CHALMERS
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Extended supplementary material

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SUMMARY
This report provides extended supplementary material to the article "Are Scarce Metals in Cars Functionally Recycled?", on data collection and assumptions used for characterising and estimating the magnitude of scarce metals in end-of-life vehicles (ELVs) entering the Swedish ELV system, and for modelling this system using Material Flow Analysis (MFA) methodology.

Keywords: Supporting information, Scarce metals, Recycling, Functional recycling, Cars, Vehicles, End-of-life-vehicles, Material flow analysis

CONTENTS

1. Applications and magnitudes of scarce metals entering Swedish ELV recycling

The main applications of individual scarce metals, their reported content and number of applications in cars used for modelling, referred to as model cars, are presented in Table 1. Additionally, estimated ranges of annual scarce metal input to the Swedish ELV recycling system are presented. Data on model cars are based on work by Cullbrand and Magnusson,[1] with minor additions made to main applications using additional sources.[2-4] Ranges are the result of multiplying metal content of individual model cars with 185 617; the number of ELVs reported for Sweden in 2012.

The model cars are three recently produced diesel-powered passenger cars manufactured by the Volvo Car Corporation for the Swedish market.[1] Car #1 is a recently produced mid-sized car with an approximate weight of 1500-1700 Kg, automatic gear box and front wheel drive (FWD). Its equipment is standard for its model type, and includes a sound system and climate unit, one 5” LCD panel, six speakers, seat heaters, electrically adjustable outer rear-view mirrors, air bags, ABS brakes and an electronic collision prevention system.

Car #2 is also recently produced, but a few years older in design. It has an approximate weight of 1800-2200 Kg, automatic gearbox and FWD. It is somewhat more equipped than Car#1, e.g. with electrically adjustable driver seats and a sound system with eight speakers.

Car #3 is similar to Car #1 with an approximate weight of 1500-1800 Kg, equipped with automatic gear box and all-wheel drive. It has the highest equipment level available in a modern Volvo, which, in addition to standard equipment, includes parking and rain sensors, 10 speakers with surround sound, electrically adjustable driver and passenger seats, sport exterior and wheels, one 7” front LCD display and two back seat LCD’s, a premium sound system, a DVD player, parking guidance camera and a blind spot information system.

The data set for these model cars originates from the International Material Data System (IMDS),[1] to which auto industry suppliers provide component content data. It includes 19 metals at component level and six metals at vehicle level.

Table 1. Scarce metal contents of model cars used for estimating annual scarce metal input to Swedish ELV recycling. Main applications and data on individual model cars provided by Cullbrand and Magnusson,[1] unless otherwise indicated.

Metal	Main applications	Car #1		Car #2		Car #3		Annual metal input to Swedish ELV recycling [tonnes/yr]
		Content [g/car][1]	Number of reported applications[1]	Content [g/car][1]	Number of reported applications[1]	Content [g/car][1]	Number of reported applications[1]	
Mn	Steel alloys, Al alloys, micro condensors[1, 3]	6e3	n.a.	7e3	n.a.	7e3	n.a.	1.1e3 – 1.3e3
Mg	Mg alloys, Al alloys[1, 3]	9e3	n.a.	3e3	n.a.	9e3	n.a.	560 - 1.7e3
Mo	Steel alloys[1, 3]	580	n.a.	500	n.a.	630	n.a.	94 – 120
Nb	Steel alloys, Nickel alloys[1]	63	336	90	426	81	380	12 – 17
Co	EEE, Ferrous alloys[1, 2, 4]	28	n.a.	38	n.a.	39	n.a.	5.2 – 7.2
Nd	Magnets, PCBs[1]	43	28	28	26	210	70	5.1 – 38
Ag	PCBs[1]	14	n.a.	21	n.a.	20	n.a.	2.6 – 3.9
Ta	PCBs[1]	5.8	72	7.0	60	11	119	1.1 – 2.0
Pt	Catalaytic converter, Particulate filter[1]	5.5	74	7.9	69	8.1	106	1.0 – 1.5
Au	PCBs[1]	6	n.a.	5	n.a.	7	n.a.	0.93 – 1.3
Li	Battery (car key), Lubricants[1]	5.2	1000	1.4	873	10	1 105	0.25 – 1.9

Pd	Catalaytic converter, Particulate filter, PCBs[1]	1.2	58	1.2	89	1.5	227	0.22 – 0.29
Dy	Magnets[1]	0.83	7	2.0	9	27	21	0.15 – 5.0
Pr	Magnets[1]	0.81	4	2.5	6	5.6	13	0.15 – 1.0
Sm	Magnets[1]	0.43	2	0.73	2	0.43	2	0.080 – 0.14
Ce	Particulate filter[1]	0.29	5	13	4	12	7	0.054 – 2.4
Ga	Magnets, LED[1]	0.08	29	0.42	21	0.56	47	0.015 – 0.1
In	PCBs[1]	0.15	107	0.38	82	0.05	174	9.3e-3 – 0.071
Y	Ceramics in electronics, LED, Nickel alloys[1, 2]	0.22	12	0.02	15	0.23	23	3.7e-3 – 0.043
La	Particulate filter, Magnets[1]	5.2	3	0	0	0.07	5	0 – 0.97
Er	LCD[1]	0.18	1	0	0	0.18	1	0 – 0.033
Yb	Ceramics in electronics[1]	0.16	1	0	0	0.16	1	0 – 0.030
Tb	Magnets[1]	<0.01	1	0	0	<0.01	1	0 – 1.9e-3
Gd	Al alloys, LED[1]	<0.01	11	<0.01	8	<0.01	11	< 1.9e-3
Rh	Electronic wiring, PCBs[1]	<0.01	2	<0.01	2	<0.01	2	< 1.9e-3

