Developing a Model for Determining the Life Cycle Assessment and the Carbon Footprint of Precious Metals

Summary

by

Prof. Dr Mario Schmidt and Benjamin Fritz, M.Sc.,
Institute for Industrial Ecology (INEC) at the Pforzheim University of Applied Sciences

On behalf of

C.HAFNER GmbH + Co. KG

Pforzheim, May 2022

Company

C.Hafner is a gold refinery based in Enzkreis near Pforzheim. It recycles precious metal scrap (traditional name: refined metal) that has already gone through a use phase (end-of-life scrap) and waste containing precious metals (traditional name : skimmings). Aside from gold, silver, platinum and palladium are also processed into pure materials. These four precious metals are recovered from the *high grade scrap* and the *low grade skimmings*. The high grade scrap is processed hydrometallurgically. The most important process is the aqua regia process. In addition to the precious metal content, the skimmings consists of non-valuable material such as polishing cloths or refuse. This is incinerated at C.Hafner and the majority of the remaining ash containing precious metals is processed by an external service provider. The precious metals are delivered in various forms, e.g. as ingots or granules, especially to industrial customers who process the metals further.

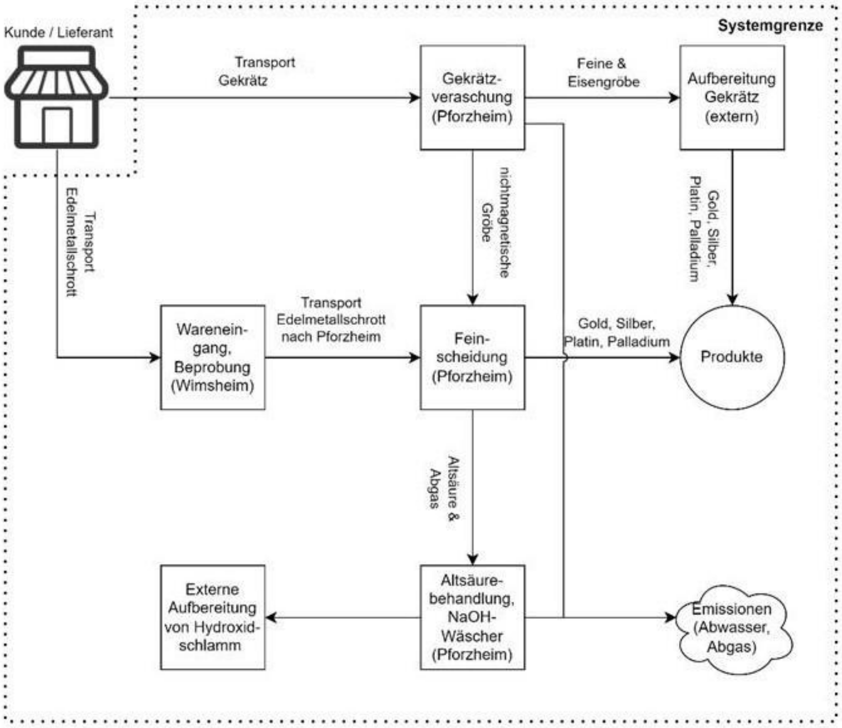
Study

Back in 2018, C.Hafner calculated the ecological footprint of its gold recovery as part of a BMBF-funded research project together with INEC. These figures were included in professional publications (Fritz et al. 2020). In 2021, Pforzheim University was commissioned to expand this study to include the accounting of the recovery of the other precious metals and to model the processes in even greater detail. A Life Cycle Assessment (LCA), including carbon footprint, was prepared for processing precious metals by C.Hafner in accordance with the regulations of ISO EN DIN 14040, 14044 and 14067. The internal report was subjected to a critical review in accordance with the above-mentioned ISO standards, which was carried out by Dr Rolf Frischknecht, treeze Ltd (CH).

Aim and scope of study

In contrast to the primary extraction of precious metals from mining, the ecological effort involved in recycling precious metals is significantly lower, especially when high-quality scrap is recycled, for example from jewellery, dental products or high-value industrial products. The aim of this study was to accurately quantify the effort involved in recycling precious metals based on direct and measured data. The functional unit, i.e. the reference value to which the quantity flows and the ecological effort were related, are the precious metal quantities produced by C.Hafner, i.e. fine gold (Au 99.99 %) in various processing forms as well as silver (Ag 99.9 %), platinum (Pt 99.95 %) and palladium (Pd 99.95 %). The results are presented per kg of fine metal in this summary.

