Material Efficiency & Resource Conservation

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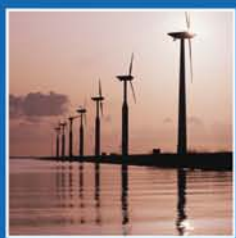
Metallic Raw Materials, Worldwide Recovery of PGM and Materials for Infrastructures

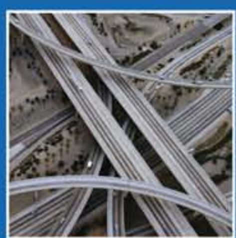
Executive Summary

Executive Summary of the results of the Task 2 of the project „Material Efficiency und Resource Conservation“ (MaRess)

ResourceEfficiency Paper 2.7





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Metallic Raw Materials, Worldwide Recovery of PGM and Materials for Infrastructures

Executive Summary

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Introduction

In order to determine the requirements and possibilities of increasing resource efficiency within important, however until today insufficiently researched areas, the knowledge basis towards environmentally relevant metal raw materials, the process for recovering platinum group metals as well as towards those raw materials linked with infrastructures was improved and analysed for possible options of action. The results show that to a considerable extent, there still exists loss of material and environmental pollution along the extraction, processing, utilization and recycling chain which could be decreased by the application of suitable measures. It is particularly necessary to promote return, collection and processing systems in areas where products (new, used or waste) are exported to countries in which, to date no sufficient recycling takes place. Domestically, in turn considerable potentials exist for future use of secondary raw materials, if the type and quantity of the stored materials in infrastructures, their foreseeable durability and the future locality of waste were regularly monitored in the future. Paving the way to „Urban Mining“, which effectively contributes towards the conservation of natural resources.

1 Environmentally Relevant Metallic Raw Materials, Task 2.1

1.1 Objectives and targets of the Task

Metallic raw materials are important for numerous technical applications. Due to the proceeding of technology in many areas, the use of metals increased rapidly within the last decades (more applications and more metals). Accordingly, most of the 60 metals are today used routinely. Thus, numerous metals that are today predominantly applied for specific tasks in small amounts accompany the ferrous metals and base metals that dominate with regard to the amounts of metals used. In this respect, the former metals can be termed as rare. Furthermore, these metals are subject of discussions due to their partly limited availability. For this reason, some of them are also termed as critical metals. Fields of application typical for these metals and with significant growth rates are electric and electronic equipment (including information and telecommunication technology (ICT) and photovoltaics technology, medical technology, and nanotechnology.

As these rare metals have received less attention in technical literature than ferrous and base metals, the availability of knowledge is also relatively limited. This is especially true regarding environmental pressures and material losses along their life cycles and their relevance in the socio-industrial metabolism. The superior aim of the MaRess task “Environmentally relevant metallic raw materials” is the enhancement of the knowledge base on rare metals and thus filling knowledge gaps in order to support the development of appropriate strategies and measures with regard to prevention, substitution, resource efficient production, and circular economy (including international aspects). For this purpose, the following steps have been carried out:

- Screening of potentially environmentally relevant metals: 66 metals (The nonmetals, lanthanides and actinides stayed unconsidered) or metal groups, respectively, were analysed with regard to the criteria reserves, reserve-to-production ratio, annual production, commodity prices, geographic concentration of production and reserves, dissipative use, environmental relevance (by Cumulative Raw Material Demand, Cumulative Energy Demand, and Total Material Requirements) and the application areas. By means of selected criteria, ten metals were identified to be examined in more detail.
- More detailed analyses of ten selected metals with potentially specific relevance. These metals were analysed in more detail with regard to their life cycle material losses and their specific environmental pressures by means of simplified substance flow analyses.

- Options for action: Based on the preceding enhanced analyses, suited measures and strategies were compiled aiming on the reduction of material losses and of the environmental pressures along the life cycle.

1.2 Results

1.2.1 Classification of metals regarding criteria on environmental relevance and rareness

An analysis was carried out on 66 metals with regard to different criteria with the following results:

- Overview of the application areas of the metals including their relative shares in the total use; in addition short descriptions on the applications in the application areas electric and electronic equipment/ICT, medical technology and nanotechnology;
- Annual production, reserves, reserve base and reserve-to-production ratio;
- Geographical concentration of primary production and reserves;
- Determination of dissipative use and other problematic use patterns of the metals;
- Cumulative Raw Material Demand (CRD), Cumulative Energy Demand (CED) and Total Material Requirement (TMR).

The measures CRD and CED were extracted from so-called environmental profiles, which were developed within the project of the Federal Environment Agency “Indicators for the Use of Raw Materials in the Context of the Discussion of Sustainability”; the determination of the TMR was based on analyses by the Wuppertal Institute. The criteria for the metal selection were the measures CRD, CED and TMR in combination with the reserve-to-production ratio and the dissipative use, while also the expected future development of the production of these metals was considered. Based on the classification of the metals with regard to these criteria, ten metals were selected for a more detailed analysis: the precious metals silver (Ag), gold (Au), palladium (Pd), the steel refiners manganese (Mn) and nickel (Ni), the heavy metals tin (Sn), zinc (Zn) as well as the "specialty metals" gallium (Ga), indium (In) and titanium (Ti).

