TEXTE
68/2017

Recycling potentials of strategic raw materials (ReStra)

Summary

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Recycling potentials of strategic raw materials (ReStra)

Summary

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Content

1 Background and objective

Many modern products contain so-called strategic raw materials, which are of major importance for their functioning. In addition to their high economic relevance, strategic raw materials are subject to supply risks, which result from geological, technical, structural, geopolitical, socio-economic and environmental settings. Thus, strategic metals shall be captured at the end of the products use phase and recycled.

It has been the objective of the project 'ReStra' to identify mass flows of strategic metals in selected products and product groups and with regard to the disposal situation in the year 2020, to identify potentials to optimise the disposal chains and to elaborate recommendations to mobilise the potentials.

2 Identification of strategic metals

In order to identify strategic metals for the in-depth analysis in ReStra, the concept of criticality matrix, which has been established in recent years for the identification of relative raw material shortages, has been applied. Criticality results in that concept from the dimension of economic relevance and from the dimension of supply risks respectively availability: the higher the supply risk and the higher the economic relevance, the higher the criticality of the examined raw material.

The criteria for the quantification of the supply risk and the economic relevance, which are used in relevant literature have been extended by an environmental perspective. The assessment of the economic relevance has been applied in the project ReStra also with regard to the relevance for next generation technologies with the potential of environmental relief. In addition to the usually applied technical, geopolitical and economic criteria concerning supply risks the criterion of environmental relevance of production of primary raw material has been applied in order to address the environmental relief effect from substitution of primary raw materials by secondary raw materials.

The indicators have been weighted as summarised in the following table.

Table 1: Weighting of criteria concerning economic relevance and supply risk

Field	Criterion	Weighting
Economic relevance	Relevance for next generation technologies with environmental relevance	25 %
	Actual consumption in Germany	25 %
	Expected global demand impulse	25 %
	Possibility for substitution	25 %
Supply risk	Country concentration reserves	15 %
	Country risk production	10 %
	Company risk	10 %
	Main-/by-product	15 %
	Environmental relevance (CED)	30 %
	Recyclability	15 %
	Recycling rate	5 %

Two sensitivity analysis have been performed in order to check robustness of the analysis. As a result, strategic metals located in the zone of high or highest criticality have been identified for in depth analysis in the course of the project 'ReStra' ('ReStra target metals'). Since production of primary gold is often characterised by high environmental relevance due to the use of Cyanide and/or Mercury (Blacksmith, 2011), it has been added to the range of metals for the in depth analysis. The following table lists the outcome of the analysis.

Table 2: Selected ReStra target metals

Element	Comment
Rare Earths	Zone of highest criticality in the basic scenario and in both sensitivity analysis
Palladium	Zone of highest criticality in the basic scenario and in both sensitivity analysis
Gallium	Zone of high criticality in the basic scenario and in one sensitivity analysis
Germanium	Zone of high criticality in the basic scenario and in one sensitivity analysis
Indium	Zone of high criticality in the basic scenario and in one sensitivity analysis
Gold	Zone of high criticality in one sensitivity analysis, environmental relevance (Blacksmith, 2011)
Rhodium	Zone of high criticality in the basic scenario and in both sensitivity analysis, due to its character as platinum group metal, Rhodium will be analysed together with Palladium
Platinum	Zone of high criticality in the basic scenario and in one sensitivity analysis, due to its character as platinum group metal, Rhodium will be analysed together with Palladium

Further refinement has been performed for Rare Earth Elements (REE). This concerns especially light REE, which are regarded as less critical. Cerium and Lanthanum have been chosen as light REE due to their mass relevance. Neodymium has been chosen for those cases where no sufficient data was available for other REE in the same application field (e.g. magnets).

Less critical elements of the heavy REE like Holmium, Thulium and Lutetium have not been further analysed. Concluding, the following REE have been identified as ReStra target metals: Yttrium (Y), Samarium (Sm), Europium (Eu), Gadolinium (Gd), Terbium (Tb), Dysprosium (Dy), Erbium (Er), Cerium (Ce) and Lanthanum (La) and, with limitations, Neodymium (Nd).

3 Identification of material flows

As a second working step the amount of selected end of life products and their content of ReStra target metals have been determined. The major approach was a (prospective) analysis where the waste volumes from selected products in the year 2020 was determined.

In addition availability and appropriateness of published waste analysis have been analysed regarding the identification of relevant waste streams with ReStra target metals. It has been found that number and characters of the published waste analysis were not appropriate as an input for the project.

A multi stage approach has been applied to determine the amount of strategic raw materials which will be available potentially as waste in the year 2020. As a first step relevant product groups have been identified on the basis of the application areas of the selected ReStra target metals. Within the next step, the product groups have been split into relevant products and prioritised according to their mass relevance of the strategic metal content.

As a subsequent step, the amounts of ReStra target metals in the selected products have been determined by applying a calculation model. This describes the amount of such metals which will potentially be available for recycling in the year 2020 in Germany.

The following table shows the product groups which have been identified based on the selection of ReStra target metals. The second and third column show the pre-selected metals and the finally selected metals, which are relevant for the identified products (column 4).

Metals, where the mass relevance have been unclear in the course of the identification of the product groups are shown in brackets.

