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The Blood Wedding Ring

Assessing the Life Cycle Lives Lost in Gold Jewelry Production

Master's thesis in the Industrial Ecology Programme

RASMUS PARSMO

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Division of Environmental System Analysis
CHALMERS UNIVERSITY OF TECHNOLOGY
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Chalmers Reproservice
Göteborg, Sweden 2015

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ABSTRACT

This study investigates the human health impact of gold jewelry during its entire life cycle. Gold has many negative impacts on human health during its life cycle, such as emissions and accidents during different stages in the life cycle. There are also indications that mining of different minerals leads to conflicts and that minerals, such as gold, are used for financing military activities resulting in people getting killed, injured or displaced. Especially the eastern part of the Democratic Republic of the Congo (DRC) is associated with conflict gold. Consequently, gold produced in the DRC is the main focus of this study, while gold produced in Sweden and South Africa are included for comparison.

The main method of this thesis is an attributional life cycle assessment (LCA) with an expanded social perspective. The disability-adjusted life years (DALY) is the indicator, and the results are quantified for the amount of gold in one typical wedding ring and per kg of gold. The indicator DALY is chosen since it allows for considering different types of causes of death and impairment, including conflicts, occupational hazards and environmental hazards. The aim is not to reach an exact figure of how many years of life that are lost, but rather to evaluate the magnitude of different processes. The three types of human health impacts that are quantified in this study are: impacts from environmental emissions, impacts from work environment accidents, and impacts from conflict.

About 0.4 years of life were lost per wedding ring for gold produced in the DRC, which is several orders of magnitude larger than the impact of gold produced in South Africa and Sweden. The calculated number for life years lost is very high for such a small amount of gold, creating credibility for the title of this study: "the blood wedding ring". The impact from the conflict is several orders of magnitude larger than the impact in any other process. If the impact assessment result from the conflict is excluded from the results, the emissions occurring at the extraction and processing of gold instead had the greatest impact, several orders of magnitude larger than any other process. In particular, mercury emissions to air had a high impact on human health during the processing of gold in artisanal mining in the DRC. The other processes have more minor impacts on human health.

Sensitivity analyses were conducted to evaluate data gaps and uncertainties. These analyses in general showed that the results of the impact assessment are reasonable. The overall conclusion is that even though the results are uncertain, the conflict's impact on human health is still several magnitudes larger than those of all other processes evaluated in the study.

Key words: Human health, conflict, social life cycle assessment (SLCA), disability-adjusted life years (DALY), mercury

Contents

Abbreviations and Notations

Abbreviations

ADF	Allied Democratic Forces
CNDP	the National Congress for the Defense of the People
DRC	Democratic Republic of the Congo
DALY	Disability-Adjusted Life Year
FARDC	the Armed Forces of the Democratic Republic of Congo
FDLR	the Democratic Forces for the Liberation of Rwanda
ISO	International Organization for Standardization
HSRP	Human Security Report Project
LCA	Life Cycle Assessment
LCI	Life Cycle Inventory
LCIA	Life Cycle Impact Assessment
MONUCO	United Nations Organization Stabilization Mission in the Democratic Republic of the Congo
SKKF	Swedish federation of crematoria
SLCA	Social Life Cycle Assessment
UN	United Nations
UNEP	United Nations Environment Programme
USD	United States Dollar
WHO	World Health Organization

Notations

Au	gold
Hg	mercury
YLL	aggregated number of years lost
YLD	aggregated numbers of years living with a disability
w	describes how serious the disability, a number between 0 and 1.
D	describes the number of years with disability
P_{gold}	market price of gold [USD/kg]
$\mathrm{M}_{\mathrm{gold}}$	total amount of gold produced [kg]
w_{gold}	weight gold get between different minerals
WE	work environment
$V_{resources}$	Value of all mineral resources encountered in this study
V_{gold}	Value of all gold

1 Introduction

1.1 Background

Gold has many negative impacts on human health during its life cycle – from raw material extraction, over production and use, to the end of life phase. Such impacts include, for example, emissions and accidents during the different stages of the life cycle. There are also indications that mining of different minerals leads to conflicts around the globe and also that minerals, such as gold, are used for financing military activities resulting in people getting killed, injured or displaced (UN, 2015). Especially the eastern part of the Democratic Republic of the Congo (DRC), is associated with conflict minerals (Global Witness, 2009; Human Rights Watch, 2005). Conflict minerals in that region are mainly tin, tantalum, tungsten, cobalt, diamonds and gold (Polgreen, 2008). The bloodiest conflicts since World War II have taken place in the DRC and a rough estimate suggests that 5.4 million people have lost their lives in the conflict (IRC, 2007). In addition, a large number of women have been raped because of the conflict, leading to great human suffering, AIDS epidemic, etc. (Soguel, 2009). There is evidence suggesting that gold mined in the DRC to large extent is sold on the black market, or relabeled in neighboring countries. For example, Uganda officially produced 500 USD worth of gold in 2007 but exported 27 million USD worth of gold the same year (CBSNews, 2009). Therefore, it is hard to evaluate how much of the gold produced today is actually extracted in the region, but a rough estimate is that 5-40 ton of gold are extracted in DRC annually (UN, 2009; Pact, 2010). The DRC is also estimated to contain "the world's largest un-tapped gold deposits" (Pact, 2010).

There are no established methods for assessing casualties in conflicts from a product life cycle perspective. However, one method that addresses human health and other social issues is social life cycle assessment (SLCA). One of the main objectives of SLCA is to be an instrument helping society towards social sustainability (UNEP, 2011). Note that the word "sustainability" is important to distinguish from sustainable development, which is the transitional process towards sustainability (Holmberg & Robért, 2000). Sustainable development is a concept used widely today and the perhaps most commonly used definition is from the so-called Brundtland report (UN, 1987):

"Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs"

The Brundtland report especially puts emphasis on meeting the needs of poor people. Since poor people are often suffering the most in severe situations, such as war, it may be desirable to also include impacts of conflicts in an SLCA. Thus, if gold production actually implies conflicts, it can be reasonable to include when assessing human health impacts along the life cycle. Another way of interpreting sustainable development is in the form of three pillars: ecologic viability, economic feasibility and social desirability (UNEP, 2011). With this interpretation in mind, SLCA is a method for assessing both negative and positive impacts related to the social pillar.

Gold is used in various applications in society, but the two sectors where most of the gold is used are jewelry (50%) and financial investment (40%). A smaller amount of gold (10%) is also used in industry (Soos, 2011). Jewelry is used for decorative purposes due to its symbolic value, indicating for example status, or in the case of a wedding ring, showing commitment.

The positive impacts of gold in jewelry are thus more socially constructed, and it is hard to argue that it has any positive impacts in terms of saving human lives and preventing injuries, as for example an airbag has (Baumann, et al., 2013). The use of gold in industry, however, includes many different applications, of which some, such as electronic equipment used in health care, may have more or less direct positive health impacts. Such impacts are probably difficult to assess, in particular when they are more indirect, such as for electronic devices used for diagnostics rather that treatment. Therefore, this study will focus on gold in jewelry.

1.2 Aim

The aim of this study is to investigate how many years of lives that are lost during the life cycle of gold in a wedding ring. The focus of the study is on the gold production in the DRC. However, two additional scenarios are included for comparison, namely South Africa and Sweden, which represent different production technologies and production scales. The aim is not to obtain an exact number on how many years of life that are lost, but rather to evaluate the magnitude of different processes, find "hot spots", and identify main contributors.

1.3 Conflict in the DRC

During history, the DRC has been facing numerous conflicts due to its natural resources. The following section describes briefly the most important historical events that have influenced the conflicts during the last 100 years. The focus is on the role of resources in the conflicts. Note that the country has changed name during this period.

This study focuses on the eastern part of the DRC, since most of the conflicts have occurred there. The eastern DRC in this study is defined as the four provinces of South Kivu, North Kivu, Katanga and Orientale (Figure 1.1). The eastern region of the DRC is especially rich in minerals – and particularly in gold.

1.3.1 Belgian Colonial Rule (1908-1960)

Belgian exploration started in 1877, but the region (the DRC) was not colonialized until 1908 (Turner, 2007). One of the main drivers for establishing a colony in Congo was to exploit the natural resources (Mullins & Rothe, 2008). At first, rubber was the main export. However, due to falling rubber prices, copper from Katanga became increasingly important. In addition, exports of agricultural products such as palm oil, cocoa, rice and cotton were important. After the First World War, the Belgians prioritized investment in exploitation of minerals. This did not only include copper from Katanga as before, but also diamonds from Kasai and gold from Orientale became increasingly important exports from the region (Turner, 2007).

When colonies around the world were getting their independence, Belgium was not so fond of the idea of leaving Congo. Therefore, they established a 15 year independence plan for Congo, a decision contributing to riots in the capital Leopoldville in 1959. (Today, the capital is called Kinshasa). However, it was not the riots and protests by the people that suddenly made Belgium decide to give the colony independence in 1960, but rather the fact that Congo was seen as an economic burden rather than an asset due to dropping copper prices in 1959 (Mullins & Rothe, 2008).

In the period after independence was achieved, several conflicts and uprisings occurred throughout the country. During the Kasai and the Katanga rebellions, both starting in 1960, the main motivation for creating autonomy was to gain control over mineral resources in the regions (Ndikumana & Emizet, 2003).

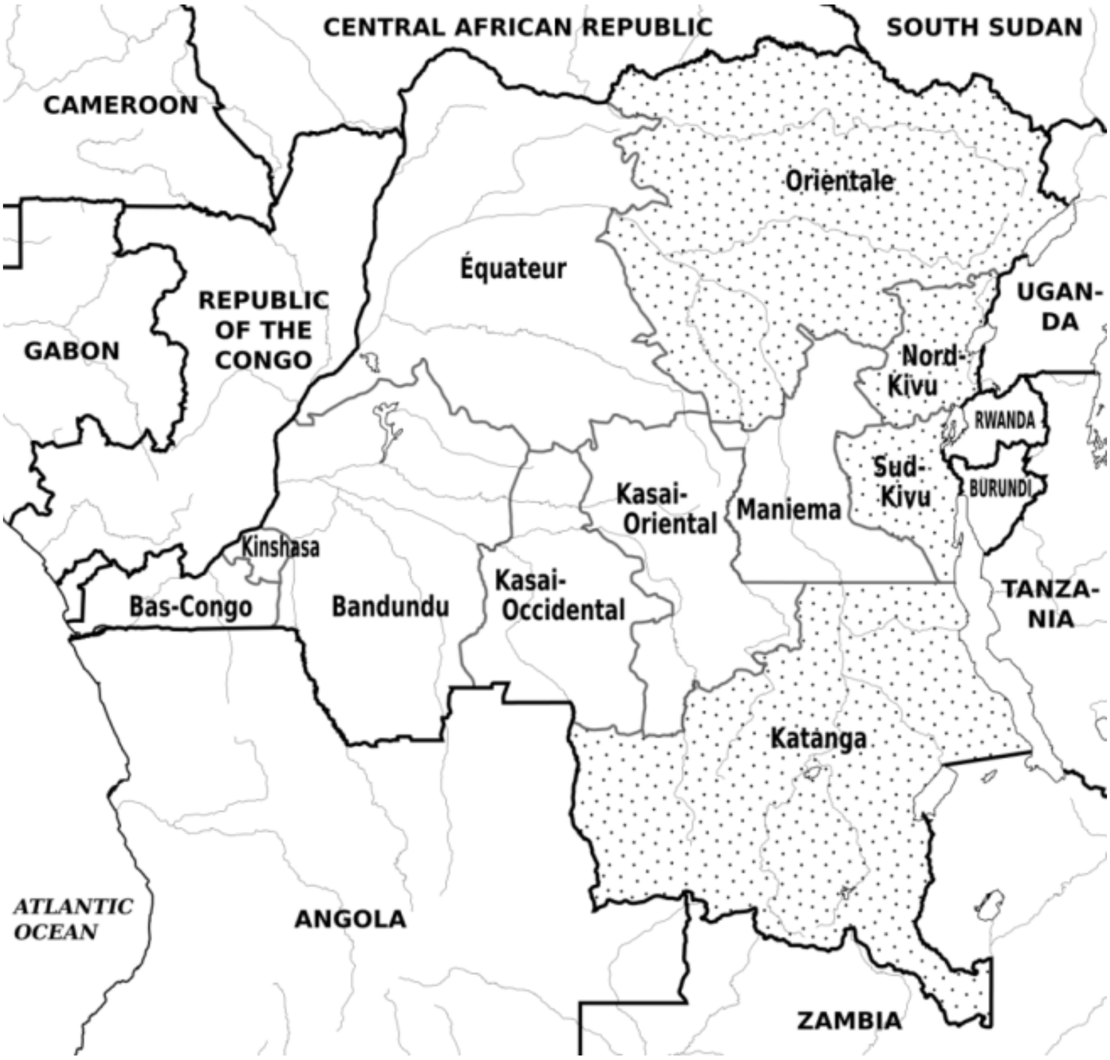

Figure 1.1 – Map of the DRC and nearby region. The dotted area is the four provinces Orientale, North Kivu, South Kivu and Katanga. In this study, those provinces are referred to as the eastern region of the DRC (TUBS & Rödl, 2012).

1.3.2 Mobutu Sese Seko (1965-1997)

Mobutu Sese Seko seized control of the DRC in 1965 and appointed himself president of the country. Corruption in combination with nepotism and nationalization of foreign companies were key components to the subsequent collapse. For example, Mobutu tried to seize control of the mineral resource in the country by creating a state company responsible of all mineral marking: Société Zairoise pour la Commercialisation des Minerals (SOZACOM) (Ndikumana & Emizet, 2003). During Mobutu's rule, the economy of the DRC declined and finally collapsed.

Three features of Mobutu's regime that may have particularly influenced the cause of civil war in the region have been identified in the literature: (1) the building of national identity, (2) the international support for his rule, and (3) making the national army less powerful (Ndikumana & Emizet, 2003). He gained international support by a combination of using natural resource and helping the West fight communism in Africa.

1.3.3 Genocide in Rwanda (1994)

One of the main trigger factors to the conflict in eastern the DRC is believed to be the genocide in the neighboring country Rwanda (Ndikumana & Emizet, 2003). The genocide was conducted during three months in 1994, and about 8-9% of the population was killed. The genocide is stated to be "the deadliest period of organized violence experienced by any country since the end of World War II" (HSRP, 2011). The genocide was conducted by the majority group in the country, Hutu, against the minority group, Tutsi, as well as against moderate Hutus (Hutus that did not support the genocide and to certain degree helped Tusti). The tension between these two groups is important for understanding the development of conflicts in eastern DRC. The genocide ended when a Tutsi rebel group lead by Paul Kagame (now president of Rwanda) managed to conquer the country and stop the brutal genocide. As a consequence of that, a massive wave of refugees, about 1.5 million, fled across the borders. Some fled to Tanzania and Burundi, but most to the DRC (Human Security Centre, 2005). The refugees were mostly Hutus afraid of reprisals from the new Tutsi-led regime. Many of the refugees were Rwandan soldiers and Interahamwe militans, the ones that organized and committed the genocide. Also, tension was created between the Tutsi groups already living in the area and the new Hutu refugees (Ndikumana & Emizet, 2003).

1.3.4 First and Second Congo War (1996-2001)

Even if the economic development was poor in the country, Mobutu managed to stay in power for 32 years until the he was overthrown by a rebellion starting in eastern Congo. The rebellion was led by Laurent Kabila and was supported by Rwanda, Uganda, Burundi and Angola. The rebellion started in 1996 and the conflict is called the First Congo War. The rebels led by Kabila managed to get control of the entire country and Kabila was appointed new president of the DRC in 1997 (Turner, 2007).

