Report

Date
August 10, 2023

CARBON FOOTPRINT OF DIAMONDS BY PANDORA COLLECTION – update 2023

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CARBON FOOTPRINT OF DIAMONDS BY PANDORA COLLECTION - UPDATE 2023

Ramboll Sweden AB

Org. nummer 556133-0506

Project name	**Pandora Brilliance, Carbon footprint, Update 2023**
Customer	**Pandora Inc.**
Document type	**Report**
Version	**4#, External use**
Date	**2023-08-10**
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1. EXECUTIVE SUMMARY

This report is an update of the 2022 cradle-to-grave carbon footprint study according to the international standard for carbon footprints of products (ISO 14067:2018), which in turn is based on the standard for life cycle assessment (LCA) (ISO 14044:2006). The study made in 2022 is verified in 2022. An update of calculations was made without any change in methodology and therefore no further review has been performed. The study assesses three jewelry rings from the Diamonds by Pandora collection. The collection features lab-grown diamonds that are physically, chemically, and optically identical to their mined counterparts (Pandora, 2022).

The update in this report implies the following:

1) The carbon footprint of the production of the lab-grown diamonds has changed due to updates in the calculations made by the suppliers and the updated data was used for this report update.

2) The energy used in cutting and polishing the lab-grown diamonds was covered by RECs in the previous study. However, only solar power was considered while it should have been a mix of solar and wind, which is now corrected in this updated report. Note that no new RECs were purchased, which means that the results of this study are still applicable for year 2022 as the original study.

The report presents scientifically based carbon footprint information for the declared lab-grown diamond rings. The purpose of this study is to communicate the results for marketing purposes. The results are not intended to be used for comparisons between the rings or other competing products, nor are any other comparative assertions made in this study. The application of the results is to be used in business-to-consumer communication.

The three assessed rings are a Sterling silver ring with a 0.15 carat lab-grown diamond, a yellow gold ring with a 1 carat lab-grown diamond, and a white gold ring with a 1 carat lab-grown diamond. The analysis is made for the entire life cycle of each ring, covering raw material acquisition, production processes, use phase, end-of-life phase, and transports. The greenhouse gas emissions are calculated and reported as carbon dioxide equivalents (CO_2e).

All three rings are made with recycled metals (silver or gold, respectively) and a lab-grown diamond. The lab-grown diamond is produced using 100% renewable electricity, i.e., renewable energy is used during the lab-grown diamond synthesis and the final cutting and polishing. The total carbon footprint is 9.17 kg CO_2e per grown, cut, and polished 1 carat lab-grown diamond.

The total carbon footprint of the Sterling silver ring with a 0.15 carat polished, lab-grown diamond is 2.9 kg CO_2e.

The total carbon footprint of the Yellow gold ring with a 1 carat polished, lab-grown diamond is 11.4 kg CO_2e.

The total carbon footprint of the White gold ring with a 1 carat polished, lab-grown diamond is 11.4 kg CO_2e.

The main study shows that the primary contributor to the carbon footprint is the production of the lab-grown diamond, which stands for 48%, 80%, and 80% for the silver, yellow gold, and white gold rings, respectively. Any improvements in the value chain should be directed toward the lab-grown diamond production. Since the data concerning the lab-grown diamonds is from a carbon footprint study with restricted access to the complete study and data, it is challenging to pinpoint detailed improvement areas. It is recommended that Pandora continues to collaborate with the lab-grown diamond suppliers to reach lower carbon impacts.

This study has some limitations that might affect the results. In general, assumptions have been made conservatively following the precautionary principle to avoid underestimating the impact of unknown data. The results in this study are potential and not predictions of impacts.

2. GOAL AND SCOPE

The Diamonds by Pandora collection features lab-grown diamonds (LGD). These stones are physically, chemically, and optically identical to their mined counterparts but are created above ground (Pandora, 2022). The pieces of jewelry with lab-grown diamonds are, for example, bracelets, rings, earrings, and necklaces. The primary metals are silver, yellow gold, or white gold.

This study is a cradle-to-grave carbon footprint study according to the international standard for carbon footprints of products (ISO 14067:2018), which in turn is based on the standard for life cycle assessment (LCA) (ISO 14044:2006). The report presents scientifically based carbon footprint information for the declared lab-grown diamond rings. The purpose of this study is to communicate the results for marketing purposes. The results are not intended to be used for comparisons between the rings or other competing products, nor are any other comparative assertions made in this study. The application of the results is to be used in B2C – Business-to-consumer – communication. The target group is primarily consumers.

The study made in 2022 is verified in 2022. An update of calculations was made without any change in methodology and therefore no further review has been performed.

2.1 Products assessed

The study assesses three jewelry rings from the Diamonds by Pandora collection, and the functional unit is based on one ring, see section 2.2. These rings are included in the Diamonds by Pandora collection and will be launched on the 16th of August 2022.

Three products are assessed in this study: sterling silver ring with a 0.15 ct. lab-grown diamond (also called silver lab-grown diamond ring), 14K gold ring with a 1 ct. lab-grown diamond (also called yellow gold lab-grown diamond ring), and 14K white gold ring with a 1 ct. lab-grown diamond (also called white gold lab-grown diamond ring). The rings' specifications are presented in Table 1, and the rings are shown in Figure 1.

Table 1 The assessed rings

Name	Primary metal	Diamond carat
STERLING SILVER RING WITH 0.15 CT TW	Sterling silver	0.15
14K GOLD RING WITH 1.00 CT TW GJ VS2	Yellow gold	1
14K WHITE GOLD RING WITH 1.00 CT TW	White gold	1

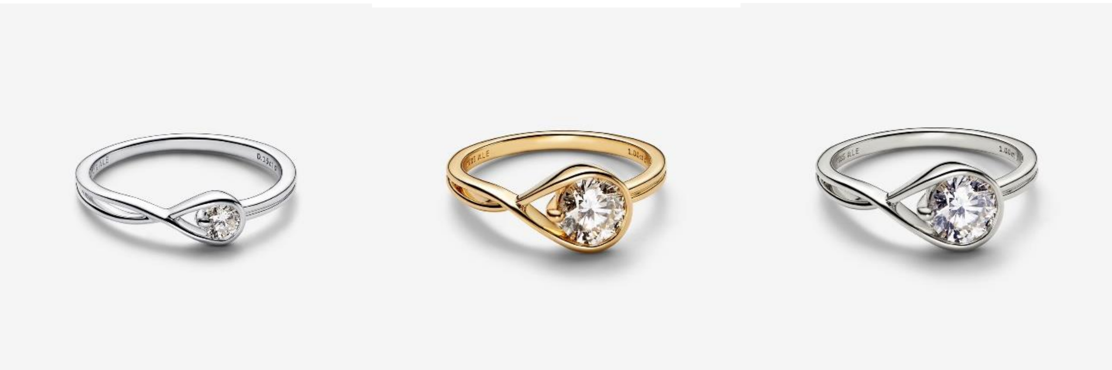

Figure 1 The first ring from the left is a solid sterling silver ring with a 0.15 carat lab-grown diamond. The second middle ring is a solid 14K yellow gold ring with a 1.00 carat lab-grown diamond. The third ring from the left is a solid 14K white gold ring with a 1.00 carat lab-grown diamond. Photos: Pandora (2022)

2.2 Functional unit

The functional unit for this cradle-to-grave study is **one metal ring with one lab-grown diamond** with a life span of 50 years.

2.3 System boundaries

The system boundaries are illustrated in Figure 2. The cradle-to-grave carbon footprint study includes all life cycle phases of the ring's life cycle, except the retail stores (dark box in the figure) and customer travel (dashed line arrow in the figure). The life cycle stages included are lab-grown diamond ring production, ring box production, use phase (not retail stores), end-of-life phase, and all transports except transport by a consumer, see 3.7 and 0. Note that the burdens of the recycling process and benefits of recycling are not included in the main study, see 2.4. Each of the stages is described further in Chapter 3.