On the one hand, the balance area includes all internal processes at C.Hafner that are necessary for producing precious metals (Foreground System). The data collection was based on the specific production and consumption figures for the year 2020. Furthermore, this includes all processes required for the external production of all energy, chemicals and other material expenditures or for the external treatment of emissions, waste and waste water. This includes, among other things, the provision of electrical energy from the German power grid (German electricity mix), but also the disposal of hydroxide sludge, for example, or the partial external incineration of skimmings. Generic data sets from the ecoinvent v.3.7.1 life cycle assessment database were used for this purpose. The calculation was carried out using the life cycle assessment software Umberto (version 11). This makes it a cradle-to-gate balance.



A1: Assessed system of the C.Hafner refinery with system boundary

Methodological specifications

Since the input material contains several precious metals that are separated from each other during the course of the process route, so-called complementary processes occur. This means the expenses have to be allocated to the different products. This allocation was carried out separately for each process and was mostly done according to the economic value of the co-products. Exceptions were processes where the mass was clearly the determining factor for the effort (e.g. transports).

Further specifications on allocations are necessary if products have several use phases, which is the case here as a result of recycling. This then gives way to the question as to how primary extraction and recycling are allocated to the different phases of use. It was decided to use a so-called cut-off approach, i.e. the input material is not burdened with an ecological rucksack or carbon footprint. The main reason for this is that C.Hafner uses either end-of-life scrap or industrial waste (e.g. press remnants) from its own customers for recycling. In this case, the latter do not receive any ecological credits for their scrap. This must also be taken into account when balancing further processing steps of the precious metals: Residual materials returned to C.Hafner or other refineries do not receive credits. At C.Hafner, they enter the balance sheet "burden free", meaning without charges.

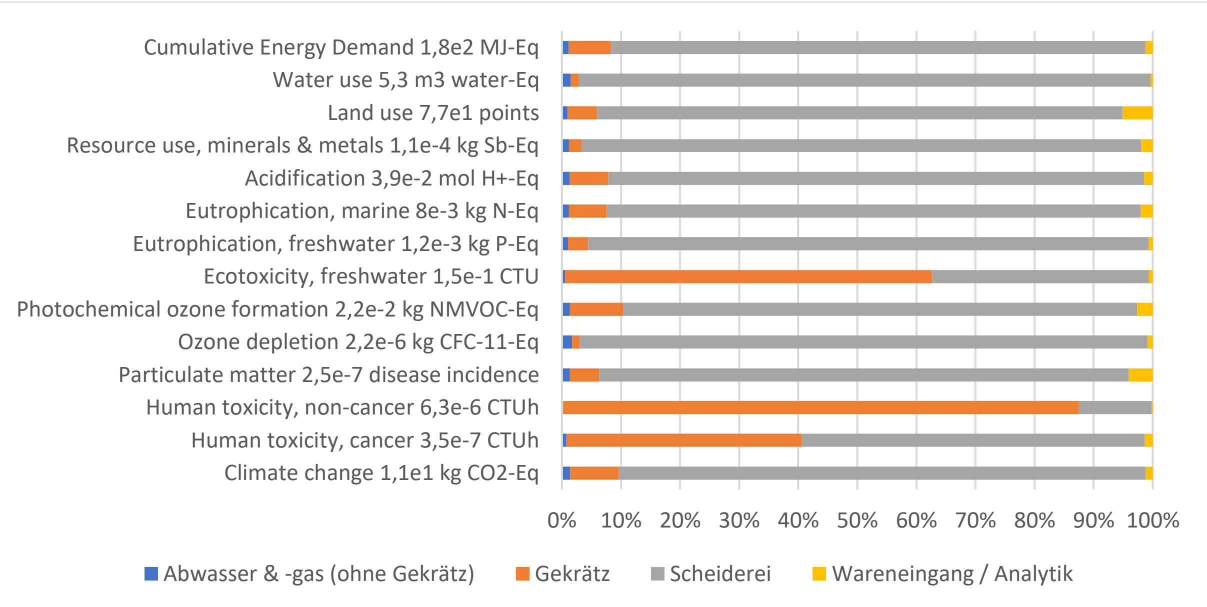
For the ecological impact assessment, the *Environmental Footprint 2.0* method was applied on a midpoint basis (https://eplca.jrc.ec.europa.eu/EnvironmentalFootprint.html), as provided by ecoinvent v3.7.1 and Umberto 11. The most important 14 environmental categories are considered here. The carbon footprint is based on the GWP100 model according to IPCC 2014.