Table 3: Overview of analysed products and metals

Product group	Pre-selected metals from identification of product groups	Relevant metals after product analysis	Analysed products
Industry catalysts	Ge, Pd, Pt, Rh, (Ce), La	Ge, Pd, Pt, Rh, Ce, La, (Nd, Pr)	FCC-Catalysts, Catalysts of the homogeneous catalysis, refinery catalysts, production of nitric acid, production of hydrocyanic acid, Solid- and fluidised bed catalysts, powder catalysts, polymerisation catalysts
Vehicle catalysts	Pd, Pt, Rh, Ce, La	Pd, Pt, Rh, Ce, La	Vehicle catalysts
Vehicle components	Gd, (Tb), Dy	Gd, Tb, Dy	Passenger cars, light duty vehicles
Metallurgy / alloys	Ce, La	Ce, La	Mix metal
Batteries	Sm, (Ce), La	SE (Ce, La, Nd, Pr)*	NiMH batteries
Application in optical industry	Er, Ce	Ce, La	Polishing agents and -sludge, special glasses
Laser applications	Er	Er	Medical laser (Er-YAg)
Wind energy plant	Gd, (Tb), Dy	Nd, Dy, Tb	DA-PM; IA-PM
Medical devices	(Tb), Dy, Gd, (Y)	Nd, Pr, Dy, Tb, Gd	MRT-appliances, X-ray appliances
Fuel cells	(Pt, Pd, Y)	Y, La	SOFC-BSZ
Optical fibre applications	Ge, Er	Ge, Er	Glass fibre infrastructure in public areas, glass fibres in data processing centres; Erbium-doted fibre amplifiers
Photovoltaic	In, Ga, Ge	In, Ga	CIGS, CdTe, a-Si
LEDs	In, Ga	In, Ga, Ce, Y, Au	LED display panel
Home appliances	(Tb, Dy)	Nd, Dy, Tb	e-bikes, hub dynamo, air conditioner
Ceramics	Y, (Ce)	Y	Grinding ceramics, ceramic heat protection
Absorber material and control sticks in nuclear power plants	In, Gd	In, Gd	Absorber material and control sticks in nuclear power plants

Product group	Pre-selected metals from identification of product groups	Relevant metals after product analysis	Analysed products
High temperature conductors	Y	Y	SQUIDs
Data processing centres	(Pd)	Pt, Pd, Au	Data processing centres

* DIRECTIVE 2010/75/EU OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 24 November 2010 on industrial emissions (inte-grated pollution prevention and control) (Recast)

The following table shows the amounts of ReStra target metals estimated to be available as waste potential in Germany in 2020. The average resp. reference values are shown in relation to the global primary production of the respective metals.

Table 4: Summary of the expected amount of ReStra target metals in the year 2020 in Germany

Element	Mass in 2020 [kg]	Global (primary-) production [kg]	Share of global primary production [%]
Pt	7.052	179.000	3,94
Pd	14.201	200.000	7,101
Rh	3.253	28.000	11,618
Au	473	2.700.000	0,018
In	121	670.000	0,018
Ga	13	273.000	0,005
Ge	2,3	118.000	0,002
Y	65.440	12.300.000	0,532
La	273.619	21.900.000	1,249
Ce	419.213	27.900.000	1,503
Nd	14.677	14.800.000	0,099
Gd	929	2.200.000	0,042
Tb	491	300.000	0,164
Dy	4.517	1.700.000	0,266
Er	14	900.000	0,002
SE, unspecified.	299.152		

Sources: USGS; Bell 2013; Du und Graedel 2011b. Data for Pt, Pd, Au, In, Ga, Ge result from U.S. Geological Survey for 2012, Data for Rh result from Bell (2013) (no year specified), data for Rare Earths result from Da und Graedel (2011) and are related to 2007.

4 Identification of recycling and substitution potentials

In the next working step it has been investigated, which technologies are currently applied for the pre-treatment and the reclamation of ReStra target metals in the selected end of life products and which technologies are available but not yet or rarely applied. The optimisation effects on recycling of the selected metals have been estimated and it has been analysed whether path-dependencies are relevant for the existing disposal chains. The applied screening of technologies also comprised technologies which are implemented on laboratory or pilot level. The subsequent analysis of the disposal chains identified losses of ReStra target metals in the current disposal chains in Germany. Based on this, optimised disposal chains have been designed as far as possible.

The following table summarises the prognosis of mass flows.

Table 5: Comparison of material loss in the current situation and with optimised disposal chains for the year 2020