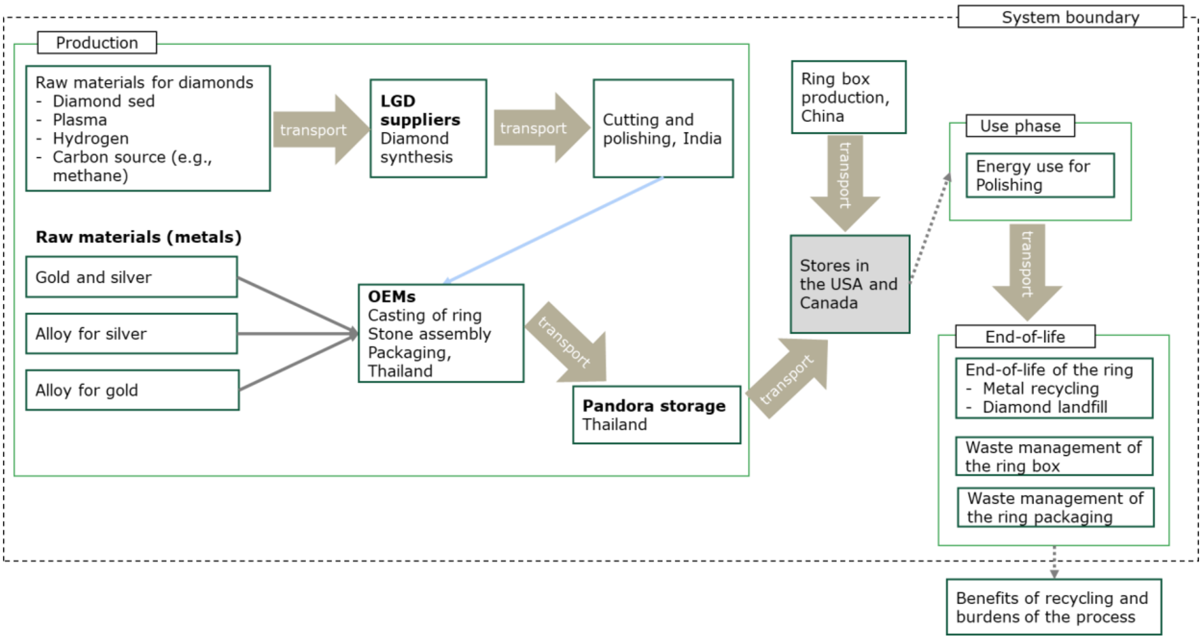

Figure 2 Simplified flow chart illustrating the flows, cradle to grave, between the processes and locations for all ring variants.

2.3.1 Time boundary

The life span for the rings is set to be 50 years; this is the assumed service life. Characterization factors for the global warming potential represent a 100-year perspective. This study's expected validity and representativeness are as long as no major changes occur within the scope. The study is based on data concerning the Diamonds by Pandora collection produced and sold during 2022 and should be used only for that collection.

2.3.2 Nature

The cradle boundary to nature is at material extraction, i.e., mining. However, there are no cradle boundaries to forestry or agriculture or grave boundaries to long-term emissions from landfills.

The greenhouse gas emissions are calculated and reported as CO_2-equivalents (CO_2e) and are not separately reported. Emission factors are assumed to contain all the relevant greenhouse gas emissions outlined in the standard.

2.3.3 Geography

The North American, i.e., USA and Canada end market is set for this study. The rings are produced in Thailand, with the raw materials and parts (lab-grown diamonds) coming from other places worldwide. The local aspects were considered whenever relevant and possible (e.g., local electricity mix). Specifications of, e.g., material origins are listed in section 3.

The environmental impacts of all activities in the life cycle are included regardless of geographic location. The sensitivity of the recipient environment in question has not been considered.

2.4 Allocation and assumptions

Total electricity consumption and auxiliary materials at the OEMs are allocated per ring. The total impact of the lab-grown diamonds is allocated per carat.

The allocation method used for recycled materials is the cut-off approach. This method means that the recycled metal used as a resource in the rings carries no burden from before the point it enters the recycling process. At the end-of-life, when the metal enters the metal recycling process, the rings carry the environmental burden until the metal reaches a recycling facility. ISO 14067 Informative Annex D (ISO, 2018) suggests other allocation principles, e.g., the closed-loop allocation. Therefore, a sensitivity analysis is done to explore the potential differences between the allocation approaches.

2.5 Cut-off

The production of auxiliary materials is not included in the study if not explicitly mentioned. Some auxiliary products used in the ring production at the OEMs were cut-off. The cut-off was a combination of lack of data and the assumed insignificance of those materials' impact on the results. These materials are used for numerous rings and other jewelry; thus, their impact share allocated to one ring is minimal. The cut-off materials are:

- Sandpaper
- Buffing wheel for polishing jewelry
- Microfiber cloth for polishing jewelry

The study does not include the production of capital goods, e.g., factories, vehicles, and Pandora stores. The effect of the cut-off is further described in 0.

2.6 Environmental impact categories

This study used the IPCC 2013 GWP 100a V1.03 whenever study-specific calculations were made.

The GHG emissions accounted for in the lab-grown diamond (LGD) study by the LGD Suppliers are based on the 100-year Global Warming Potential figures published in the Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report (IPCC, 2014) and include those required by the GHG Protocol Product Standard. The footprint was calculated in accordance with; PAS 2050:2011 – Specification for the assessment of the life cycle greenhouse gas emissions of goods and services, and ISO 14067:2018 – Greenhouse gases – Carbon footprint of products – Requirements and guidelines for quantification.

2.7 Interpretation

The findings of the inventory analysis and the impact assessment are evaluated concerning the defined goal and scope to reach conclusions and recommendations. The main results are presented and analyzed per ring. No comparisons are made between the rings since this is not the purpose of the study. The analysis of the contribution of different life cycle stages, separate processes, and materials is done to identify areas of potential improvement. Two sensitivity analyses are made to evaluate the effect of the choice of allocation method and electricity mix for cutting and polishing.

2.8 Data quality

Most data were collected from Pandora's primary sources, the data quality is judged to be good. The lab-grown diamond study data is assumed to be of good quality since the study is almost exclusively based on primary data.

2.9 Data collection procedures

This study is attributional. Whenever relevant and possible specific data was collected from Pandora and suppliers. All the environmental data for processes, except for the lab-grown diamond carbon footprint, are generic. The limitations due to data selection and quality are presented in section 0. In general, assumptions have been made conservatively following the precautionary principle to avoid underestimating the impact of unknown data.

The specific supplier data is collected from Pandora suppliers, i.e., OEMs. The specific data from the suppliers are for the year 2022, involving the Diamonds by Pandora collection based on previous data and data collected in 2021.

All otherwise not specified data is collected from Pandora. Section 3 presents the inventory and some specific information regarding data collection.

The result from a carbon footprint cradle-to-gate study for lab-grown diamonds by the LGD Suppliers is used as input data for this study; the data in the original study was for 2021 (the LGD Suppliers, 2022); the update was done with the updated data from 2023 (LGD Suppliers, 2023).

The LGD Suppliers' Carbon Footprint study is according to standards PAS 2050:2011 and ISO 14067:2018 and is third-party reviewed by Carbon Trust. The synthesis process of the lab-grown diamonds is conducted using 100% renewable electricity. The LGD Suppliers provide the certificates of the guarantee of origin (renewable electricity) for the review of this study.

The data used for the carbon footprint of the recycled gold and silver as well as the primary copper in the alloys are from the study done by Sphera Solutions GmbH (2020). Literature and datasets for secondary/recycled metals are studied in the Sphera Solutions GmbH study, and recommendations are made on which data is the most relevant for Pandora's supply chain (Sphera Solutions GmbH, 2020). The data for the other metals in the alloys are based on Ecoinvent 3 (2022), as implemented in SimaPro (Pré Consultants, 2022).

The carbon footprint data for transport included in this study are from the UK Government GHG Conversion Factors for Company Reporting (UK Government, 2021). The data for road transport includes both fuel production and combustion emissions. The emission factor for freight flight includes fuel production and operation emissions, including the indirect effects of non-CO_2 emissions. The distances for road transport are according to the longest route recommended by Google Maps (Google, 2022). The distances for air transport are according to Flight connections, direct flight when possible, and transit when necessary (Flight Connections, 2022). The distance by boat is according to the Ports.com web page (Ports.com, 2022).

The electricity mix used at the suppliers is a low voltage mix for the Thailand market; the data is from Ecoinvent 3 (2022), the cut-off alternative, as implemented in SimaPro (Pré Consultants, 2022). The data for auxiliary materials is based on a literature study by Sphera Solutions GmbH (2020), UK Government GHG Conversion Factors for Company Reporting (UK Government, 2021), and Ecoinvent 3 (2022), as implemented in SimaPro (Pré Consultants, 2022). Some of the auxiliary materials were left out due to data gaps.

The data for incineration (cardboard, wood, and plastic) is based on Ecoinvent 2 (2022), as implemented in SimaPro (Pré Consultants, 2022).

3. LIFE CYCLE INVENTORY

Included stages of the life cycle and parts of the production stage are described below in detail, including some specific information regarding data collection. More detailed input and output data lists are found in the appended excel book.

3.1 Lab-grown diamond production

The diamonds used in the rings are lab-grown diamonds produced by the LGD Suppliers. Rough diamonds are synthesized in the USA. The lab-grown diamonds are then transported to India for cutting and polishing. The finished lab-grown diamonds are transported to Thailand, to be used in Pandora's production at the OEM sites.

The cutting and polishing of the lab-grown diamonds occur in India. The Renewable Energy Certificates (RECs) have been purchased for the energy needed to cut and polish all the lab-grown diamonds needed for the Diamonds by Pandora collection. The documentation is provided for review.

The RECs for cutting and polishing were purchased after the LGD Suppliers' (2022) carbon footprint study was completed. Therefore, the RECs are not included in the study. The data for the lab-grown diamond production needed to be modified to include the RECs. The carbon footprint of cutting and polishing (using Indian grid electricity) was subtracted from the total carbon footprint of the lab-grown diamond and substituted by the carbon footprint from cutting and polishing using renewable energy (wind and solar power, according to the RECs documentation). The recalculation is based on the energy consumption (in kWh) for cutting and polishing per carat. The data for wind and solar power is based on Ecoinvent 3 (2022), as implemented in SimaPro (Pré Consultants, 2022).