Results

The climate footprint per kilogram of precious metal (Product Carbon Footprint, PCF) is approx. 11 kg CO_2 equivalent for silver, approx. 40 kg CO_2 equivalent for gold, approx. 60 kg CO_2 equivalent for platinum and approx. 180 kg CO_2 equivalent for palladium (see Table T1). For all precious metals, about 80-90 % of the PCF is caused by the use of chemicals and electrical energy.

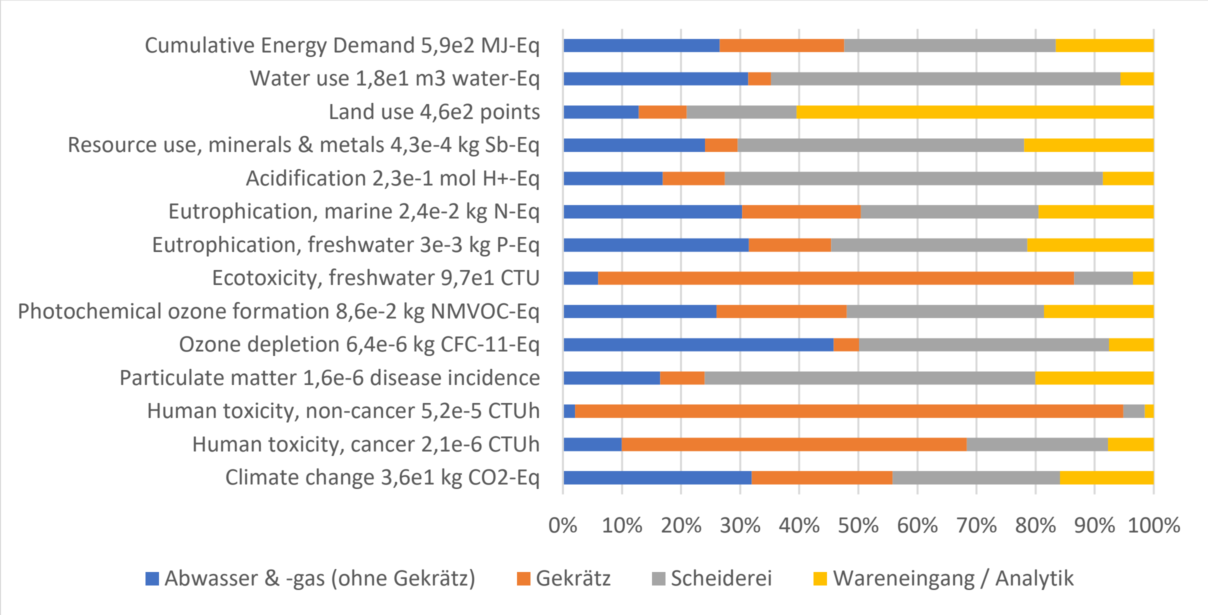
T1: Environmental impact for the recovery of metals at C. Hafner in units per kg of fine metal