Product	Current situation	Optimised disposal chain	Difference
PGM-containing industry catalysts	74-80 kg Pt 213-234 kg Pd 34-38 kg Rh	58-62 kg Pt 139-153 kg Pd 34-38 kg Rh	15-18 kg Pt 74-81 kg Pd 0 kg Rh
FCC-catalysts	189-331 t REE	27-48 t REE	162-283 t REE
Vehicle catalysts	756-798 kg Pt 778-793 kg Rh 134.077-134.178 kg REE	427-451 kg Pt 578 – 589 kg Rh 134.077-134.178 REE	329-347 kg Pt 200-204 kg Rh 0 kg REE
Other vehicle components	55.102-55.770 kg REE	Depends on compo-nent	-
Special glasses	860 kg Ce	-	-
Photovoltaic	41-347 kg In 1-62,9 kg Ga	38-300 kg In 0,2-25 kg Ga	3-47 kg In 0,8-38 kg Ga
Heat protection ceramics	709-1.786 kg Y	Unclear	-
Mix metals	106-133 t Ce 46-58 t La	-	-
Batteries	187-303 t SE	112-197 t SE	75-106 t SE
Polishing agents	70-102 t Ce 1,2-5,5 t La	21-73 t Ce 0,4-3,9 t La	29-49 t Ce 0,9-1,5 t La
Laser applications	14 kg Er 8 kg Y	-	-
Wind energy plants	1.308-4.470 kg Nd 119-409 kg Dy 3-11 kg Tb	65-224 kg Nd 6-20 kg Dy 0,2-0,6 kg Tb	1.243-4.246 kg Nd 113-389 kg Dy 2,8-10,4 kg Tb
Medical devices	1.004-4.923 kg REE	134-710 kg REE	870-4.213 kg REE
Fuel cell (SOFC)	50.186 – 78.152 kg Y 30.767 – 47.770 kg La	-	-
Optical fibre applications	4 mg Er 1,2-3,4 kg Ge	-	-
LEDs display panels	0,14 kg Ga 0,11 kg In 0,03 kg Ce 0,96 kg Y 3,14 kg Au	Unclear	-
e-bikes	4.768-6.399 kg Nd 1.192-1.600 kg Dy 238-320 kg Tb	691-928 kg Nd 173-232 kg Dy 35-46 kg Tb	4.077-5.471 kg Nd 1.019-1.368 kg Dy 203-284 kg Tb
Hub dynamos	1.372-1.453 kg Nd	199-208 kg Nd	1.173-1.227 kg Nd
Air conditioner	2.036-2.135 kg Nd 509-534 kg Dy 102-107 kg Tb	585-614 kg Nd 146-154 kg Dy 29-31 kg Tb	1.451-1.521 kg Nd 363-380 kg Dy 73-76 kg Tb
Grinding ceramics	25-2.160 kg Y	-	-
Absorber materials and control sticks in nuclear power plants	70 kg Gd 650 kg In	-	-
High temperature supra conductors	42-140 kg Y	Unclear	-

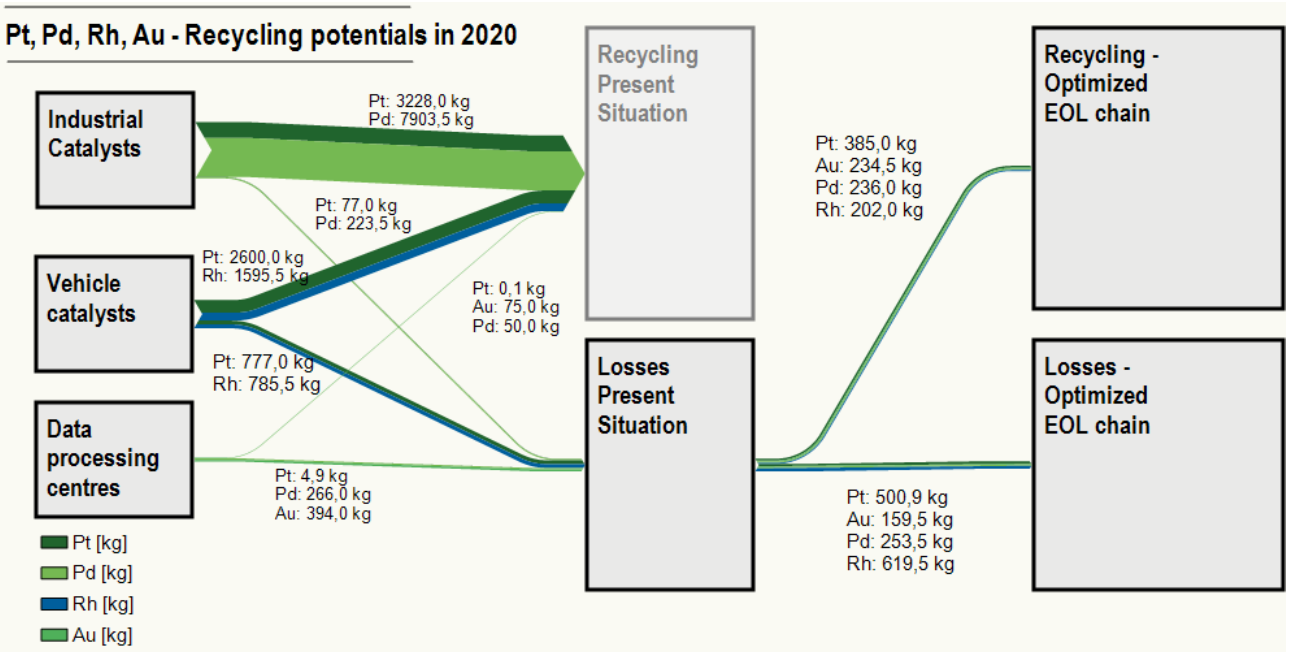
Product	Current situation	Optimised disposal chain	Difference
Data processing centres	350-438 kg Au 4-5,8 kg Pt 239-293 kg Pd	142-177 kg Au 1,7-2 kg Pt 97-118 kg Pd	Average scenario: 75-94 kg Au 1,3-2 kg Pt 75-93 kg Pd low end scenario: 142-177 kg Au 1,7-2 kg Pt 97-118 kg Pd

Optimising potentials have been identified for the following products:

PGM-containing industry catalysts, FCC catalysts, vehicle catalysts, data processing centres, NiMH-batteries, polishing agents, MRTs, photovoltaic modules, wind power plants, e-bikes, hub dynamos, air conditioner.