Rwanda and Uganda supported Kabila in the First Congo War. However, some months after the war (in 1998), Rwanda was ordered by Kabila to leave the country. That was the start of the Second Congo War. The war was fought between the newly installed Kabila government and foreign powers such as Rwanda, Uganda and Burundi. In addition, many different militant groups joined the fighting, most notably Mai-Mai and Interahamwe on the DRC side and RCD on the other side. At first, the foreign forces advanced rapidly. However, thanks to intervention by Kabila's African allies, including Angola, Namibia and Zimbabwe, the advancement was stopped and resulted in local conflicts with small territories held by different groups. After Kabila came into power, and also during the Second Congo War, Rwanda and Uganda occupied the eastern region of the DRC. Frequent incidents of pillage of minerals and other resources by foreign powers as well as native Congolese have been documented (UN, 2003). Reports even suggested that aircrafts from Rwanda and Uganda were flying in military with equipment to the region, and flew back with gold, diamonds and other resources (Turner, 2007).

1.3.5 Current Situation (2002-2015)

Rwanda and Uganda officially withdrew their troops from the eastern region of the DRC in 2002 and 2003, which created a situation where various uncontrolled militia groups took control over the region instead of the Congolese government (Human Rights Watch, 2005; Mullins & Rothe, 2008). In the period after that and up until now, numerous military groups have been and some still are active in the region including the FDLR, CNDP, Mai-Mai, FARDC (the DRC national army), MONUCO (UN peace keeping force), RCD, and FRF, to mention a few (UN, 2003; UN, 2009; UN, 2015). These groups are mainly active in the eastern part of the DRC and that region is also where the majority of the 5.4 million reported deaths have occurred (IRC, 2007).

One militia group that has been especially active during the whole period after the Second Congo War is the FDLR, which stands for Democratic Forces for the Liberation of Rwanda. FDLR consists of the Hutu militia groups fleeing from Rwanda after the genocide. The existence of these Hutu militants in the eastern DRC is seen as a major security threat by the Rwandan government. Since the genocide, Rwanda has intervened militarily in the region on several occasions, directly or indirectly (with proxy rebel groups) due to the presence of the FDLR. Documentation from South and North Kivu describes that profit from minerals is being used by the FDLR to obtain weapons and other resources to remain in control over areas in the region (UN, 2009). They have even set up political, economic and social structures in certain areas due to their dominance in the mining business. The FDLR has been accused of serious violations against human rights, and witness reports describe how they abuse local populations for mining of minerals (Global Witness, 2009). However, lately, the FDLR has been losing importance in the region.

Still in 2014, gold is smuggled out from the DRC into countries such as Uganda. Extensive documentation from for example the UN shows that gold from mines driven by the Mai-Mai and the FDLR ends up in Kampala, the capital of Uganda. The Ugandan government has shown little interest in providing UN with accurate data on the relation between production and export of gold (UN, 2015).

2 Method

The main method of this study is an attributional life cycle assessment (LCA) from cradle to grave with an expanded human health focus. The disability-adjusted life years (DALY) is the applied indicator, and the results are quantified for the amount of gold in one typical wedding ring and per kg of gold.

2.1 Social Life Cycle Assessment (SLCA)

The LCA method was originally developed to quantify different environmental impacts during a product's life cycle (Baumann & Tillman, 2004). Today, it is widely used in decision- and policy-making at a strategic level, leading up to standardizations of how to conduct an LCA, such as ISO 14040. In parallel, a number of specific impact assessment methods have also been developed, including Eco-indicator 99 (Baumann & Tillman, 2004) and ReCiPe (Goedkoop, et al., 2013). Recently, not only environmental issues but also the costs of products have been assessed from a life cycle perspective. The method for such assessments of life cycle costs is called life cycle costing (LCC) and is used for including external costs and benefits in the economic calculations. However, LCA and LCC only cover two of the three pillars of sustainability. That is why a third method called social life cycle assessment (SLCA) has begun to emerge (UNEP, 2011).

A number of scholars have discussed SLCA, providing somewhat different interpretations (O'Brien, et al., 1996; Dreyer, et al., 2006; Norris, 2006; Parent, et al., 2010). The United Nations Environment Programme (UNEP) together with the Society of Environmental Toxicology and Chemistry (SETAC) suggested a framework that considers stakeholders who are affected by the production in different ways. According to UNEP (2011), the stakeholders in an SLCA can be of various kinds, such as workers, local communities, society and consumers. All stakeholder categories can then be divided into different subcategories. For workers, relevant subcategories or topics could be child labor, salary and working hours. Indicator data for some subcategories are available from international institutions such as the International Labour Organization (ILO), or may have to be collected separately from field work. Indicator results for these subcategories can be used in an impact assessment evaluating human rights abuse, working condition, etc., and with those numbers the overall social impact of a product can be assessed, and social hotspots can be mapped. Worth noting is that sometimes products that show good environmental performance can have negative social performance, and vice versa (UNEP, 2011).

SLCA can also be used to evaluate a product's impacts on human health. Frequently, health impacts are evaluated according to their impacts in the use phase, even if not with the LCA method, for example investigating how effective a medication is in improving health. However, it is also interesting to understand how human health is affected in other parts of the product life cycle. For example, airbag systems save human lives during the use phase, but it can also be interesting to investigate how many lives are lost or impaired due to accidents and work place emissions in the factories producing components and due to emissions associated with the production of the airbag system, and then compare those with the number of lives saved (Baumann, et al., 2013). One main idea with SLCA in that case is to account for deaths and injuries that happen everywhere in the product chain, for example during mining and other raw material extractions, since that information is otherwise typically not easily available to the final consumer and other actors.

SLCA is a relatively new research field, implying that many areas need further development. One area that this project researches deeper into is: “methods for the assessment of impacts and cause-and-effect relationships for social aspects” (UNEP, 2011). It is also another case study using the method developed by Baumann et al. (2013), and developing it further through the inclusion of conflict-related losses of life years.

2.2 Attributional Life Cycle Assessment

There is a growing consensus among researchers that there are two different types of LCA, namely attributional LCA (also called accounting) and consequential LCA (also called change-oriented) (Hillman, 2008). This project employs the attributional approach, implying that the study answers the question: *which impacts is the gold in a wedding ring accountable for?* This study thus does not evaluate the “consequences of alternative courses of action”, which is typical in a change-oriented LCA (Baumann & Tillman, 2004).

An LCA consists of four phases: (1) Goal and scope definition, (2) inventory analysis, (3) impact assessment and (4) interpretation (Baumann & Tillman, 2004; Hellweg & Canals, 2014). In this report, these phases are described briefly below. Later on, they are described in more detail for this specific study in Chapter 3, 4, 5, and 6, respectively.

The goal of this LCA is to evaluate how many years of life that are lost during the gold’s complete life cycle. The study also includes activities that are not normally included in an LCA, such as the number of lives lost in war as a consequence of gold extraction and production. The scope of the study includes the definition of functional unit, system boundaries, allocations and assumptions (Baumann & Tillman, 2004).

The inventory analysis is the phase where the flow model for the technical system is described. Relevant flows of mass and energy are outlined and negligible flows are excluded. The model relates different input and output flows, such as emissions, energy and mass flows, to the functional unit (Baumann & Tillman, 2004).

Inventory data relevant for the selected impacts are gathered in the inventory analysis. In this study, those are: (1) damage to human health from emissions of toxic substances along the life cycle, (2) accidents during extraction and transport of minerals, and (3) casualties due to conflict in the region where the gold is extracted. Information and data for the study are collected from: (1) scientific literature and (2) LCA databases, in particular the Ecoinvent version 2.2 database.

DALY is the indicator used to quantify all three health impacts included in this study. The indicator describes the mortality and health impacts to humans, and was originally developed in the WHO project “global burden of disease” in 1990 (WHO, 2015). In short, DALY describes the number of human years lost due to some kind of impact, such as a disease or accidents, and can be used to express both positive and negative health impacts. From an ethical perspective, DALY gives equal value to all humans regardless of age, and it also gives weight to disabilities and impairments, such as chronic respiratory impacts caused by dust in mining.

For emissions, DALY is calculated according to the following equation:

$$DALY_{emission} = YLL + YLD \ (1)$$

where YLL is the aggregated number of years lost, and YLD is the aggregated number of years of disability. YLD is a weighted function:

$$YLD = w \cdot D \ (2)$$

where w describes how serious the disability is. 0 means completely healthy, while 1 is totally disabled. The factor D describes the number of years with disability (Baumann, et al., 2013). The result is expressed as a ratio between DALY lost and the output of the product (1 ring or 1 kg), see equation 3.

$$Emissions\ impact\ of\ gold\ on\ Human\ health = \frac{DALY_{Emission}}{Output_{gold}} \ (3)$$

Impacts on human health from emissions will be quantified using a method developed in the Netherlands called ReCiPe (Goedkoop, et al., 2013). The method first identifies categories at a midpoint level, such as global warming potential and human toxicity potential, and then aggregates them into different endpoint categories. One such endpoint category is called damage to human health. In ReCiPe, the indicator used to quantify endpoint impacts to human health is DALY. The procedure can be seen in Figure 2.1. This method is therefore suitable to use in this study.

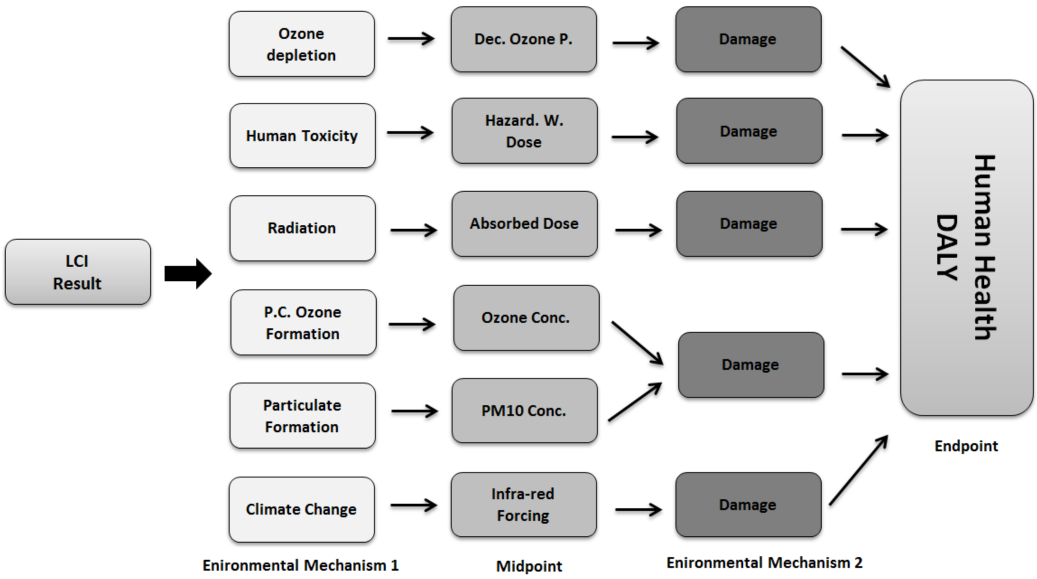

Figure 2.1 – Method for identifying the end point damaged on human health, from midpoint indicators and LCI results (Goedkoop, et al., 2013).

Results may vary depending on which cultural value perspective is chosen in the assessment. Three different value perspectives are included in ReCiPe: the individualist, hierarchist, and egalitarian perspectives. In short, one could say that the individualist is a technological optimist that mainly considers short term impacts, while the egalitarian has a more precautionary approach to the environmental impacts, and are also considering long-term impacts. However, the baseline scenario in this study is based on the hierarchical perspective, since the hierarchical perspective is considered to be based on "the most common policy principles" (Goedkoop, et al., 2013). Value choices could affect parameters such as the time horizon and the discount rate. For example, the individualist has an assumed discount rate of 5%, the hierarchist has 3% discount rate, and the egalitarian has a discount rate of 0% in some impact assessment models (de Schryver, et al., 2011). One study comparing results based on values from these perspectives even showed a difference of six orders of magnitude for different characterization factors (de Schryver, et al., 2011). Therefore, this aspect is also reflected upon later in the interpretation.

Impacts from work environment accidents are estimated using a method that quantifies DALY due to fatal and nonfatal injuries and illnesses during the production and transport of the various products. This is conducted by dividing the total number of accidents in one sector with the output of that specific sector, see equation 4 (Scanlon, et al., 2014).

$$CF_{WE_n} = \frac{DALY_{WE_n}}{Output_n} \quad (4)$$

In equation 4, *n* is a specific sector, CF stands for characterization factor and WE stands for work environment.

Impacts from the conflict due to gold extraction are also assessed in terms of DALY. There is yet no standardized method for assessing this in an SLCA. This study uses a similar method as the one presented in equation 4 for assessing work environment impacts. The total numbers of DALY lost in the conflict is divided by the output of the product, times the weighted value for the product (in this case gold), see equation 5.

$$DALY\ lost\ in\ the\ conflict\ per\ kg\ gold = \frac{DALY_{Conflict}}{Output_{gold}} \cdot w_{gold} \quad (5)$$

The weighting factor, w_{gold}, is explained later in Section 3.3.The result of the three methods is finally expressed as a ratio between DALY lost and the output of the product, see equation 6.

$$Total\ impact\ of\ gold\ on\ Human\ health = \frac{Total\ amount\ DALY_{gold}\ lost}{Output_{gold}}$$
$$= \frac{DALY_{Conflict} \cdot w_{gold} + \sum_{i=1}^{n} \frac{DALY_{WE_i}}{Output_i} + DALY_{Emission}}{Output_{gold}} \quad (6)$$

The results will be presented so that it is understandable for the intended audience. Therefore, results are presented both as number of years of life lost (or impaired) for the gold required for one typical wedding ring, but also for 1 kg of gold. The audience is in this case mainly three types of stakeholders, namely the mineral and jewelry industries, the SLCA community and the general public.

Different features of the results will be interpreted, as for example which process is the most dominant contributor and which factors influence the result the most. The interpretation will also include control of robustness, where sensitivity will be discussed and analyzed. Extra emphasis will be put on discussing the inclusion of conflicts in the calculation, since that is not usually included in an SLCA.

3 Goal and Scope Definition

The goal of this LCA is to evaluate how many years of life are lost during the life cycle of gold in jewelry. This study also includes scenarios with activities which are not normally included in an LCA or SLCA, such as number of lives lost in conflicts as a consequence of gold production. The scope is presented in Sections 3.1-3.4, and contains the definition of functional unit, system boundaries, allocations and other assumptions.

3.1 Functional Unit

The functional unit is one golden wedding ring, which corresponds to approximately 4 gram of gold according to measurements reported for an 18 karat wedding ring (Steinhauser, 2008).[1] This functional unit is used since it is something that people can easily relate to in their everyday life. Worth noting is that only the gold in a typical wedding ring is included. However, gold wedding rings usually also contain other metals, such as silver and copper, and might even include gemstones, but the impacts of those are not considered in this study. 1 kg of gold will also be used as an alternative functional unit, since that is a more standardized flow which can be used for comparisons with other studies.

3.2 System Boundaries

3.2.1 Boundaries in Relation to the Natural System and within the Technical System

For emissions and accidents, the life cycle in this study starts at the extraction of the gold, meaning that the mining process is the first process. The system ends when the gold is recycled or lost. However, only emissions and accidents for extraction, production and transport are included in the study. All other emissions and accidents are excluded. The impact on human health in the use and retailer phases is believed to be rather small compared to those of the other processes and is therefore also excluded. Many minor contributions from inside the technical system are neglected in the study, such as impacts from machines and infrastructure.

3.2.2 Geographical Boundaries

The geographical location for gold mining and production in this study is the DRC. This case will be compared with two different scenarios in which gold is instead extracted in South Africa and Sweden. The gold is assumed to be transported to Sweden, where it is used as jewelry. In reality, there is perhaps not so much gold which is transported directly from the DRC to Sweden (see subsection 4.1.5), and if the gold enters Sweden at all, it does so via intermediate countries such as the United Arabian Emirates, China or perhaps by recycling of old jewelry or electronics that have been imported in the past (UN, 2015). However, the gold still needs to be transported the distance to enter Sweden, even if it goes though intermediate locations.