per kg of metal	Silver	Gold			Palladium	Platinum	
Impact indicator	Granulate	Cast ingots	Embossed ingots	Granules	Platelet	Platelet	Unit
Climate change	1.10E+01	3.79E+01	4.28E+01	3.63E+01	1.83E+02	5.96E+01	kg CO2 eq.
Human toxicity, cancer	3.50E-07	2.11E-06	2.20E-06	2.09E-06	7.35E-06	3.64E-06	CTUh
Human toxicity, non-cancer	6.34E-06	5.21E-05	5.25E-05	5.19E-05	1.46E-04	1.01E-04	CTUh
Particulate matter	2.50E-07	1.57E-06	1.61E-06	1.56E-06	5.50E-06	1.92E-06	disease incidence
Ozone depletion	2.24E-06	6.47E-06	6.61E-06	6.43E-06	4.28E-05	1.08E-05	kg CFC-11 eq.
Photochemical ozone formation	2.20E-02	8.83E-02	9.49E-02	8.62E-02	4.08E-01	1.40E-01	kg NMVOC eq.
Ecotoxicity, freshwater	1.45E+01	9.78E+01	9.95E+01	9.73E+01	3.69E+03	6.97E+02	CTU
Eutrophication, freshwater	1.17E-03	3.19E-03	3.96E-03	2.95E-03	1.36E-02	4.99E-03	kg P eq.
Eutrophication, marine	8.02E-03	2.51E-02	2.72E-02	2.44E-02	1.58E-01	4.64E-02	kg N eq.
Acidification	3.90E-02	2.35E-01	2.46E-01	2.31E-01	8.57E-01	2.91E-01	mol H+-eq
Resource use, minerals & metals	1.10E-04	4.40E-04	4.82E-04	4.27E-04	2.46E-03	7.16E-04	kg Sb eq.
Land use	7.70E+01	4.63E+02	4.86E+02	4.56E+02	1.36E+03	5.22E+02	points
Water use	5.25E+00	1.87E+01	1.96E+01	1.84E+01	1.27E+02	2.85E+01	m3 water eq.
Cumulative energy demand	1.77E+02	6.17E+02	7.03E+02	5.90E+02	3.21E+03	9.98E+02	MJ eq

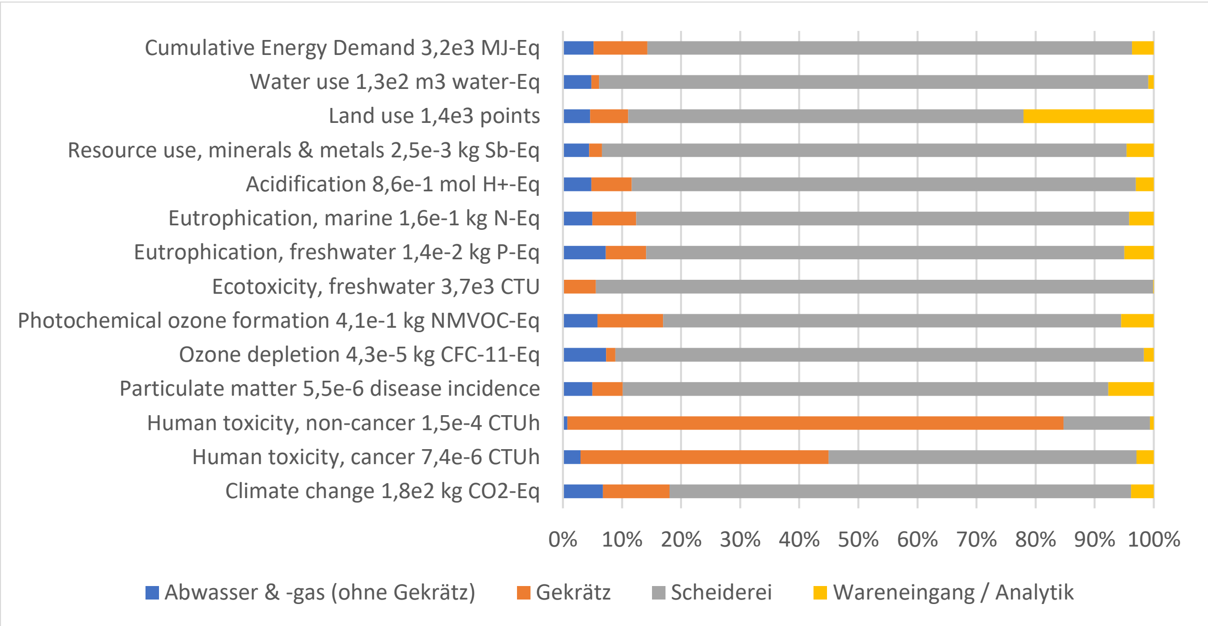


A2: Environmental impacts for the recovery of silver at C.Hafner (per kg), subdivided according to the contributing process areas