1.2.2 Analysis on ten selected metals

For each of the ten metals, an analysis of the global substance household was performed along the full life cycle according to a defined scheme, in order to increase the comparability between the metals (Fig. 1.1). For each process of the system, both relevant metal losses and relevant specific environmental pressures were determined along the life cycle; this summary focuses on the metal losses th1at imply an increase in the primary production and the increased environmental pressures that they are generally involved with[1].

Fig. 1.1: Reference metal system for displaying the metal systems including the metal losses

The undesirable metal flows (losses) are shown dashed. The white boxes are stocks of the corresponding metals.

As expected, the substance flow systems of the single metals vary considerably. With regard to the material losses, the following differentiated pattern was achieved:

- *Relative Material Loss of the Use Phase (RLU)*: This is the annual material loss from use and recycling related to the annual input into the use phase. It varies by factor 8 between the ten metals, ranging from more than 70 % for tin to less than 10 % for gold; it is a question of the "minimal recycling potential" that occurs at the use and recycling phase[2] (it would be increased by further processes residing domestically);
- *Relative Material Loss of the Total Life Cycle (RLT):* This is the total annual material loss along the life cycle related to the annual input into the use phase[3]. They

[1] A complete description of all environmental pressures that emerge could not be carried out in the course of this study due to the multifaceted processes during the production and use of the metals.

[2] Insofar, this potential is generally located in the sphere of influence of national policies, in contrast to the potential of processes, which are located in foreign countries and are additionally covered by the "Relative Total Material Losses".

[3] Due to the reference to the input into the use phase, relations greater than 100 % are possible.

range between ca. 110 % for manganese and ca. 20 % for gold; it is a question of the "maximal recycling potential" on global scale.

The losses of the other metals are each between the extreme values indicated above. Furthermore, the study reveals, in which life cycle step the relevant material losses occur as shown in Tab. 1.1. Attention should be given to the phenomenon that the environmental relevance of the material losses varies between the metals[4], however, a comparison between the specific environmental pressures, which are associated with the material losses, was not feasible within this study due to data constraints. Therefore, more studies are required to improve the current data.

Tab. 1.1: Overview on the relative losses within the various processes, and on the total annual material loss of the investigated metals[5]

The symbols show the relevance of the losses by the single processes: xxx = share exceeding 25 %, xx = share between 25 and 10 %, x = share falling below 10 %, o = no significant losses, n.s. = not specified.

<table>
<tr><th></th><th>Mn</th><th>Sn</th><th>Pd</th><th>In</th><th>Ni</th><th>Ag</th><th>Zn</th><th>Au</th></tr>
<tr><td>Extraction</td><td>o</td><td>o</td><td>xx</td><td>n.s.</td><td>xxx</td><td>xx</td><td>n.s.</td><td>xxx</td></tr>
<tr><td>Beneficiation</td><td>xxx</td><td>xx</td><td>x</td><td>xxx</td><td>xx</td><td>xx</td><td>xxx</td><td>n.s.</td></tr>
<tr><td>Processing</td><td>xxx</td><td rowspan="2">x</td><td>x</td><td>n.s.</td><td>xx</td><td>n.s.</td><td>n.s.</td><td>n.s.</td></tr>
<tr><td>Production</td><td>x</td><td>x</td><td>x</td><td>x</td><td>n.s.</td><td>xx</td><td>xx</td></tr>
<tr><td>Use phase</td><td>xx</td><td>xxx</td><td>xx</td><td>x</td><td>xxx</td><td>xxx</td><td>X</td><td>x</td></tr>
<tr><td>Recycling[6]</td><td>n.s.</td><td>n.s.</td><td>xxx</td><td>x</td><td>n.s.</td><td>xx</td><td>n.s.</td><td>xxx</td></tr>
</table>

In relation to the input into the use phase, the relative material losses within the total life cycle amount to (figures rounded on 5 %):

RLT [%]	**110**	**80-85**	**65**	**50**	**40-45**	**35**	**30**	**15-20**

4 The environmental pressures are both specific to metals and to processes, as the „ecological rucksack" grows by progression of the processes.

5 For an assessment of the losses of Gallium and Titan, sufficient results were not available. Therefore, a presentation of these was left out here.

6 Inclusive so-called „downcycling", by which the metal loses it´s specific functionality. Generally, this is associated with a significant loss in value.

