Öko-Institut e.V.
Institut für angewandte Ökologie
Institute for Applied Ecology

"Potentials for Climate Protection offered by Metal Recycling and the Anthropogenic Metal Stock"

Report produced on behalf of Metals pro Climate, a company initiative in the WVMetalle (German non-ferrous metals association)

Darmstadt, July 2016

Authors

Dr. Matthias Buchert, Dr. Winfried Bulach, Dr. Hartmut Stahl
Oeko-Institut

Freiburg Office
Postfach 17 71
79017 Freiburg
Office adress
Merzhauser Straße 173
79100 Freiburg
Telephone +49 (0) 761/45295-0

Berlin Office
Schicklerstraße 5-7
10179 Berlin
Telephone +49 (0) 30/405085-0

Darmstadt Office
Rheinstraße 95
64295 Darmstadt
Telephone +49 (0) 6151/8191-0

info@oeko.de
www.oeko.de

Table of Contents

Table of Figures

Executive Summary

The objective of the study was to determine the annual GHG savings which could be achieved by recycling the NF metals aluminium, lead, copper, nickel and zinc in Germany. A further aim was to estimate the development of the so-called "anthropogenic stock" for these 5 NF metals, and based on this data, the potential for climate protection presented by this stock.

In 2014 a total of approx. 2.5 million tons of the NF metals aluminium, lead, copper, nickel and zinc were produced in Germany. In this figure secondary production accounted for a share of 49%. The production of these 2.5 million tons of NF metals, including all upstream chains, was responsible for total greenhouse gas emissions of around 10.8 million tons. Secondary production represented 14% of these emissions.

The greenhouse gas emissions directly saved by secondary production in Germany totaled around 7.3 million tons for 2014. This corresponds approximately to the greenhouse gas emissions generated by the annual power consumption of 3.8 million households or 3.2 million passenger cars with an annual mileage of 15000 km each.

The analysis of the NF metal stock in Germany for 2014 yielded the following results:

- In absolute terms, the NF metal stock in Germany in 2014 amounted to around 76.5 million tons. This corresponds to approx. 950 kg NF metals per capita which are trapped in the anthropogenic stock, i.e. in buildings, infrastructure, vehicles, etc. The absolute quantity of trapped NF metal stock in Germany in 2014 is equivalent to more than thirty times the German annual production in the same year.
- Based on average scrap metal prices, the anthropogenic stock in 2014 represents a total value of around EUR 132 billion, which corresponds to a per capita value of EUR 1,656.
- Up until 2050 it is estimated that the NF metal stock in Germany will grow to around 130 million tons, or over 1600 kg of NF metal per capita. Based on current scrap metal prices, the anthropogenic stock in 2050 will represent a total value of around EUR 245 billion, which corresponds to a per capita value of EUR 3,065.
- Each year the NF metal stock per capita grows by around 19 kg, which in terms of value equals an increase of approx. EUR 36.
- If the NF metal stock were to be fully exploited through recycling, the theoretical savings potential for greenhouse gas emissions would total around 390 million tons of greenhouse gases for the 2014 stock and around 634 million tons for the 2050 stock. The latter figure is equivalent, for instance, to 3.9 times the current CO2 emissions of the transport sector in Germany.

The growing NF metal stock in Germany is a resource and energy store for future recycling which will always be available to subsequent generations for recycling without any loss in quality. Primary metal production is however still necessary due to growing markets (incl. lightweight construction, renewable energies, electric mobility) and the limited availability of scrap metal due to the frequently long periods of metal entrapment. Additional savings of greenhouse gases will be possible by 2050 if the growing NF metal stock in Germany is efficiently exploited. This will be contingent on the continued improvement of basic parameters for efficient recycling, e.g. in the context of the current debate on the circular economy.

1. Goals of the study and project framework

The objective of the Oeko-Institut study commissioned by WVMetalle was to determine the potential for climate protection afforded by recycling the NF metals aluminium, lead, copper, nickel and zinc and the anthropogenic stock of these 5 NF metals. Germany was chosen as the study area, and the years 2014 to 2050 as the time window for the analysis. The anthropogenic stock is defined as the sum of the NF metals in use and hence trapped (e.g. in buildings, infrastructure, vehicles) in Germany in any given year.

The study aims to provide an initial estimate of the order of magnitude of climate protection potentials. Therefore, the data acquisition was restricted exclusively to the analysis of published sources/statistics, supplemented by recent expert assessments. The essential data sources for the study were the metal statistics collected by WVMetalle and the Federal Institute for Geosciences and Natural Resources (Bundesanstalt für Geowissenschaften und Rohstoffe (BGR)) as well as the lifecycle inventory database Ecoinvent 3.2 for specific data on greenhouse gas emissions. The data on the anthropogenic stocks of NF metals was compiled from various publications and, like all data, validated in expert surveys.

Concerning the greenhouse gas potentials for 2050 a conservative approach was selected, i.e. the specific emission values (per ton NF metal) from 2014 were also used for 2050. This was to ensure that no possible external effects could influence the results. This means that the anticipated effects of the energy transition etc. were deliberately omitted in order to avoid obtaining results distorted by a blend of different developments.

In compiling the data on the anthropogenic NF metal stock and estimating the climate protection potentials, the key objective of the Oeko-Institut and WVMetalle is to present orders of magnitude. Potential in-depth studies on individual aspects (e.g. bottom-up studies in the near future on developments of the NF metal stock in Germany) are welcome and meet with the full support of the Oeko-Institut and WVMetalle.

The project team of the Oeko-Institut (Dr. Matthias Buchert, Dr. Hartmut Stahl, Dr. Winfried Bulach) would like to thank the following experts for releasing important documents and/or for significant contributions to the preparation of this study.

- Rainer Buchholz, WVMetalle,
- Dr. Ladji Tikana, Deutsches Kupferinstitut (DKI),
- Jörg Schäfer, Gesamtverband der Aluminiumindustrie (GDA),
- Dr. Sabina Grund, Initiative Zink (IZ),
- Stefan Buch, Berzelius Metall GmbH,
- Dr. Mark Mistry, Nickel Institute,
- Dr. Barbara Reck, Yale University,
- Andreas Ruh, BEFESA.

