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A Life Cycle Assessment of Jewelry

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ABSTRACT Jewelry is unique in that it is not a necessity, yet it holds sentimental and material value to the owner. Jewelry sales in the US have increased throughout time, meaning the demand for gold has almost always been increasing, as well. With more than half of the gold mined going towards the production of jewelry, it is the product with the highest demand of the resource. However, mining for the metals to produce a piece of jewelry, specifically gold, has negative consequences on both the environment and the people working in or living near mines. This study is a life cycle assessment using OpenLCA to determine the global warming impacts of the mining process of metals used in jewelry production. Our results are surprising in that the global warming potential of a 14 carat gold 8 g piece of jewelry (288.2 kg CO2 eqivalents) was more than 100 times that of an equal mass piece of jewelry made from sterling silver (2.68 kg CO2 equivalents). Gold mining has a high environmental impact, therefore conscious consumerism and purchasing jewelry made of sterling silver may be the better option.

INTRODUCTION

While not a necessity, jewelry is in high demand in both specialty stores and diversified retailers like Target (Bloomfield, 2018). Sales data indicate this demand: in 2016, US jewelry stores sold 31.03 billion dollars of jewelry (Statista, 2019). Some jewelry is passed on through generations or gifted to loved ones, while some is bought merely as an accessory item. Jewelry is also historically significant. Since the discovery of precious stones and metals, like gold, humans have embellished themselves in extravagant pieces of jewelry. Jewelry has served as a symbol of culture and societal and economic class.

A variety of metals are commonly used in the production of jewelry, including silver, gold, copper, platinum and titanium. Most of the metals used in jewelry are mined from ores underground. However, some metals, like silver, can be produced as a by-product when mining for other metals, like copper (King, 2019).

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Gold is especially popular in jewelry production for various reasons. Gold is unique in that it is durable, has monetary value and a unique yellow color – a characteristic that is absent in most other metals (Norgate & Haque, 2012). Of all the gold mined annually 50%, or 2,000 tons, is used in the production of jewelry (Norgate & Haque, 2012). This gold comes from deposits in several locations including Australia, Russia, some countries of South Africa (Norgate & Haque, 2012) and Latin America (Urkidi, 2010). Both open-pit and underground techniques are used to mine for gold, however open-pit is more popular, with cyanide leaching being one of the most common ways to extract gold from rock (Urkidi, 2010). In countries where artisanal, small-scale gold mining takes place, mercury – a lethal chemical to both the environment and living beings – is most commonly used to retrieve gold from sediment (Norgate & Haque, 2012).

Small-scale mining is invasive both to the environment and living organisms. A recent study published in 2018 found a correlation between the prevalence of mercury (Hg) in individuals of communities living near current or abandoned mining sites (Vega, Orellana, Oliveira, Hacon, & Basta, 2018). Mining for metals, both legal and illegal, has also been recognized as one of the top contributors to deforestation in the Amazon. A study released in 2014 shows a significant loss in forest cover between 2001 and 2013, as well as a decrease in forest cover gained (Alvarez-Berríos & Aide, 2014). Mining infrastructure is also thought to bring larger populations of humans into an area, which also increases forest loss and the threat to biodiversity (Sonter, Ali, & Watson, 2018). Different mining techniques cause different types of environmental degradation, just like the extraction of different minerals also has different impacts. Quite possibly the hardest consequences of mining to measure is the affect that high levels of carbon emitted through the mining process will have on biodiversity globally as part of anthropogenic climate change (Sonter et al., 2018).

The Intergovernmental Panel on Climate Change (IPCC) predicts a warmer, drier climate as a result of land use change and degradation among tropical forests. This change in climate is predicted to rapidly change the biomes among South America, including an increase in loss of tropical rainforests (Moraes et al., 2013). One of the largest contributing factors of climate change, resulting in these drier conditions, includes carbon dioxide (CO2) emissions from deforestation (Franchito & Rao, 2013). With oceans and forests sequestering about half of all carbon emissions, these carbon sinks are extremely important when considering future climate scenarios and conditions. Climate change projections that take into consideration future carbon cycles and decreased transpiration from vegetation predict a CO2 concentration about 80% higher than those that do not consider such impacts (Cox et al., 2004). In this study, we quantify the effect of mining metals for jewelry on climate change (measured in kg CO_2 equivalent). Some of mining's contribution to climate change is due to carbon released from deforestation.