1.3 Options for action

For the last years and with increased intensity during the period of the project, diverse professional articles have been published on substance flows of rare and precious metals. These deal predominantly with the possibilities to improve recycling from technical, logistical and institutional points of view[7]. In combination with the specific recycling potentials[8] determined by means of the ten studies within the scope of this project, the following set of options for action was considered jointly for the diverse metals:

- Increasing the collection volumes of end-of-life products, which contain rare metals in relevant amounts, in Germany and in foreign countries; for example of end-of-life electric and electronic equipment, which contain significant amounts of palladium, gold and silver, as well as used batteries with regard to their manganese content;
- Setting-up or adaptation of existing product-specific collection systems, e.g. for motor vehicles or ICT, in developing countries by governmental or private agendas, in order to allow a subsequent recycling by application of best available techniques on-site or in developed countries[9]; in doing so, protection of efficient collection systems with positive employment effects, and reduction of harmful effects on health and of environmental pressures in the informal recycling sector;
- Setting-up of transnational redistribution systems for scraps of specific product groups, which are relevant for the management of rare metals; for example, the collection performance should be supported within the scope of extending product stewardship for catalytic converters in end-of-live vehicles (ELV) with focus on those countries, where material losses are at the highest. Potential measures are logistical support of collection systems, training courses or agreements to take; potential addressees are manufacturers of vehicles and/or catalytic converters, and specialised recycling companies (via voluntary commitment)(cf. MaRess Task 2.2); long-term security of supply by secondary raw materials could be an incentive for the addressees.
- Support of more detailed manual or automated disassembling respectively, and sorting of old appliances, which contain rare metals in relevant amounts and for which the recovery rate can be increased, e.g. waste of electric and electronic equipment (WEEE) (especially drives, power supply units), or motor vehicles. In fu-

7 The articles considered within this study are listed in the final report of task 2.1.

8 Attention should be given that in this sub-project the material losses are considered as „theoretical“ potential (i.e. maximal potential to be supposed) to prevent losses. Therefore, the diverse technological and institutional possibilities regarding the „practical“ potential to prevent the material losses should be assessed by a further step.

9 Shipping of dismantled and selected components of scrap to (European) BAT recycling plants is called „best of two worlds approach BAT“. BAT means "best available techniques".

ture studies, it will be necessary to determine more precisely, which components have the largest potentials;

- Monitoring of the flows of old goods and of the recovered amounts of metals for inspecting the achievements of the management of rare metals (effectivity and efficiency of the recycling);
- Monitoring of the interfaces of the recycling chain in order to enhance market transparency, including all stakeholders involved in the processing (collection, treatment, recycling);
- Setting-up of a continentally to regionally adapted supply of product-specific treatment and recycling processes that improves the effectivity of the recovery of rare and precious metals globally by differentiated treatment of the end-of-life products and their delivery to sophisticated recycling plants;
- Periodic accounting of the treatment processes with regard to rare metals aiming at the optimisation of processes for the concentration of rare metals in recycling fractions;
- Comparative analysis and evaluation of re-use and recycling referring to the consumption of raw materials and to environmental pressures with regard to regional distinctions and product group-specific differences between recycling systems;
- Classifying and Certification of recycling technologies by criteria on resource efficiency and resource conservation (reducing the raw material requirements and environmental pressures compared to the primary route);
- Cooperative Governance aiming on binding quality standards regarding the treatment and recycling, including the certification of stakeholders, if need be (cf. MaRess Task 2.2);
- Formulation of a national or international target respectively, to reduce the primary raw material requirements of metals considering the raw materials, which were used along the life cycle, for the production of imported goods, with focus on selected sectors, in which relevant recycling potentials exist (e.g. the recovery of a given share of the gold in WEEE and/or the input of a minimum share of secondary metals in the production);
- Localisation of market failure and formulation of potential framework requirements, which enable the market launch of effective, but currently uneconomical treatment and recycling systems for rare metals.

Besides, the geographic component of the substance flows of rare metals is to be considered: Extraction, production, use and recycling of both old metals and of scrap from production are, in general, spatially heterogeneously distributed. Due to the low amounts of turnover of rare metals and the high investment costs for high-tech recycling plants, only relatively few central recycling plants are cost-effective. Thus, the recirculation of the end-of-life products containing rare metals plays a decisive role. The challenge in this regard is to organise the waste phase of end-of-life products – especially of potential recyclable small electric equipment – in such a way that they are collected as completely as possible.

Beside the collection, the treatment before the actual recycling is vital: Here, the old appliances have to be sorted and separated to route the rare metals to fractions as completely as possible that can be delivered to specialised recycling plants. Thus, from a resource policy point of view, it is required to direct the metal flows, especially the cross-border ones, effectively and efficiently, and to set up collection and treatment systems, which ensure a sufficient collection and treatment performance.

As losses reoccur for each life cycle of the products, besides recycling, also the actual life-time of the products is potentially relevant in order to increase the resource efficiency of the metal systems. However, the prolongation of the life-time of the products competes generally with progress regarding energy efficiency, with progress of the performance of the products, or also with fashion aspects of products. It is suggested to perform scenario analyses for the assessment of recent developments of the life-time of products with regard to their effects on material efficiency.

The knowledge base on the environmentally relevant rare metals could significantly be enhanced and consolidated within MaRess Task 2.1. Nevertheless, the results are intermediate as relevant knowledge gaps and uncertainties still remain that ought to be investigated by more detailed substance flow analyses – based on what has been achieved so far. The largest knowledge gaps with regard to the material losses remain for the metals gallium and titanium regarding the environmental pressures along the life cycle, relevant gaps remain for all metals.

2 Worldwide Recovery of PGM, Task 2.2

2.1 Objectives and targets of the task

Globally the use of platinum group metals (PGM) with its main representatives of platinum, palladium and rhodium in technology-oriented applications continues to increase. The driving factors are the growing demand from industry, particularly in applied fields as autocatalysts and consumer electronics. Simultaneously with these applications the secondary commodity potential grows, which is disposable after the utilisation phase.