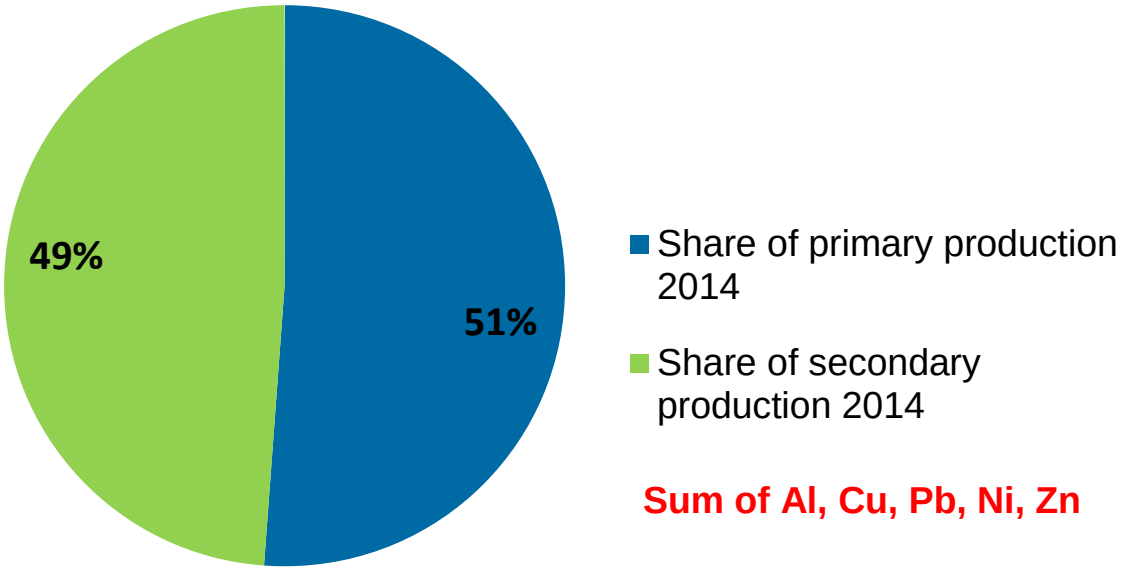
2. Non-ferrous metal production in Germany and greenhouse gas emissions 2014

The data on the NF metal production in Germany was compiled from the metal statistics of WVMetalle (Metallstatistik 2014), the BGR data on the raw material situation (BGR 2014) and expert assessments from the circle of experts mentioned in Section 1.

Since there is no domestic nickel production in Germany, the nickel content used in the German stainless steel production (by far the most important use of nickel worldwide) was taken as the basis of the statistic. Since data protection restrictions are applicable for some of the detailed information, in such cases the production data of the 5 NF metals aluminium, lead, copper, nickel and zinc are given as an aggregate value (see Fig. 1).

In 2014 a total of approx. 2.5 million tons of the NF metals aluminium, lead, copper, nickel and zinc were produced in Germany. In this figure secondary production accounted for a share of 49%. Almost half of these 5 NF metals is currently produced in Germany from secondary material.

Figure 1 Distribution of NF metal production in Germany 2014



The entire production of 2.5 million tons NF metals in Germany in 2014, including all upstream chains, was responsible for greenhouse gas emissions totalling around 10.8 million tons. However, secondary production represented just 14% of these emissions. The signification contribution to climate protection made by NF metal recycling is clearly visible when we compare the proportion of NF metal secondary production (49%) with the share of greenhouse gas emissions for which it is responsible (14%).

The calculation of the greenhouse gas emissions was based on the lifecycle inventory database Ecoinvent 3.2 (cutoff modelling). The data was validated by discussions with experts and supplemented where necessary. For the entire data on greenhouse gas emissions all upstream chains were taken into account, i.e. including emissions generated outside Germany (e.g. ore mining).

Figure 2 **Distribution of GHG emissions from NF metal production in Germany 2014**

