETH NO. 19490. ETH ZURICH.

Stern, N. 2006. Stern Review Report on the Economics of Climate Change. Cambridge: Cambridge University Press.

Tol, R. 2011. The Social Cost of Carbon. Annual Review of Resource Economics, Annual Reviews, 3(1), p. 419-443.

Van der Ploeg, S., de Groot R. S. 2010. The TEEB Valuation Database – a searchable database of 1310 estimates of monetary values of ecosystem services. Foundation for Sustainable Development, Wageningen, the Netherlands.

World Bank Group. 2014. State and Trends of Carbon pricing. World Bank Group. Climate Change. Washington DC, United States.

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PANDORA Net Benefit Analysis: Scope, Assumptions and Limitations

Material	Functional Unit	Scope of Analysis	Environmental KPIs	Analysis Methodology	Data Sources	Important Limitations
Diamond	1kg Rough Diamond	Cradle to Gate Emissions from Energy Only	Greenhouse Gases Air Pollutants • PM10 • NH3 • NOx • SO2 • NMVOC	Estimation of energy consumption in diamond mining based on corporate disclosures of energy use and diamond production	• Corporate disclosures from Debeers (all mines) and Rio Tinto (Argyle mine (Australia) and Diavik mine (Canada) • Ecoinvent database (Wernet et al, 2016)	• Analysis is limited to impacts from disclosed energy consumption and does not consider other material environmental impacts of diamond mining, such as land use, water use, and land and water pollution • Analysis is based on data from a limited number of mines and may not be representative of diamond mines globally • Due to data limitations it is assumed that total disclosed energy consumption for each mine / producer is attributable to the production of diamonds and that no co-products are produced from the mine • The results presented represent an order of magnitude approximation of the impacts arising from energy use in diamond mining but do not constitute a complete ISO standard or screening Life Cycle Assessment
Cubic Zirconia	1kg zirconium oxide	Cradle to Gate Emissions from Energy Only	Greenhouse Gases Air Pollutants • PM10 • NH3 • NOx • SO2 • NMVOC	Energy consumption associated with zircon mining and zirconium oxide estimated based on data from the Ecoinvent database	• Ecoinvent database (Wernet et al, 2016)	• Analysis is limited to impacts from estimated energy consumption zircon mining and zirconium oxide production, and does not consider other material environmental impacts of zircon mining, such as land use, water use, and land and water pollution

						• Zirconium oxide is assumed to be approximately equivalent to unprocessed cubic zirconia due to data limitations. This may not be accurate and may lead to an underestimate of the environmental impacts of cubic zirconium production. • The results presented represent an order of magnitude approximation of the impacts arising from energy use in unprocessed / un-cut cubic zirconium but do not constitute a complete ISO standard or screening Life Cycle Assessment
Mined Gold	1kg Gold	Cradle to Gate	Greenhouse Gases Air Pollutants Land and Water Pollutants Water Depletion Land Occupation	Screening LCA based on data for gold mining in Australia, Canada and Rest of World (Ecoinvent average)	• Ecoinvent database (Wernet et al, 2016)	• No primary data was collected in this study and the results are based on secondary Life Cycle Inventory data published in the Ecoinvent database • Geography selections were made based on data availability and no information was available on the actual sourcing geographies for gold used by Pandora • The results presented represent a screening LCA for gold mining and do not constitute a complete ISO standard Life Cycle Assessment
Recycled Gold	1kg Gold Recycled from Electronics Scrap	Cradle to Gate	Greenhouse Gases Air Pollutants Land and Water Pollutants Water Depletion Land Occupation	Screening LCA based on data for gold recycling in Rest of World (Ecoinvent average)	• Ecoinvent database (Frischknecht et al, 2005)	• No primary data was collected in this study and the results are based on secondary Life Cycle Inventory data published in the Ecoinvent database • Ecoinvent data for precious metal recovery from electronic scrap utilises some proxy data for copper recycling due to data limitations

						• Gold recycling from high value sources (such as coins and jewellery) was not considered due to data limitations. High value gold recycling is a significant source of recycled gold on global markets and thus the results presented here are unlikely to be representative of average recycled available on the market. • The results presented represent a screening LCA for gold recycling and do not constitute a complete ISO standard Life Cycle Assessment
Mined Silver	1kg Silver	Cradle to Gate	Greenhouse Gases Air Pollutants Land and Water Pollutants Water Depletion Land Occupation	Screening LCA based on data for silver mining in Papua New Guinea, Canada and Rest of World (Ecoinvent average)	Ecoinvent database (Wernet et al, 2016)	• No primary data was collected in this study and the results are based on secondary Life Cycle Inventory data published in the Ecoinvent database • Geography selections were made based on data availability and no information was available on the actual sourcing geographies for silver used by Pandora • The results presented represent a screening LCA for silver mining and do not constitute a complete ISO standard Life Cycle Assessment
Recycled Silver	1kg Silver Recycled from Electronics Scrap	Cradle to Gate	Greenhouse Gases Air Pollutants Land and Water Pollutants Water Depletion Land Occupation	Screening LCA based on data for gold recycling in Rest of World (Ecoinvent average)	• Ecoinvent database (Frischknecht et al, 2005)	• No primary data was collected in this study and the results are based on secondary Life Cycle Inventory data published in the Ecoinvent database • Ecoinvent data for precious metal recovery from electronic scrap utilises some proxy data for copper recycling due to data limitations • Silver recycling from high value sources (such as coins and jewellery)

						was not considered due to data limitations. High value silver recycling is a significant source of recycled silver on global markets and thus the results presented here are unlikely to be representative of average recycled available on the market. • The results presented represent a screening LCA for silver recycling and do not constitute a complete ISO standard Life Cycle Assessment

Wernet, G., Bauer, C., Steubing, B., Reinhard, J., Moreno-Ruiz, E., and Weidema, B., 2016. The ecoinvent database version 3 (part I): overview and methodology. The International Journal of Life Cycle Assessment, [online] 21(9), pp.1218–1230.

Frischknecht R., Jungbluth N., Althaus H.-J., Doka G., Dones R., Heck T., Hellweg S., Hischier R., Nemecek T., Rebitzer G. and Spielmann M., 2005, The ecoinvent database: Overview and methodological framework, International Journal of Life Cycle Assessment 10, 3–9.