The following graphs display the current and estimated optimised mass flows. The additional mass flows to the recycling in the optimised disposal chains show the potentials for substituting primary by secondary metals[1].

Figure 1: Mass flows of Pd, Pt, Rh and Au in the current situation and with optimised disposal chains



[1] The arithmetic averages have been calculated in the case of ranges.

Figure 2: Mass flows of Nd, Dy and Tb in the current situation and with optimised disposal chains

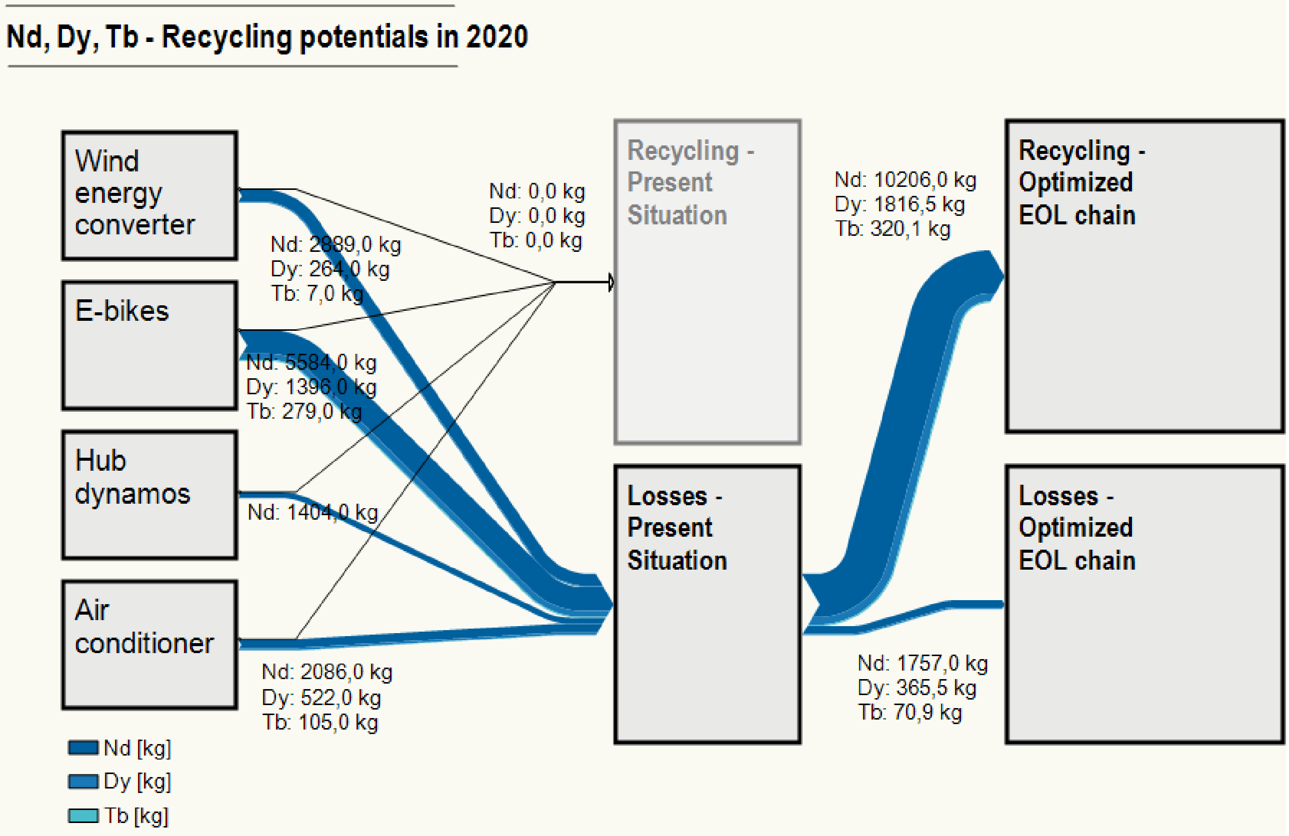


Figure 3: Mass flows of Ce, La and unspecified REE in the current situation and with optimised disposal chains