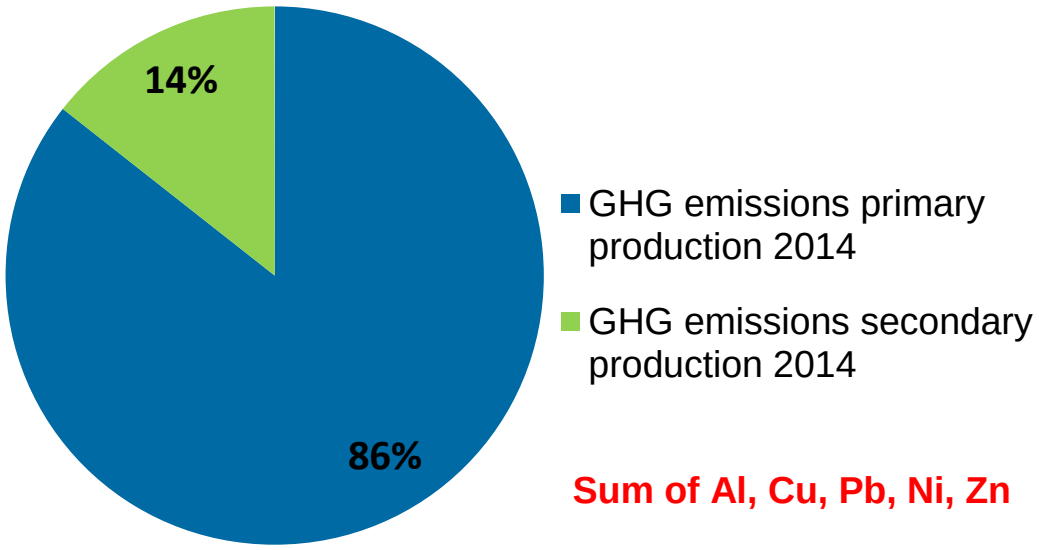
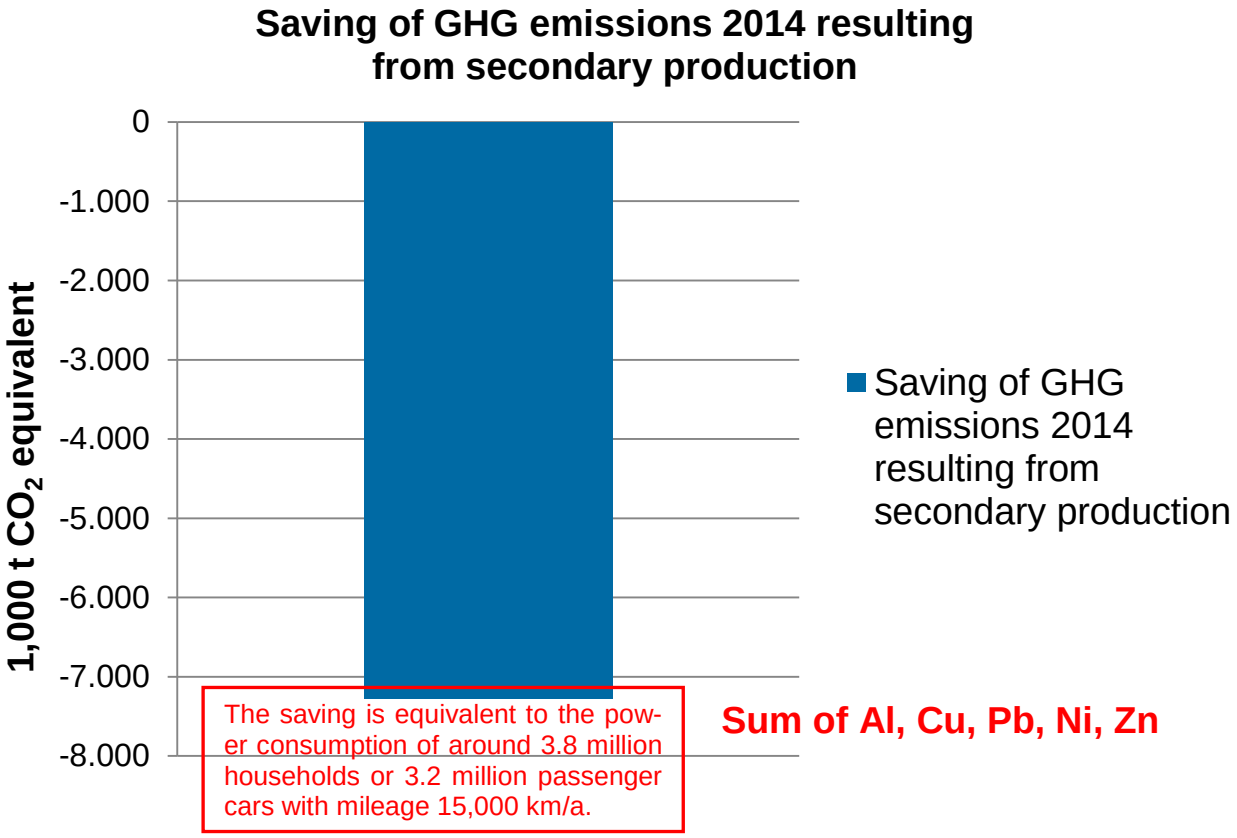


Figure 3 below shows the saved greenhouse gas emissions due to secondary production of NF metals in 2014 by comparison to primary production.

Figure 3 **Potential GHG savings resulting from secondary NF metal production 2014**



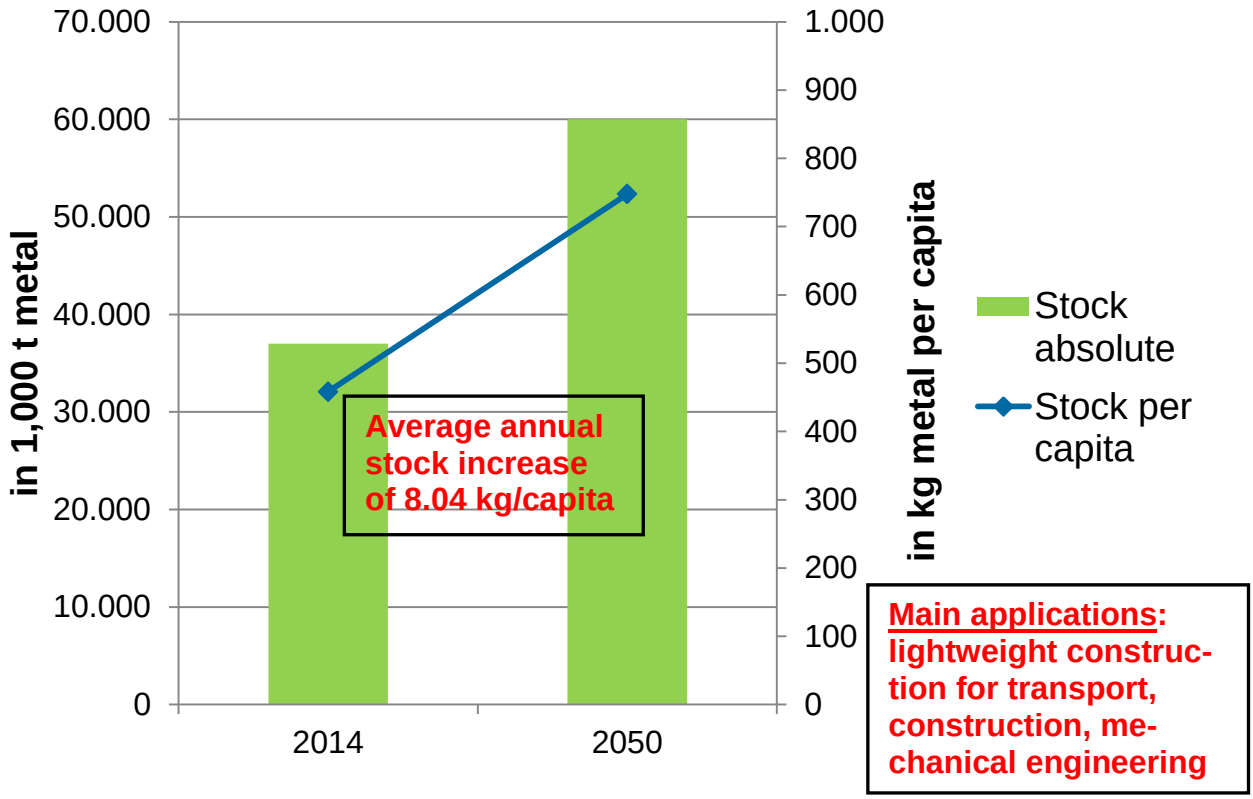
The greenhouse gas emissions directly saved by secondary production in Germany totaled around 7.3 million tons for 2014. This corresponds approximately to the greenhouse gas emissions generated by the annual power consumption of 3.8 million households or 3.2 million passenger cars with an annual mileage of 15000 km each. This is a conservative estimate, since the direct use of scrap metal in factories producing semi-finished products, which is not captured in overall statistics, has so far not been taken into account. Apart from the GHG savings, the high level of secondary metal production provides a variety of further ecological and economic benefits such as reduction of the growing dependencies in the supply of raw materials. Primary metal production is however still necessary due to growing markets (incl. lightweight construction, renewable energies, electric mobility) and the limited availability of scrap metal due to the frequently long periods of metal entrapment.