3.2 Metals

Recycled gold and silver are used and supplied. The alloys consist of primary copper and other primary metals; see specification in Table 2. Several suppliers supply the alloys. In Table 2, primary metals and alloy composition are specified for each ring.

Table 2 Primary material and composition of alloys specified per ring.

Ring	Primary metal	Alloy composition
Sterling silver ring with 0.15 ct lab-grown diamond	silver	Zinc, Copper, Tin, Boron, Silicon
14K Yellow Gold Ring with 1.00 ct. lab-grown diamond	gold	Copper, Zinc
14K White Gold Ring with 1.00 ct. lab-grown diamond	gold	Copper, Zinc, Silicon

3.3 Transport of raw materials

The carbon footprint data of the lab-grown diamond production includes transportation from the production facility to an unknown external service provider in Thailand. For this study, the additional calculation for the transportation of the lab-grown diamond was done from an airport (since the exact location of the external supplier is unknown). Road transport to the designated OEMs was added. The transportation is done with a diesel van, and the distance is the specific distance from the airport to the respective OEM.

The shipment of the metals and alloys from outside Thailand was made by air. A diesel van was assumed for all road transport between airports and sites. That is, from the production facility to the nearest airport and from the airport to the OEMs.

3.4 Complete rings production

The OEMs receive the main metals and alloys from the suppliers. The metal rings are cast and pre-polished. The lab-grown diamond is set (mounted), and the final polishing of the complete ring is done before it is packaged.

An individual ring is first put in a smaller plastic zip-lock bag, and then 100 rings are collected in a larger plastic zip-lock bag. At one group of OEMs, ten large bags are put in a cardboard box, i.e., containing 1000 rings. The small bags are labeled at another group of OEMs, and a small piece of paper is put together with the ring. Next, 30 large bags (containing 100 rings) are put in a cardboard box, i.e., now containing 3000 rings. The boxes from both OEMs are delivered via a diesel van to Pandora's storage facility in Bangkok.

The two OEMs deliver different quantities of each ring to Pandora. The shares of delivery percentage are listed in **Error! Reference source not found.**. The share affects the final ring's carbon footprint impact since the OEMs have a slightly different impact per ring.

The electricity mix used at the suppliers is a low voltage mix for the Thailand market. Most auxiliary materials used in production are specified by one group of OEMs and used in the study. The data amount for auxiliary materials provided by another group of OEMs were less than that of the data received from other OEMs. Some of the auxiliary materials were left out due to data gaps.

After the rings are finished, they are transported to Pandora's storage facility, where they are further shipped to Pandora stores, see section 3.5. Diesel vans made the ring transportation between the OEMs and Pandora facility.

3.5 Transport to stores

From Pandora's storage facility, all the rings are transported to the Pandora distribution centers for each market and then to the stores. For this study, the North American market was chosen as a focus; thus, the transport considered was concerning transportation to Pandora stores in the USA and Canada. The rings are assumed to be transported to the distribution center in Baltimore by plane. Then further on with air service to cities where stores are located. The transportation from the airport to the stores is assumed to be made by a diesel van.

There are numerous Pandora stores, and no data was collected on specific transportation routes to each store or any average distances. Therefore, this study considers an average shipment scenario based on an average transport distance to three locations – Los Angeles, New York, and Toronto. The transportation to each location was calculated, and then an average was considered. As mentioned above, the shipment from Baltimore is made by air service. From each respective city airport, the transportation was considered to be by a diesel van. The distances were chosen for stores located in the area but furthest away from the airport. These assumptions were made to account for conservative scenarios.

3.6 Ring box production and transport

The rings are sold in a ring box; see Figure 3. The ring boxes are produced in China, shipped to Pandora's warehouses worldwide, and from there to the stores. Jewelry is placed in boxes in the Pandora stores.

Figure 3 Pandora ring boxes

The ring box contains paper/cardboard and textile with water-based matt varnish and print.

The ring boxes are packed for transportation. The ring boxes are packed into inner boxes (48 boxes per inner box) and then in a master (outer) box (336 ring boxes in a master box). The packages are transported with the use of a EUR pallet. In this study, the shipment of the boxes is calculated to the North American market, similarly to the rings.

The boxes are transported from China to the USA by boat and plane (50% / 50%). The shipment is considered from Shanghai to Baltimore. From Baltimore, they are transported to the stores. The transport from Baltimore was calculated the same way as for the rings; see the detailed description in 3.5.

3.7 Use phase

The customers' transport to the store is not included in the study as it is considered that the customers do not travel to Pandora stores separately but rather do that in junction with other errands.

The use phase includes polishing the rings. Based on information from Pandora, it is assumed that professional polishing is done once a year for gold rings and once every 5 years for the silver ring. The energy consumption for the polishing is calculated from the energy consumption of a buffing machine per minute and the time for one polishing. The time for one polishing was assumed to be 5 minutes. No transportation is included for the polishing as it is assumed that this is done in combination with other errands.

3.8 End-of-life phase

At the end-of-life phase, the rings are assumed to be sold for recycling. The metals are sent to recycling, where gold is recovered from the yellow and white gold rings, and silver is recovered from the silver ring. Since there is a data gap concerning the end-of-life and diamond recovery rates, a worst-case scenario was assumed. The lab-grown diamond is assumed to be discarded, i.e., landfilled.

No burdens of the recycling process or benefits of recycling are included in the study, following the cut-off approach allocation method, see 2.4.

The end-of-life of the ring box and all the packaging is included in the study. The carton/paper in the ring box and its packaging and the rings' packaging are sent to recycling, incineration, and landfilling (62%, 7%, and 31%, respectively) (EPA, 2018a). The textile from the ring box is assumed to be sent to a landfill (EPA, 2018b). The EUR-pallet is assumed to be incinerated.

Transportation to the recycling facility is included (for the ring and all packaging), and the impact is calculated based on the emission factor for waste transportation (UK Government, 2021).

3.9 Sensitivity analyses

This section presents the background for the analysis for estimating the effects of the choices made regarding electricity mix data and allocation on the outcome of the main study.

3.9.1 Electricity mix for cutting and polishing

At the time of the LGD Suppliers’ carbon footprint study, the production of the lab-grown diamond was only partly based on using renewable energy. 100% renewable energy was used in the synthesis process (in the USA). However, ordinary grid electricity was used in India for cutting and polishing processes. At the request of Pandora, the LGD Suppliers have purchased Renewable energy certificates (RECs) for the electricity used to cut and polish the lab-grown diamonds used in the Diamonds by Pandora collection. The documentation supporting this is provided for review. This change makes the lab-grown diamonds in the collection produced with 100% renewable energy (wind and solar), which is reflected in this study. However, according to the standard (ISO, 2018), a sensitivity analysis should be done in cases using green electricity certificates. Therefore, sensitivity analyses without using REC for cutting and polishing are included in the study. In this case, the original data from the LGD Suppliers’ study is used for lab-grown diamond production without any modifications.

3.9.2 Allocation

The allocation method used for recycled materials is the cut-off approach. However, the informative Annex D (ISO, 2018) suggests other allocation principles, such as closed-loop allocation and open-loop allocation; therefore, a sensitivity analysis was done using closed-loop allocation to explore the potential differences in the results.

The closed-loop allocation of recycling applies when the material is recycled back into the same product life cycle or recycled into another product but without a change in inherent material properties. Since gold and silver are recycled without much change in the material, a closed-loop approach could be applicable in this study. The closed-loop approach suggested by ISO 14067 (informative Annex D) implies that all burdens and benefits of recycling are assigned to the product that generates recycled material. Thus, using recycled material is assigned the same burdens as using primary material. For the sensitivity analysis, virgin gold and silver emission factors were used instead of the recycled/secondary emission factors used in the main study. The burdens and benefits of recycling silver and gold were included during the end-of-life phase.

The gold recovery rate in the yellow and white gold rings is assumed to be 90% (Gold.info, 2022; Sphera Solutions GmbH, 2020), while the silver recovery rate in the silver ring is 20% (The Silver Institute, 2021). The silver in the white gold ring is assumed not to be recovered. The other metals, e.g., materials in the alloys, are assumed not to be recovered. This omission is a conservative assumption to avoid overestimating the benefits of recycling. Hence, no credit is given for recycling the alloys.

4. RESULTS

The results from the main study are presented for each ring together with the two sensitivity analyses concerning the electricity mix and allocation approach.

4.1 Sterling silver ring with 0.15 carat lab-grown diamond

The carbon footprint of the entire life cycle of the silver ring with 0.15 carat lab-grown diamond produced with 100% renewable electricity is calculated to be 2.88 kg CO_2e. The total impact and distribution between different life cycle stages are presented in Figure 4 and Table 3 below.