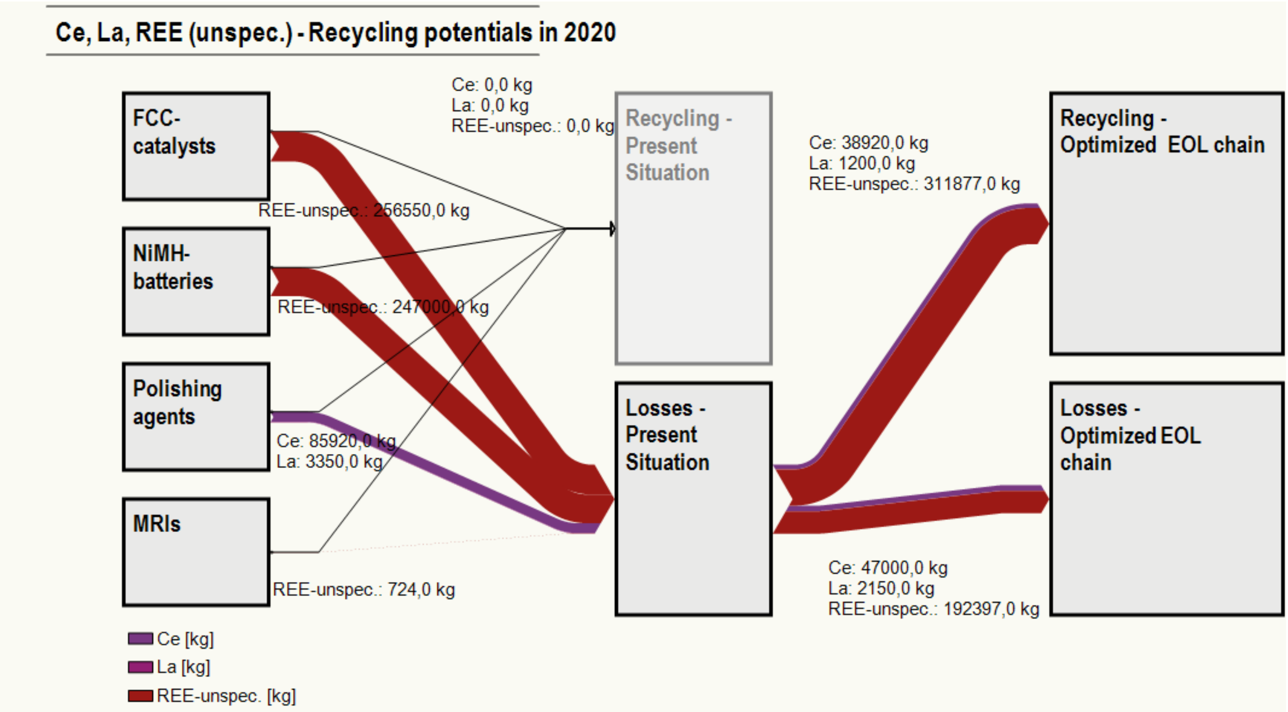
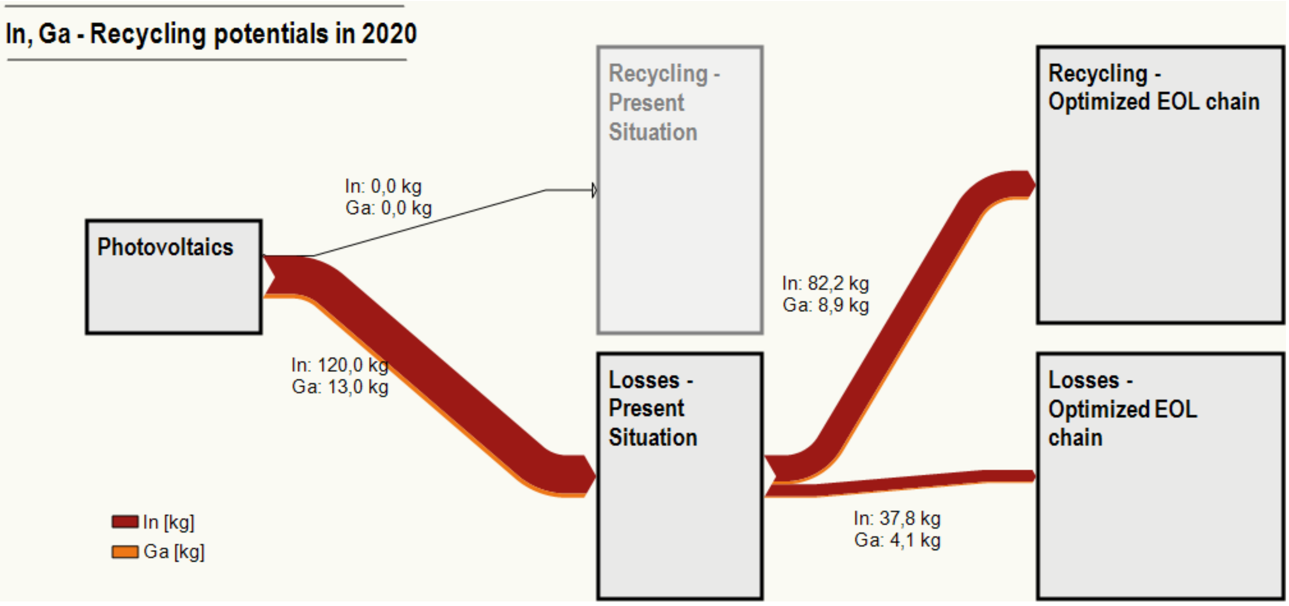


Figure 4: Mass flows of In and Ga in the current situation and with optimised disposal chains



5 Proposals

Based on the analysis in the previous working steps and for cases where optimising potentials have been identified, proposals have been deducted for a resource efficient design of the disposal chains of products.