3. Development of the total German stock of non-ferrous metals from 2014 to 2050

In this section the development of the NF metal stock (anthropogenic stock) for the 5 NF metals aluminium, lead, copper, nickel and zinc will be described both individually and in total. As practised in other relevant studies (cf. UNEP 2010), a per capita approach is used for the quantification of the anthropogenic stock. For simplification purposes when quantifying the absolute NF metal stock, a constant population figure of 80 million inhabitants is assumed for Germany between 2014 and 2050. Since the purpose of this study is to determine orders of magnitude, this simplification is justified.

In the following figure, the development of the German **aluminium stock** between 2014 and 2050 is depicted.

Figure 4 Development of the German aluminium stock from 2014 to 2050

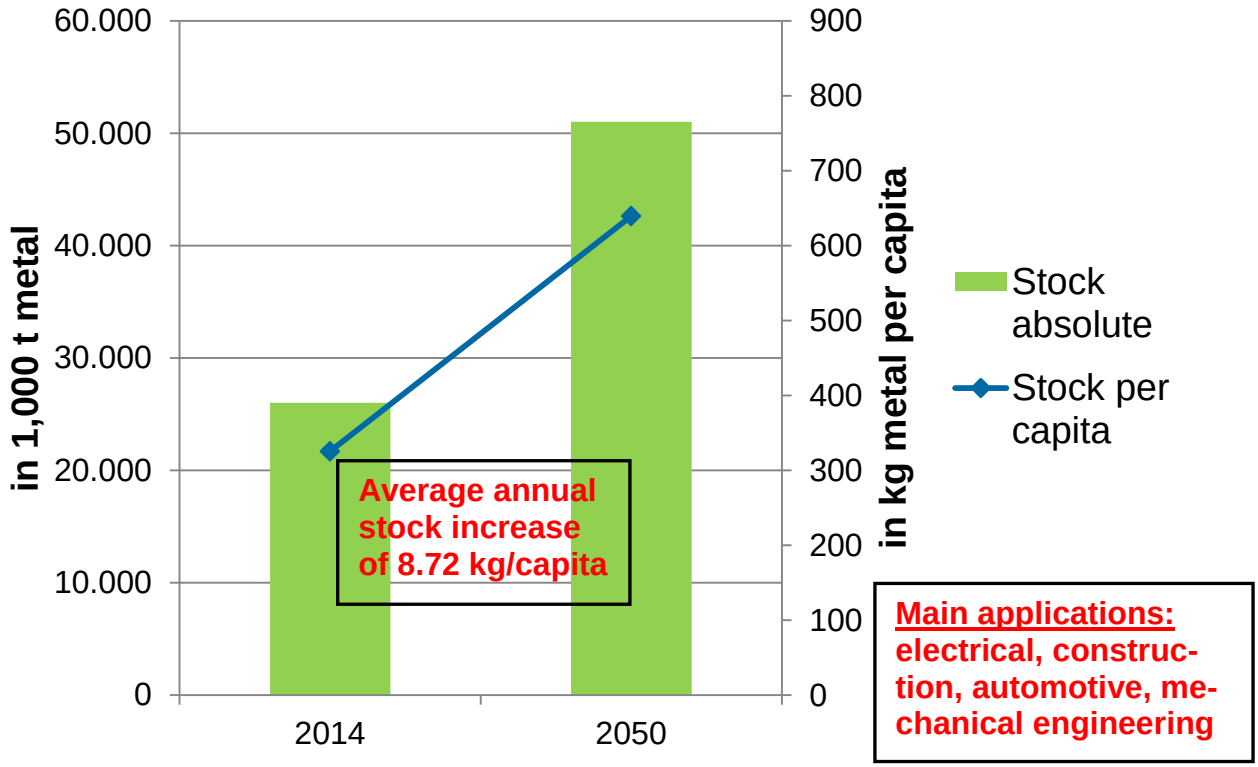


In 2014 the aluminium stock in Germany amounted to 458 kg per capita. This value was taken from a source with reference year 2010 for Germany (Liu et al. 2013) and was adjusted with an annual increase of 8 kg aluminium per capita and year (data of the International Aluminium Institute: http://www.world-aluminium.org/) until 2014 and then on a linear basis until 2050. Accordingly, the aluminium stock in Germany will amount to an estimated 748 kg per capita in 2050.

In absolute terms, this means that the aluminium stock in Germany totaled around 37 million tons in 2014, and will rise steeply to around 60 million tons by 2050. This is mainly due to enduring applications in the construction, mechanical engineering, automobile and transport sectors.