This study especially focuses on the eastern part of the DRC, since most of the conflicts have occurred there. The eastern DRC in this study is defined as the four provinces South Kivu, North Kivu, Katanga and Orientale (Figure 1.1).

[1] 74.5% of gold in a 5.6 gram 18 karat gold wedding ring.

3.2.3 Temporal Boundaries

Since this LCA is an attributional LCA that investigates which health impacts the product can be accounted for retrospectively, it evaluates the historical impact (Hillman, 2008). The time period which is of particular interest in this study is August 1998 to April 2007, since there has been an evaluation of how many deaths can be associated with the conflict during that period (IRC, 2007). According to official statistics, the average marriage in Sweden last for 25 years (SCB, 2013). Therefore, the wedding ring is expected to be used for 25 years. However, the influence of recycling is also discussed in a sensitivity analysis, thus considering potentially longer uses.

3.3 Allocation

All allocation procedures in this study are based on the economic value of the products. The allocation could also be based on mass or volume. However, these methods do not reflect the demand for the product in the same way as an economic allocation does. Economic allocation is particularly relevant for products that have a high economic value per mass and volume, such as gold.

3.3.1 Allocation between Minerals in the Conflict

Different minerals are extracted in the eastern region of the DRC and different impacts can be given to particular a particular mineral depending on how it has influenced the conflict. Since it is hard to evaluate exactly how much each mineral is contributing to the conflict, the allocation is based on the mass and economic value of each mineral. This is because the weighting then reflects how much money different groups can make from their activities related to this mineral, reflecting for example the ability to buy weapons. The higher the value of the mineral, the more likely it is that different parties will be interested in getting their hands on that particular mineral. The weighted value for gold (w_{gold}) is calculated according to equation 7.

$$w_{gold} = \frac{P_{gold} \cdot M_{gold}}{V_{resources}} \quad (7)$$

In equation 7, M_{gold} is the total amount of gold produced in the region in kilograms, $V_{resources}$ is the total economic value of production of minerals in the DRC (in USD), and P_{gold} is the world market price of gold (in USD/kg). Even though prices may vary between the DRC and the international market for gold, international prices of minerals can work as a reasonable proxy, since all relevant mineral prices can be assumed to vary to the same degree. Also, in a field study conducted in South Kivu, retailers stated that they used market price for gold for deciding their buying and selling prices (Geenen, 2011).

This allocation procedure between different minerals probably underestimates the impact of gold. Gold should probably be given a higher weight than what is implied by its mere value since it has a high value per volume which makes it easier to transport and harder trace later in the process (Geenen, 2011; UN, 2015). That is reflected upon in the interpretation of the result in Section 6.3.

3.4 Assumptions and Limitations

3.4.1 Relationship between the Conflict and the Minerals

It is assumed in this study that minerals are the main reason for the life years lost in the DRC conflict. However, the conflict in the DRC is a consequence of various causes, including ethnic tension, poor economy, bad leadership, colonial power, conflict over land, absence of security and none-functional government institutions (Ndikumana & Emizet, 2003; Turner, 2007), see Section 1.3 for more detailed information. It is hard to evaluate which causes are the most important ones and which are the root-causes to the conflict. However, there are observable direct deaths with a causal connection to minerals, at least on a local level (Global Witness, 2009; Human Rights Watch, 2005; Amnesty International, 2013; UN, 2015). Some relationships between the conflict and the presence of minerals are:

- Witness reports from the area suggest that the minerals are one of the root-causes of the conflict (Global Witness, 2009). Case studies have been made in the area reporting, for example, observation of overtaking of mines by various militant groups such as the FDLR, promises of gold to people joining militant forces such as the UPC, and direct killing of people to get access to mineral rich areas (Global Witness, 2009; Amnesty International, 2013; Human Rights Watch, 2005).
- The revenue from minerals serves as an economic basis for providing weapons. An evaluation of eight conflicts in the DRC between 1960 and 2000 concluded that seven out of eight conflicts were partly our fully financed by natural resources (Ndikumana & Emizet, 2003). The revenues can come directly from the minerals or from enforcing road taxes on transporting minerals. For example, the FDLR has been reported to make millions of dollars in profit from gold trade, and the CNDP (not active anymore) used an efficient road taxation system for generating revenue from mineral transport (Global Witness, 2009). In South Kivu, gold and other minerals are almost the only way to get hold of foreign currency (Geenen, 2011). It is minerals that are linking the regional economy to the world economy, providing the opportunity to buy weapons and ammunition.
- Many neighboring countries, most notably Rwanda, Burundi and Uganda, have an economic interest in the mineral extraction and people living in these countries are benefiting economically from the trade (Global Witness, 2009; Mullins & Rothe, 2008; Ndikumana & Emizet, 2003). Also, as mentioned earlier, Rwanda and Uganda were heavily involved in the First and Second Congo Wars (Ndikumana & Emizet, 2003; Turner, 2007).
- An economic study evaluating parameters increasing the probability of civil war concluded that natural resources significantly increased the probability for civil war in the region, especially during the 1990s. However, key determinants were the geographical concentration and unequal distribution of the natural resources, rather than the resources themselves (Ndikumana & Emizet, 2003).
- Without the money from minerals, the conflict might have ended earlier – so even if was not the initial cause, it finances the war now and is thus a cause to its continuation.

Even though ethnic tension and other factors play, and have played, an important role in the conflict (Turner, 2007), this report assumes as a baseline scenario that the minerals are accountable for all deaths in the conflict.

3.4.2 Minerals that are Included in the Weighting

The DRC holds many of the mineral resources which are needed in our modern society, such as tantalum, tungsten and tin used in electronics. This study considers tin, tantalum, tungsten, cobalt, diamonds, gold and copper, since those have a high economic value and have mines that have been identified in the literature and data for the region. All other minerals will be omitted from the allocation. However, one could also argue that other resources of high value should be included in the study. One resource that is particularly interesting is land, since some fighting seems too have been about the right to land properties (Amnesty International, 2013). That is discussed later in the interpretation of the results in Section 6.3.

4 Inventory Analysis

Elemental gold is an inert substance. It is neither toxic nor polluting, and can even be eaten by humans without any harm (Lenntech, 2015). However, toxic and polluting emissions occur during the life cycle of gold in jewelry, depending on many different factors such as technology, environmental regulations and the scale of mining. This study primary focusses on the DRC, and this type of gold production process is thus described in Section 4.1. Human health impact data based on the ReCiPe impact assessment method for large-scale gold mining has been obtained from the Ecoinvent database for the South Africa and Swedish scenarios, which are also included in the study (Appendix B). However, these processes, which are very different from the production process in the DRC, for example due to different scales and technologies, are not explained further in this report. In addition, since there are no recent conflicts connected to the gold production in South Africa and Sweden, there is no contribution to the DALY from conflicts for those types of gold. However, life years lost due to accidents and emissions are included in the South African and Swedish scenarios.

4.1 Damage to Human Health from Emission

In this study, the term gold production refers to the processes where gold is mined, separated and processed, which are explained in Subsections 4.1.1-4.1.3. Subsections 4.1.4-4.1.8 explains the processes between the production and the end use of the jewelry.

4.1.1 Extraction – Artisanal Mining

Much of the mining in the DRC is small-scale and carried out with hand-held tools. This is also known as artisanal mining. However, lately, the country has also experienced an increase in industrial, large-scale mining (Amnesty International, 2013). An example is the newly opened gold mine in Kibali (Orientale province), where 15-18 metric ton of gold is estimated to be extracted every year once the mine is fully operational (Jones, 2014). However, since this study is retrospective and the Kibali mine has just started to operate, the focus is on artisanal mining.

Artisanal mining is widespread in the eastern DRC and employs a large proportion of the population in the area. A rough estimate is that about 400 000-550 000 people are working with artisanal mining on a regular, seasonal or supplementary basis in Katanga, Ituri district (Oriental), South Kivu and North Kivu. However, the number of miners depends on the mineral prices and the workforce increases when the price on minerals is high (Pact, 2010). A rough estimate is that as many as 13-20 million people in the world work with artisanal mining (Darby & Lempa, 2013; Hinton, et al., 2003).

Artisanal gold mining can be carried out in many different ways, and there is no standardized process. In the DRC, artisanal mining is formally defined as “any activity by means of which a person of Congolese nationality carries out extraction and concentration of mineral substances using artisanal tools, methods and processes, within an artisanal exploitation area limited in terms of surface” according to the governmental 2002 DRC Mining Code (Pact, 2010). One common artisanal mining process in the DRC is from open shafts, carried out with very simple tools, such as shovels and hoes. In some cases, dynamite is used to weaken the rock. The ore is then transported to where it is processed (Pact, 2010). The heavy ore is often transported by foot and is usually processed close to the mining site. Another common method in the world is the alluvial extraction method (Valdivia & Ugaya, 2011). Sediments or soil is then taken directly from the ground to be processed. Artisanal mining can also be as simple as panning for gold in rivers.

Artisanal mining in the DRC is associated with many social problems such as child labor and health issues. Besides the conflict, health issues directly associated with the mining have also been identified. Accidents are common due to lack of safety thinking and equipment, resulting in falling people and rocks.

4.1.2 Separation

If the ore material is rock or harder sediments, it needs to be crushed in order to extract the gold from the ore. However, manual separation with hand picking can be conducted before the crushing. The crushing can be conducted with simple tools, for example a hammer, or some kind machine for crushing if one is available. Separation is also typically conducted with some kind of gravity method. A ball mill can be used for breaking the material into even smaller pieces. The mill can be driven by hand, animals, wind, water or electricity. With this procedure, the ore is transformed into a powder containing gold, and emissions occur if the mill is driven by for example diesel aggregates (Valdivia & Ugaya, 2011; Hinton, et al., 2003).

If the alluvial method is used, the sediments can be separated by for example using pumped water and then using a woolen carpet. A large portion of the gold will then get caught in the carpet. At the end of the shift of work, the carpet is brushed out, resulting in sediment with a high concentration of gold (Valdivia & Ugaya, 2011).

In the mining and separation processes, dust is inhaled, but the health impacts of that are not included in the study since there is no data available. However, in two case studies of artisanal gold mining performed in Peru, inputs, outputs and emissions were identified, including diesel use, oil spill, and water use. The two case studies are analyzed in one scientific article and the whole inventory from those two case studies can be found in Appendix A (Valdivia & Ugaya, 2011). Even though the conditions in the DRC may be different from Peru, this data will be used as a typical case, since specific data for the DRC is missing, and so are global average emissions from artisanal gold mining. One of the case studies in Peru is used as a baseline scenario, since the output flow in that case is almost 100% gold (Peru cases study 1), whereas in the other study, the output flow is just 80% gold (Peru case study 2) (Valdivia & Ugaya, 2011). The second case study is used for comparison in the sensitivity analysis. It is important to notice that the mercury use and emissions are not obtained from any of those studies, but instead obtained from other sources.

4.1.3 Processing with Mercury

There are many different ways to separate the gold from sediments. One method frequently used is the process when mercury is added to the sediment. Mercury is added to the residual sediment after separation, since mercury and gold react with each other and form an alloy. In simple terms, one can say that mercury "draws out" the gold from the sediment and turns it to an amalgam (AuHg):

$$2Au + Hg_2 \rightarrow 2AuHg \quad (8)$$

If mercury is added, it is possible to see the resulting amalgam, which is separated from the other sediments. The waste water containing mercury is recycled or emitted to soil or water. The gold- and mercury-containing compound amalgam is then heated up and the mercury is vaporized, while the gold remains. In low income countries, such as the DRC, often no protection is used and the mercury is inhaled by the person heating the amalgam (Veiga & Telmer, 2009; Pact, 2010). The mercury vapor later condenses and is then polluting the soil and the water nearby the mining and processing site (Veiga & Telmer, 2009).

Inhalation of mercury fumes or intake of contaminated water can lead to serious health problems including "tremors, emotional changes, insomnia, neuromuscular changes, headaches, disturbances in sensations, changes in nerve responses, performance deficits on tests of cognitive function. At higher exposures there may be kidney impacts, respiratory failure and death" (EPA, 2014). In addition, mercury can react with other substances and may create even more toxic compounds resulting in damaged to the gastrointestinal tract, the nervous system, and the kidneys. Symptoms may also consist of skin rashes and dermatitis, mood swings, memory loss, mental disturbances, and muscle weakness (EPA, 2014).

Although there are methods to avoid mercury use in the process, most artisanal mining of gold is conducted with mercury. This is due to several factors. Mercury is cheap, has a high accessibility, is effective in capturing gold, makes miners independent and is easy to use. It is important to notice that miners often do not have any option or lack knowledge about alternative methods. Also, knowledge about health risks is missing amongst many miners (Veiga & Telmer, 2009). In the world today, on average 1000-1400 metric ton/year of mercury is estimated to be emitted from artisanal gold mining, corresponding to roughly a third of all anthropogenic mercury emission (Veiga & Telmer, 2009; UNEP, 2012).

It is hard to estimate how much mercury is used in artisanal mining since it depends on which processes are used. Especially recycling of mercury at site can reduce mercury use considerably (Veiga & Telmer, 2009). There is currently no data available about how much mercury is emitted from gold production in the DRC, or the impacts of mercury pollution. The study by Veiga and Telmer suggests that 3 kg mercury per kg of gold is a reasonable low estimate on average for artisanal mining (Veiga & Telmer, 2009). That can also be derived from global averages of mercury pollution which is: 2.5-3.5 kg mercury per kg gold (Darby & Lempa, 2013)[2]. Due to lack of surveillance, regulations and follow up, there are no reasons to believe that artisanal mining in the DRC is emitting less mercury than what is emitted globally. Thus, the estimate of 3 kg mercury per kg gold constitutes the baseline scenario for mercury emissions in this study. In the two case studies conducted in Peru, it was reported that 0.2-2.2 kg mercury per kg of gold was emitted from gold extraction (Valdivia & Ugaya, 2011). The lower case is when mercury was recovered (recycled) and is used in the sensitivity analysis as a lower emission limit. However, in extreme case of mercury pollution, emissions can be up to 50 kg mercury per kg gold (UNEP, 2012), which is used as an upper limit of emission in the sensitivity analysis.

A study from the region of Katanga in the DRC showed statistically significant higher concentration of various metals (including Cd, Co, Cu, Pb and U) and metalloids (including As) in urine samples taken from people living in proximity to mining sites (Banza, et al., 2009). However, this type of emission is usually not associated with artisanal gold extraction, but rather other types of mineral extraction in the DRC. Although there could be other toxic emissions in the extraction phase, they are not

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[2] 1000-1400 ton mercury per 400 ton globally produced artisanal gold gives: 2.5-3.5 kg mercury/kg gold

included in this study. One specific emission that could be interesting to investigate further is the highly toxic cyanide. However, even though cyanide processing of gold is common in the world, that method is often used in gold production of larger scale and the process is also more complicated. Therefore, it is not frequently used in small scale artisanal mining (Hinton, et al., 2003).

4.1.4 Transport from Mine to Comptoir

In the DRC, the gold produced is transported in several different ways from the mine to regional *comptoirs*. A comptoir (French for counter or trading firm) is a person who can sell the gold to traders on the international market. The comptoir is the endpoint for the gold in the DRC before it enters the global market. The gold could be transported by foot for long distances, since infrastructure is lacking (Pact, 2010). In addition, airplane and road transport can be used for the whole or parts of the distance. Frequently, militia groups stop the transport at different checkpoints to collect taxes, in cash or minerals, to guarantee passage (Global Witness, 2009).