Basically, economic considerations determine the decisions about the reclamation of strategic metals in the current situation. That should be re-thought with regard to environmental aspects and political resource strategies, especially with regard to the strategic relevance of those metals for a high tech oriented economy. Ensuring partly autarky based on domestic raw material sources and the related robustness against raw material constraints and flexibility for technological developments should be taken into account in that context even where these factors cannot be directly transposed in monetary effects. Recycling becomes even more sensible when avoided environmental costs of primary raw material production are taken into account.

When future framework conditions are developed aspects of prospective supply safety and environmental costs shall be considered in addition to the economic situation which results from the current framework conditions. By considering those aspects, intermediate storage and material pools, where waste fractions are stored until recycling, are sensible even if profitability of reclamation is currently not given in all cases.

Basically, it is seen as sensible also to implement the objectives of resource efficiency and a mass flow oriented circular economy in a revised European Waste List e.g. in the form of a more material oriented structure of the catalogue.

The analysis of the current situation, the restrictions and the path dependencies showed that improved availability of information about the presence of ReStra target metals is an important option for improvement. In order to be efficient and effective the type of information and the way the information is provided must be closely adapted to the waste management practice.

Extended (obligations for) separate collection and implementation of best practice approaches for transport and handling have been identified as important topics to ensure improved recyclability of ReStra target metals.

The example of reclamation of ReStra target metals from automotive components has shown that "design for recycling" might be focussed on "design for dismantling" approaches in order improve the economic situation for the reclamation of ReStra target metals.

Improved circularity can be achieved for the majority of analysed end of life products via extended dismantling and treatment requirements. The requirements shall be made obligatory because an economic self-steering in the right direction currently does not exit.

In addition, development of treatment and reclamation chains shall be promoted (e.g. Yttrium from high temperature ceramics or Gadolinium from x-ray machines).

The analysis also revealed that the highest efficacy of interventions can often be expected when dual approaches are realised. The example of magnets with REE has shown that dual approaches are appropriate to solve the "hen and egg" problem, according to which no reclamation plants are run as long as there is no input material and at the same time no input material is generated as long as no recycling paths are available. Dual approaches support that magnets will be separated in pre-treatment (and ensure that input material is available) and at the same time recycling on industrial level is supported via process related measures.

Efficacy of dual approaches have also been identified in the area of information flows and design for dismantling approaches. By establishing corresponding measures on the product level and for the waste phase it is possible to reduce the risk of ineffective (isolated) measures.

The following table provides an overview of the measures, estimated efforts and expected effects of the measures.

Table 6: Overview of proposed measures

<table>
<tr><th>ReStra-EoL product (ReStra-target metal)</th><th>Measure</th><th>Efforts initialisation</th><th>Efforts performing</th><th>Effect mass</th><th>Effect env. (KEA*share)</th><th>Criticality EU (2014)</th></tr>
<tr><td rowspan="2">Homogeny catalysis (Pd, Pt)</td><td>Optimised information</td><td>Low</td><td>Low</td><td rowspan="4">Low</td><td rowspan="4">High</td><td rowspan="4">High</td></tr>
<tr><td>Separate collection</td><td>High (new law)</td><td>Average</td></tr>
<tr><td rowspan="2">Environmental catalyst (Pt)</td><td>Optimised information</td><td>Low</td><td>Low</td></tr>
<tr><td>Separate collection</td><td>High (new law)</td><td>Average</td></tr>
<tr><td>FCC catalyst (Ce, La)</td><td colspan="6">See raw material related measures below</td></tr>
<tr><td rowspan="2">Vehicle catalyst (Pt, Rh, La, Ce)</td><td>best practice transport</td><td>High (new law)</td><td>Low (low number of affected parties)</td><td>Average to high</td><td>High</td><td>High</td></tr>
<tr><td colspan="6">For Ce and La see raw material related measures below</td></tr>
<tr><td rowspan="5">Vehicle components (Gd, Dy, Tb, Nd)</td><td colspan="6">General measures regarding REE see below</td></tr>
<tr><td>Design for dismantling</td><td rowspan="2">Average in case of voluntary activity, high in case of new laws</td><td rowspan="2">Low to average</td><td rowspan="5">Low</td><td rowspan="5">Low</td><td rowspan="5">High</td></tr>
<tr><td>Optimised information</td></tr>
<tr><td>Dismantling requirements</td><td>High (new law)</td><td>High</td></tr>
<tr><td>Interface to WEEE legisl.</td><td>High (new law)</td><td>Low</td></tr>
<tr><td>Photovoltaic-module (In) (no measures for Ga, Ge)</td><td>Treatment requirement</td><td>High (new law)</td><td>High</td></tr>
<tr><td>Heat protection ceramics (Y)</td><td>Support of development of recycling technologies</td><td>Low</td><td>High (financial)</td><td>Low</td><td>Low</td><td>High</td></tr>
<tr><td>Polishing agent (Ce, La)</td><td colspan="6">For La & Ce see raw material related measures below</td></tr>
<tr><td rowspan="3">NiMH batteries (Ce, La, Sm)</td><td colspan="6">For La & Ce see raw material related measures below</td></tr>
<tr><td>Optimised information</td><td>No (already initialised)</td><td>Low</td><td rowspan="4">Average</td><td rowspan="4">Average</td><td rowspan="4">High</td></tr>
<tr><td>Treatment requirement</td><td>Average (within the development of the treatment ordinance of the ElektroG2))</td><td>Average</td></tr>
<tr><td rowspan="3">MRT (Dy, Tb)</td><td>Optimised information</td><td>No</td><td>Low</td></tr>
<tr><td>Treatment requirement</td><td>Average (within the development of the treatment ordinance of the ElektroG2))</td><td>Average</td></tr>
<tr><td colspan="6">General measures regarding REE see below</td></tr>
<tr><td>X ray</td><td>Development of treatment and reclamation processes</td><td>Low</td><td>High (financial)</td><td>Average</td><td rowspan="2">Low</td><td rowspan="2">High</td></tr>
<tr><td></td><td>Interface ElektroG2</td><td>High (new law)</td><td>Low</td><td>Low</td></tr>
</table>