This analysis was completed via a life cycle assessment. Life cycle assessments (LCA) are internationally recognized as a systematic way to interpret a product's environmental impact in a cradle-to-cradle perspective. The purpose of this study was to calculate the global warming potential (in kg CO2 equivalents) of mining necessary for an 8g ring (9, 10, 14 and 22 carats of yellow gold) and a sterling silver necklace of equal weight. Our results can be used to inform consumers interested in conscious consumption.

METHODS

The first step to completing the life cycle assessment was to define the functional unit of the experiment. To do this, we had to determine what kind of jewelry was the most popular among consumers – this included weight and carats. To begin researching, we visited several jewelers and conducted face-to-face interviews with the employees, which included questions pertaining to what the most popular items that were sold at that store were, what the most common carat sold at that store was, what the most common type of gold sold at that store was, what the expected lifetime of these pieces were, where the metals were mined from and what alloy metals were used in the pieces. From these interviews, we found that engagement rings were the most popular items, with necklaces being the next popular. Every store had a different type of gold and carat that was the most popular, and most of the stores said each piece should last a lifetime with proper maintenance. None of the employees of the jewelry stores knew where the gold was mined or what alloy metals were mixed in each piece.

It is projected that about 85% of all the world's gold is still in use or available for recycling (Norgate & Haque, 2012). Since there is not necessarily an 'end phase' for gold and none of the jewelers could give an exact date for lifetime we conducted a convenience survey to determine how long a majority of people thought an engagement ring should last to further strengthen the duration aspect of the functional unit. Out of the 40 people that responded, 18 people said an engagement ring should last forever, and 5 people said an engagement ring should last a lifetime. A lifetime is a more quantifiable than forever, and with majority of the jeweler employees responding to this question with the same answer, a lifetime was reasoned a suitable duration. To define how many years a lifetime was we then used the US census website to determine the average age of marriage and the average age of death, from there we took the difference of the two numbers and used this to define a lifetime. In 2017, the average age of marriage of men in the US was 29.5 years, while the average age of marriage of women in the US was 27.4 years, together these ages average to 28.45 years. In 2016, the average lifespan of a man in the US was 76.1 years and 81.1 years for women, which makes for an average lifespan of 78.6 years. After finding the difference between average age of death and marriage in the US, we determined the lifespan of an engagement ring is about 50 years.

From this information, we determined our functional unit, an 8-16 gram item of jewelry lasting for 50 years – including both a heavier weight and lighter weight ring in gold and silver for comparison:

Quantity	One 8g 9k gold ring; One 8g 10k gold ring; One 8g 14k gold ring; One 8g 18k gold ring; One 8g 22k gold ring; One 8g sterling silver ring
Quality	We assumed that the ring was maintained throughout the years it was worn and that rings were typically between $400-$3,500 in cost.
Duration	The difference between the average age of death and the average age of marriage was 50.15, which we rounded to 50 years. This may not be the full lifetime as jewelry can be recycled.

Table 1. Functional unit for jewelry

After determining a functional unit, we chose pieces of jewelry (Table 1) based on our findings to complete the life cycle assessment, and then weighed them. It should be noted that the weight for both the college signet ring and the sterling silver necklace included the stone featured in each piece, however gemstones were outside the scope of this study and therefore not included in the life cycle assessment. It would be interesting to look at the impacts of mining, processing and cutting gemstones in future research.

Once we picked our jewelry and weighed the pieces, we had to determine what alloy metals were used and what percentage of the pieces' weight contributed to what metal. Since the previous face-to-face interviews did not give us any information of alloy metals, we researched the World Gold Council's website to find more information on this topic. There we found a detailed chart explaining what alloy metals are used to make certain types of gold and how much of each metal is used per carat. Using the Silver Institute's website, we determined that sterling silver is most commonly used for jewelry and the most common alloy metal used to produce it is copper. Table 2 gives these numbers for gold from the World Gold Council's website and sterling silver from the Silver Institute's website (The Silver Institute, 2019; World Gold Council, 2019). From here, these percentages determine how much of each metal was used in each of the pieces we weighed. We completed this step for every piece we weighed including all five carats, – 9k, 10k, 14k, 18k, and 22k – three types of gold – yellow (YG), rose (RG) and white (WG) gold.