From a resource and environmental policy perspective, PGM recycling can make an important contribution to national commodity security, resource conservation and environmental protection.

- Keyword commodity security: as the supply of the primary resources depends on very few countries (mainly Russia and South Africa), any additional ton of recycled PGM could help to reduce the dependency on those countries as well as of price developments in oligopolistic structured markets.
- Keyword resource conservation: PGM raw material reserves are limited. Increasing PGM recycling could preserve primary resources and save them for future generations.
- Keyword environmental and climate protection: PGM recycling is associated with distinctly lower environmental impacts as the extraction of primary resources.

Nevertheless, the economic and environmental benefits of PGM recycling have not yet been sufficiently exploited, mainly due to the export of used cars and used electronic equipment to countries lacking an adequate recycling infrastructure. Because of this PGM material gets lost for a global recycling treatment. At the same time dissipative applications are increasing in the electronics sector; those very small quantities cannot be recovered with conventional recycling technologies.

Against this background, the task "Worldwide Recovery of PGM” develops proposals for an optimisation of an international PGM resource management in selected application fields. For this purpose, the following steps were carried out:

- Identification of potentially problematic export flows and of significant PGM losses in different application fields.
- More detailed actor-related case studies in the fields of autocatalysts and selected consumer electronics (mobile phones and flat screens); deficit analysis relating to logistic collection, dissipative losses and regulatory deficiencies in selected target countries

- Deduction of strategies und measures leading to prevention of PGM losses and substitution of PGM material as well as a more efficient international PGM recycling. Priorisation of the proposed options.

2.2 Results

2.2.1 Conditions and trends in PGM recycling

Nearly 50 percent of the (primary and secondary) production of platinum, palladium and rhodium are used in autocatalysts. Other important applications include electronics, jewellery and process catalysts in the chemical and petroleum refining.[10]

PGM demand is influenced by different market based and technological factors. After the sales declined due to the economic and financial crisis in 2009, a mass related growth of primary production reappeared in 2010, which is in particularly driven by technological application areas. Also the increasing importance of photovoltaics and electro-mobility as application fields should be recognised (see Hagelüken/Buchert 2010). PGM consumption in various demand sectors and their development in the last 3 years is shown in Tab. 2.1.

Tab. 2.1: Development of the global consumption of platinum, palladium and rhodium, based on different application fields (2008 - 2010) in tonnes

Platinum	*2008*	*2009*	*2010*	*Palladium*	*2008*	*2009*	*2010*	*Rhodium*	*2008*	*2009*	*2010*
Auto catalysts	103,6	61,9	84,6	Auto catalysts	126,5	114,8	**146**	Auto catalysts	21,7	17,5	20,6
Electro	6,5	5,3	6,3	Electro	38,8	36,0	**39,8**	Electro	0,08	0,08	0,1
Invest	15,7	18,7	12,3	Invest	11,9	17,7	18,9				
Jewellery	58,4	79,6	68,6	Jewellery	27,9	21,9	17,8				
Glass	8,9	0,2	**10,3**					Glass	0,9	0,5	**1,6**
Medicine	6,9	7,0	7,2	Dental	17,7	18,0	17,5				
Chemistry	11,3	8,2	**12,7**	Chemistry	9,9	9,2	**10,9**	Chemistry	1,9	1,5	1,8
Others	15,0	11,3	12,0	Others	2,1	1,9	2,2	Others	0,6	0,5	0,5
Con-sumption	**226,5**	**192,6**	**214,3**	**Con-sumption**	**235,0**	**219,7**	**253,4**	**Con-sumption**	**25,4**	**20,2**	**24,8**
Recycling	51,8	39,8	52,1	Recycling	45,7	40,5	**52,3**	Recycling	6,4	5,3	6,7
Net con-sumption	174,6	152,8	162,1	Net con-sumption	189,2	179,1	201,1	Net con-sumption	18,9	14,9	18,0
Stocks	6,2	18,0	8,2	Stocks	18,0	22,1	1,2				

Source: Own combination and calculation in tonnes on the basis of indications in Johnson Matthey 2010. The values for 2010 are estimated values on the basis of the first 9 months, growth rate in bold.

[10] See also data in Tab. 1.1

The presented data shows that there was a distinct shift during the world economic crisis of 2009 from technology-related applications to value-related uses and that in general the consumption decreased in the crisis year 2009. The area of autocatalysts is for all three metals distinctly the dominant application area. Here it is significant that the proportions between platinum and the lower cost palladium have shifted distinctly[11]. In the field of glass applications for platinum and rhodium there is a significant growth in demand, but also the consumption of platinum and palladium in the chemical industry shows increasing values.

Recycling is increasingly becoming a strategic relevance for commodity security, since there are considerable problems in the expansion of primary production, which in Russia is coupled to the nickel production and in South Africa continually affected by the lack of power.