The gold can be transported to regional centers such as Goma in North Kivu or Bakuvu in South Kivu and is then collected by a comptoir. However, the gold can take several different routes before it reaches the comptoir. Generally some kind of *negociant* is involved. Negociants (French for trader or commercial partner) are people that who provide capital to the miners so that the miners can start their businesses. Negotiates are the link between the miners and the comptoir, and their trade is often in smaller scale (Pact, 2010). The gold can also be transported to cities in neighboring countries, such as Kigali in Rwanda, Bujumbura in Burundi, and Kampala in Uganda. No-one knows exactly how much minerals are transported via neighboring countries. But as an example of the magnitude of the trade, a business man in Burundi estimated that 75% of all gold in Burundi came from the DRC. However, the Burundi government officially denies that any gold exported from the country is from the DRC (Global Witness, 2009).

Even though many lives could be lost during this transport, it is assumed that the impact on human health is zero. Also, emissions from this transport are excluded since the distance is negligible compared to the distance when the gold is exported to other parts of the world. This process is however discussed in the interpretation in combination with other accidents, see Section 6.2.

4.1.5 Transport from Comptoirs to Sweden

The international trade companies buy the gold from comptoirs and can then transport it to smelting sites elsewhere in the world where it is mixed with gold from other parts of the world (Human Rights Watch, 2005). Thereafter, the gold is transported to where the wedding ring is manufactured. The transportation is assumed to be carried out with aircraft, since that is the only transportation method mentioned in the studied literature, and also since gold has such a high value per mass and volume which is typical for air cargo.

Impacts on human health in this process are due to emissions and accidents. The emission data is gathered from the Ecoinvent database for intercontinental freight, see Appendix E (Frischknecht, et al., 2005). The data for accidents when transporting freight by aircraft are gathered from statistics for US and $1.02 \cdot 10^{-7}$ DALY per ton and km (Scanlon, et al., 2014).

In Sweden, large jewelry chains mainly use recycled gold in the production, or gold extracted in Sweden. The jewelry retailer *Smycka* in Sweden states that they use 95-100% recycled gold in their production. Another Swedish company, *Guldfynd*, states that up to 90% of their gold is recycled gold. Both companies say that the rest of the gold comes from a Swedish mine operated by the company Boliden. However, both companies also say that it is impossible to trace where the recycled gold is coming from (Olander, 2014; Kloo, 2014). Therefore, it is unlikely that the gold from the DRC enters the Swedish jewelry market directly. If it enters the market at all, it is probably in the form of recycled gold, with help from intermediaries. However, the gold has to travel the distance from the DRC to Sweden in some way if it enters the market at all. The minimum distance that the gold travels is thus the distance between the DRC and Sweden. The distance the aircraft is assumed to travel is from Goma in the DRC to Stockholm in Sweden. However, one additional scenario is also included in the sensitivity analysis where the plan first lands in Beijing (China) and then travels to Stockholm.

For the comparative cases, the gold produced in South Africa is assumed to be traveling between Cape Town and Stockholm. The gold in Sweden is assumed to travel from Gällivare to Stockholm. Gällivare is the place where the copper ore is extracted in Sweden, and gold is a by-product from that copper production. Even though it is being processed in Skellefteå in reality, the longer distance from Gällivare is chosen. All distances are summarized in Table 4.1.

Table 4.1 – Flight distances between different cities.

From city – to city	Distance [km]
Goma-Stockholm	6740
Goma-Beijing-Stockholm	14063
Cape Town-Stockholm	10230
Gällivare-Stockholm	898

4.1.6 Jewelry Production

Goldsmiths seem to have conducted craftsmanship in a similar way throughout history (Walton, 1992). Due to the softness of gold, it is often combined with other metals, such as silver and copper, in jewelry to improve its mechanical properties, (Drost & Hausselt, 1992). However, all substances except gold are excluded in this study.

There is no general data available for emissions and energy flows form jewelry production. In this process, only the energy for melting the gold is therefore included, since the gold has to be melted to produce a wedding ring as a minimum requirement. Physical properties of gold require a minimum of 0.018 kWh per kg gold to liquefy gold from a solid state (Periodic Table, 2015). However, compared to gold melting devices used today, it seems likely that the efficiency is lower than this theoretical case, ranging 0.1-0.9 kWh/kg. Accessible technology probably reflects the reality better than the theoretical value. This study therefore assumes that the jewelry production process requires 0.5 kWh of electricity per kg of melted gold on average. The inventory data for electricity production in Sweden is gathered from the Ecoinvent database and can be found in Appendix F.

4.1.7 Retailer and Use Phase

There are many different retailers of various sizes for jewelry in Sweden, and since gold has such a high value, all of them are exposed to the risk of being robbed

(Ljungholm, 2013). In addition, private persons may be exposed to risks from owning jewelry (DN, 2012). There are no specific data on how many people are injured or killed in this type of robberies each year. However, the impact on human health in the use and retailer phase is believed to be rather small compared with other processes. The baseline scenario is therefore that the gold has no impact on human health in this phase.

4.1.8 Recycling and Grave

Most gold in a wedding ring goes to recycling, and a small amount goes to the graveyard (burned with the body) (SKKF, 2010). Some of the material disappears during usage. One study showed that 6.15 mg of gold lost in one wedding ring is lost due to abrasive wear (Steinhauser, 2008). The implication of this is that most gold that has been extracted still is a part of the technosphere[3]. When the gold is recycled the impact on human health will be lower per golden ring or kg gold. However, since this study mainly focuses on newly produced gold, recycling is not a part of the baseline scenario. The implication of recycling of gold is however discussed in the interpretation, see Section 6.5. The wedding ring is there assumed to be recycled (i.e. re-melted) and not re-used. The electricity used for recycling is the same as in the production process, see Section 4.1.6.

4.2 Work-Related Health Issues during Transportation and Extraction

In the DRC, there are laws and regulations for addressing work environment related problems associated with mining sites. However, these regulations are not enforced due to lack of capacity and incentive to do so (Pact, 2010). In some rare cases, miners are forced to take risks. However, more frequently, miners choose to take risks since it saves time and costs to conduct the work in a less safe way. In addition, many miners lack knowledge about risks, safety and potential precautions. In general in the world, accidents in artisanal mining are linked to machinery accidents, ground failure and shaft collapses (Hinton, et al., 2003).

One particular study, conducted on artisanal mining in the DRC, concludes that the relatively high cash flow in the DRC in artisanal mining communities led to high consumption of alcohol and other drugs, which in turn led to liver disease and violence. Also, due to the high percentage of male artisanal miners and the alcohol consumption, prostitution is really common in artisanal mining areas. Prostitution increase the risk for illness, and especially HIV/AIDS is common amongst artisanal communities (Pact, 2010). However, these types of work-related accident or diseases are not included in this study.

Since work environment data is lacking for the DRC, average data of accidents in mining from the US is used to estimate for DALY in mining, which is $6.5 \cdot 10^{-8}$DALY per kg mineral; see Appendix C for data (Scanlon, et al., 2014). However, even though this figure may be relatively reasonable for large-scale gold production in South Africa and Sweden, it is probably not reasonable to assume for the DRC case. Since data is missing, the US data will be the baseline scenario also for the DRC and is later tested by increasing the amount of accidents occurring in

[3] The technosphere is defined as the material side of society (Karlsson, et al., 1996)

artisanal mining, see Section 6.2. Both accidents from gold mining and mercury mining are included.

Transportation data for DALY for intercontinental freight in air freights are also gathered from the US statistics and is $2.1 \cdot 10^{-10}$ years per metric ton and km (Scanlon, et al., 2014). The distances are the same as for the calculation of emission-based health impacts, see Table 4.1.

4.3 Casualties due to Conflict about Minerals

4.3.1 Number of Causalities in the Conflict in DRC

During the Second Congo War (1998-2001), approximately 145 000 people died in direct battle. However, such deaths do not reflect the actual amount of people dying in a war. In developing countries, many more die from war-related diseases and malnutrition than by weapons in conflicts. This is due to many different factors, such as displacement of people resulting in overloaded refugee camps with bad food, poor sanitation, contaminated water, etc. The camps also create a basis for diseases and put stress on resources in the region, such as food and water. In addition, health infrastructure is lost in conflicts, making it even harder to treat injured people. The total number of deaths in the Second Congo War (1998-2001) has been estimated to be 2.5 million (Human Security Centre, 2005). If mortality rates are used in retrospective, one study suggested that around 5.4 million people lost their lives between 1998 and 2007 as a consequence of the conflict, including excess deaths (IRC, 2007). Excess deaths mean all extra deaths that occur in the region except those who would have died anyway. In short, the method calculates the number of deaths by comparing the number of deaths that occurred in the period with how many that would have died if there was no war. Therefore, 5.4 million is applied as an assumption about the total number of deaths in the conflict in the baseline scenario.

The study by IRC (2008) includes two different age groups, 0-5 and >5. The DALY is calculated by taking the year of life expectancy for Sub-Saharan Africa, which is 56 years (World Bank, 2012), and then subtract that from the assumed age of death. This study assumes that the average death occurs at 2.5 years for age group 0-5 and at 28 years $(56/2)$ for age group >5. The number of years is then multiplied by the number of deaths for each age group. The total number of DALY lost due to the conflict then adds up to 215 million years, i.e. $DALY_{Conflict} = 215\,million$. However, this number is most probably too low; since the age structure of Congo has the pyramid shape typical for expanding populations in developing countries, see Figure 4.1. Even if it is more reasonable to believe that more young people are dying than older people, the assumption of 28 years is still applied as baseline scenario.

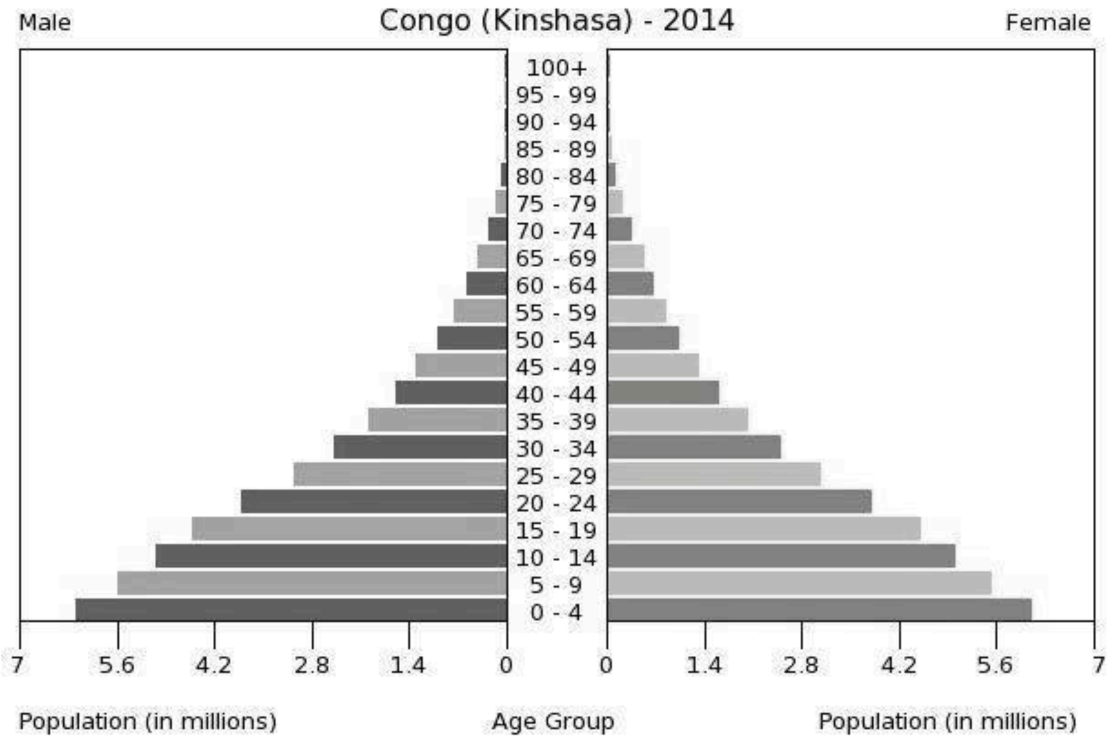

Figure 4.1 – Population pyramid for the DRC (Central Intelligence Agency, 2014).

4.3.2 Data for Allocation between Minerals

The minerals included in the allocation of the deaths in the conflict are tin, tantalum, tungsten, cobalt, diamonds, gold and copper. The exports of all minerals except gold is based on the official statistics from four different reports (Stockwell, et al., 2002; Hetherington, et al., 2007; Brown, et al., 2012; Brown, et al., 2015). The market prices of these minerals are based on statistics from a US database that is adopted to allow for data comparison between minerals through time (Kelly & Matos, 2013). All data on exports and prices can be found in Appendix D.

It is also hard to estimate the amount of gold that is extracted and processed in the DRC every year, but rough estimates varies between 6-10 metric ton (Pact, 2010). However, one governmental person even estimates that as much as 40 ton is being produced in the DRC each year (UN, 2009). One conclusion that can be drawn is that the official statistics for production of gold for the period are not accurate, considering that so many people are working with gold production. It is for example not reasonable to believe that only 50 kilo of gold was extracted in the DRC 2005 (Hetherington, et al., 2007; Pact, 2010). This study assumes a baseline scenario in which 10 ton of gold are produced annually during the period. Since this figure is questionable, the result is tested for a range of different masses in a sensitivity analysis, from 5 ton up to 50 ton.

4.4 Summary of Data and Flow Processes

Table 4.2 – Summary table of data for baseline scenario of the DRC.

Process	Data	Source
Transport distance	6740 km	Assumption
Amount of gold extracted	10000 kg	(Pact, 2010)
DALY lost in conflict	215 million DALY	(IRC, 2007) (World Bank, 2012)
Emission during production	Appendix A	(Valdivia & Ugaya, 2011) (Frischknecht, et al., 2005)
Mercury emissions	3 kg mercury/kg gold	(Veiga & Telmer, 2009)
Ratio between mercury emission to air and total	1/3	(Veiga & Telmer, 2009) (Hinton, et al., 2003)
Data gold production South Africa and Sweden	Appendix B	(Frischknecht, et al., 2005)
Data on accidents	Appendix C	(Scanlon, et al., 2014)
Data on export of minerals	Appendix D	(Stockwell, et al., 2002; Hetherington, et al., 2007; Brown, et al., 2012; Brown, et al., 2015)
Data on prices of minerals	Appendix D	(Kelly & Matos, 2013)
Emission during transport	Appendix E	(Frischknecht, et al., 2005)

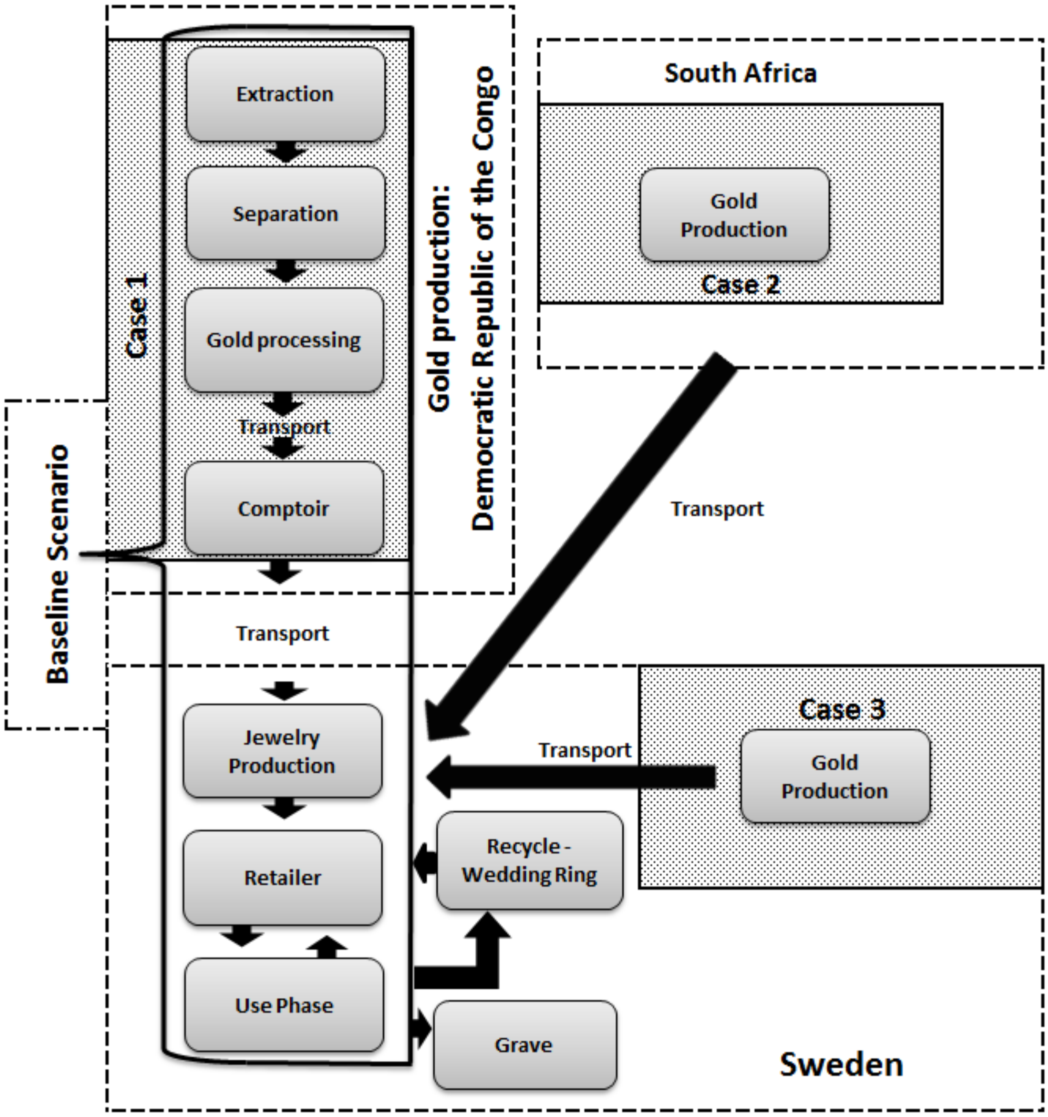

Figure 4.2 – Flow chart for gold in jewelry, including the three different gold production scenarios of this study: DRC (baseline), South Africa and Sweden.