When all of the percentages were completed, we selected metal processes from Gabi databases to represent the materials used in jewelry creation, then using these inputs, used OpenLCA to convert inputs to impacts (i.e. global warming potential in kg CO_2 equivalents). Some assumptions were made based on the description and technology used to mine each metal. For instance, the gold in this project is mined in a large-scale process using cyanide, the silver is a by-product of copper mining, the copper is mined in three different ways: the Outokumpu process, the ISA smelt, and the Mitsubishi process. Palladium and platinum are mined as a by-products of nickel mining. Using both Gabi precious metals and Gabi nonferrous metals databases in OpenLCA we determined the impacts that mining these specific metals has on the environment, like its effect on global warming. Table 3 shows the data source and reference process for the metals that were entered into OpenLCA. We report results from OpenLCA for yellow gold including various carats in this paper.

RESULTS

The results from OpenLCA included many impacts like eutrophication, acidification, ecotoxicity, human health (considering both carcinogens and non-carcinogens), resource depletion, etc. However, we are focusing specifically on the results pertaining to global warming, which is measured in kg CO2 equivalents. We have also chosen to focus specifically on 14k gold when comparing the impacts of the different pieces together because it was the most common carat among the pieces used in our experiment and it is the middle ground of all five carats data was gathered for.

Table 2 shows our results from OpenLCA for 14 carats, specifically. This table gives an idea of how much CO2 is released per piece depending on its weight. Figure 1 also visually explains the difference in kg CO2 equivalent per piece of jewelry.

After comparing the impacts between each item of jewelry using 14 carats, we wanted to compare how the impacts differed for each piece as a different carat. Table 3 shows the results of this for the 8g men's wedding ring. Figures 2 and 3 give a visual comparison of these numbers. Figure 2 shows the kg CO2 equivalents for the piece of jewelry at each given carat divided among the alloy metals to show exactly how much CO2 equivalent is attributed to each metal. Figure 3 shows the percent of CO2 equivalents released from each metal to emphasize which metal has the biggest impact.

DISCUSSION

Mining of metals necessary to produce an 8g 14k gold men's wedding band are equivalent to about 288kg of CO2. That means for every 1g of gold that is mined, more than 35kg CO2 equivalent are released into the atmosphere. Additionally, we see that white gold has a bigger impact than yellow gold, while only by 3kg or so, due to the added copper in white gold (Table 4). These results were higher than we were expecting. It is important to note that our results reflect the impacts of cyanide gold mining, which is used in large-scale gold mining production, however, small-scale alluvial gold mining utilizes techniques with mercury, which may have far greater impacts considering the lack of safety procedures in place at these mines.

This life cycle assessment included the mining process of jewelry making; therefore, we did not take into consideration the chemicals and heat needed to actually create a piece of jewelry from the metals. However, the mining process makes a big enough statement on its own without the added energy needed to produce the piece of jewelry. Specifically, the mining of gold makes the largest impact. Of the 288.23kg CO2e released from the 8g wedding ring, 287.36 kg, or 99.73%, of that is caused by the mining of gold. While silver comprised 30% of a 14 k yellow gold ring, it contributed less than 1% of the total impact. The large proportion of impacts due to gold compared to the other metals stays consistent throughout all the carats of yellow gold, as well as the increase of total CO2e – anywhere from 10-28% – as carat increases (Table 5; Figure 3).