Despite these constraints, there are still large differences in the cycle of PGM. In industrial applications, for example industrial catalysts reach recycling rates of up to 90 % (see Saurat/ Bringezu 2008 & 2008a). In contrast to this, the recycling rates in the fields of consumer goods are much worse. For example, the contribution of recycling for the supply of palladium in automobile exhaust catalysts is 26 % in 2010 (in 2006 it was 20 %). In the consumer electronics sector the recycling quota is set to rise from 19 % in 2006 to 31 % in 2010 (JM 2010, p. 36). JM expects most of the recycling quotas in open loop systems to improve, due to more effective government incentive schemes. Looking at this it should be considered that due to the decline in prices in 2009 a lot of material was stored, which reached the market with a time lag in 2010. Therefore it should be observed whether the high recycling quota can be stabilised in future.

An important trend is the rising internationalisation of PGM flows. An increasing part of secondary resources is accumulated in the growing product related stocks of the so called emerging nations. Because of this the globally acting smelters/refiners started to establish international redistribution systems providing there „Integrated Smelters“ with input. Those activities are mostly separated from the stateside waste regulation and differ from country to country.

A significant amount of PGM material goes to countries without an adequate recycling infrastructure (like Russia, countries in Middle-Asia, South-East Asia, Middle East and West Africa). Those shifting stocks from Germany to other countries are due to the export of used (and new) consumer goods as cars and consumer electronics.

This problematic has been particularly tackled in two case studies: 1. Autocatalysts (see index 2.2.2) and 2. Consumer Electronics (see index 2.2.3).

[11] While palladium is used to large parts in gasoline engines, in diesel vehicles now mainly the much more expensive platinum is used, which is effective even at lower operating temperatures (see Brenscheidt 2001, 24).

2.2.2 Case study „PGM-recovery from autocatalysts“

In 2008 only 15 % of a total of 3 Million deregistered German cars has been brought to waste treatment in Germany, 8 % has been exported as used cars to other EU-countries (mainly the new member states, BMU/UBA 2010). Further on – after a time of using – those cars are exported again to Non-EU-Countries. 23 % of the outflow is statistically unidentified. The following illustration shows an update of the statistical exports:

Fig. 2.1: Destination of the deregistered German cars in 2008

Source: BMU/UBA 2010 related to data of Kraftfahrtbundesamtes (Deregistration,Re-registration) and the Federal Statistic Agency (Waste Statistics, Foreign Trade Statistics)

On the basis of the available statistical sources a reliable assessment is not possible. The registration of exported cars within the foreign trade statistics relating to the intereuropean trade is incomplete due to turnover-related registration duties. Another failure is due to various registration criteria in EU-countries. Last but not least follow-up exports of imported cars are totally intransparent. Against this background it can be very much appreciated that the EU-Commission and Eurostat has launched an instruction how to come to a better and more comparative data base in the case of end-of-life vehicles treatment (European Commission 2010).

As a result of the expert interviews and the country studies it is obvious, that the exports to the GUS-countries and the middle-asian countries (like Kazakhstan) are getting more and more important. Those are countries in which the national car fleets are growing rapidly, but at the same time where there is no effective recycling scheme and awareness of car functionality. Those framing conditions are strongly related to the ability of PGM-recycling.

The country studies also showed the relation between car fleet modernisation and PGM potential. In coming years - for example in the metropol regions of Russia (Moscow, St. Petersburg) – most of the passenger cars will be equipped with a common threeway catalysts converter. For those new cars an additional risk of PGM-losses can be expected if not a stricter technical control of cars will be established. Poor maintenance request in combination with poor condition of streets will lead to more damages of autocatalyst converters and to dissipative losses of the PGM-loadings. In fact, we could indentify only some unsystematic practice of catalyst recycling, mostly in grey markets with unregistered outflows of PGM from country to country.

Bringing some of the discussed problems to a solution a roadmap was created by the project team and presented to different stakeholders at a workshop in Berlin held in 2009 (Lucas/Wilts 2009). The proposed measures for optimising the global PGM-recovery, which were welcomed by the participants of the workshop, are the following:

- A stronger commitment between the actors in the PGM-redistribution-chain addressing common quality standards for dismantling processes, catalytic converters logistics and conditioning.
- Obligation of the car companies and catalyst producers for a recycling quota related to their production and targets for the use of secondary PGM
- Establishing redistribution systems from the target markets of used car exports to the integrated smelters. Strengthening producer’s responsibility by the industrial partners (car industries, converters producers).
- Technical marking by means of RFID: In general this could help to indentify export flows and the final destination of autocatalysts as well as support the redistribution management of private companies. On the other hand the declaration duties of car retailors should be extended.

For all these measures, a time window of 10 to 15 years is needed, because within this time frame most of the cars in the target countries will be equipped with a conventional three way converter. This may differ from country to country.

2.2.3 Case study „PGM-recovery from electrical and electronic equipment” (EEE)

The volume of WEEE in the EU is growing faster than all other fractions of municipal waste (cf. UNU 2008, 3). From a technical point of view recovery rates up to 95% can be achieved by the recycling of printed circuit boards that contain the bulk of the palladium. The relevant deficits are on the one hand the redistribution and the other hand the proper treatment and processing. A major problem is the fact that relevant quantities of used EEE leave the European Economic Area. According to Sander/ Schilling (2010), in 2008 approximately 155,000 t of used EEE exports electrical and electronic equipment have been exported from Germany, including about 2 million monitors. On a global scale one must assume that only about 10% are actually recycled (cf. LaDou et al. 2007 and UNEP 2010). However, an international market for re-use could certainly be established in the medium term based on internationally binding commitments to high quality standards for recycling.