Table 3 Carbon footprint of the sterling silver ring with 0.15 ct. lab-grown diamond

	Raw materials excl lab-grown diamond	Production of lab-grown diamond	OEM Process	Transport	Ring box	Transport to store (ring + box)	Use phase	End-of-life	**TOTAL**
Sterling silver ring with 0.15 ct. TW	0.047	1.375	0.695	0.004	0.052	0.525	0.161	0.017	**2.88**

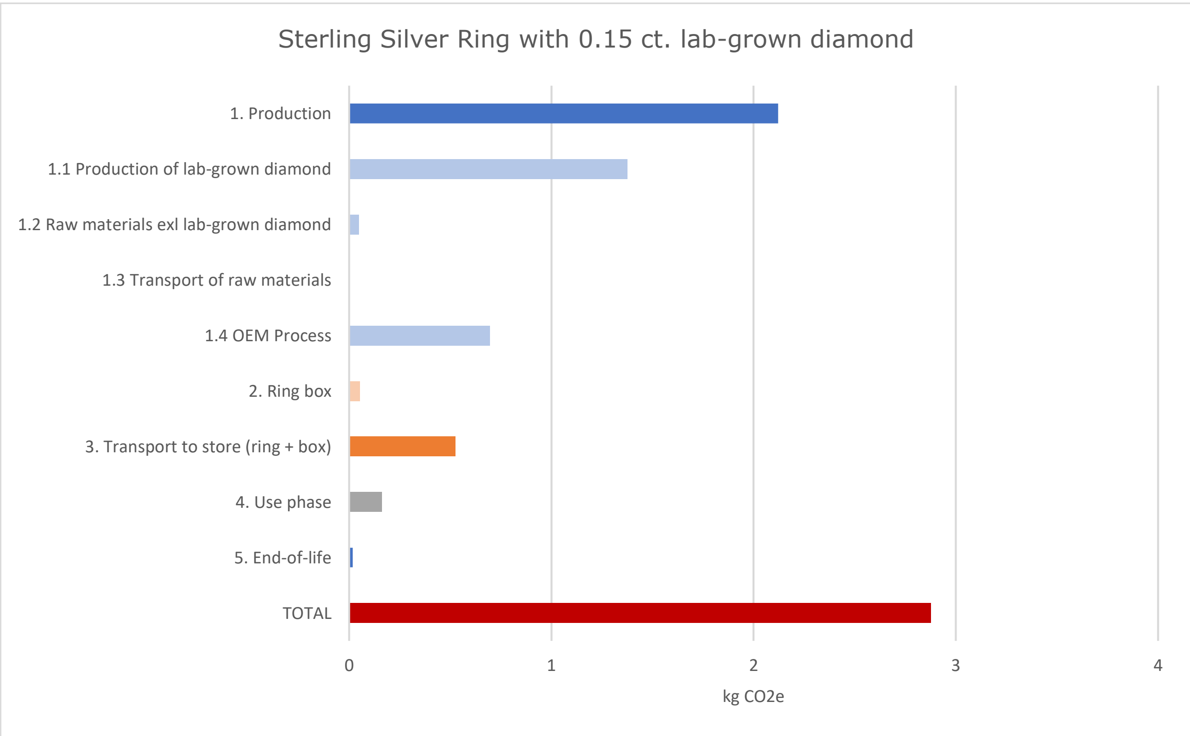

Figure 4 Carbon footprint of the sterling silver ring with 0.15 ct. lad-grown diamond

As seen in Figure 4, the carbon footprint is dominated by the production of the ring, which stands for approximately 74% of the total life cycle carbon footprint. The lab-grown diamond has the highest contribution to the silver ring carbon footprint, with 48% of the total impact. Lab-grown diamond production stands for 65% of the complete production carbon footprint. The silver ring's second highest impact (24% of the total) originates from the OEMs. i.e., the production of the ring, which is dominated by electricity use.

The third most significant impact contributor is the transport of the ring from production to the stores, with 18% of the total carbon footprint. The air transport of the rings and boxes from the Pandora storage to Pandora stores in North America (although an average) completely dominates the impact; the road transport is insignificant in comparison.

4.1.1 Sensitivity analysis – electricity mix for cutting and polishing

The sensitivity analysis comprises using Indian grid electricity for the cutting and polishing process instead of renewable energy with RECs. The results are presented in Figure 5 and show that the total carbon footprint of the silver ring almost doubles without the use of RECs in the cutting and polishing process. When using RECs in the cutting and polishing phase, the highest impact on lab-grown diamond production comes from the synthesis. This impact is because lab-grown diamond synthesis contributes a large share of the total carbon footprint, even when using 100% renewable energy. In contrast, without RECs, the most significant part of the lab-grown diamond's carbon footprint becomes cutting and polishing. Hence, the choice of energy used for lab-grown diamond production dramatically impacts the overall result.

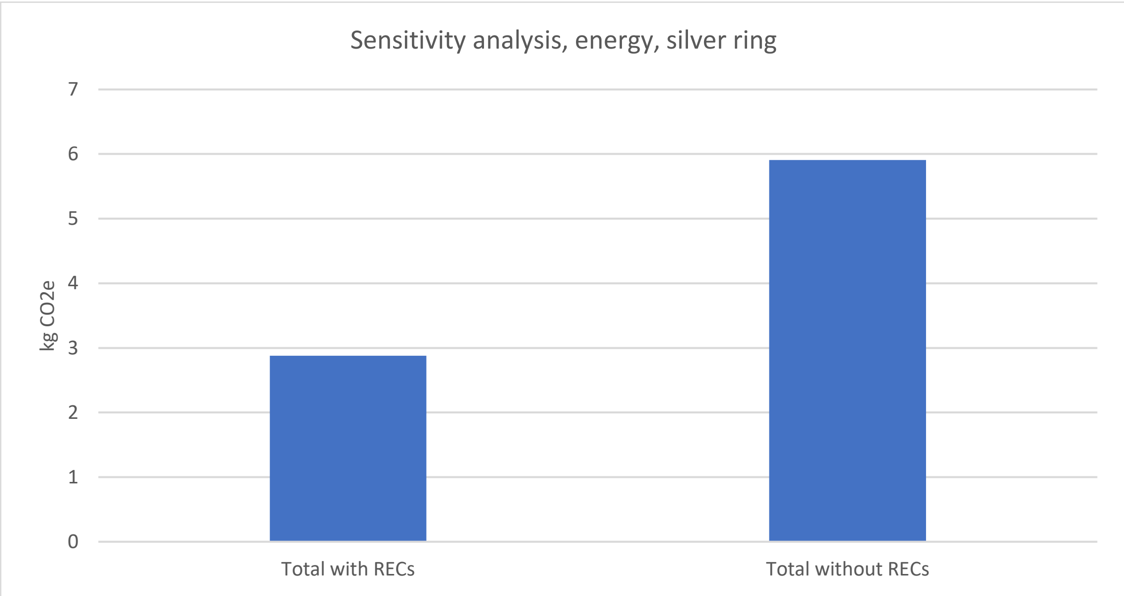

Figure 5 Carbon footprint of a silver ring with and without the use of RECs for the cutting and polishing process

4.1.2 Sensitivity analysis – allocation

The sensitivity analysis results with the closed-loop allocation are presented in Table 4 and Figure 6. The overall carbon footprint over the entire life cycle is higher when using closed-loop allocation than the cut-off approach. The closed-loop allocation leads to a higher impact from the raw materials since there is no benefit to using recycled content. If only considering cradle-to-gate impacts, the cut-off approach leads to a significantly lower carbon footprint compared to the closed-loop allocation approach.

Table 4 Results of the sensitivity analysis with the closed-loop allocation compared to the main approach

	Sterling Silver Ring with 0.15 ct. lab-grown diamond	
	Cut-off approach	Closed-loop allocation
Cradle-to-gate	2.12	3.49
Transport to customer	0.58	0.58
Use phase	0.16	0.16
End-of-life	0.02	-0.17
Total	**2.88**	**4.05**

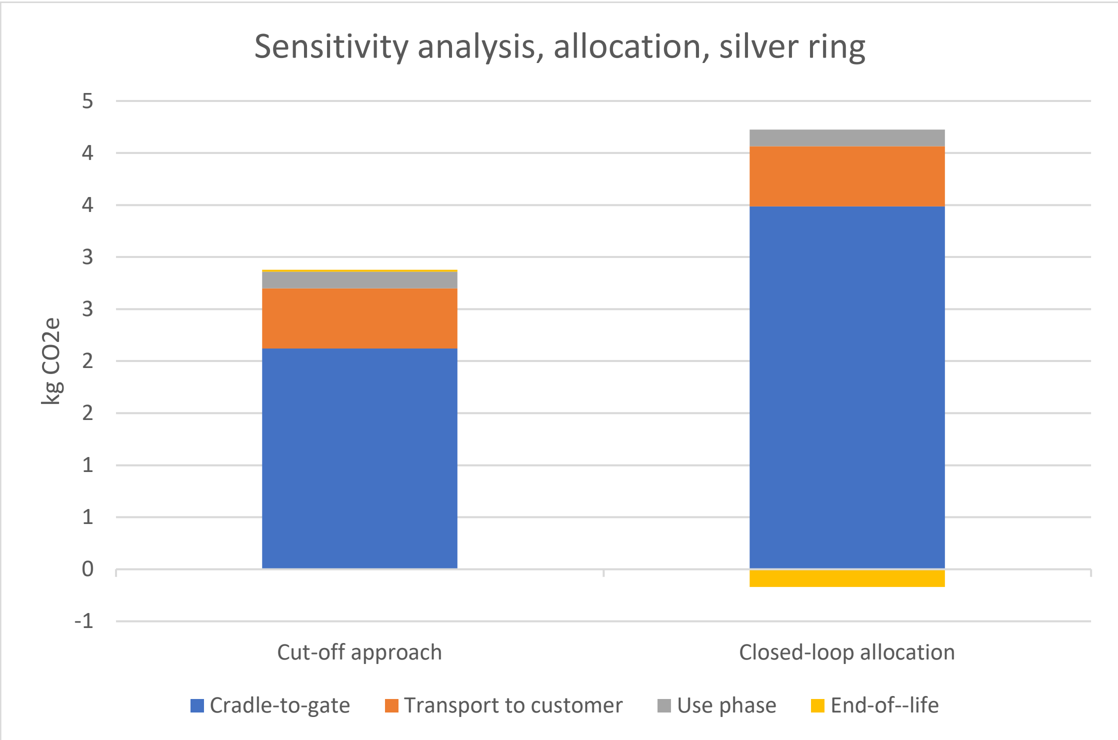

Figure 6 Carbon footprint of a silver ring with 0.15 ct. lab-grown diamond with two allocation approaches