The impacts of gold mining are high. This can be illustrated by comparison. Take, for instance, an electric bike. According to a life cycle assessment completed in China in 2005, an electric bike has a global warming impact of 8,991.186kg CO2e during its production stage. This means the global warming impact produced due to the mining of metals for the 8g wedding ring is about 3%, of the CO2e released from the production of an electric bike. While this comparison doesn't seem that persuasive consider the average weight of an electric bike with a lithium battery, which is 44.1 lb., compared to the 8g wedding ring (0.01764 lb.). The wedding ring is only 0.04% of the weight of the electric bike, yet the global warming impact of the ring is 3% of that of the electric bike. Bearing in mind the large amount of jewelry that is bought each year in the US, 31.03 billion dollars' worth in 2016 (Statista, 2019), and the considerably small amount of electric bikes sold each year, 77.1 million dollars' worth in 2017 (Statista, 2019), this is a considerable comparison as far as how much of an impact mining for metals, specifically gold, has on the environment.

The results for the global warming impact of silver were considerably less harmful. The mining process for the 8g sterling silver necklace has a global warming impact of 2.68kg CO2e, which is only 00.81% of the CO2 emitted from the mining process for the 8g yellow gold wedding ring (Tables 4 & 5, Figures 1 & 2). It is clear that gold causes the most damage and by mining for silver rather than gold for the purpose of making jewelry the impact would decrease significantly. This is good news for people looking to purchase less impactful jewelry without doing much research into ethical mining and jewelry companies.

For those interested in conscious consumption, some companies and organizations are making an effort to clean up the gold mining industry as far as pollution and environmental degradation is concerned. There are efforts to certify artisanal small-scale mines as official mines run with rules and regulation (i.e. FairMined certifications, the Responsible Jewelry Council, etc.), while other companies are grounding their business in recycled jewelry (i.e. Brilliant Earth). Aware of both the social and environmental consequences surrounding gold mining, the founders of Brilliant Earth wanted to create a market for recycled jewelry. By recycling precious metals from existing jewelry, industrial use metals and electronic components, then refining them back into their pure forms, Brilliant Earth can create high quality jewelry without the same impact as buying newly mined precious metals would have.

Jewelry is a unique want and is symbolic of economic class, relationship status or personal style. And, while it is not a necessity, many pieces of jewelry hold sentimental value, while some jewelry is also fashionable one week and collecting dust in a jewelry box the next. No matter what the purpose or value an item of jewelry has, the impact of mining for metals to produce said piece of jewelry are concerning. The results for gold mining are the most alarming with gold being responsible for nearly 99% of the global warming impact for all the pieces involved in this study. From our results, we can see that silver is clearly the more sustainable choice when it comes to mining for metals. However, combined efforts from mining communities, international efforts to create a more sustainable mining process, and consumer pressure on the mining industry may be an important to revolutionizing the impact of the jewelry industry.

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APPENDIX

Percent metal composition of different jewelry						
	Caratage	Gold(Au)	Silver (Ag)	Copper (Cu)	Zinc (Zn)	Palladium (Pd)
Yellow Gold	9k	37.5%	42.50%	20%		
Yellow Gold	10k	41.70%	52%	6.30%		
Yellow Gold	14k	58.30%	30%	11.70%		
Yellow Gold	18k	75%	15%	10%		
Yellow Gold	22k	91.70%	5%	2%	1.30%	
White Gold	9k	37.5%	62.5%			
White Gold	10k	41.7%	47.4%		0.9%	10%
White Gold	14k	58.30%	32.20%			9.50%
White Gold	18k	75%				25% (or Pt)
White Gold	22k	N/A	N/A	N/A	N/A	N/A
Rose Gold	9k	37.5%	20%	42.5%		
Rose Gold	10k	41.70%	20%	38.3%		
Rose Gold	14k	58.30%	9.2%	32.5%		
Rose Gold	18k	75%	9.2%	22.2%		
Rose Gold	22k	91.7%		8.40%		
Sterling Silver	N/A		92.5%	7.5%		

Table 2. Information on caratage and alloy metals taken from the World Gold Council (2019) and The Silver Institute (2019).