The monitors and mobile phones, the palladium containing products analyzed in detail, are characterized by different circumstances: Mobile phones on the one hand are usually legally exported as a functioning used equipment with a positive market value, monitors on the other hand (especially CRT monitors) are normally illegal exports because of the costs of disposal in Germany exceeding the total export costs. But also domestically deficits result in the circulation result because waste EEE is not collected within the dedicated systems with a high-quality recycling. For both products together, mobile phones and monitors, at the present state of the art recycling an additional theoretical potential for Germany of about 0.75 t PGM was estimated, which would exceed the total European net demand for electronic applications (see JM 2010).

Based on this analysis the developed policy proposals address different spatial levels and aim to improve the coordination of existing initiatives in the field of used and waste EEE. The underlying approach is to strengthen the producer responsibility for the end of life phase of its products, as stated in the WEEE-Directive, but so far undermined by legal and illegal exports (cf. Wilts 2009). Specifical priority should be given to the following measures:

- Approaches of technology and knowledge transfer should be extended to those developing and emerging countries where the use phase of electrical and electronic equipment ends (both imported and domestically generated). These countries are usually characterized by very high collection-rates, but completely lack the necessary recycling infrastructure (cf. Yu et al. 2010). This could open up significant win-win potentials, if the precious metals such as on dismantled circuit boards are supplied to the internationally networked smelters instead of to a backyard recycling causing severe risks to health and environment. The revenues of recovery significantly exceed the additional transportation costs (cf. Hagelüken 2010).
- For mobile phones there is a need to significantly increase the domestic collection rate. Best practice examples for optimized redistribution systems for example with designated recycling fees in combination with intensive public relations (national day of action, teaching materials, etc.) exist e.g. in Switzerland (cf. SWICO 2009). A deposit system for mobile phones could be an additional incentive (cf. MPPI 2009).
- With regard to monitors the illegal export of waste products has to be contained by product-specific regulations for the distinction between waste and used equipment. In addition, the devices should be no longer collected together with bulky waste from the roadside. Direct collection of waste EEE from households could avoid damages and the theft of valuables (Sander / Schilling 2010) as well as increase transparency and security.

2.3 General aspects of an international governance-approach regulating PGM-material flows for recycling

The investigations described here indicate in both action fields that international management of secondary PGM-resources is strongly influenced by international market development and less influenced by national waste regulation. In the near future an international obligatory regulation of this issue within the wto-regime can probably not be expected. Because of this background we propose a cooperative governance approach which should lead the actors in the recycling value chain to a more obligatory understanding of quality standards and environmental targets. For the implementation of those standards the international acting refiners of PGM-material could take a leading role because they will benefit directly by this kind of agreement.

Such cooperative structures could be supported bilateral or mulitilateral by government activities or their subordinated environmental agencies. Also UNEP with its international resource panel could play an important role by co-ordinating the experience exchange about how to improve the efficiency of international acting recycling systems (see UNEP 2010). But at least the key for a new recycling model lies in the hands of the big players in the refining business and their customers in the car industry.

Public authorities could help to optimise the information flow in the PGM-recycling chain by addressing more reporting duties mainly of the retailers. Furthermore, the aimed standards for best available technologies should be considered by laws (Likewise ELV and WEE Regulation). Another field of governmental action should be the different technology and qualification levels between OECD-countries and the target countries, which import used consumer goods. A convenient tool for problem solving could be the promotion of technology and a qualification programme, which would enable the target countries to establish a systematic dismantling, collection and redistribution of PGM containing consumer goods. This programme should be initially designed for new EU-member states and CEEC-countries. As far as we know new refining plants in the emerging economies are not being planned, so the existing redistribution routes will remain in the meantime. It can be expected that upon condition of free trade international material flows of secondary PGM will go ahead.

3 Material Stock and Flows in Infrastructures, Task 2.3

3.1 Objectives and targets of the task

Infrastructure systems can cause severe environmental impacts, as they require large quantities of raw materials for their construction and maintenance. A sustainable resource management should hence aim at decreasing the absolute quantity of primary raw materials while increasing the proportion of secondary raw materials being used. In order to provide the required basic data, task 2.3 of the MaRess-Project analysed relevant on-grid infrastructures in Germany in terms of their material stocks and annual material flows for maintenance and expansion. Four infrastructure systems were considered:

- transport networks,
- drinking water and wastewater infrastructures,
- communication systems,
- electricity, gas and district heating networks.

Analysing the material stocks and annual material flows of relevant infrastructures provides an input to a consistent country-wide data base, in order to identify and discuss potentials for resource conservation in infrastructures. Furthermore, the project provides useful information about which materials are potentially available for recycling purposes when infrastructures are being dismantled and can be useful for assessing the material dimension of certain energetic development goals (e.g. DENA national grid studies).