Of the 5 NF metals analysed, **copper** follows in second place with a stock of around 326 kg per capita in 2014. This start value was calculated from a mean value derived from four scientific sources (Sörme et al. 2001, Murakami 2006, Brunner et al. 2006, Ruhrberg 2006) for 2000 and updated annually by almost 9 kg per capita (Graedel et al. 2010) until 2014. This annual growth value was then carried forward on a linear basis until 2050. Hence a German copper stock of approx. 639 kg per capita can be assumed for 2050.

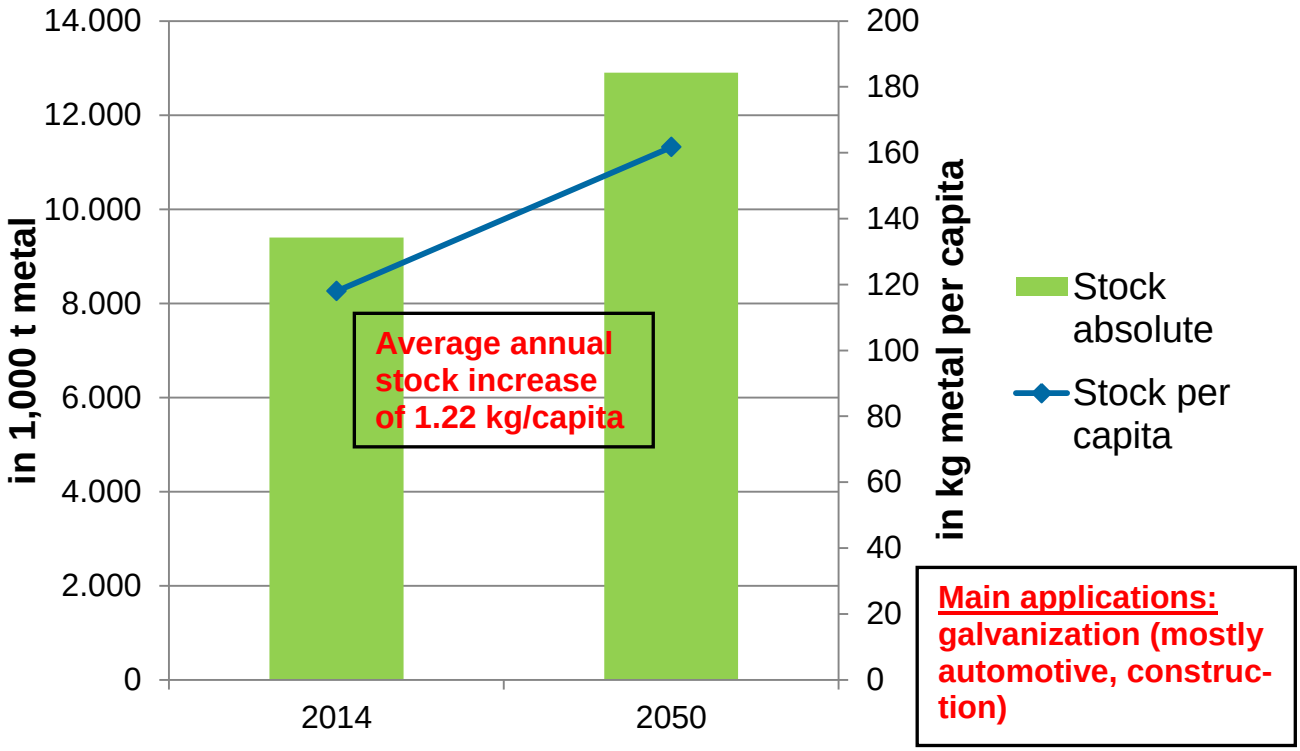
Figure 5 Development of the German copper stock from 2014 to 2050



Of the 5 NF metals investigated, it is expected that copper will experience the steepest growth in anthropogenic stock in Germany up to 2050. In absolute terms, the German copper stock for 2014 is estimated at around 26 million tons. This German copper stock will almost double to 51 million tons by 2050. Enduring applications such as the electronics sector, the automotive sector, mechanical engineering and the construction industry are the primary contributors to this development.

The figure below depicts a graph of the development of the German **zinc stock**. Assuming a start value of around 118 kg zinc per capita in 2014 and an annual growth rate of around 1.22 kg zinc per capita, a quantity of approx. 162 kg zinc per capita can be expected for 2050. This data was derived from various sources (Sörme et al. 2001, Murakami 2006, Brunner et al. 2006, Ruhrberg 2006, Graedel et al. 2010).