Details about the data used for each of the metals		
Metal	Data Source	Reference Process
Gold	Gabi Precious Metals	Gold (primary), production mix, at plant, primary route, underground mining, underground mining and leaching, 19.32 g/cm3, 196.97 g/cm3
Silver	Gabi Precious Metals	Silver mix, consumption mix, to consumer, from electrolysis, solid, density: 10.49 g/cm3, molar mass: 107.86 g/mol
Copper	Gabi Nonferrous Metals	Copper mix (99.999% from electrolysis), consumption mix, to consumer, from electrolysis, 99.999% Cu
Palladium	Gabi Precious Metals	Palladium mix, production mix, at plant, primary production, solid, density: 11.99g/cm3, molar mass 106.42g/mol
Zinc	Gabi Professional	Zinc redistilled mix, consumption mis, to consumer, technology mix, 7.14g/cm3, 65.38 g/mol
Platinum	Gabi Precious Metals	Platinum mix, production mix, at plant, primary production, sold, density. 21.45 g/cm3, molar miss 195,048 f/mol. Electrical conductivity: 9.43 E06 A/(V .m)

Table 3. Data sources and reference processes of each metal that was analyzed using OpenLCA.

Global Warming Potential of Jewelry Pieces (kg CO2 eq)					
8g YG Men's Wedding Ring			**3g YG Necklace (Chain)**		
	Mass(g)	kg CO2 eq		Mass (g)	kg CO2 eq
Gold	4.664	287.3605967	Gold	1.749	107.7602238
Silver	2.4	0.869735111	Silver	0.9	0.326150667
Copper	0.936	0.004193372	Copper	0.351	0.001572514
	Total kg CO2e	288.2345252		**Total kg CO2e**	108.087947
16g YG College Signet Ring			**16g YG Necklace (Chain & Pendant)**		
	Mass (g)	kg CO2 eq		Mass (g)	kg CO2 eq
Gold	9.328	574.7211935	Gold	9.328	574.7211935
Silver	4.8	1.739470222	Silver	4.8	1.739470222
Copper	1.872	0.008386743	Copper	1.872	0.008386743
	Total kg CO2e	576.4690504		**Total kg CO2e**	576.4690504
3g WG Women's Ring			**8g Sterling Silver Necklace**		
	Mass (g)	kg CO2 eq		Mass (g)	kg CO2 eq
Gold	1.749	107.7602238	Gold	none	none
Silver	0.966	0.350068382	Silver	7.4	2.681683259
Copper	0.285	3.498334123	Copper	0.6	0.002688059
	Total kg CO2e	111.6086263		**Total kg CO2e**	2.684371318

Table 4. Results from OpenLCA for 14 carats, specifically. This table gives an idea of how much CO2 is released per piece depending on its weight.

Global Warming Potential of Different Carats of Men’s Ring (kg CO2 eq)						
8g Yellow Gold Men’s Wedding Ring						
	9K Kg CO2e	10K KgCO2e	14K Kg CO2e	18K Kg CO2e	22K Kg CO2e	Sterling Silver Kg CO2e
Gold	184.837434	205.539226	287.3605967	369.674867	451.9891376	0
Silver	1.23212474	1.50754086	0.869735111	0.43486756	0.014495585	2.68168326
Copper	0.00716816	0.00225797	0.004193372	0.00358408	7.16816E-05	0.00268806
Zinc					0.000291921	0
Total kg CO2e	186.0767265	207.049025	393.1257514	370.1133188	452.0039968	2.68437132

Table 5. Results from OpenLCA comparing the 8g men’s wedding ring in various carats.