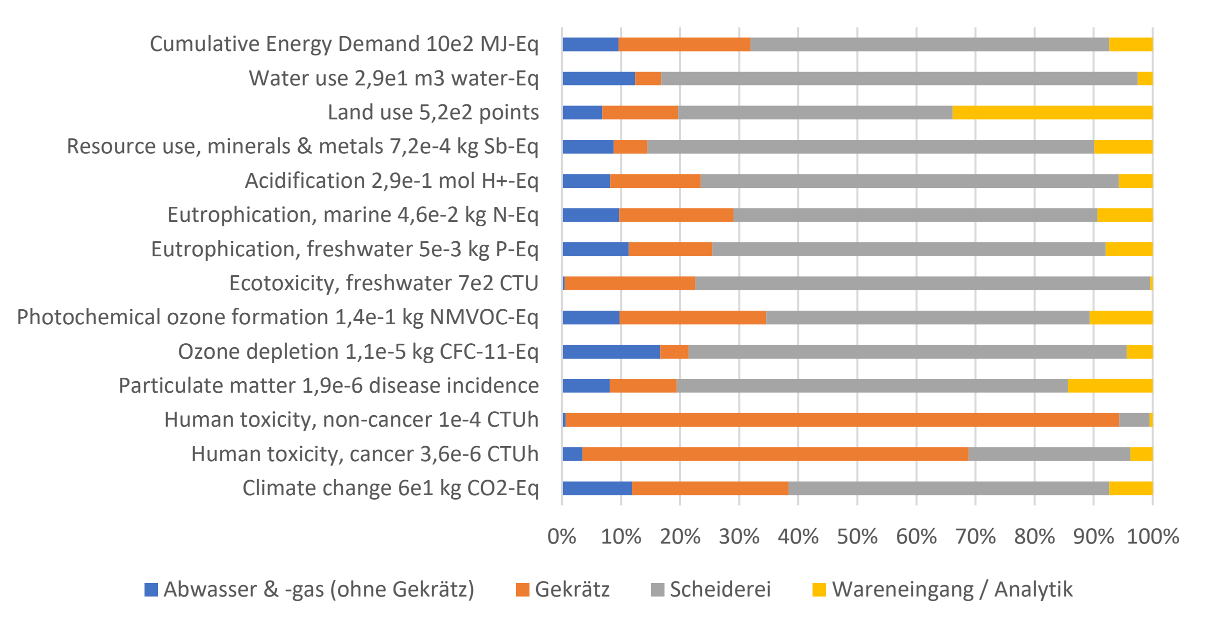
The individual results for the four precious metals, subdivided by process area, are depicted in Figures A2-A5. The results of the LCA demonstrate that in almost all of the 14 environmental categories examined, except for "*human toxicity, non-cancerous*", the refinery causes the greatest environmental impacts with its hydrometallurgical processing of the precious metals. For most environmental categories (eleven out of 14), *electrical energy* and *chemicals* dominate. The high contribution to toxicity results from the external ashing and processing of the skimmings, for which a generic process from the ecoinvent database was conservatively used.



A3: Environmental impacts for the production of gold granules from scrap and skimmings at C.Hafner (per kg), subdivided according to the contributing process areas



A4: Environmental impacts for palladium (per kg), subdivided according to the contributing process areas