5 Impact Assessment

As can be seen in Table 5.1 and Table 5.2, the DALY from the conflict by far exceeds any other processes. In the baseline scenario, 94 years of lives are lost per kg of gold extracted in the DRC due to the conflict, which can be compared to the second largest contributor, which is the DRC production process emissions, for which only about 0.63 life years are lost (mainly due to mercury emissions). One can also conclude from the results in the tables that all contributions are of different magnitude. DALY for gold production in Sweden and South Africa are notably lower that in the DRC. Excluding the conflict, emissions from the production processes for all three cases by far exceed all other contributions.

To visualize these differences, the results are also presented in Figure 5.1, Figure 5.2 and Figure 5.3, in the form of bar diagrams. The result in these figures compares different impacts for one typical wedding ring.

Table 5.1 – Results for DALY lost per wedding ring produced in different processes and for different countries.

	DRC	South Africa	Sweden
Production (emissions)	2.5E-03	4.8E-04	1.1E-04
Accidents extraction	1.1E-09	2.6E-10	2.6E-10
Conflict	3.8E-01	-	-
Transport (emissions)	5.0E-08	7.6E-08	6.7E-09
Jewelry melting (emissions)	1.2E-09	1.2E-09	1.2E-09
Accidents transport	5.7E-09	4.2E-09	3.7E-10
In total	3.8E-01	4.8E-04	1.1E-04

Table 5.2 – Results for DALY lost per kg of gold produced in different processes and for different countries.

	DRC	South Africa	Sweden
Production (emissions)	6.3E-01	1.2E-01	2.7E-02
Accidents extraction	2.6E-07	6.5E-08	6.5E-08
Conflict	9.4E+01	-	-
Transport (emissions)	1.3E-05	1.9E-05	1.7E-06
Jewelry melting (emissions)	3.1E-07	3.1E-07	3.1E-07
Accidents transport	1.4E-06	1.0E-06	9.2E-08
In total	9.5E+01	1.2E-01	2.7E-02

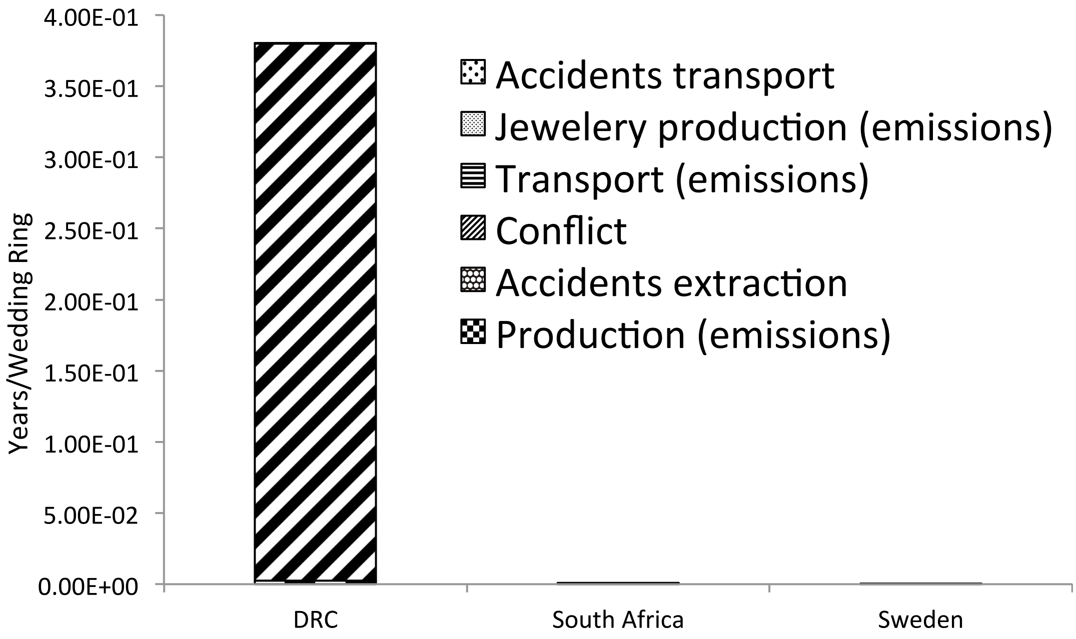

Figure 5.1 – The figure illustrates the total health impact from production of one golden wedding ring.

As can be seen in Figure 5.1, the conflict has a considerable impact on human health. The magnitude is almost 0.4 years of life lost per wedding ring (approximately 5 months). The only other process that can be seen (hardly) is the impact from gold production emissions in the DRC (coming mainly from mercury). Consequently, the results are also visualized with the DALY from conflict excluded in Figure 5.2. The Swedish and South African cases can now actually be seen, even if they are still small in comparison to the DRC case. This result indicates that emission impacts on human health are the main contributor apart from the conflict, and it is clear that it is much larger for artisanal mining than for large-scale mining. The main emission behind this higher DALY is mercury used in artisanal gold production.

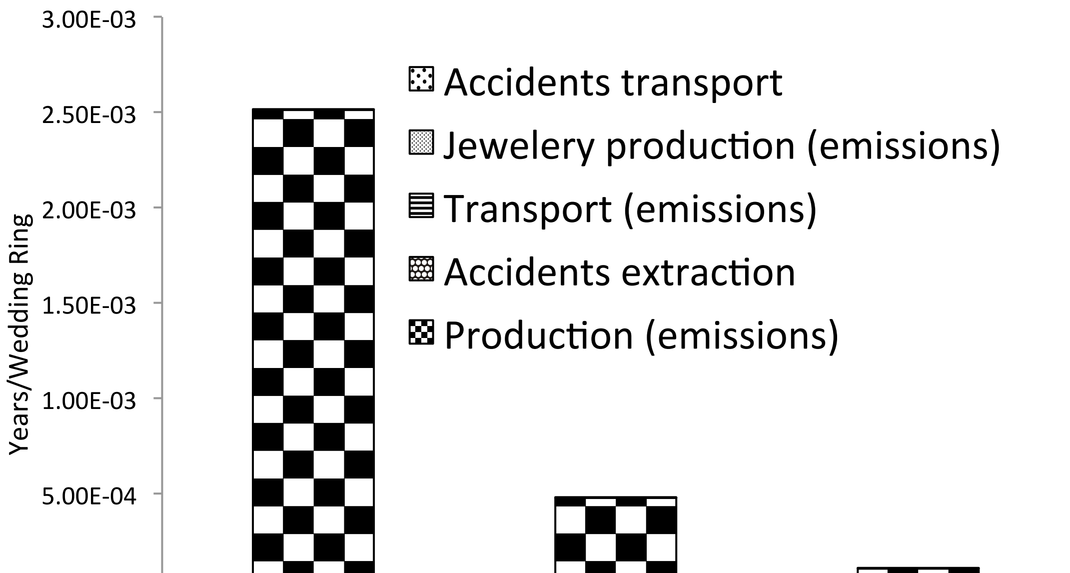

Figure 5.2 – The figure illustrates the results of impact for different processes and cases but excludes DALY due to the conflict.

However, it is still not possible to see the impacts of any other process except for production emissions in Figure 5.2. Therefore, also the production process is excluded in Figure 5.3. Figure 5.3 clearly illustrates the difference between impacts from accidents on human health compared to emission impacts on human health for transports. The result from the ReCiPe impact assessment method for transport is higher than the impacts from accidents. Accidents occurring in the extraction process are not even visible in the figure. Notably, the result for the DRC and South Africa are of the same magnitude when the conflict and production emissions are excluded. That is reasonable, since the only variable factor for transport between the cases is the distance and South Africa is further away from Sweden than is the DRC. This shows that it is indeed the conflict and the use of mercury in artisanal mining that lead to higher DALY in the DRC case than in the other two cases.

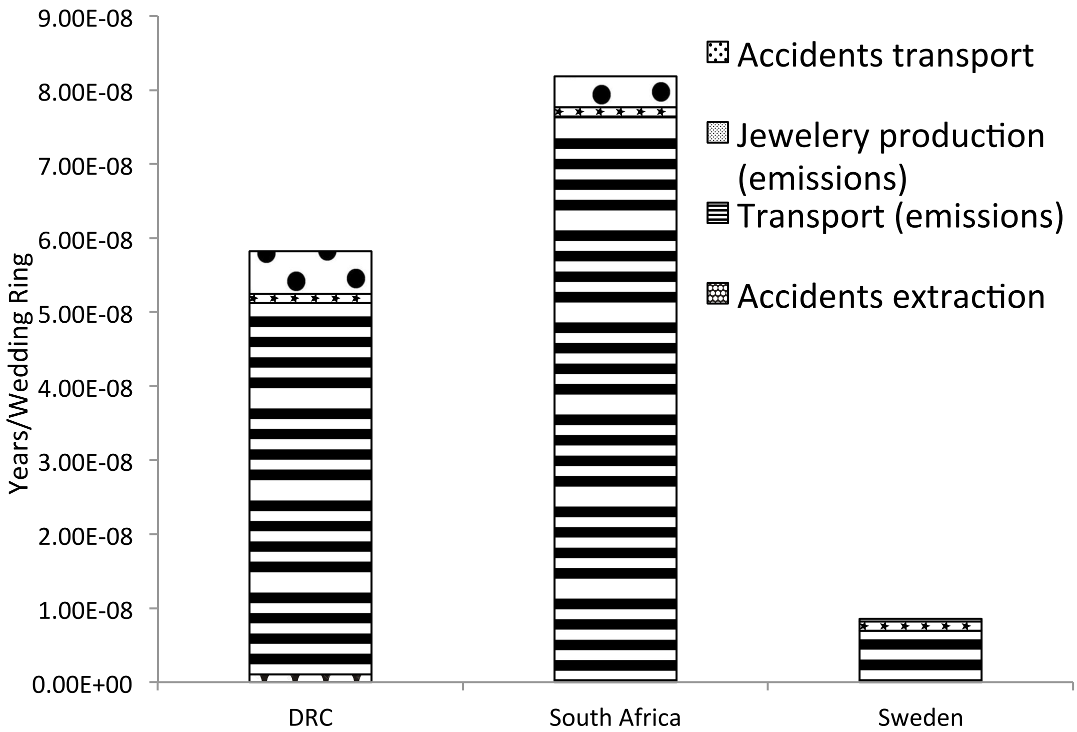

Figure 5.3 – The figure illustrates the results of impact for different processes and cases but excludes DALYs lost due to the conflict and emissions during production.

6 Interpretation

This chapter has five sections. The first three sections analyze the results of the impact assessment regarding emissions, accidents and conflict, respectively. After these three sections, two new aspects are discussed, namely positive impact and end use.

6.1 Damage to Human Health due to Emissions

This section interprets the impact assessment results for emissions, presented in Chapter 5, further. The section only included sensitivity and contribution analyses for the processes where emissions occurred. In subsections 6.1.1-6.1.2, the DRC, South African and Swedish scenarios are included. In subsections 6.1.3-6.1.5, only the DRC scenario is included since those subsections are about the emissions in the DRC.

6.1.1 Contribution Analysis for Gold Production Process

A deeper analysis of the emission impacts shows that human toxicity has the greatest impact on human health in the DRC and South African scenarios (Figure 6.1). In the DRC scenario, this is mostly due to the emissions of mercury to air, which stands for about 86% percent of the total impact on human health. In South Africa, 70% of the impact on human health comes from emission of manganese and arsenic during gold production. Figure 6.1 also shows that the particulate matter formation is the most important impact in the Swedish gold production. However, in the Swedish case, no single impact category is as dominant as in the two other scenarios.

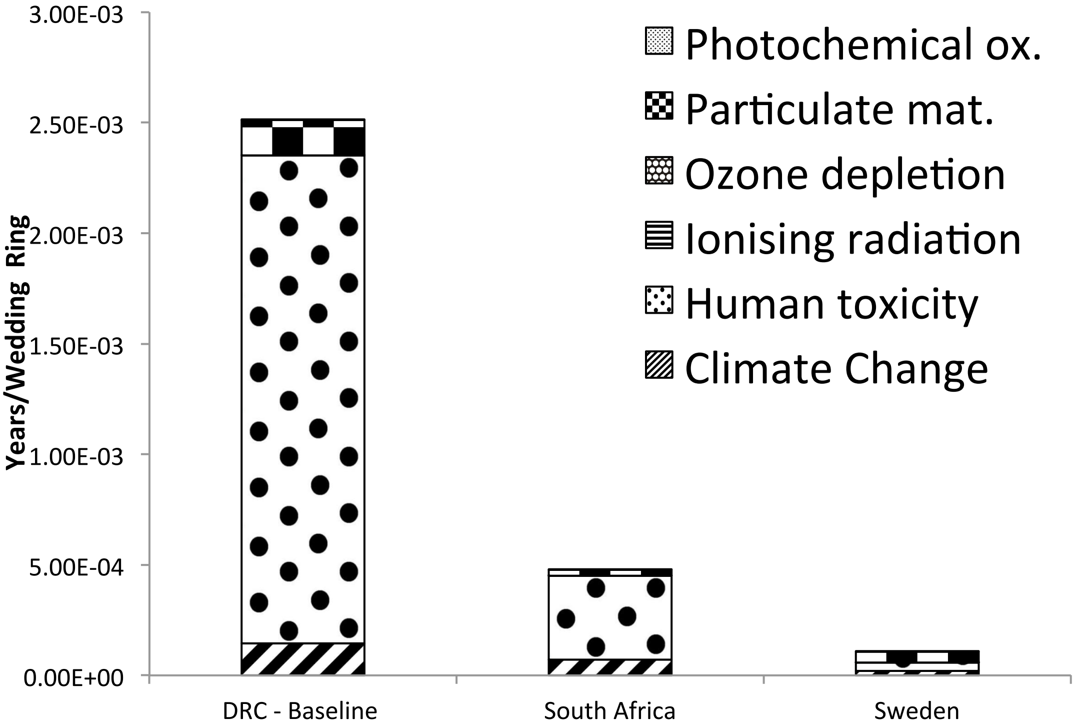

Figure 6.1 – The figure compares impacts on human health from emissions for gold production from different countries (i.e. only DALYs from production emissions are included). It shows which type of emission category that is the most contributing to human health impacts.