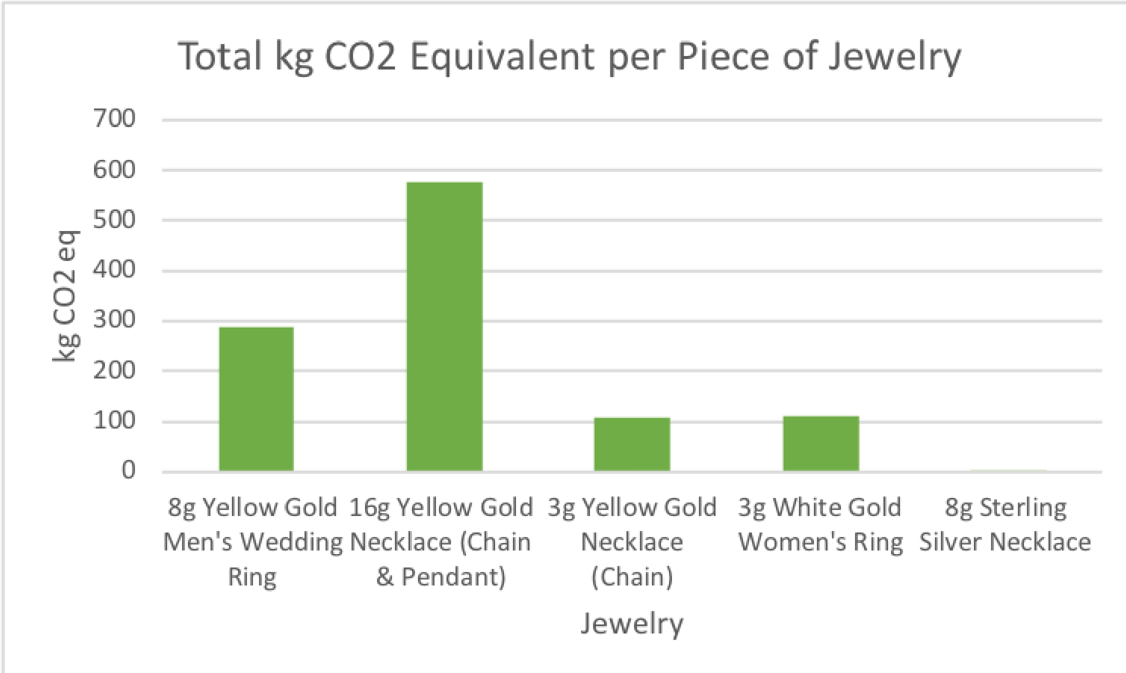

Figure 1. Results from OpenLCA for 14 carats specifically.

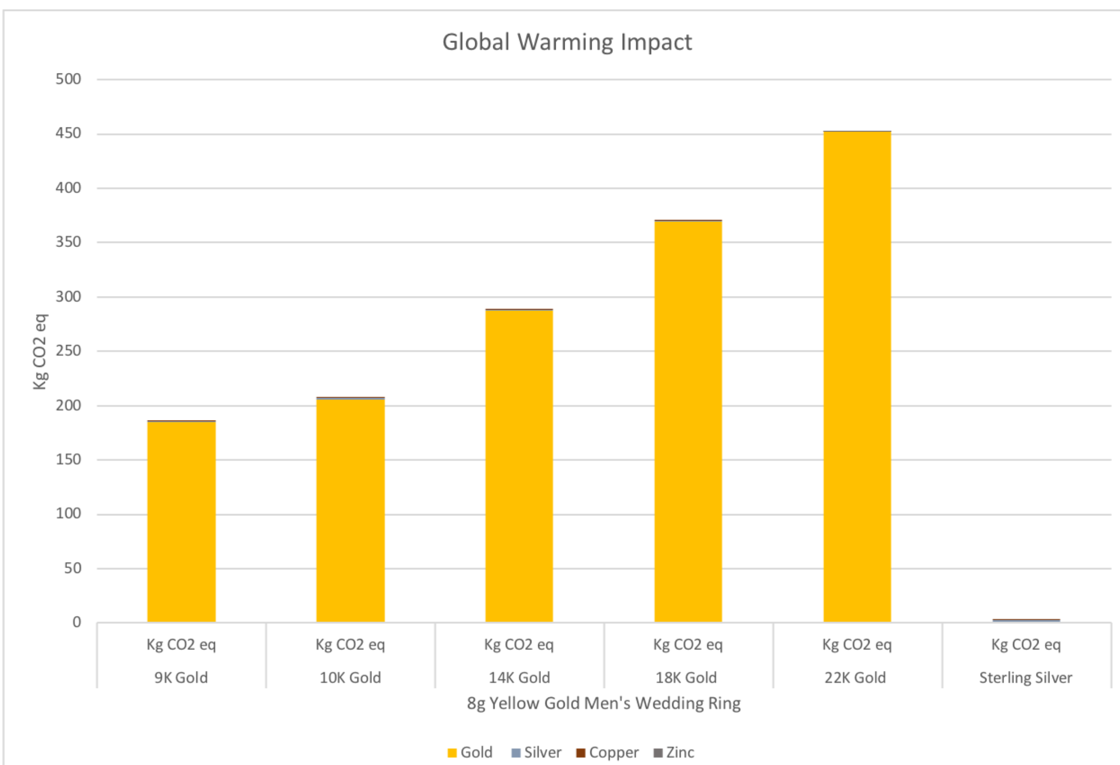

Figure 2. Kg CO2 equivalents for the piece of jewelry for both various carats of yellow gold and sterling silver divided among the alloy metals to show exactly how much CO2 equivalent is attributed to each metal.