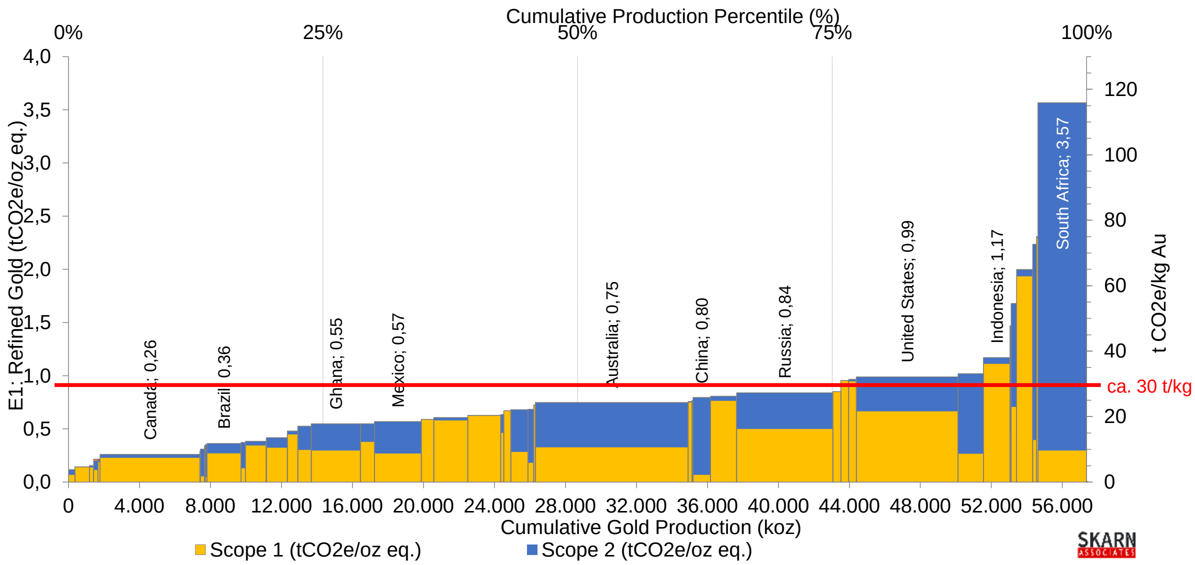


A5: Environmental impacts for platinum (per kg), subdivided according to the contributing process areas

For four exemplary impact categories, a further comparison with other LCA data sets (from ecoinvent v.3.7.1) was carried out for gold originating from e-waste recycling and mines respectively (see Table T2). Assessing the values showed that the environmental impact of processing at C.Hafner came out lower by several decimal powers compared to extraction from mining. Even compared to e-waste recycling, the environmental impact of the gold recovered by C.Hafner is significantly lower across the board, by a factor of approx. 40 in the case of the CO_2 footprint. The difference is even more pronounced when current evaluations from mines are taken into account (see Figure A6). Here, the average value per kg of gold is even around 30 t $CO_{2\ eq}$, although with a wide variation depending on the country of origin.

T2: Comparing the selected environmental impacts of C.Hafner's gold production with gold production (generic values) from e-waste (WEEE) or mining.

Indicator	Value per kg of gold granules			Unit
	C.Hafner	WEEE (ecoinvent)	Mining (ecoinvent)	
Cumulative energy demand (total)	590	11616	476990	MJ eq
Climate change	36	1496	10988	kg CO_2 eq.
Particulate matter	1.56E-06	2.85E-05	2.97E-03	disease incidence
Eutrophication, freshwater	2.95E-03	1.54E-02	4.68E-01	kg P eq.



A6: Distribution of the carbon footprint of gold production from different countries. According to Skarn Associates Limited (2022).

Critical examination

The reviewer, Dr Rolf Frischknecht from treeze Ltd (CH), summarised his critical review on 29 April 2022 with the following conclusion:

The reviewer concludes that

- the methods, models and principles used for carrying out the LCA comply with the international standards ISO 14040 and 14044;
- the methods used for carrying out the study are "scientifically justified" and demonstrate a "state of the art" LCA technique that is reliable for the statements of the study;
- the quality of the primary data used is very good in relation to the aim of the study and the data are fit for purpose;
- the evaluations take appropriate account of the identified limitations and the objective of the LCA;
- the technical report is coherent and transparent;

and draws the following conclusion:

Assessing the facts that

- the activities and processes of C. Hafner are complex;
- C. Hafner has provided comprehensive and detailed primary data;
- the availability of up-to-date and representative life cycle inventory data on individual chemicals and on skimmings processing is limited, partly for reasons of effort;
- the LCA model provides a detailed and appropriate modelling and description of C. Hafner's activities and processes;
- the environmental topics addressed are meaningful and appropriate for the aim and object of the study;

the reviewer confirms that this final report meets the requirements and specifications of the ISO 14044 and 14044 standards.

Bibliography

Fritz, Benjamin; Michele, Carin; Schmidt, Mario (2020): Environmental impact of high-value gold scrap recycling. In: *The international journal of life cycle assessment*, P. 1–12. DOI: 10.1007/s11367-020-01809-6.

Skarn Associates Limited (2022): Mining-ESG Bulletin #14. Lichfield, England: Skarn Associates Limited. Available online at https://www.skarnassociates.com/news