4.2 Yellow gold ring with a 1 ct. lab-grown diamond

The carbon footprint of the complete life cycle of the yellow gold ring with 1 carat lab-grown diamond produced with 100% renewable electricity is calculated to be 11.44kg CO2e. The impact distribution between different life cycle stages is presented in Table 5 and Figure 7.

Table 5 Carbon footprint of the yellow gold ring with 1 ct. lab-grown diamond

	Production of lab-grown diamond	Raw materials excl. lab-grown diamond	Transport of raw materials	OEM Process	Ring box	Transport to store (ring + box)	Use phase	End-of-life	TOTAL
14K GOLD RING WITH 1.00 ct. TW GJ VS2	9.170	0.101	0.023	0.722	0.052	0.551	0.806	0.017	**11.44**

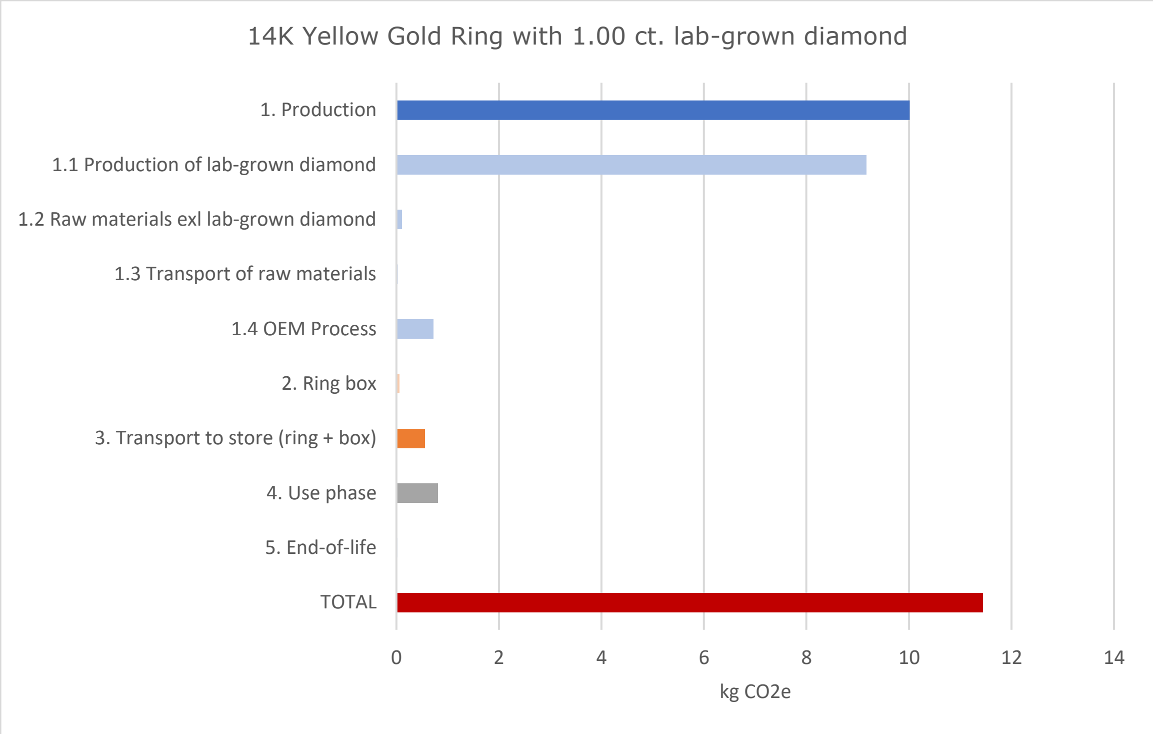

Figure 7 Carbon footprint of the yellow gold ring with 1 ct. lab-grown diamond

Figure 7 illustrates that the carbon footprint is dominated by the production of the ring, which stands for approximately 88% of the total life cycle carbon footprint. The lab-grown diamond contributes the most, with 80% of the total impact. Lab-grown diamond production stands for 92% of the production carbon footprint. The second highest impact of the yellow gold ring footprint originates from the use phase (7%) due to the polishing of the ring. The use phase impact is closely followed by the OEM process (6%), which is dominated by electricity use.

4.2.1 Sensitivity analysis – electricity mix for cutting and polishing

The sensitivity analysis comprises using Indian grid electricity for the cutting and polishing process instead of renewable energy with RECs. The results are presented in Figure 8 and show that the total carbon footprint of the yellow gold ring almost doubles without the use of RECs in the cutting and polishing process. When using RECs in the cutting and polishing phase, the highest impact on lab-grown diamond production comes from the synthesis. This impact is because lab-grown diamond synthesis contributes a large share of the total carbon footprint, even when using 100% renewable energy. In contrast, without RECs, the most significant part of the lab-grown diamond's carbon footprint becomes cutting and polishing. Hence, the choice of energy used for lab-grown diamond production dramatically impacts the overall result.

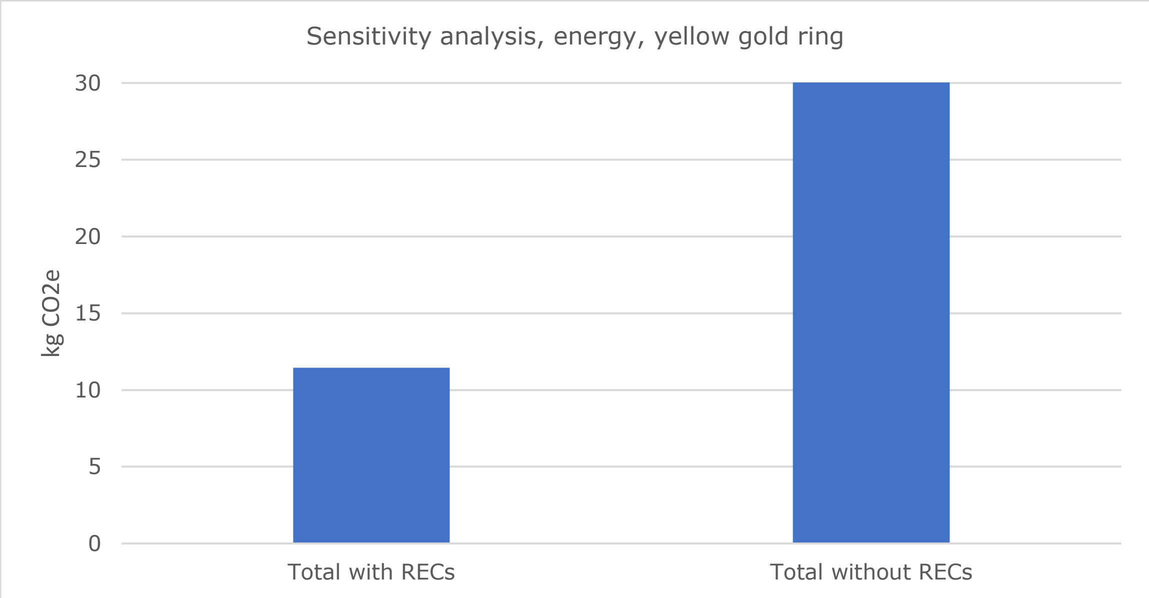

Figure 8 Carbon footprint of a yellow gold ring with and without the use of RECs for the cutting and polishing process

4.2.2 Sensitivity analysis – allocation

The sensitivity analysis results with the closed loop allocation are presented in Table 6 and Figure 9 below. The overall carbon footprint over the whole life cycle is higher when using closed-loop allocation due to the accounting for burdens of virgin metals, which is not included when using the cut-off approach allocation method. However, the cut-off approach leads to a significantly lower carbon footprint when only considering the cradle-to-gate phases.