The part has been divided into four steps:

- Step I: Identify relevant types of infrastructure / reference systems;
- Step II: Determine the present size of infrastructures and amount of the material bound in the reference systems;
- Phase III: Determine the annual material flows of the reference systems;
- Phase IV: Conclusions and further research needs.

In most cases, a bottom-up-approach has been used in order to determine the material stocks and flows: Lengths / numbers of the particular reference systems have been linked with specific material coefficients and extrapolated to the total stock (or the annual expansion or renovation). When possible, material flows resulting from the dismantling of infrastructures have been calculated in the same way. We determined the specific material coefficients by analysing relevant databases and literature (Ecoinvent, various life cycle analyses), complemented by extensive own research (technical literature, product catalogues, expert interviews). In order to systematically determine and visualise inputs, outputs and stocks of materials in infrastructures, we used the material flow analysis (MFA). Furthermore, we determined the total material requirement (TMR) of the identified material stocks and flows in order to calculate the specific ecological rucksack and hence illustrate the ecological relevance of the particular reference systems.

3.2 Results

3.2.1 Transport networks

In terms of transport networks, we analysed material stocks and annual flows of streets as well as railways and waterways, including civil engineering structures (bridges, tunnels along railways and motorways, gates and harbours along waterways).

The material stocks of the German road network (more than 7.3 billion tons) were calculated for one square meter reference-road based on technical road construction standards, which define the build-up of different street categories. The results were then extrapolated on the total length of the Germen road network, based on reference profiles. Annual renovation needs have been extrapolated based on the specific operating life.[12] Material stocks include the road space as well as the civil engineering structures along motorways. Food and bicycle paths, noise and beam barriers, which are also parts of the road network, have not been included. In terms of the railway material stocks, we could use data of another recent UBA-project (Schmied/Mottschall 2010) and hence make reliable calculations of the material stock (1.35 billion tons). Extrapolations of the material bound in waterways (more than 200 million tons), including inner harbours, are based on earlier analyses at the Wuppertal Institute (Stiller 1995; Manstein/Stiller 2000).

The quantity of mineral building material bound in the road network is multiple times higher than in other infrastructure systems. Furthermore, the annual material flows in transport networks, in contrast to other infrastructure systems, are mainly induced by maintenance and renovation: Annual material flows for the maintenance of roads and streets (104 million tons) are five time higher than for expansion activities (21 million tons). Due to their length, municipal roads in terms of expansion as well as maintenance induce the majority of material flows. In contrast, motorways are the most material intensive type of road in relation to their length. The railway network, too, induces the better part of its annual material flows for maintenance reasons, as there is nearly no expansion taking place any more. Regarding water ways, the annual material flows induced by maintenance activities could not be reliably calculated due to lack of data.

[12] As far as no detailed information was available, we proceeded the same way for other infrastructures.

Hence, annual material flows have only been calculated based on expansion and upgrading activities[13].

[13] Renovation and expansion of sluices often go hand in hand and are hence hard to distinguish.

3.2.2 Drinking water and wastewater infrastructures

The following reference systems in the field of drinking water and wastewater infrastructures were identified and analysed:

- Water supply infrastructures: barrages, water works, cisterns, pipe network
- Wastewater infrastructures: sewer network, inspection chambers, stormwater overflow, wastewater treatment plants

Partly we could use existing material coefficients from other analyses, which merely had to be modified with regard to German conditions. In addition, extensive research in technical literature, product catalogues and expert interviews in most cases lead to a reliable data basis. However, through the project it became clear that particularly concerning annual material flows data needs to be improved.

Water and wastewater infrastructures tie up around 1.8 billion tons of materials. These consist mainly (99%) of mineral construction materials, due to the pipe beddings. In addition, reinforced concrete plays a major role in the construction of wastewater facilities (475 million tons). In contrast, metals (around 20 million tons, mainly steel and iron) and plastics (< 2 million tons) only play a minor role. Furthermore, they are in most cases built in underground pipe networks, hence poorly accessible.

Annual material flows are still caused by mainly expansion rather than (various) maintenance and renovation activities. However, the calculated annual flows are probably underestimated due to insufficient data, particularly with regard to maintenance and renovation. For renovation activities, material input even lies below material output due to the use of new materials (plastics).

However, against the background of expected massive investment needs[14] for renovation in German water and wastewater infrastructures, annual material flows are expected to grow more significant in the future.

3.2.3 Electricity, gas and district heating networks

The analysed energy infrastructures can be differentiated into energy production and energy distribution. In this part we analysed nine types of energy production[15]. We did not include facilities with low relevance for the German energy supply (e.g. geothermal energy) and those serving mainly household self supply (photovoltaic). In terms of energy distribution systems, data for electricity, gas and district heating grids have been calculated.

[14] Projections range from 65 (Reidenbach et al. 2008) to 150 to 250 billion Euro (Kluge et al. 2003) for municipal replacement expenditures in the field of water and wastewater infrastructures.

[15] These are conventional power plants (black coal, lignite), gas power plants, nuclear power plants as well as water and wind power plants (on-shore) and biogas for renewable energy production. In addition, cogeneration and block heat and power plants have been assessed.