6.1.2 Sensitivity Analysis on Human Values

Human values differ from person to person and these values can be categorized into the three perspectives: hierarchical, egalitarian or individualistic (Goedkoop, et al., 2013). Adopting a hierarchical, egalitarian or individualistic perspective influences the overall results, since the perspectives assume different value choices when characterization factors are created for the different impacts categories. Value choices could affect choices such as the time horizon and the discount rate. For example, for some models for creating impact categorization factors the individualist has an assumed discount rate of 5%, the hierarchist has 3% discount rate while the egalitarian has a discount rate of 0% (de Schryver, et al., 2011).

This study assumed a baseline scenario with a hierarchical perspective. However, it is also interesting to know the results for other perspectives. Figure 6.2 compares the ReCiPe endpoints results for the gold production from the DRC, Sweden and South Africa with different cultural perspectives. However, only emissions occurring during gold production are included. The results show that the egalitarian perspective gives the largest impact for all three cases. The hierarchical has the second largest impact. The impact on human health for the individualistic perspective is only slightly lower than the results for the hierarchical perspective. That is an expected result, since the egalitarian perspective has a longer time horizon and a lower discount rate than the other two perspectives. However, what is notable is that the impact per weeding ring increases more in the South African and Swedish scenarios (a factor of 37 and 17, respectively) than in the DRC scenario (a factor of 3). Notably, the South African gold production processes has the highest impact per wedding ring with an egalitarian perspective.

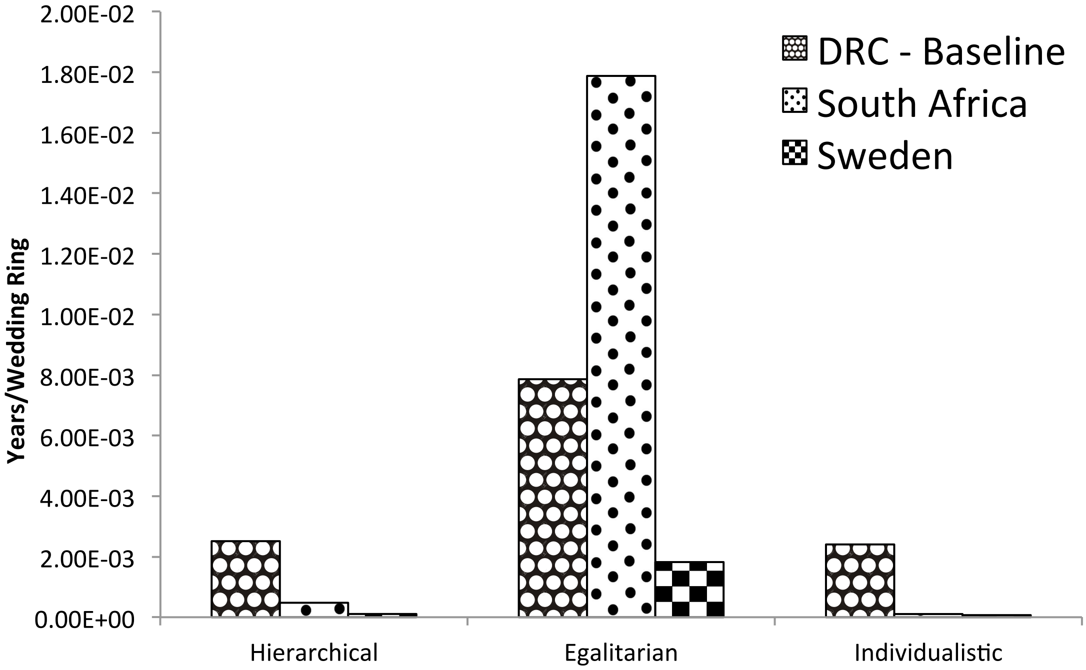

Figure 6.2 – Sensitivity analysis on human values for the gold production process in the DRC, South African and Swedish scenarios. Note that only gold production emissions are included here.

To analysis this further, one needs to see which categories are contributing the most in the egalitarian perspective. In Table 6.1, the result shows that human toxicity is the most important contributor, which is reasonable since all scenarios have metal emissions that may cause impacts for a longer time period. In the ReCiPe method, the only difference between the egalitarian perspective and the hierarchical perspective for human toxicity is the time horizon. The hierarchical perspective has a time horizon of 100 years while the egalitarian perspective has an infinite time horizon for human toxicity (Goedkoop, et al., 2013). The emissions influencing human toxicity most in the South African and the Swedish scenarios are selenium and manganese emissions, while mercury is the main contributor in the DRC scenario. It is not clear from the ReCiPe method why selenium and manganese have larger impacts than for example mercury for the egalitarian perspective with the longer time horizon.

Table 6.1 – Contribution analysis for the egalitarian perspective, describing the percentage of each impact category to the total impact on human health.

	DRC	South Africa	Sweden
Climate Change	4.5%	1.0%	2.5%
Human toxicity	93.4%	98.9%	94.8%
Ionizing radiation	0.0%	0.0%	0.0%
Ozone depletion	0.0%	0.0%	0.0%
Particulate mat.	2.0%	0.1%	2.7%
Photochemical ox.	0.0%	0.0%	0.0%

6.1.3 Sensitivity Analysis of Emission in DRC

The data set for all emissions (except for mercury) from artisanal mining was obtained from one case study conducted in Peru. This is problematic, since this is just one case of artisanal mining, and artisanal mining can be conducted in many different ways. The question is how typical this case of artisanal mining is? To investigate this, the inventory data set is swapped to the second case study of artisanal mining conducted in Peru (Valdivia & Ugaya, 2011), and the results are compared with the results from earlier. The inventory data from the second Peru study is called alternative scenario. Keep in mind that the second case study has as slightly different output, 80% gold instead of 100%, and the comparison should therefore be taken with some caution. The results are shown in Figure 6.3.

As can be seen in Figure 6.3, the total impact on human health in the alternative inventory varies slightly between the baseline and alternative scenarios. The total impact is higher for the alternative scenario: $3.2 \cdot 10^{-3}$ years per kg gold compared to $2.5 \cdot 10^{-3}$ years per kg gold in the baseline scenario. The total impact on human health is still of the same magnitude as in the baseline scenario. Worth noting is that human toxicity is still the dominating impact, which is mainly based on mercury emissions, for which data is gathered from global studies of mercury emissions in artisanal mining and not obtained from any of the two Peruvian case studies. Consequently, even if data from a less efficient artisanal mining process is used in the analysis, mercury emissions are still the most important contributor.

Considering the differences in the non-toxicity impact categories in Figure 6.3, which are otherwise masked by the high contribution from the mercury, one can conclude that the results from the inventories vary a lot. That is mainly due to the fact that the alternative scenario uses a lot more fossil fuels than the baseline scenario, which causes an increase of a factor of 3-4 for all impact categories except human toxicity.

However, in absolute terms, just particulate matter and climate change are visible in Figure 6.3.

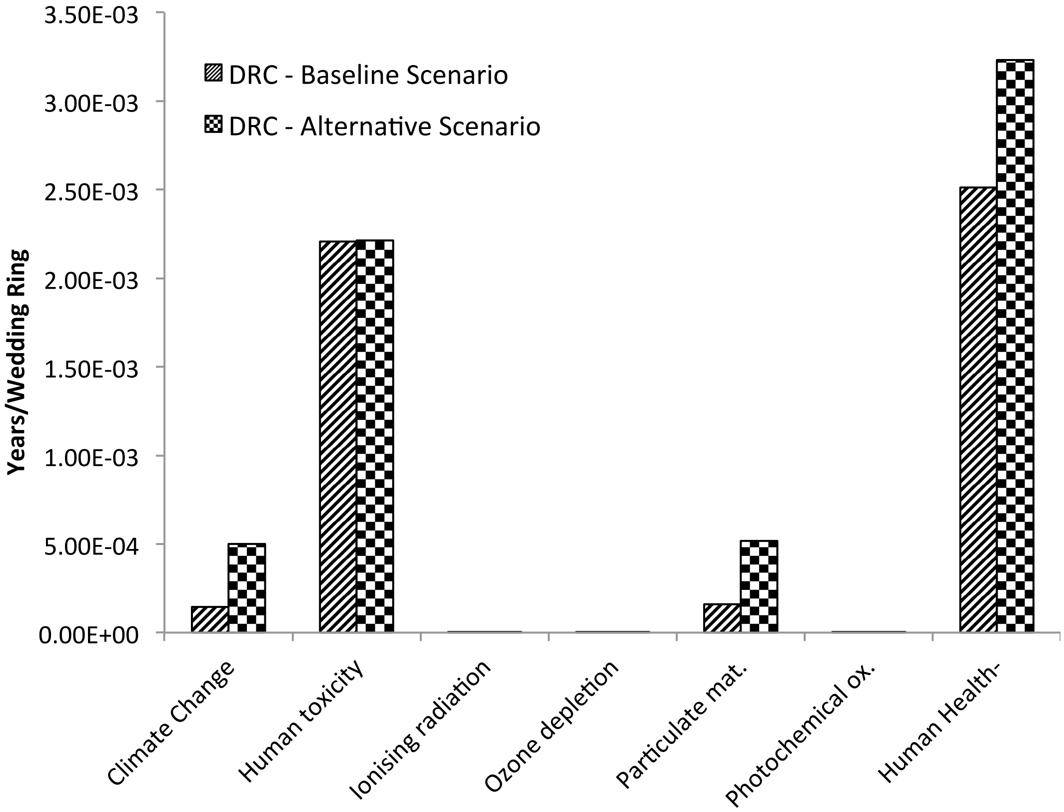

Figure 6.3 – Human health impacts from emissions from gold production in the DRC, with data from two different Peruvian case studies presented in the same article (Valdivia & Ugaya, 2011). The first case study is the baseline scenario and the second is the alternative scenario in this figure. Mercury emission, affecting human toxicity, is however obtained from another source (Veiga & Telmer, 2009), and is the same for both scenarios.

6.1.4 Sensitivity Analysis of Mercury Emissions

Mercury has the most notable impact on human health of the emissions during the life cycle of gold from the DRC. The amount used in the baseline scenario is however just an estimate of the mercury emissions, and the mercury emissions can vary considerably from one mining site to another. In the baseline scenario, 3 kg of mercury emitted per kg of gold was assumed. However, in the first Peru case study, only emissions of 0.2 kg mercury per kg gold was reported (Valdivia & Ugaya, 2011), while another study reported emissions as high as 50 kg mercury per kg gold (UNEP, 2012). Figure 6.4 illustrates the importance of this difference. If recycling of mercury is conducted as in the Peruvian study, the impact on human health would be reduced to only $2.5 \cdot 10^{-4}$ DALY per wedding ring. In that scenario, other impact categories such particular matter formation and climate changes become much more relevant in comparison. On the other hand, if the high case of 50 kg of mercury emission is used the total impact on human health increases notably up to $3.7 \cdot 10^{-2}$ years per wedding ring. The impact of mercury emissions is then only an order of magnitude lower than the conflict impact.

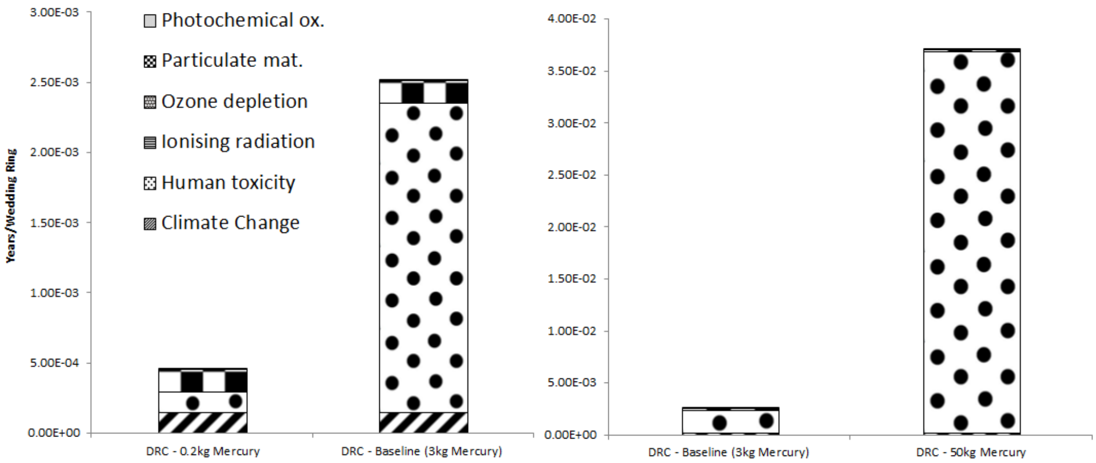

Figure 6.4 – To the left, the scenario with lower mercury emissions (0.2 kg per kg gold) is compared to the baseline scenario. To the right, the baseline scenario is compared to a scenario with 50 kg mercury per kg gold.

According to the ReCiPe impact assessment method, mercury emissions to air has a characterization factor of $3.6 \cdot 10^{-1}$years per kg, while mercury emissions to soil has a characterization factor of $6.6 \cdot 10^{-3}$years per kg. This is illustrated in Figure 6.5, where the baseline scenario of 3 kg mercury would results in $4.3 \cdot 10^{-3}$years lost due to mercury emissions given that 100% of the emission went to air. However, only $7.92 \cdot 10^{-5}$years are lost if just 1% of the mercury emissions goes to air. In the baseline scenario, this air/soil emission ratio was assumed to be 33%, but this was an assumption that is not based on reported data. In the two case studies from Peru (Valdivia & Ugaya, 2011), this number varied between 9% and 30%. However, the break even analysis in Figure 6.5 shows that the emissions to air needs to be as low as 2% of the total mercury emissions to be equal to the second largest emission impact category, which is particulate matter formation.

One conclusion that can be drawn from comparing Figure 6.4 with Figure 6.5 is that if the characterization factors for emission in ReCiPe are used to quantify impact on human health, mercury emission is the most important impact. It is therefore crucial to try to reduce these emissions. Closing the cycle of mercury should therefore be a priority compared to improving other processes. However, it is the emissions to air that are the main contributor, and it is not entirely clear in the studies about mercury use in gold mining if the proportion going to air is a constant, or if it depends on the amount of vaporized amalgam (Veiga & Telmer, 2009; Valdivia & Ugaya, 2011; UNEP, 2012; Darby & Lempa, 2013; Soos, 2011; Hinton, et al., 2003).