Table 6 Results of the sensitivity analysis with the closed-loop allocation compared to the main approach

	14K Yellow Gold Ring with 1.00 ct. lab-grown diamond	
	Cut-off approach	Closed-loop allocation
Cradle-to-gate	10.02	76.08
Transport to customer	0.60	0.60
Use phase	0.81	0.81
End-of-life	0.02	-59.38
Total	**11.44**	**18.11**

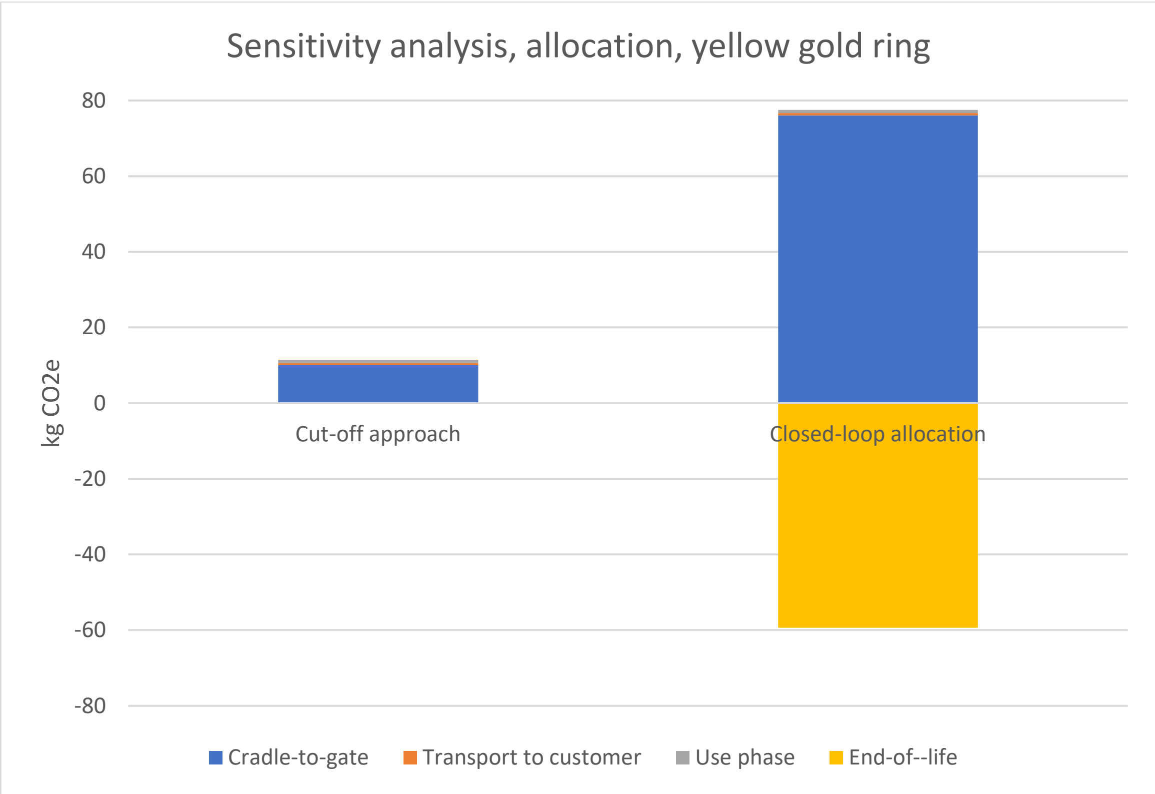

Figure 9 Carbon footprint of a yellow gold ring with 1 ct. lab-grown diamond with two allocation approaches

4.3 White gold ring with a 1 ct. lab-grown diamond

The carbon footprint of the complete life cycle of the white gold ring with 1 carat lab-grown diamond produced with 100% renewable electricity is calculated to be 11.40 kg CO2e. The total impact and distribution between different life cycle stages are presented in Table 7 and Figure 10.

Table 7 Carbon footprint of the white gold ring with 1 ct. lab-grown diamond

	Production of lab-grown diamond	Raw materials excl. lab-grown diamond	Transport of raw materials	OEM Process	Ring box	Transport to store (ring + box)	Use phase	End-of-life	**TOTAL**
14K WHITE GOLD RING WITH 1.00 ct. TW	9.170	0.101	0.004	0.696	0.052	0.552	0.806	0.017	11.40

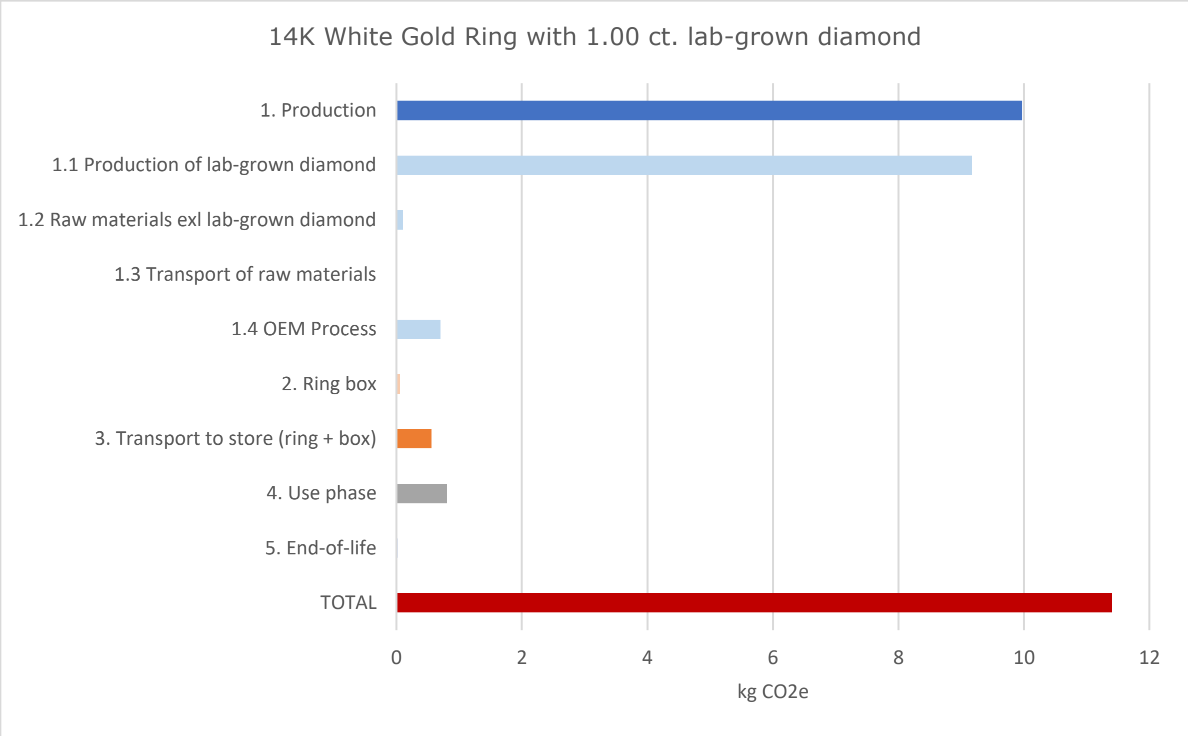

Figure 10 Carbon footprint of the white gold ring with 1 ct. lab-grown diamond

In Figure 10, it is apparent that the carbon footprint is dominated by the production of the ring, which stands for approximately 87% of the total life cycle carbon footprint. The lab-grown diamond contributes the most, with 80% of the total impact. Lab-grown diamond production stands for 92% of the production carbon footprint. The second highest impact of the white gold ring footprint originates from the use phase (7%) due to the polishing of the ring. The use phase impact is closely followed by the OEM process (6%), which is dominated by electricity use.

4.3.1 Sensitivity analysis – electricity mix for cutting and polishing

The sensitivity analysis comprises using Indian grid electricity for the cutting and polishing process instead of renewable energy with RECs. The results are presented in Figure 11 and show that the total carbon footprint of the white gold ring almost doubles without the use of RECs in the cutting and polishing process. When using RECs in the cutting and polishing phase, the highest impact on lab-grown diamond production comes from the synthesis. This impact is because lab-grown diamond synthesis contributes a large share of the total carbon footprint, even when using 100% renewable energy. In contrast, without RECs, the most significant part of the lab-grown diamond's carbon footprint becomes cutting and polishing. Hence, the choice of energy used for lab-grown diamond production dramatically impacts the overall result.