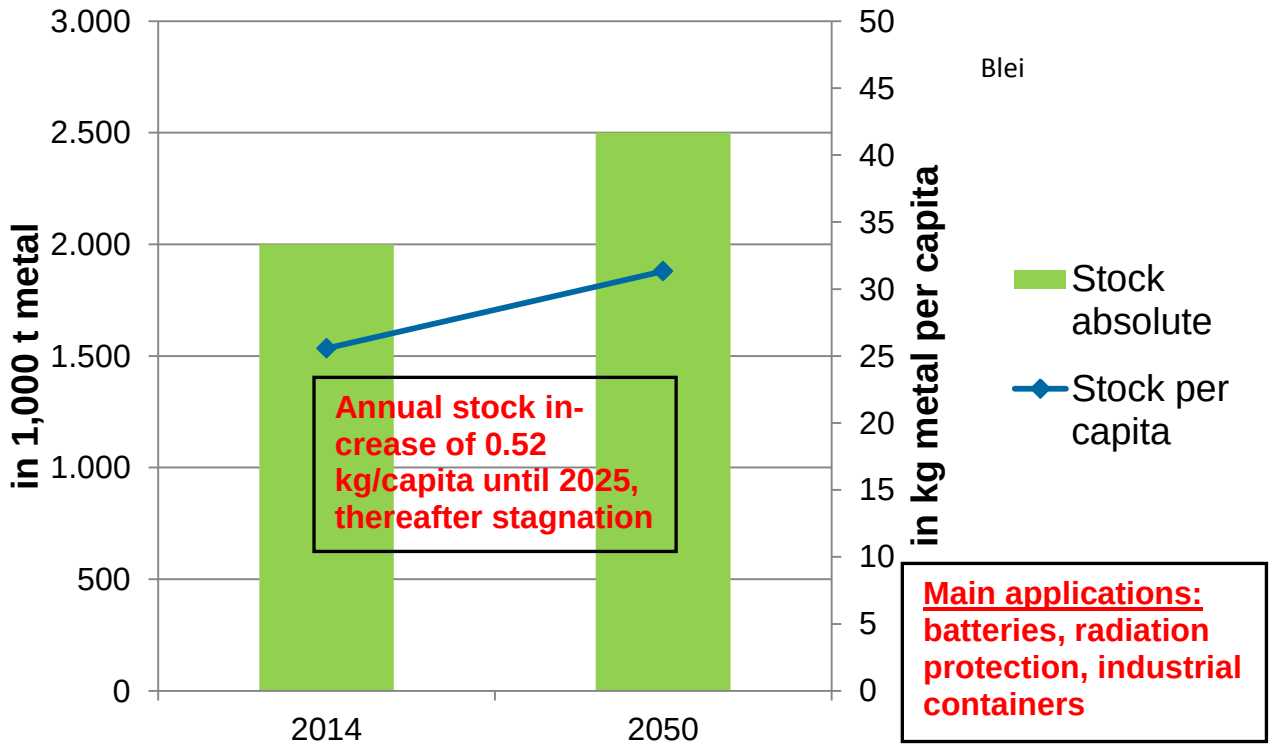
Figure 6 Development of the German zinc stock from 2014 to 2050



Accordingly the German zinc stock is expected to grow in absolute terms from approx. 9.4 million tons in 2014 to around 12.9 million tons in 2050. The main contributors to this growth are galvanized products used in the construction and automotive sectors.

The development of the **lead stock** in Germany is depicted in Fig. 7. The initial value for 2014 was derived from a start value for 2000 (Graedel et al. 2009) using an annual growth factor of just over 0.5 kg lead per capita (Graedel et al. 2010). This results in a lead stock in Germany of around 26 kg lead per capita in 2014. In consultation with the experts involved in the preparation of the study, the annual growth rate of 0.5 kg lead per capita was carried forward until 2025, and from then on it was assumed that the German lead stock would cease to grow.

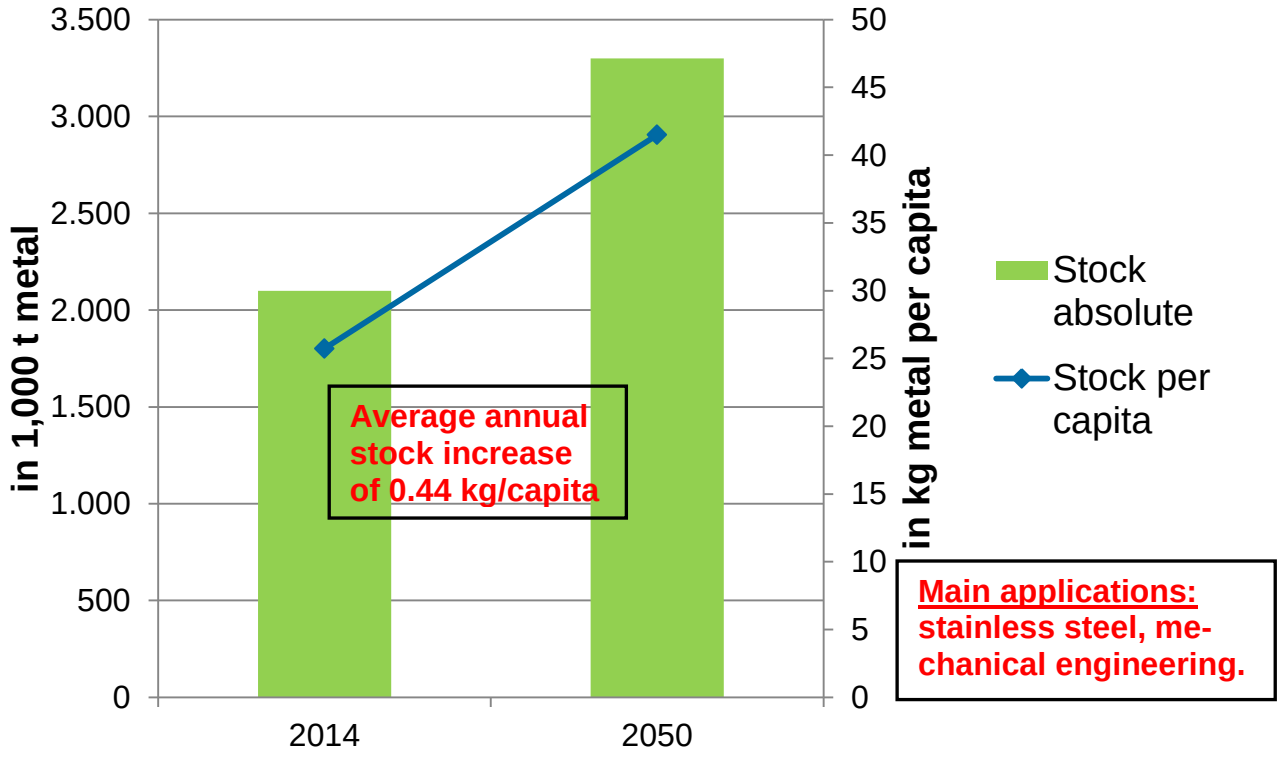
Figure 7 Development of the German lead stock from 2014 to 2050



Hence the absolute value of the lead stock in Germany amounted to around 2 million tons in 2014. For 2050 the stock is estimated at 2.5 million tons. The by far most significant application for lead is in lead-acid batteries (starter batteries). However, to a certain extent it is also used in radiation protection and industrial containers (chemical industry).