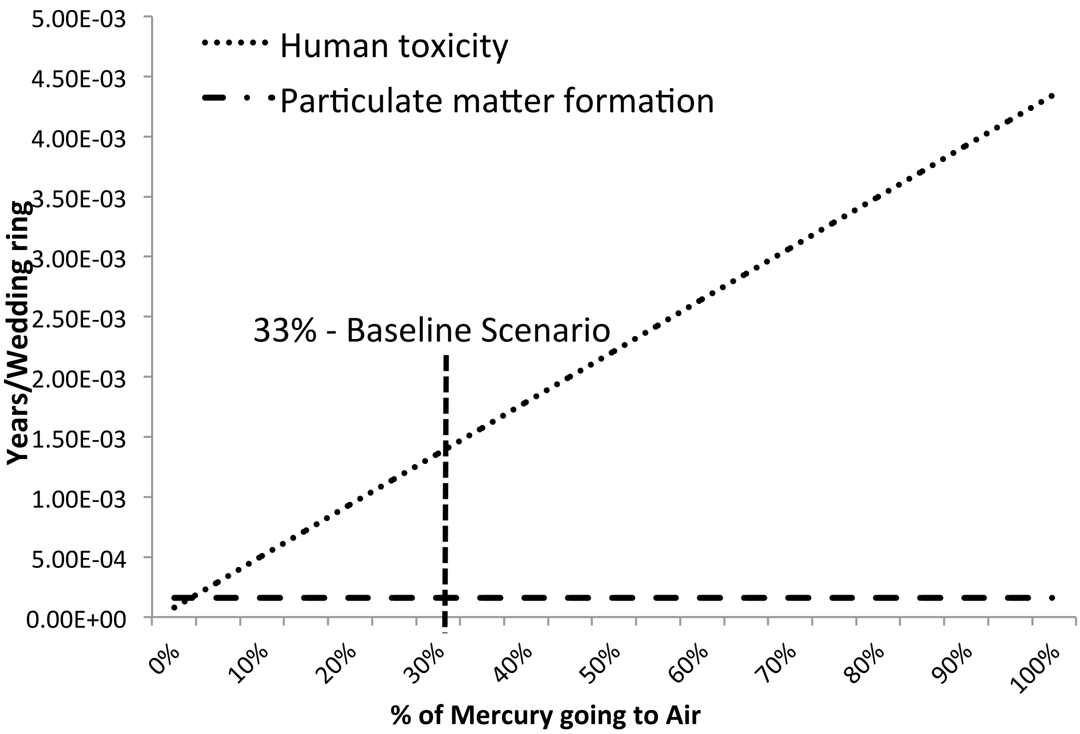

Figure 6.5 – Sensitivity analysis of mercury emissions to air and soil, respectively. The figure illustrates the difference in impact on human health if the mercury emissions go to air instead of soil.

6.1.5 Sensitivity Analysis of Transport Emission

One assumption in the study was the distance that the aircraft travels when transporting the gold from the DRC to Sweden. In the baseline scenario, the shortest distance the gold would need to travel was assumed. This is probably not the case in reality, but the aircraft instead probably travels a route through another country. However, even if the flight takes the longest route identified, which is via China, the impact of the emissions from this transport is still much lower than the impact from emissions from gold production, as can be seen in Table 6.2.

Table 6.2 – Sensitivity analysis of transport emission impacts.

Process	DALY per Wedding ring
Production	2.52E-03
Transport - Baseline	5.20E-08
Transport via China	1.05E-07

6.2 Accidents in Gold Production and Transportation

This section interprets the impact assessment results for the work-related accidents in transport and gold production, presented in Chapter 5, further.

6.2.1 Break Evan Analysis of work-related Accidents

The data on work-related accidents in mining is based on US data. It is not applicable for this study for several different reasons. The first problem is that it is based on data from US, which not necessarily correspond to Swedish or South American conditions, and definitely not to the DRC conditions. The other problem is that the range of data for accidents in mining is large. The lowest impact is $2.3 \cdot 10^{-10}$ years/kg and the highest impact is $3.9 \cdot 10^{-7}$ years/kg, see table C.1 in Appendix C. The difference between those figures is about a factor of 1700, creating a large uncertainty about how frequently accidents occur in mining.

A break-even analysis is conducted in order to find out when the impacts are equally large, and to investigate how large the differences between the different processes are. Since the DRC scenario is the main focus of this study, the Swedish and South Africa scenarios are not included in this analysis.

The comparison in Table 6.3 shows that the accidents occurring in mining need to be 2.4 million times as frequent (or severe) in the DRC as in the US to be comparable to the amount of life years lost due to emissions in gold production. The magnitude difference between the DALY lost in the conflict and the DALY lost in accidents (extraction) is over 360 million. One can therefore conclude that even if accidents occurring in the DRC are much more frequent then assumed in the baseline scenario, it is most probably not even close to the life years lost in the conflict and from emissions in production.

The results of the break-even analysis in Table 6.3 also show that the differences between the other processes are not so great, max a factor of 48 for transport emissions. Considering the large data uncertainties in this study, one cannot concluded which processes has the largest impact of the four processes.

Table 6.3 – Break-even analysis for accidents and all other main processes in the DRC scenario. The table shows the ratio between the processes to the left of the table and the work related accidents. The ratio is the point when break-even occurs.

Relative Process Comparison	Ratio (Accidents in extraction)
Production (emissions)	2.4E+06
Conflict	3.6E+08
Transport (emissions)	4.8E+01
Jewelry melting (emissions)	1.2E+00
Accidents in transport	5.5E+00

6.3 Casualties due to Conflict about Minerals

This section interprets the impact assessment results for the conflict, presented in Chapter 5, further. It only includes the DRC scenario, since the conflict only occurred there.

6.3.1 Uncertainty Analysis for Amount of Gold Produced

As can be seen in Figure 6.6, the relationship between the weight of gold produced in the DRC and life years is just a slightly sloping curve. The notation $V_{resources}$ was introduced in equation (7). However, the notation can be rewritten according to equation (8), since the value of gold is included in the total value of all minerals.

$$V_{resouces} = V_{resources-gold} + V_{gold} \quad (9)$$

where V_{gold} is the total value of gold, i.e.: $P_{gold} \cdot M_{gold}$. Combining equations (5), (7) and (9) gives equation (10):

$$DALY\ lost\ in\ conflict\ per\ kg\ gold = \frac{DALY_{Conflict}}{M_{gold}} \cdot w$$
$$= \frac{DALY_{Conflict}}{M_{gold}} \cdot \frac{V_{gold}}{V_{resources-gold} + V_{gold}}$$
$$= \frac{P_{gold} \cdot DALY_{Conflict}}{V_{resources-gold} + P_{gold} \cdot M_{gold}} \quad (10)$$

Since $V_{resources-gold} \gg P_{gold} \cdot M_{gold}$ and M_{gold} is the only variable in the analysis, the function is not so sensitive to changes in the amount of gold extracted. One interesting feature, however, is that the function is more sensitive to changes in prices than in mass. This is an interesting aspect, since the market price of gold seems to decide how many people are working with artisanal mining (Pact, 2010) and also reflects the revenue that is generated to military groups. These facts favor the usage of the selected allocation method. One further conclusion that can be drawn from this is that if the method and data used are reasonable, the amount of life years lost per wedding ring will still be of the same magnitude regardless of how much gold that is extracted in the region.

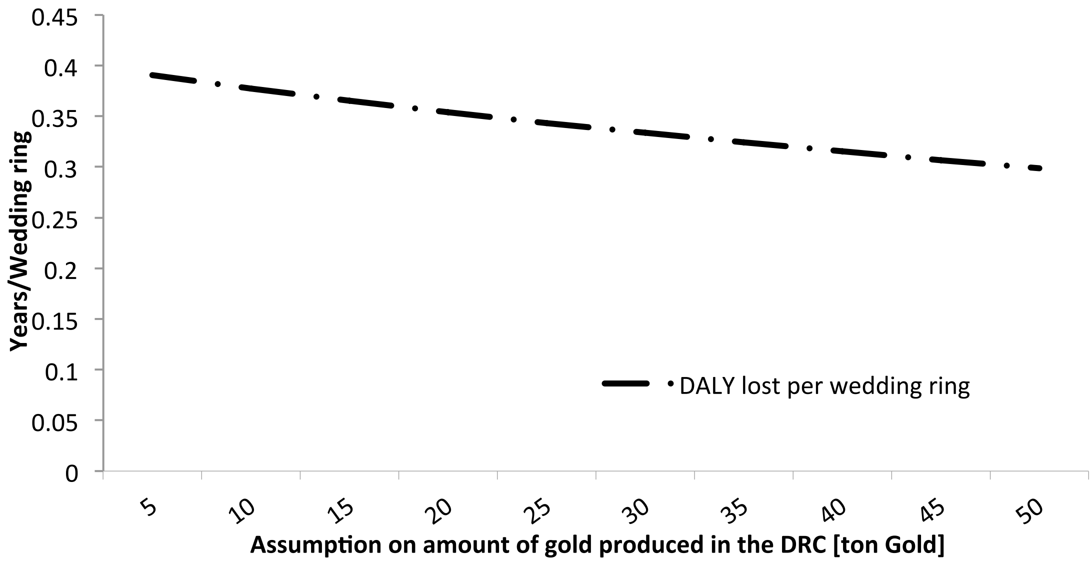

Figure 6.6 – Relation between amount of gold produced and years of life lost per gold wedding ring.

6.3.2 The Relationships between the Conflict and Minerals

As mentioned in Section 4.3, "it is assumed in this study that minerals are the main reason for the life years lost in the DRC conflict". However, even though one could argue that the mortality rates for the DRC would corresponds to Sub-Sahara African levels if the region was not so rich in minerals, the same argument could perhaps be true if one of the other conflict factors impacting the situation in the region was removed. Important conflict factors identified in the literature were: ethnic tension, poor economy, bad leadership, colonial power, conflict over land, absence of security and none-functional government institutions. Especially the ethnic tension is important in this context, since the tension had a clear impact on the conflict. The Rwandan genocide shows that it was possible to kill a lot of people without any (at that time) notable mineral resources. However, the conditions in Rwanda are different from the DRC. For example, Rwanda is very densely populated and mainly contains just two ethnic groups, the governmental institutions were also stronger in Rwanda at the time of the genocide, than they are in the DRC. Also, the Rwandan genocide occurred during a three month period. It was not a prolonged conflict as in the DRC. These factors make it difficult to compare the different cases.

Another important aspect is that different conflict factors affect each other in one or several ways and “chicken or the egg” causality dilemmas are created[4]. One example on such a dilemma is: “the presence of minerals creates greediness for recourse and power, therefore military groups created. The groups themselves make the institutions weaker” or “weaker institutions create a security vacuum and military groups fill this vacuum. To finance their business, they need foreign capital that is attained with mineral resources”. Therefore, is it impossible to come up with any good allocation procedure between the different conflict factors. However, one can at least argue that minerals should bear some burden to the conflict and that it should be attributed at least part of the life years lost in conflict.

Nevertheless, even if the minerals get an allocation proportion as low as 1%, compared to other conflict factors, the number of DALY lost per wedding ring still exceeds the second largest impact, see Figure 6.7. The second largest impact is DALY lost due to (mainly mercury) emissions in the extraction process, as can be seen in the break-even analysis in the top left corner of Figure 6.7. All other processes are not even of the same magnitude. However, it is probably not reasonable to give minerals such a low weight, see arguments in Section 4.3.

Furthermore, gold could be given a higher allocation weight than other minerals because of its physical properties, which is not the case in in Figure 6.7, nor in the overall results, Chapter 5. This can be argued for several reasons. Firstly, gold is easy to smuggle due to its high value per weight and volume. Secondly, copper and cobalt mining often are of large scale, using modern technologies. That makes it harder for the military groups to conduct or to be involved in the extraction. Thirdly, copper is usually not even considered to be a conflict mineral. Cobalt and copper mining makes up about 75% of the total weight to the conflict, w, in equation 5, see also Table 6.4. Therefore, gold’s impact on human health could even be higher than suggested in Figure 6.7. These arguments confirm the general conclusion that the number of life years lost due to the conflict is of another order of magnitude than for all the other processes.

Table 6.4 – Results for allocation of different minerals in the DRC baseline scenario. The allocation is based on the economic value of the minerals during the period 1998-2012, see Appendix D.

Mineral	**Weight,** w
Gold	6.6%
Copper	37.1%
Cobalt	37.8%
Tin	3.7%
Tungsten	3.7%
Tantalum	1.0%
Diamonds	10.2%

[4] The chicken or the egg causality dilemma is: “which came first, the chicken or the egg?”

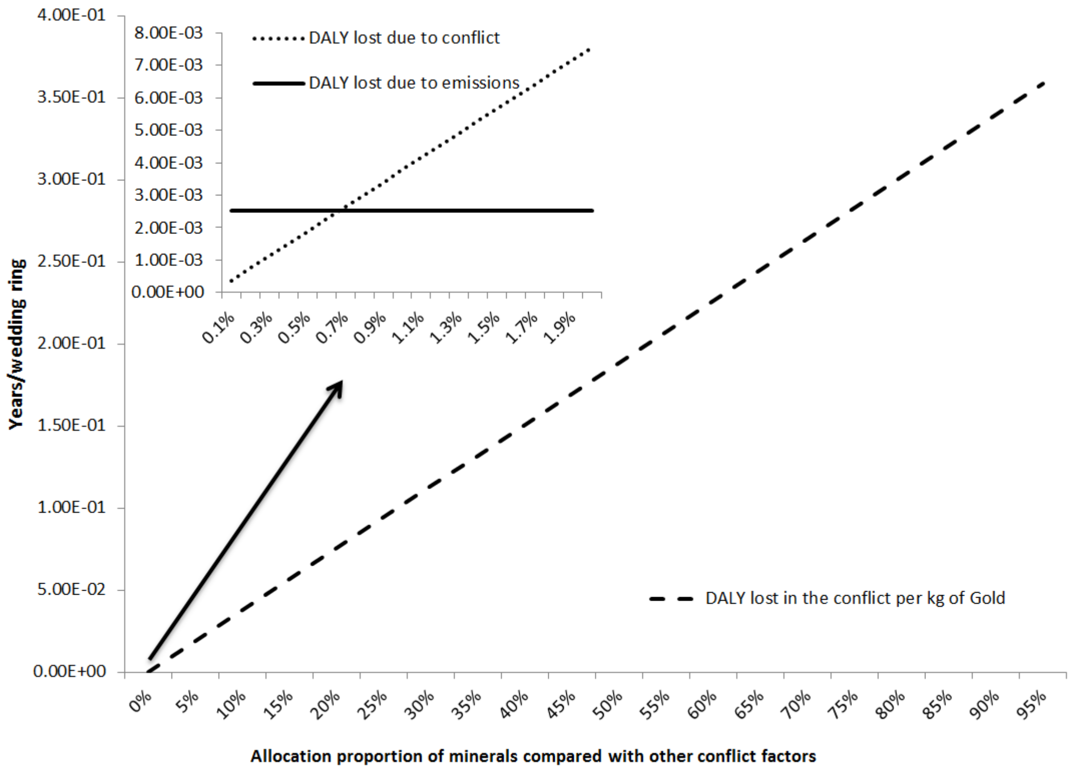

Figure 6.7 – Allocation proportion of minerals compared with other conflict factors. The break-even analysis in the top left corner shows that the allocation proportion for minerals needs to be really small to be of the same magnitude as DALY lost due to emissions occurring in the gold production phase.

6.3.3 Discussion about total Death Toll in DRC

In the HSRP report from 2011, the authors argue that mortality rates cannot be used for estimating the number of deaths in a war, at least not in longer conflicts such as the one in the DRC (HSRP, 2011). The main reason for that is that there is empirical evidence that mortality rates actually drop during war time in poor countries. This is consequence of two facts: (1) the "revolution of child survival" and (2) wars nowadays are less deadly than during the Cold War years. The increase in child survival is a consequence of low-cost nationwide, public health intervention, which has been possible due to WHO and UNICEF long-run global campaigns. The campaign includes, for example, immunization against several severe illnesses. This long-term campaign also bears fruit during war time, even though vaccination is performed mostly during peace time. Since the impacts of vaccination are longer-term, fewer children, and in the long run also fewer adults, die because of illness. Even if many people die in war times, the impact of war is minor compared to the positive effect of vaccination during peacetime. Ironically, war in itself can sometimes even lower the mortality rate in poor countries. This is an effect of humanitarian institutions putting up efficient assistance, including for example health care, nutrition and shelter, in war regions.

Furthermore, some assumptions in the IRC report (2007) are not considered to be reasonable (HSRP, 2011). The pre-war mortality rate in the DRC is assumed to be the same as Sub-Sahara average mortality rates. However, the mortality rates in the DRC were probably higher than the average mortality rates for Sub-Sahara at that time.