The material stocks of the energy distribution grids (650 million tons) are – mainly due to the sandbeds (585 million tons) – more material intensive than the energy production infrastructure (88 million tons). Besides sand, it is mainly concrete (94 million tons) and steel (37 million tons) which dominate the material stocks of energy infrastructures – similar to water and wastewater infrastructures.

Most conventional power plants have reached the end of their life cycle and need to be renovated or replaced by other energy production facilities – e.g. based on decentralised renewable energy sources. This induces relevant material flows. Our analyses show that decentralised facilities are also linked with high material flows for their construction. On the other hand, the construction phase of renewable energy plants is more than compensated by their utilisation phase, when they induce only little material flows for maintenance activities and consume much less fossil resources than conventional power plants. With an expansion of decentralised energy production facilities and a regional shift of the energy supply (offshore wind energy in Northern Germany), expenditures for power line construction on all voltage-levels will rise. Overall, annual material flows in the area of power grids and renewable energy production are still based on expansion and upgrading rather than renovation and maintenance.

3.2.4 Telecommunication systems

Originally, the project scheduled to analyse the communication infrastructure in terms of fixed and mobile networks. However, fixed network infrastructures could not be analysed, as no data with regard to their expansion was accessible. Company data or data from the Federal Network Agency (BNetzA) could not be used due to business secrets confidentiality obligations.

First, material stock and flows of the mobile networks (GSM, UMTS) were assessed, based on information of network operators and life cycle inventory analyses. As data from different sources is not consistent, we worked with ranges. Other studies that worked on the material dimension of information and communication technologies (e.g. Borderstep-study on behalf of the UBA on material stocks of computing centres) have already shown that the particular ICT-components of the mobile network cannot be divided into separate material categories due to aggregated data. More complex modules can in most cases only be calculated with regard to their weight but not divided into different material categories. Due to the dynamic development of network technologies, LCA-studies are often out-dated after only two years.

An essential finding is, that the material stocks (around 137 thousand tons) as well as the annual material flows (around 17.000 tons) in mobile network infrastructures are comparably irrelevant in comparison to the other three infrastructure systems. If material stocks of fixed network infrastructures were included, the significance of the communication systems for the total infrastructure material stock would be much higher (sandbeds of copper cables). Furthermore, the current ICT-infrastructure offers a high recycling-potential, due to the future expectedly net-conversion into glass fibre cables.

3.3 Recommendations and further research needs

Growing Material Stocks generally lead to increasing material flows for maintenance and renovation. Any expansion activities should hence be generally questioned. Limiting the scope of infrastructure systems is necessary in order to get the constantly growing maintenance costs under control and to restrict the increasing consumption of resources.

With regard to road construction, reviewing the construction standards in co-operation with civil engineers and other experts (e.g. road safety) could lead to enormous saving potentials of mineral construction materials (thinking e.g. of reducing the road width when expanding or renovating). Resource aspects should become part of investment decisions of infrastructures as a matter of principle, combined with preferably resource conserving technologies. When renovating infrastructures at the end of their life-cycle (e.g. bridges and tunnels), resource efficient processes should be preferred.

As far as technically possible and ecotoxicologically harmless recycling material should be used for required maintenance and expansion activities. When dismantling infrastructures, the proportion of recycling should be maximised.

For grid-bound infrastructures it makes sense to pursue a strategy of pro-active land management: That means to use existent area reserves (brownfields, empty building lots, vacant areas), in order to prevent or minimise further expansion of pipes and cables. Furthermore, processes of urban consolidation should aim at preserving a structural density, thus sustaining the efficiency of on-grid infrastructures. Hence, a grid deconstruction should take place from the ends instead of running disperse.

Built on the project's experiences, further research needs focussing on improving the data basis. Many extrapolations are based on assumptions, other infrastructures had to be neglected, as adequate data was not existent or accessible. It would be helpful for future analyses of material stocks and flows (especially regarding their later usability potential), if municipal cadasters would integrate position and type (incl. material) of underground sewers, pipes and cables; or if network operators would inventory and regularly update their material stocks. Furthermore we recommend that the data of the Federal Network Agency, accredited by the net operators, should be made (anonymously) accessible for scientific analyses, in order to make use of them for scientific and statistic purposes.

The annual material flows for renovation and maintenance in particular need to be analysed in more detail. Therefore, it would make sense to co-operate with a utility, in order to analyse the data precisely for their specific service area (rural, urban) and empirically assess the underlying assumptions.

For a potential reduction of maintenance needs, LCAs should be used in order to analyse, how far alternative constructions (e.g. concrete surface replacing asphalt surface in road construction) can reduce maintenance intervals and hence minimise overall environmental impacts.

In order to better forecast future material flows for construction and renovation on the one hand, for solid waste on the other, a dynamisation of the present material flow analysis is required, based on the age structure of the German infrastructure systems. Furthermore it should be analysed, how far infrastructures are being deconstructed at present and if they are being withdrawn from underground.

Based on the provided material inventory, information and management systems for a potential urban mining need to be further developed, in order to foster a sustainable resource management based on an optimised use of secondary raw materials from and into civil engineering.

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