ReStra-EoL product (ReStra-target metal)	Measure	Efforts initialisation	Efforts performing	Effect mass	Effect env. (KEA*share)	Criticality EU (2014)
Wind power plant (Nd, Dy)	Treatment requirement	Average (within the development of the treatment ordinance of the ElektroG2))				
	General measures regarding REE see below					
E-bike (Nd, Dy, Tb)	Treatment requirement	Average (within the development of the treatment ordinance of the ElektroG2))	Average	High	High	High
	General measures regarding REE see below					
Hub dynamos (Nd, Pr)	Treatment requirement	High (new law)	Average	Low	Average	High
	General measures regarding REE see below					
Air conditioner (Nd, Dy)	Treatment requirement	Average (consideration within the development of the treatment ordinance of the ElektroG2))	Average	Low	Average	High
	General measures regarding REE see below					
Data processing centre	Treatment requirement	Average (within the development of the treatment ordinance of the ElektroG2))	Average	Low	Average	High
	General measures regarding REE see below					
Dual approach for appliances of REE Magnets		Different, mostly average to high		High	High	High
Raw material related measures for CE & La						
Legal framework						Different

Legend: Categories for mass share and environmental: low: up to 10 %, average: >10 % to 30 %, high: >30 %

The analysis of the legal framework conditions has revealed that interfaces between legal areas should be optimised or realised (example: interface between ELV legislation and WEEE legislation regarding treatment of electronic appliances in vehicles). In other areas concrete legal bases to optimise circularity of strategic raw materials are missing. The following table summarises the findings.

Table 7: Overview of proposals for the further development of the legal framework regarding the objective of the project ReStra

Product	ReStra target metal	Legal framework existing	Legal framework to be developed	Separate collection responsibilities existing	Separate collection responsibilities to be developed	Treatment requirements existing	Treatment requirements to be developed	Labelling/ information requirements existing	Labelling/ information requirements to be developed
Industrial catalysts	Ge, Pd, Pt, Rh, (Ce), La		Raw material ordinance		Commercial user		Shipment to reclamation, for La and Ce long term storage if needed		Information obligation producer → user
Vehicle catalysts	Pd, Pt, Rh, Ce, La	ELV ordinance		Last owner (shipment to dismantling company)		Separation and shipment to reclamation,	best practice transport and treatment		-
Automotive components	Gd, Tb, Dy	ELV ordinance		Last owner (shipment to dismantling company)			Separation of REE magnets, shipment to reclamation		Information obligation producer → waste management
Photovoltaic	In, Ga	ElektroG (WEEE law)		Last owner			Separation of REE magnets, shipment to reclamation		Label (PV-module)
Heat protection ceramics	Y		Raw material ordinance		User		Shipment to reclamation		Information obligation producer → user
NiMH batteries	SE (Ce, La, Nd, Pr)*	BattG (Battery law), ElektroG2 (WEEE law)		Last owner (collection system according to BattG), Waste management (separation from end of life product)		Separation from appliance in the framework of the ElektroG2	Shipment to Reclamation	Label	
Polishing agent	Ce, La				User		Shipment to reclamation or long term storage		Information obligation producer → user

Product	ReStra target metal	Legal framework existing	Legal framework to be developed	Separate collection responsibilities existing	Separate collection responsibilities to be developed	Treatment requirements existing	Treatment requirements to be developed	Labelling/ information requirements existing	Labelling/ information requirements to be developed
MRT	Nd, Pr, Dy, Tb, Gd	ElektroG (WEEE law)		Last owner, collection system according to ElektroG			Separation of REE magnets, shipment to reclamation		
X-ray		ElektroG (WEEE law)		Last owner, collection system according to ElektroG			Separation Gd-component, shipment to reclamation		Label (component)
Wind power plant	**Nd, Dy, Tb**		**Raw material ordinance**		**Owner (Destruction company)**		**Separation of REE magnets, shipment to reclamation**		
e-bike		ElektroG (WEEE law)		Last owner, collection system according to ElektroG			Separation of REE magnets, shipment to reclamation		
Hub-dynamo			Raw material ordinance		Waste management		Separation of REE magnets, shipment to reclamation		Label component (hub dynamo)
Air conditioner		ElektroG (WEEE law)		Last owner, collection system according to ElektroG			Separation of REE magnets, shipment to reclamation		Label component (compressor)
Data processing centre	Pt, Pd, Au	ElektroG (WEEE law)		Last owner, collection system according to ElektroG		Partly	Separation of REE magnets, shipment to reclamation		

In addition the instrument of “Best Available Techniques” in the framework of the Industrial Emission Directive[2] is seen as an option to improve recycling of strategic raw materials.