Another problem according to the HSRP study is that survey areas were not randomly selected, which is necessary when samples are used to extract general data. Also, a disproportionally high weight was given to results from small towns. The HSRP report also questions the overall method in the IRC study and question if mortality rates at all should be used in retrospective as a measurement of deaths in conflict. Since IRC's estimated number of deaths is the number used in the baseline scenario in this study, a sensitivity analysis is performed for this number.

One problem with the critical study of HSRP is that it does not come up with an alternative estimated number of deaths for the whole period. The HSRP study just advocates that the IRC number of deaths in the period 1998-2001 is far too high (2.5 million). However, HSRP gives a best estimate of 0.86 million deaths for the period 2001-2007 (IRC estimate for 2001-2007 is 2.83 million), even though they questioned the accuracy of also that result. Therefore, a sensitivity analysis in this study is performed for 0.86 million deaths during the second period (2001-2007) and 0.76 million[5] deaths during the first period (1998-2001), resulting in a total death toll of 1.6 million compared with the IRC baseline scenario of 5.4 million. Recalculating number of deaths to DALY results in a total of 64.5 million years lost in the conflict or 0.11 years/wedding ring if all other factors are kept the same. However, one should be aware that this figure is arbitrary and that it could be lower.

Another problem with the death toll is how it is transformed from number of deaths to years of life lost. As mentioned in Section 4.3, the death is assumed to occur at the age of 28 for people over 5, which is half of the life expectancy in Sub-Sahara Africa. However, that is problematic since the age structure in the DRC suggests that most people in the DRC are below 28 years, see Figure 4.1. Therefore, a sensitivity analysis is conducted where the assumed age of death for people above 5 years is varied between 10 and 30 years. In this analysis, the lower estimate of war deaths of 1.62 million is also included.

As can be seen in Figure 6.8, the curves are not so steep for the relationship between assumed age of death for age group >5 and the total impact. This is due to the fact that the age group between 0-5 years, which is the dominant contributor, remains constant. Therefore, the results are still of the same magnitude.

[5] 0.75 million is derived by assuming that the first inaccuracy is of the same range as for the second inaccuracy, i.e. $\frac{0.86 million}{2.83 million} \cdot 2.5\ million = 30\% \cdot 2.5 million = 0.76 million$

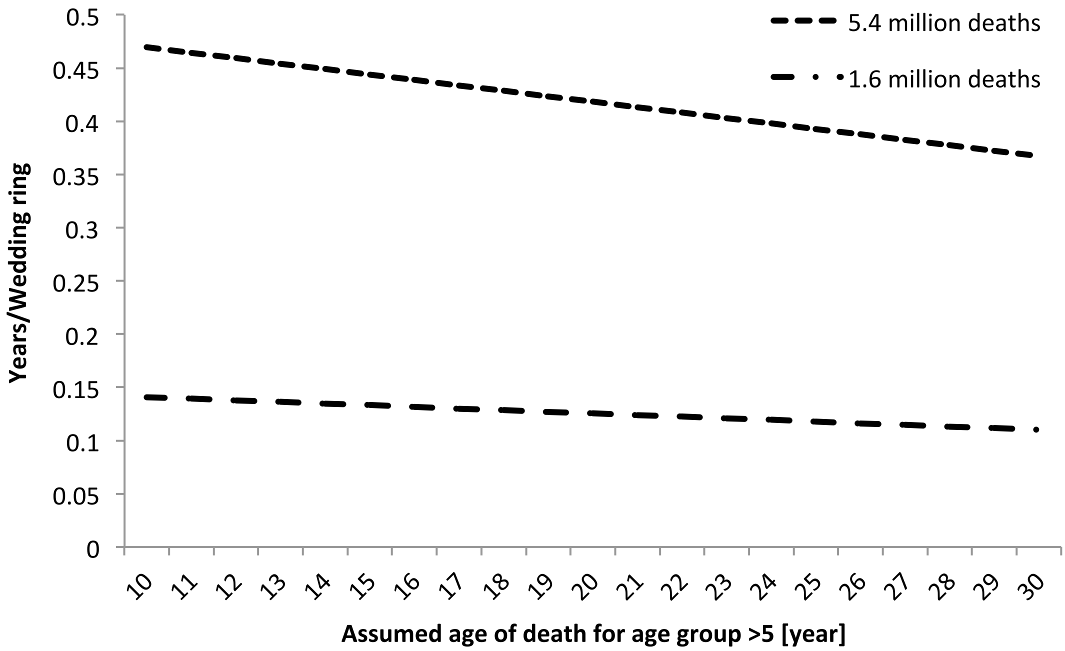

Figure 6.8 – Showing how the impact on human health varies depending on the assumed age of death for age group >5 for two different death tolls in the DRC conflict.

6.4 Positive Impacts on Human Health

Some positive impacts on human health of gold mining in developing countries are possible. These are mainly associated with economic factors, including increased purchasing power of poor people, which generally is associated with ability to buy medicine, food, shelter etc. A study evaluating socio-economic impacts of artisanal mining in the Congo basin (in proximity to eastern DRC) suggests that artisanal miners are "slightly wealthier than the average Cameroonian and three times wealthier than an average non-miner in the Sangha Tri-National" (Ingram, et al., 2011). On the other hand, witness reports from the eastern region of DRC describes people getting evicted due to new mines and that local people even are forced to work (Amnesty International, 2013; Global Witness, 2009). It is therefore difficult to evaluate the impact of economic contribution of gold mining.

One method of assessing life expectancy for gains in income is with the Preston relationship. Gains or losses in life expectancy can be transformed to DALY, so therefore the Preston relationship can be useful for evaluating such positive health impacts of gold mining. The Preston relationship is an econometric relationship that describes the correlation between life expectancy and gross domestic product. One study that assessed the Preston relationship for a single country concluded some criteria that should be fulfilled if the Preston relationship should be of any notable magnitude (Feschet, et al., 2013). One main criterion was that the region should not be suffering from any crises such as conflicts, which the DRC certainly has done recently.

Even though positive impacts on human health due to mining in the region are not directly included in this study, some potentially positive short-term impacts on human health in the DRC are indirectly included in the figure for causalities for the DRC. The number of casualties in the conflict is based on mortality rates for the country compared to sub-Saharan African mortality rates. If the mining had any positive impact on human health, it should be visible in dropping mortality rates. The DRC has high mortality rates compared to other regions in Sub-Saharan Africa, which could be an indication that negative health impacts by far exceed the positive economic benefits of mining. However, it could be interesting to separate the overall positive health impacts from the negative health impacts to see of which magnitude each impact are. This could be something for future studies to investigate.

6.5 Discussion about End of Life for Gold

The recycling phase is not included in the baseline scenario in this study. This is reasonable if the wedding ring is used only by one person and after that is lost, for example if it is burned with the body. However, if the gold is recycled, the attribution of life cycle lives lost per wedding ring can be conducted in several different ways. This study brings up two different methods to approach the end of life of gold jewelry. The first approach is that the impact of the wedding ring is recycled a number of times and the impact on human health is distributed evenly on the number of wedding rings that are produced with the same gold. The other approach is to approximate the usage of a wedding ring as consumption of gold per year. Since the DRC is the main focus in this study, the gold from the results from the DRC baseline scenario is used.

6.5.1 Recycling of a Wedding Ring

One way to interpret recycling is that one weeding ring is worth many wedding rings if it is recycled. If the wedding ring for example is recycled one time, the impact should be divided on two wedding rings instead of one. This is the same as closed loop recycling, see Baumann and Tillman (2004). The results of this can be seen in Figure 6.8. The amount of wedding rings on the x axis corresponds to the recycled wedding rings plus the original wedding ring. If the weeding is recycled, 0.5 kWh of electricity per kg of melted gold is used to melt the gold. However, the impact of this electricity is negligible compared to the other processes and is therefore excluded in this analysis.

The number of times the wedding ring is recycled affects the impact per extra recycled wedding ring to a lesser extent, since the function has an inverse proportionality, i.e. is of the form of $y \propto \frac{k}{x}$. If the wedding ring is recycled infinite times, the impact per wedding ring approaches 0. However, it is not reasonable that the wedding ring has 100% recycling rate, since some wedding rings are burned with the body, and some gold in the wedding ring is lost during usage.

One could argue that the impact should be prescribed after some years. One can for example assume a prescription time of 100 years. If the wedding rings expected life time is 25 years the total amount of wedding rings is 4, corresponding to a total impact on human health of almost 0.1 DALY/wedding ring according to Figure 6.8. However, another way of interpreting recycling is to assume some loses. If for example 6.15 mg of gold is lost per wedding ring and year (Steinhauser, 2008), no gold remains after about 650 years. If the average marriage lasts for 25 years no gold remains when the wedding ring has been recycled 26 times. The weight of the gold during these 26 times corresponds to about 13 wedding rings, including the original wedding ring, since not all gold is recycled every year, see equation 11.

$$Wedding\ ring\ usage = \frac{weight\ of\ recycled\ gold}{weight\ of\ one\ wedding\ ring} + original\ ring$$
$$= \frac{\int_{t=1}^{26} 4 - 25 \cdot 6.15 \cdot 10^{-3} \cdot tdt + 4}{4} + 1 = 13\ wedding\ rings \quad (11)$$

According to Figure 6.9, the total impact per wedding ring would then around 0.03 years/wedding ring. So depending on which perspective that is taken, the results will vary.

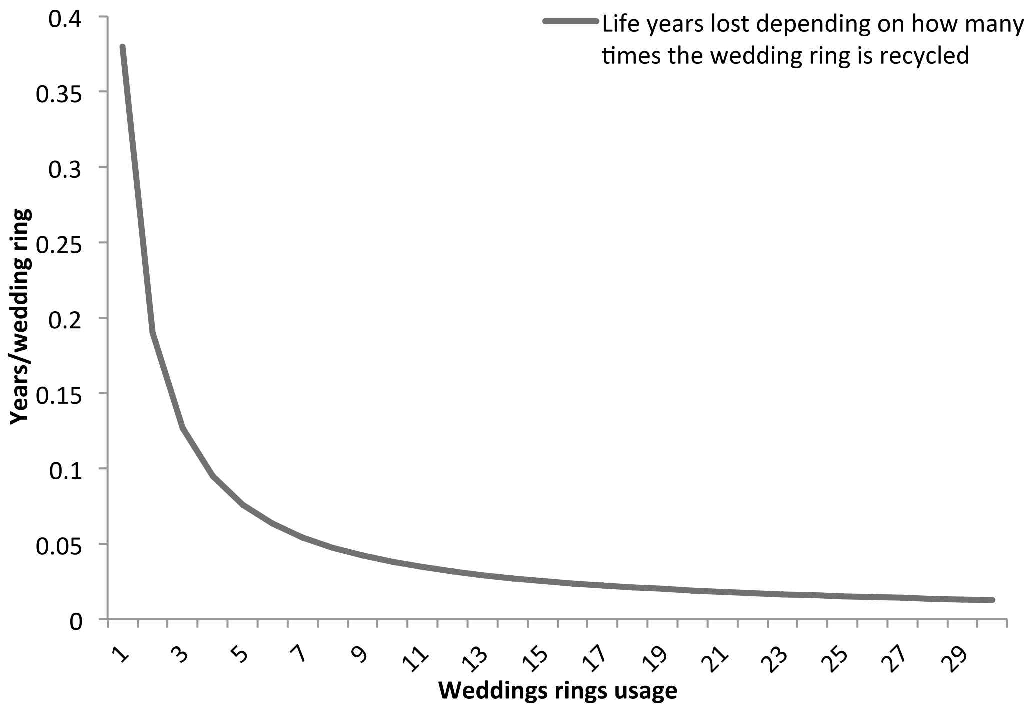

Figure 6.9 – The graph shows the total impact on human health depending on how many times a wedding ring is recycled, assuming 100% recycling rate every time. Wedding rings on the x axis are the recycled wedding rings plus the original wedding ring.

6.5.2 Marginal Gold Consumption Perspective

As mentioned in section 4.1.8, when a wedding ring is carried some gold is naturally lost due to for example abrasive wear. Theoretically what happens is that the gold gets spread in different environments in society and it is therefore a lot harder to extract the gold again. The study conducted by Steinhauser (2008) shows that about 6.15 mg of gold lost in one wedding ring is lost per year due to abrasive wear. Whether that is true for a wedding ring in general is hard to evaluate, but it is however reasonable to assume that at least some gold in the wedding ring is lost during the use phase. If indeed 6.15 mg of the gold is lost every year, corresponding to 0.154 % losses of the gold in the ring[6], the impact of one year's usage of a wedding ring would be $5.84\ 10^{-4} DALY/year$ according to equation 12.

[6] $\frac{6.15 mg\ gold}{4g\ gold} = 0.154\ \%$

$$
\begin{aligned}
&Impact\ of\ one\ years\ \ use\ of\ a\ wedding\ ring \\
&\qquad = losses \cdot Total\ impact\ on\ Human\ health\ for\ one\ wedding\ ring \\
&\qquad = 0.154\ \%/year \cdot 0.38\ DALY =\ 5.84 \cdot 10^{-4}\ DALY/year \quad (12)
\end{aligned}
$$

However, in this case the functional unit has changed from "one wedding ring" to "one year of wedding ring usage". One problem with this functional unit is that it is not so intuitive. In addition, it is perhaps strange to refer to a wedding ring in years of usage, since the consumer in that case needs to know how long the marriage will hold in order to know the total impact. Another problem is that the data of losses is just based on one study of one wedding ring. Typical losses of gold in a wedding ring can be completely different. It may also vary, since some people wear their wedding rings almost every day, while others hardly wear them at all.

7 Conclusions

Gold produced in the DRC baseline scenario had a much higher impact on human health, 0.4 lost years per wedding ring, than gold produced in South Africa and Sweden. The impact from the conflict is several orders of magnitude larger than the impact of any other process. If the impact assessment result from conflict is excluded from the results, the emissions occurring at the extraction and processing of gold instead had the greatest impact, which was several orders of magnitude larger than any other process. In particular, mercury emission to air has a high impact on human health during the processing of gold in artisanal mining. The other processes have varying impacts on human health, but large uncertainties due to data gaps and assumptions make it hard to conclude that they are different from each other.

Sensitivity analyses were conducted to evaluate the data gaps and assumptions. These analyses in general showed that the results of the impact assessment are reasonable. However, worth noting is that some results that were based on the ReCiPe's characterization factors varied greatly. Altering assumption about the time horizon made a difference of a factor of 37 on the result in the impact assessment of the gold from the DRC.

Three different sensitivity analyses were conducted for the result from the impact assessment of the conflict. The first analysis was about the amount of gold produced. That analysis showed that the mass of the gold produced was not so influential on the overall result. More important was the price of the mineral, indicating that the selected allocation method is relevant. The second sensitivity analysis was about the causal relationship between the conflict and minerals. That analysis showed that even though minerals get an allocation proportion as low as 1%, compared with other factors that may have caused the conflict, the impact results from the conflict were still higher than those of all other process. The last sensitivity analysis was about the estimated death toll in the conflict. It showed that the results varied with changing estimates and assumptions, but the magnitude of the impact is still higher than the impact from any other process. The overall conclusion is thus that even though the results are uncertain, the conflict's impact on human health is still of a different magnitude than all other processes evaluated in the study.

This study does not evaluate system change, but rather accounting the historical impact of gold production. This distinction is important to notice when interpreting the results. Even though the result points in a direction that mining of gold in the DRC has very high health impacts, the result does not say that stopping gold production in the DRC or gold export from the DRC necessarily is a good thing. To make such conclusions, one needs to consider the impacts of making such specific changes in the system. This is a more complex question to evaluate, and such study needs to consider many other aspects, for example whether it is possible (at all) to make such a change and evaluate different possible future outcomes.

However, the results in this study do constitute a foundation for which processes that should be prioritized inside the system. The results suggest that the most important intervention point in the system is to improve the general situation in the DRC, i.e. stop the conflicts. Lowering mercury emissions should also be a priority.

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