The figure below depicts the metal stock development of the fifth NF metal investigated in our study, **nickel.** For the starting year 2014 a nickel stock of 26 kg per capita of the German population is assumed. This nickel stock will grow on average by around 0.44 kg nickel per year until 2050 and hence is estimated to reach around 41 kg nickel per capita in 2050. This data was obtained on the basis of several literature sources (Sörme et al. 2001, Graedel et al. 2010) and personal expert assessments.

Figure 8 Development of the German nickel stock from 2014 to 2050

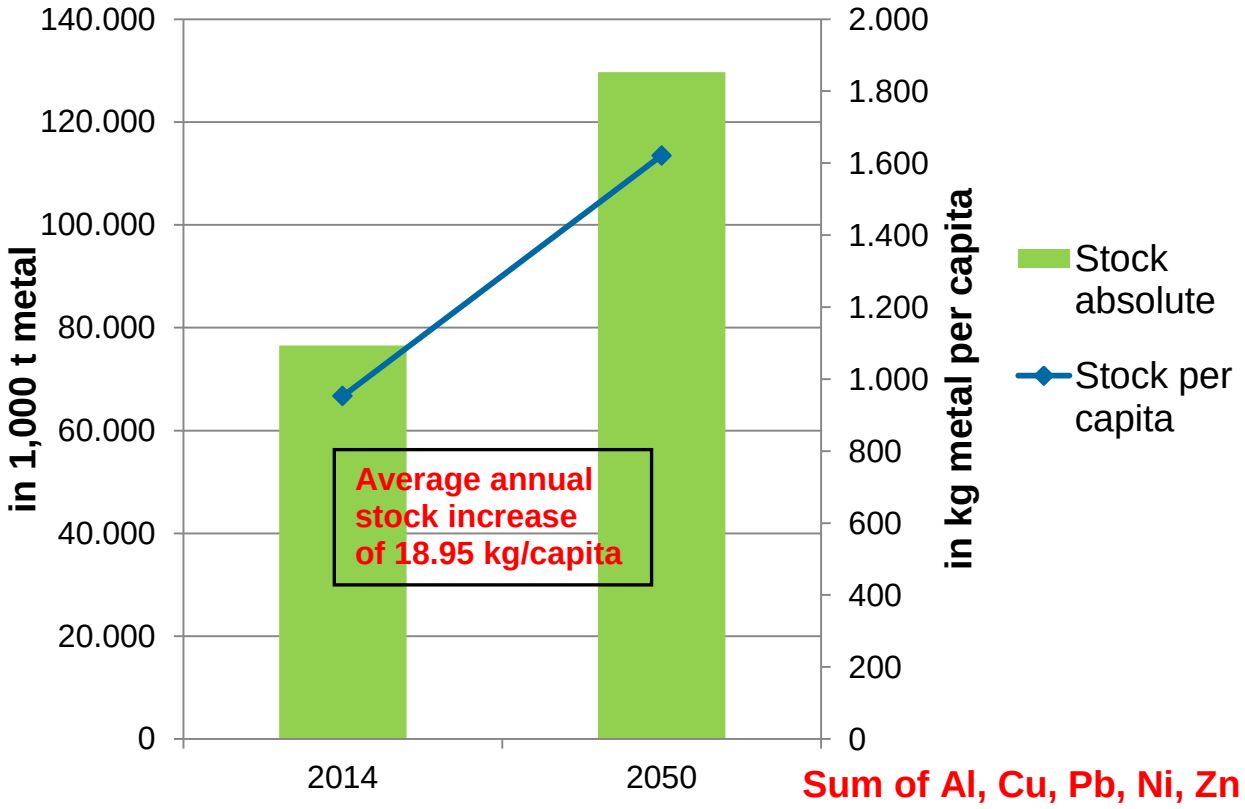


The absolute value of the nickel stock in Germany will grow from around 2.1 million tons (2014) to 3.3 million tons (2050). The primary applications for nickel are as a component of stainless steel and in mechanical engineering.

The analysis of the NF metal stock in Germany for 2014 and its development until the year 2050 yielded the following results (see the following figure).

In absolute terms, the **NF metal stock in Germany** in 2014 amounted to around 76.5 million tons (aggregate value for aluminium, lead, copper, nickel and zinc). This corresponds to approx. 950 kg NF metals per capita which are trapped in the anthropogenic stock, i.e. in buildings, infrastructure, vehicles, etc. The absolute quantity of trapped NF metal stock in Germany in 2014 is equal to more than thirty times the German annual production in the same year. The anthropogenic NF metal stock is supplied by German production (primary and secondary) and by imported NF metals. The analysis further revealed an estimated growth of the NF metal stock in Germany by the year 2050 up to around 130 million tons, or over 1600 kg of NF metal per capita of the population. The annual growth of the NF metal stock per capita amounts to approx. 19 kg. The primary contributors to the NF metal stocks both in 2014 and 2050 are aluminium and copper.