[2] Directive 2010/75/EU

6 References

Blacksmith Institute (2011): The World's Worst Toxic Pollution Problems. Report 2011. http://www.worst-polluted.org/2011-report.html, last visited 29.5.2012

BMWi 2010: BMWi: Rohstoffstrategie der Bundesregierung - Sicherung einer nachhaltigen Rohstoffversorgung Deutschlands mit nicht-energetischen mineralischen Rohstoffen, Berlin, 2010, http://www.bmwi.de/Dateien/BMWi/PDF/rohstoffstrategie-der-bundesregierung, last visited 02.05.2015

Bringezu 2011: Bringezu, S., et al.: Metallische Rohstoffe, weltweite Wiedergewinnung von PGM und Materialien für Infrastrukturen - Abschlussbericht zu AP2 des Projektes MaRess, Wuppertal, 2011, http://ressourcen.wupperinst.org/downloads/MaRess_AP2_8_AbschlussBer.pdf, last visited 30.03.2015

EU 2014: European Commission: COMMUNICATION FROM THE COMMISSION TO THE EUROPEAN PARLIAMENT, THE COUNCIL, THE EU ROPEAN ECONOMIC AND SOCIAL COMMITTEE AND THE COMMITTEE OF THE REGIONS On the review of the list of critical raw materials for the EU and the implementation of the Raw Materials Initiative, Brussels, 2014, and REPORT ON CRITICAL RAW MATERIALS FOR THE EU Report of the Ad hoc Working Group on defining critical raw materials, Brussels, 2014, http://ec.europa.eu/enterprise/policies/raw-materials/files/docs/crm-report-on-critical-raw-materials_en.pdf, last visited 02.05.2015

FEM 2015: pers.com. Dr. Völker FEM, 11.5.2015

Gößling-Reisemann, S. (2012): Persönliche Mitteilung vom 7.6.2012.

JRC 2015: European Commission's Joint Research Centre (JRC): Best Environmental Management Practice, Sectoral reference document for the Car Manufacturing sector, http://susproc.jrc.ec.europa.eu/activities/emas/car.html, last visited 30.03.2015

Kennedy 2014: Kennedy, P.: Aufbereitung und Verarbeitung von Seltenenerdmetallen, in: Kausch, P. et al. (Hrsg.), Strategische Rohstoffe — Risikovorsorge, DOI 10.1007/978-3-642-39704-2_14, © Springer-Verlag Berlin Heidelberg 2014

Mitsubishi 2015: Mitsubishi Electric: Newly Developed Automatic Dismantling Equipment Removes and Recovers Rare Earth Magnets in Just 30 Seconds, http://www.mitsubishielectric.com/company/environment/ecotopics/rareearth/how/index.html, last visited 30.03.2015

MORE 2014: Bast, U, et.al.: Recycling von Komponenten und strategischen Metallen aus elektrischen Fahrantrieben, 2015

Progress 2012: BMUB (HG): Deutsches Ressourceneffizienz-programm (ProgRess), Stand Kabinettsbeschluss: 29. Februar 2012, Berlin, http://www.bmub.bund.de/service/publikationen/downloads/details/artikel/deutsches-ressourceneffizienzprogramm-progress/, last visited 30.03.2015

Sander 2010: Sander, K., Schilling, S.: Optimierung der Steuerung und Kontrolle grenzüberschreitender Stoffströme bei Elektroaltgeräten/Elektroschrott, UBA FKZ 3708 93 300, Dessau, 2010, http://www.umweltbundesamt.de/publikationen/optimierung-steuerung-kontrolle, last visited 02.05.2015

Schöne 2015: pers. com. Dr. F. Schöne, Duesmann und Hensel Recycling GmbH, März 2015

Stiftung ear 2015: Bestimmung der jeweils relevanten Faktoren für die Berechnung des Garantiebetrages; https://www.stiftung-ear.de/nc/hersteller/produktbereiche-regelsetzung-und-regeln/produktuebergreifende-arbeitsgruppe-pbue/regelsetzung-garantiehoehe/, last visited 30.03.2015

USGS 2015: Mineral Commodity Summaries – Indium 2015, http://minerals.usgs.gov/minerals/pubs/commodity/indium/ last visited 30.03.2015

USGS 2015a: Mineral Commodity Summaries – Gallium 2015, http://minerals.usgs.gov/minerals/pubs/commodity/gallium/ last visited 30.03.2015

Buchert 2013: Buchert, M., Manhart, A., Sutter, J.: Untersuchung zu Seltenen Erden: Permanentmagnete im industriellen Einsatz in Baden-Württemberg, Feiburg, 2013 http://www.oeko.de/oekodoc/2053/2014-630-de.pdf, last visited 30.03.2015