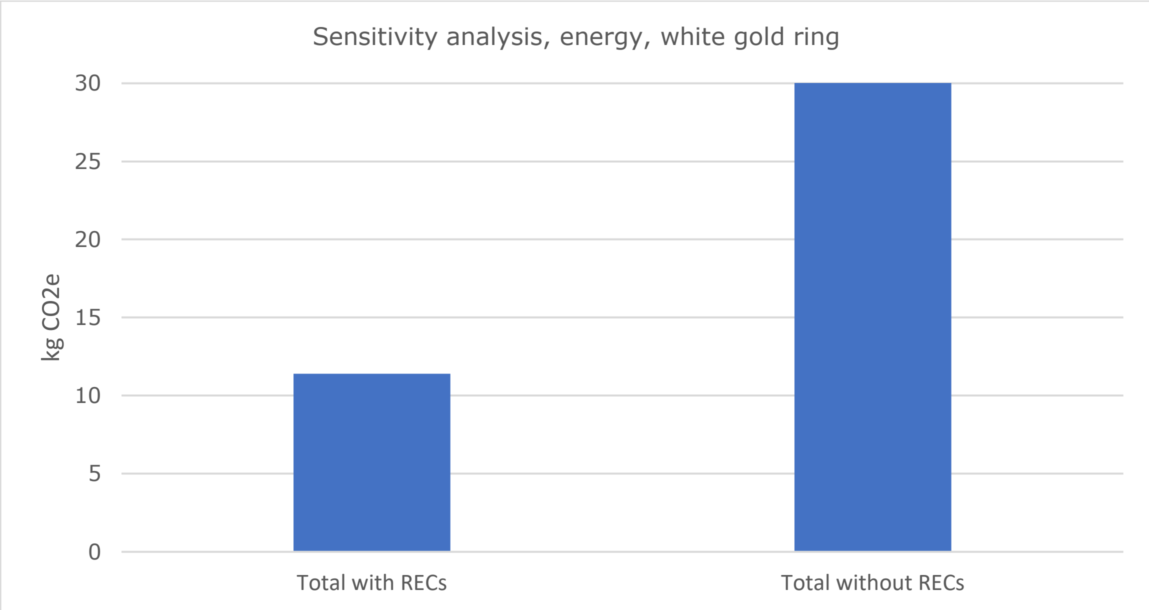

Figure 11 Carbon footprint of a white gold ring with and without the use of RECs for the cutting and polishing process

4.3.2 Sensitivity analysis – allocation

The sensitivity analysis results with the closed loop allocation are presented in Table 8 and Figure 12 below. The overall carbon footprint over the complete life cycle is higher when using closed-loop allocation due to the impact of virgin metals, which is not included when using the cut-off approach allocation method. If only considering cradle-to-gate, the cut-off approach delivers a significantly lower carbon footprint.

Table 8 Results of the sensitivity analysis with the closed-loop allocation compared to the main approach

	14K White Gold Ring with 1.00 ct. lab-grown diamond	
	Cut-off approach	Closed-loop allocation
Cradle-to-gate	9.97	75.40
Transport to customer	0.60	0.60
Use phase	0.81	0.81
End-of-life	0.02	-58.79
Total	**11.40**	**18.02**

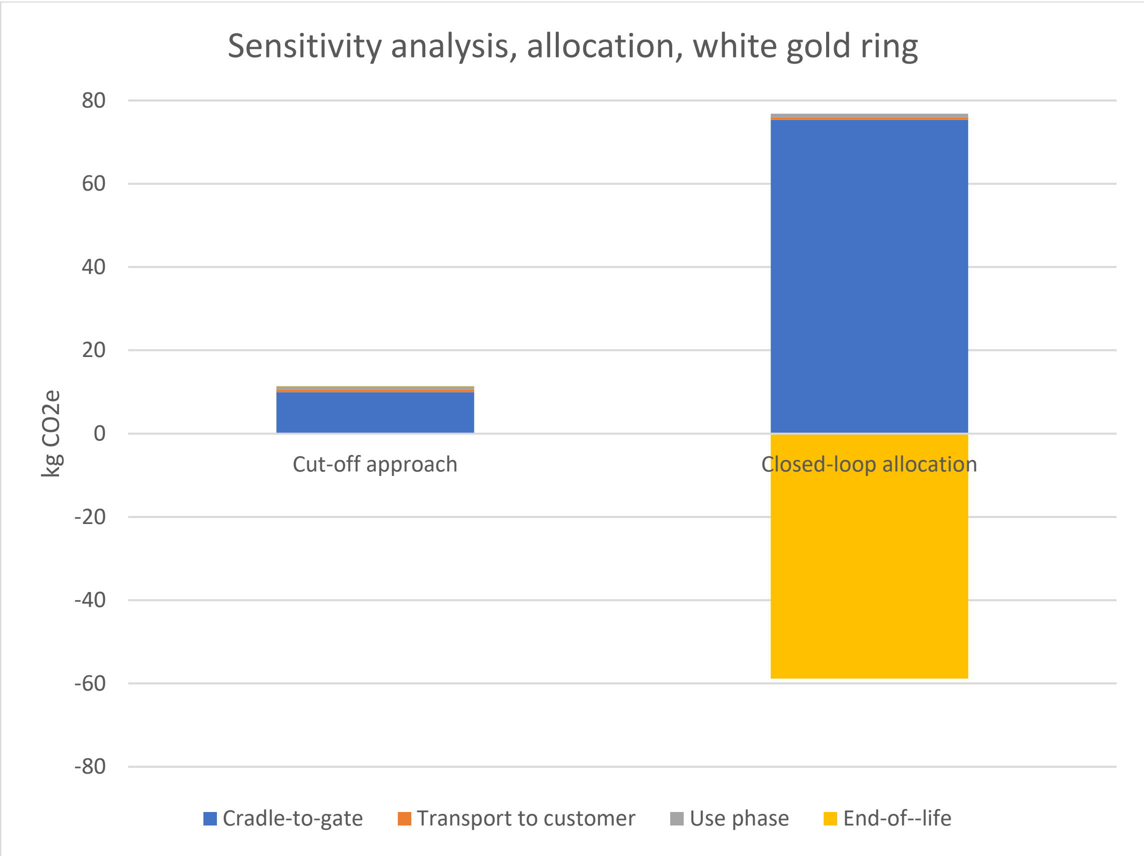

Figure 12 Carbon footprint of a white gold ring with 1 ct. lab-grown diamond with two allocation approaches

4.4 Limitations

This study has several uncertainties and limitations that might affect the results. These could be a consequence of, e.g., data gaps and quality. In general, assumptions have been made conservatively following the precautionary principle to avoid underestimating the impact of unknown data.

The explicit underlying greenhouse gases, e.g., CH_4 and N_2O, are not presented or calculated separately. This limitation means that the contribution of different greenhouse gases is unknown. It is unclear what emissions are accounted for and, as a consequence, the transparency of this study is affected. There might also be an inconsistency between the characterization factors in this study and referenced study from the LGD Suppliers (2023) and Sphera Solutions GmbH (2020).

The data collected from the two Pandora's OEMs in Thailand vary in completeness. One group of OEM's process and auxiliary material data are much more detailed, while other OEMs' data are less detailed. However, the impact share originating from auxiliary materials from OEMs are slight compared to impact from, e.g., raw materials. This small share indicates that the auxiliary material data gap from OEMs is not likely to have a noticeable impact on the total results.

There are uncertainties and data gaps in the ring box production – the production process data is missing, and thus the impact of the ring boxes might be underestimated. The data gap is assumed to have an insignificant effect on the result since the process impact with a high probability is lower than the ring box material impact and the total contribution by packaging is minimal.

There are uncertainties concerning the transportation routes for the rings and ring boxes. Conservative assumptions are made to decrease the risk of underestimating the impact.

The impacts of the Pandora retail store are not included in the study. The retail impacts are to be allocated to all jewelry sold at the shop, and the impact shared by a ring is assumed to be very small or insignificant. Hence, the final effect on the result is minor.

The customer's transportation to a store and a jeweler for polishing is not included. It is assumed that visits to a Pandora store are done together with other errands, and the impact of that transportation is shared between the different activities making it very small or insignificant. However, if a customer drives a car specifically to go to a Pandora store, that would significantly affect the total carbon footprint of the ring. It could be argued that since Pandora cannot influence the customer’s traveling habits directly, the impact of customer transport should be omitted from this study.

The reuse rate of the lab-grown diamond is assumed to be 0%. There is a data gap concerning diamond reuse rates, and a worst-case scenario was assumed to avoid overestimating the benefits in the end-of-life phase. It is not unreasonable to assume that some lab-grown diamonds are reused in new jewels, other applications, or similar. The lab-grown diamond end-of-life phase benefit might be underestimated in this study.

One general limitation of any carbon footprint study is that it does not include other resource uses and environmental impact categories. This limitation could lead to an impact shift between life cycle phases or other impact categories when intended measures are applied to lower the carbon footprint.

5. CONCLUSIONS AND DISCUSSION

The carbon footprint was calculated cradle-to-grave for three lab-grown diamond rings, and the results for the main study and sensitivity analyses are presented and discussed. The total carbon footprint is 9.17 kg CO_2e per grown, cut, and polished 1 carat lab-grown diamond.

The total carbon footprint of the Sterling silver ring with a 0.15 carat polished, lab-grown diamond is 2.88kg CO2e.

The total carbon footprint of the Yellow gold ring with a 1 carat polished, lab-grown diamond is 11.44kg CO2e.

The total carbon footprint of the White gold ring with a 1 carat polished, lab-grown diamond is 11.40kg CO2e.

In the main study, the results show that the primary contributor to the carbon footprint is the production of the lab-grown diamond, which stands for 48%, 80%, and 80% for the silver, yellow gold, and white gold rings, respectively. Any improvements in the value chain should be directed toward diamond production. The synthesis process is the most energy-demanding part, even more extensive than the energy demanded by the cutting and polishing process (Sphera Solutions GmbH, 2020). It can also be noted that the cutting and polishing process is similar regardless of the origin of the diamonds. Since the data concerning the lab-grown diamonds is from a carbon footprint study with restricted access to the complete study and data, it is challenging to pinpoint detailed improvement areas.