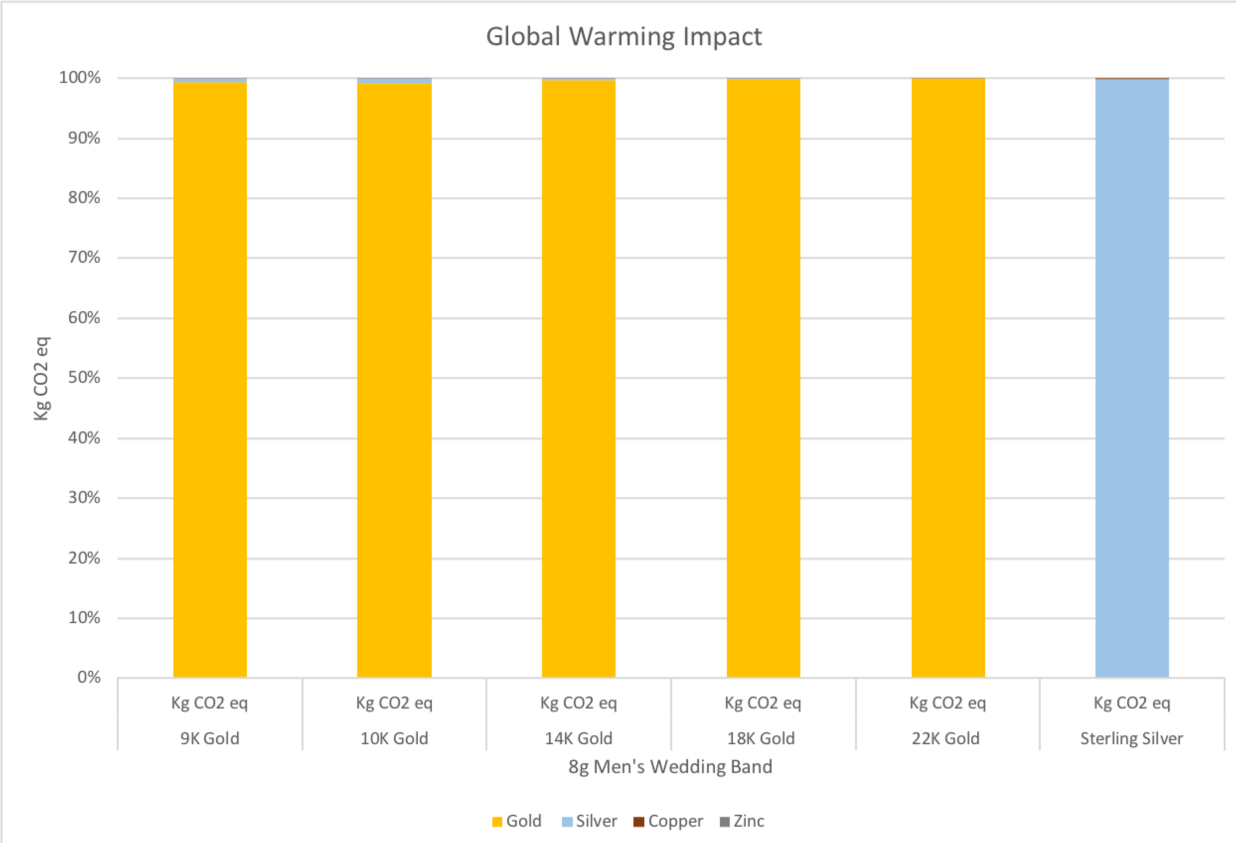

Figure 3. The percent of CO2 equivalents released from each metal to emphasize which metal has the biggest impact.