Figure 9 Development of the total German NF metal stock from 2014 to 2050

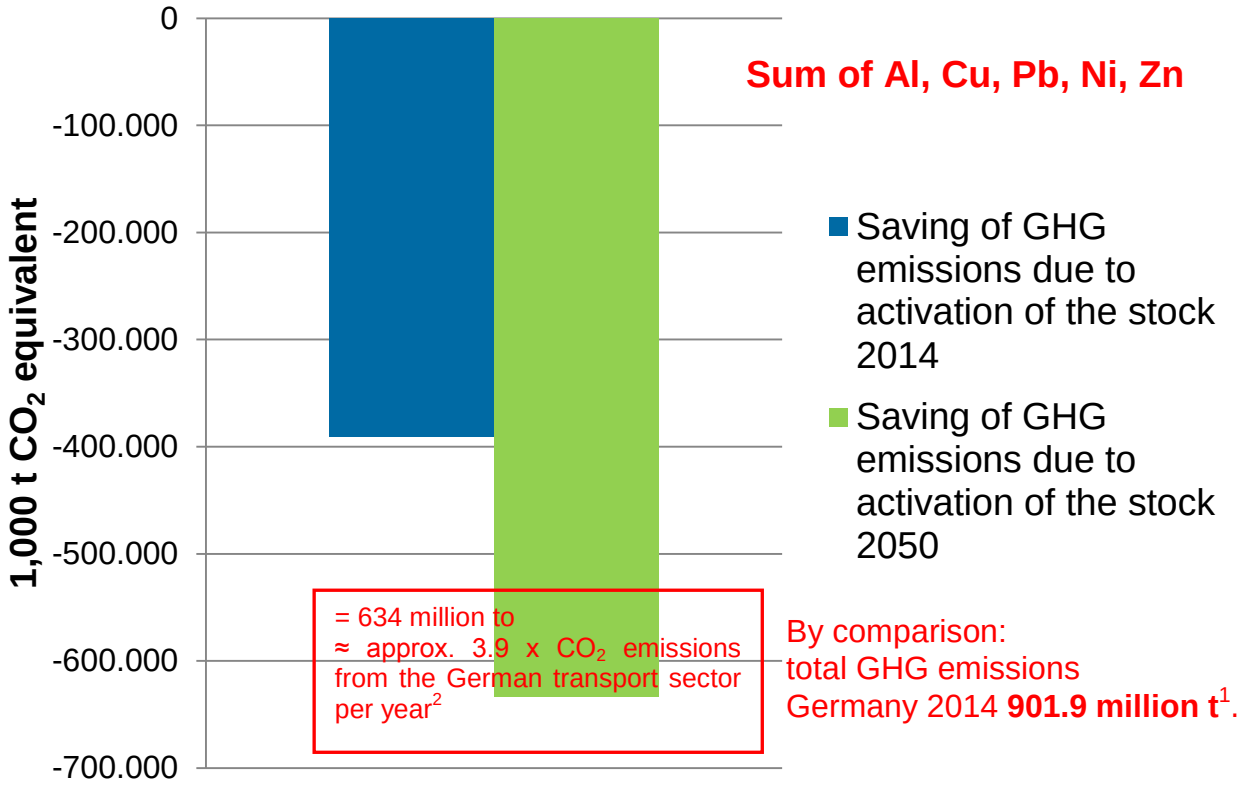


According to estimates by WVMetalle based on average scrap prices for 2015/2016, the nominal value of the total NF metal stock of the 5 metals investigated here amounted to around EUR 132 billion in 2014. This is equivalent to a per capita value of approx. EUR 1,656 for every German inhabitant. In the year 2050 this treasure trove of NF metals locked in the anthropogenic stock - assuming that prices remain unchanged - will have increased to a total value of EUR 245 billion or EUR 3,065 per capita of the population. Year by year the per capita value of the NF metal stock grows by just over EUR 36.

4. Potential savings for greenhouse gases by exploitation of the non-ferrous metal stock

If the NF metal stock were to be fully exploited through recycling, the theoretical savings potential for greenhouse gas emissions would total around 390 million tons of greenhouse gases for the 2014 stock and around 634 million tons for the 2050 stock. The latter figure corresponds, for instance, to over 3.9 times the current CO2 emissions of the transport sector in Germany. It is also noteworthy that parts of the NF metal stock will already have been recycled several times over during the period up to 2050. The ever-growing NF metal stock in Germany represents a continuously increasing potential for GHG emission savings. Of course this is nothing more than a mathematical exercise, since, depending on the entrapment duration of the metals, it will only be possible to exploit the growing potential from the NF metal stock in Germany step by step and in the long term.

Figure 10 **Theoretical GHG savings potential achievable by total exploitation of the NF metal stock 2014 to 2050**



5. Overall summary

The savings of greenhouse gas emissions resulting from secondary metal production were - at 7 million tons - already significant in the base year 2014. Additional savings of greenhouse gases will be possible by 2050 providing that the NF metal stock in Germany is efficiently exploited. The growing NF metal stock in Germany is a resource and energy store for future recycling which will always be available to subsequent generations for recycling without any loss in quality. This will be contingent on the continued development/improvement of basic parameters for efficient recycling, e.g. in the context of the current debate on the circular economy.

6. References

BGR 2014 Huy, D. et al.: Deutschland – Rohstoffsituation 2014, Bundesanstalt für Geowissenschaften und Rohstoffe, Hannover, November 2015.

Brunner et al. 2006 G. Schöller, C. Oberleitner, R. Fehringer, G. Döberl, P. H. Brunner. Verknüpfung Rohstofflager - antropogene Lager - letzte Senken im Bundesland Steiermark, Vienna University of Technology. Vienna 2006.

Graedel et al. 2009 J. S. Mao, T. E. Graedel. Lead in-use stocks; Journal of Industrial Ecology 2009, 13, 112-127.

Graedel et al. 2010 T. E. Graedel and J. Cao; Metal spectra as indicators of development; PNAS, December 7, 2010, Vol. 107, No. 49.

Liu et al. 2013 Liu, G. et al.: Centennial Evolution of Aluminum In-Use Stocks on Our Aluminized Planet, Environ. Sci. Technol. 2013, 47, 4882-4888.

Metallstatistik 2014 WirtschaftsVereinigung Metalle (WVM) (Editor), 2015.

Murakami 2006 S. Murakami, Material Flows and Stocks of Metals Surrounding Japan, Symposium on Advanced Material Flow Analysis for the Sustainable Society, Sendai, Japan, 2006.

Ruhrberg 2006 M. Ruhrberg. Assessing the recycling efficiency of copper from end-of-life products in Western Europe. Resources, Conservatioin & Recycling 2006, 48, 141-165.

Sörme et al. 2001 L. Sörme, B. Bergbäck, U. Lohm, Century perspective of heavy metal use in urban areas. Water, Air & Soil Pollution. Focus 2001, 1, 197-211.

UNEP 2010 Graedel, T.E. et al.: Metal Stocks in Society – Scientific Synthesis, International Panel for Sustainable Resource Management (Editor), UNEP 2010.