5.1 Sensitivity analysis – electricity mix

The sensitivity analysis with the change of electricity mix for cutting and polishing emphasized the electricity choice's importance for diamond production as well as the overall carbon footprint of the ring. Without the use of RECs for the cutting and polishing process, the impact of the silver ring would be nearly doubled and close to tripled for the yellow and white gold rings carbon footprint.

5.2 Sensitivity analysis – allocation

The allocation choice is less critical if the whole life cycle is considered, but the impact differs depending on the approach. The closed-loop allocation approach results in a higher impact for all analyzed rings. This difference is due to the raw materials since there is no benefit to using recycled content. However, accounting for the benefits of recycling leads to a moderately lower carbon footprint, though not as low as the cut-off approach. The choice of allocation method also showed a higher impact on the gold rings' carbon footprint than the silver ring since the impact of the virgin gold is much higher than silver. It should be noted that if any benefits were credited to a share of diamond reuse, the total impact of the closed-loop allocation would be lower than that of the cut-off approach.

The sensitivity analysis concerning the allocation choice shows that the impact of the main metals (gold and silver) is relatively low owing to the recycled content. The overall impact would be significantly higher if virgin metals were used instead of recycled. The impact share by virgin gold is eight times higher than that from the diamond production of a 1 ct. stone. The emission factor for virgin gold is about a factor of 600 higher than for recycled gold.

This study has some limitations that might affect the results. In general, assumptions have been made conservatively following the precautionary principle to avoid underestimating the impact of unknown data. The results in this study are potential and not predictions of impacts.

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7. REVIEW REPORT ON CARBON-FOOTPRINT STUDY OF THREE PANDORA RINGS

Tomas Ekvall, Gothenburg, August 10th 2022

7.1 Summary

This carbon-footprint (CFP) study is based on the international standard for CFP: ISO 14067. The methods used in the calculations are consistent with the standard. The choice of data sources is adequate. The calculations are commendably transparent. They are also correct, given the methodological choices made in the study. The main results and conclusions of the study are valid given these choices.

Several aspects of the rings, their production, and the calculation methods combine to reducing the results in the main calculations:

- there is no Rhodium plating on the rings,
- the gold and silver in the rings are recycled metals,
- the production, cutting and polishing of diamonds are done with electricity contracted as renewable energy, and
- the main calculation approach is attributional, which means that the rings benefit fully from the use of recycled material and from the use of renewable electricity.

The study report is clear and concise. The short format makes the report accessible to readers. However, it does not allow for including all information required by the international standard.

7.2 Background

The jewelry company Pandora commissioned Ramboll to compare the carbon footprint (CFP) of three diamond rings in the Diamonds by Pandora Collection. The study is made using the methodology of the international standard for carbon footprints of products (ISO 14067:2018), which in turn is based on the standard for life cycle assessment (LCA; ISO 14044:2006). The results will be used for marketing purposes, but are not intended to be used for comparisons between the rings or with other competing products.

Due to EU legislation on green claims, Pandora needs a 3rd party verification of the environmental claims that will be based on the carbon footprint calculations. ISO 14067 requires that a review, if any, is conducted according to ISO/TS 14071.

The focus of this review is on:

- the consistency with the methodology in ISO 14067
- a selection of important input data
- important parts of the calculations
- the results of the study; and
- the validity of the conclusions, given the goal, scope and limitations of the study.

The review also addresses the completeness of the report in relation to requirements in ISO 14044 and ISO 14967, and the transparency and technical validity of the report. ISO 14044 (§5.2) requires that a transparent third-party report be made available to any external party to which the results are communicated. Section 5 in ISO 14044 and Section 7 in ISO 14067 details what should be included in such a report.

The review was made in three rounds. A first set of written comments was based on partial carbon footprint calculations provided by Ramboll. A second set of comments was written based on a preliminary full CFP report from Ramboll. This final review report is based on a revised report for internal use at Pandora. The publicly available report will exclude confidential information that is available in the internal report.

Because of the iterative process and constructive cooperation by staff at both Ramboll and Pandora, most of the review comments have been adequately dealt with before this final review statement.

7.3 General comments

This CFP study relies on data from previous cradle-to-gate studies made on behalf of Pandora for the most important parts of the value chain: the production, cutting and polishing of diamonds, the production of gold, and the production of silver. The reports from these studies were made available to the reviewer, which made it possible to review these data to some extent. Much of the remaining input data are from the Ecoinvent database, but these data had little impact on the total results.

The use of cradle-to-gate data from other studies made the calculations less complex for Ramboll. These calculations were done and presented in MS Excel with commendable transparency and clear references. A few calculation errors were found and eliminated in the review process.

The methods used in the calculations are consistent with ISO 14067. The main calculations deviate from the possible procedures for modelling recycling presented in Annex D of the standard. However, this annex is informative and not normative, which means that the calculations need not adhere to it. Also, the approach suggested in by Annex D is applied in a sensitivity analysis in the CFP study.

The main calculations approach is attributional, which means it only accounts for emissions that occur in the life cycle of the rings. A consequential approach, in contrast, accounts for impacts on emissions that occur both within and beyond the boundaries of the life cycle.

The calculations are all made in CO_2 equivalents, rather than in terms of emitted substances (CO_2, CH_4, N_2O, etc.). As indicated in Section 4.4, this reduces the transparency of the study.

7.4 Diamond production

This part of the calculations is based on data from suppliers, but revised and updated by Ramboll. The electricity used for growing the diamonds and for cutting and polishing the stones are bought with Renewable Energy Certificates, which allows for the use of low emission factors for electricity production in calculations. This is extremely important for the total results, as indicated by the report, because even with the low emission factors, the electricity used for diamond production dominates the climate impact of the rings.

7.5 Metals

The gold and silver in the rings are recycled metals. This is particularly important for the gold rings, as indicated by the sensitivity analysis on allocation (Subsections 4.2.2 and 4.3.2).

The rings are not coated with Rhodium, which is otherwise common for jewelry of white gold and Sterling silver. As indicated in Section 4.4, this can be significant for the results since Rhodium-plated rings need to be replated several times during the use phase to retain the color and shine.

7.6 Auxiliary materials

Almost all processes use a host of auxiliary materials. Most data sets in the study, however, include an incomplete set of auxiliary materials or do not include auxiliary materials at all. Hence, the list of excluded auxiliary materials is probably much longer than what is indicated in Section 2.5; the production of most auxiliary materials used in the life cycle is probably not included in the calculations. This is not likely to have a noticeable or at least not significant impact on the total results.

7.7 Transports

The climate impact of transports is estimated through an ambitiously elaborate calculation. The total transports in the life cycle have a climate impact of over 0.5 kg CO_2-eq. per ring. This is nearly 20% of the total climate impact of the silver ring. The unusually high impact of transports is because the rings and their packaging material are transported by air between and across continents.

7.8 Use phase

The use of the rings is modelled under the assumption that the silver rings are polished on average every 5 years, while the gold rings are polished every year. These assumptions are based on information from Pandora. Given the variability of consumer behavior, the impact of the use phase is likely to depend heavily on the specific user. However, the impact on the total results is limited. If a gold ring is polished only once in 5 years, the impact of the ring is reduced by 0.54 kg CO_2-eq., which is about 5% of its total climate impact.

7.9 Sensitivity analysis – allocation at recycling

A sensitivity analysis with the closed-loop approach is included in the study, because the international standard requires a sensitivity analysis when several allocation methods are applicable. The closed-loop approach is the method suggested by 14067, when recycling does not significantly affect the inherent properties of the materials. The closed-loop approach means that the use of recycled material is considered equivalent to the use of primary material. The full benefit of recycling is instead assigned to the product generating material for recycling.

The application of the closed-loop approach requires data or assumptions on the recycling and reuse rates of the rings after use. In this study the recycling rate is 90% for gold and 20% for silver. It accounts for no credit for recycling of other metals or for reuse of the diamonds. These are conservative choices, and contribute to increasing the results for the rings in this sensitivity analysis.

7.10 Sensitivity analysis – electricity

ISO 14067 (§6.4.9.4.4) states that a sensitivity analysis with average grid data should be made when green certificates are used in a country where such certificates can be sold without excluding the renewable energy from the supplied (residual) mix. The report includes a sensitivity analysis where average grid data are used for electricity in India, but REC data for electricity in the US. This reflects a situation where green certificates can be sold without excluding the renewable energy from the mix in India, but not in the US.

7.11 Results and conclusions

The results and conclusions are valid given the methodological choices, assumptions, and input data used in this study. Note, though, that many ways to perform carbon footprint calculations are consistent with the international standard. A change in methodology will affect the numerical results.

The main conclusions in the report are modest and seem robust with respect to changes in the methodology.

7.12 The report

The report is clear, concise, and rather brief. The short format makes the report accessible to readers. However, it does not allow for including all information required by a third-party report according to ISO 14044 or a CFP report according to ISO 14067. More information is likely to be missing in the publicly available report, since this will exclude confidential information in the internal report on which this review statement is based.

Part of the missing information (additional input data, additional references, and calculation procedures) is in the Excel file where calculations are made. Non-confidential parts of this file could be made available to readers as supplementary information.