2. Processes and material flows in Swedish ELV recycling

The constructed model of the Swedish ELV recycling system covers six process groups: (1) Dismantling, (2) processing of dismantled components and materials, (3) shredding operations, (4) post-shredding operations, (5) energy recovery and slag treatment, and (6) metal refining. Modelling is based on officially reported ELV statistics of 2012, literature sources and assumptions (Sections 2.1-2.6), and is done using the software STAN, provided by the Research Centre of Waste and Resource Management (IWR) at Vienna University of Technology.[5]

2.1. Dismantling

The modelling of dismantling is mainly rooted in reported ELV statistics of 2012. The statistics include data, provided by the Swedish road administration, on the mass of annually reported ELVs, which in turn is based on the curb weight of each vehicle. Additionally, statistics include the mass of generated waste by dismantling, shredding and post-shredding activities. This data is based on material reports electronically submitted by each individual dismantling and shredding actor each year. Reported mass is divided into *reuse* (spare parts), and materials going to *recycling*, incineration for *energy recovery*, or *disposal* through landfilling. Allocation is based on how different waste streams generated by dismantling are subsequently treated, i.e. the receiving party of any waste stream from dismantling is required to electronically report the shares of the stream going to treatment types corresponding to each division. The ELV directive requires that the quantity of any exported ELVs is reported; for 2012, the reported quantity was zero. Data collection is organised by BIL Sweden and delivered to the Swedish EPA, which in turn reports all data to European authorities. See Table 2 for statistics of Sweden. Note that there is a discrepancy of 1 tonne between the mass of incoming ELVs and reported mass generated by dismantling, shredding and post-shredding. It is assumed that this is due to incorrect rounding of reported quantities.

Table 2. Reported data to European authorities by the Swedish EPA on recycled, incinerated and landfilled materials from dismantling, shredding and post-shredding operations.[6]

Reporting category	Quantity [tonnes]	Share of input [%]
Incoming ELVs	231 218	100
Dismantling		
Reuse	46 701	20
Recycling	8 022	3
Energy Recovery	2 326	1
Disposal	152	< 1
Sum, dismantling	57 201	25
Shredding and post-shredding		
Recycling	141 736	61
Disposal	21 626	9
Energy Recovery	10 654	5
Sum, shredding and post-shredding	174 016	75
Exported ELVs	0	0

The sum of recycling, energy recovery, and disposal filed under dismantling (Table 2), represents the amount of dismantled components and materials, excluding spare parts (reported as reuse) and dismantled ELVs going to shredding. According to Swedish reporting standards, reuse is not reported, but calculated as the difference between incoming mass and reported quantities, i.e. any not reported mass is assumed as reuse. Note that the reporting system was changed in 2012, to include eight new component and material categories for facilitating separate reporting of reuse and recycling which was previously aggregated. Reported reuse of 2012 represents roughly 80% of the total dismantled mass (Table 2). However, it is expected that reuse mainly originates from a limited number of newer ELVs provided by insurance companies, as they in contrast to older ELVs hold spare parts with market demand. Furthermore, dismantling of aluminium for material recycling is expected to represent a significant share of total dismantled mass. This indicates that reporting routines of actors in 2012 were not yet fully in line with the modified reporting standards, and that some of the reported reuse in reality is materials dismantled for recycling.

The magnitude of actual reuse is estimated through personal communication with three Swedish dismantlers,[7-9] providing sales data or personal estimates on type and weight of the most frequently sold spare parts. It is assumed that one of each of those spare parts is removed from an average insurance car, resulting in a total amount of roughly 0.2 tonnes per car. Roughly 50 000 ELVs are insurance cars,[10] resulting in a total annual reuse of 10 000 tonnes, i.e. only 20% of reported reuse of 2012. In correspondence with dismantlers,[7-9] this estimated value is somewhat low, while the reported value is high. Therefore, the average value between reported and estimated reuse, 28 000 tonnes, is used for modelling. Remaining 18 701 tonnes are transferred to the new reporting categories of 2012.

The basis for transferring mass is data in material reports that underpin Swedish statistics.[11] The reports provide the annual quantity of generated materials per treated ELV for three groups of dismantlers with differing organisational affiliations. We calculate one set of transfer coefficients per group, and for each, scale up the annually generated outputs using the number of reported ELVs by each group. The approach is the same used by BIL Sweden and Swedish EPA to calculate official statistics.[12] Subsequently, the distribution of mass among new reporting categories is used to allocate transferred reuse. Some outputs are excluded to simplify modelling (Table 3). With the exception of copper components, excluded outputs are not expected to hold significant amounts of scarce metals. Copper components are typically discarded car generators,[13] which likely contain magnets in use of scarce metals.[4, 14] The mass of a generator is estimated to 7 Kg.[7-9] Assuming one generator of such mass per ELV, the estimated dismantled quantity (Table 3), constitute 17% of annual flows, and is hence not the main pathway for generators, which instead is to follow dismantled ELVs to shredding. Final estimated outputs and corresponding material transfer coefficients for dismantling are shown in Table 3, where new reporting categories of 2012 and categories for which dismantling is regulated due to ELV regulation are marked accordingly.

Table 3. Material transfer coefficients used for modelling Dismantling.

Process types/process outputs	Estimated quantity [tonnes]	Transfer coefficients used for modelling [%]
Dismantled ELVs for shredding	174 016	75.3
Outputs to recycling, energy recovery or disposal		
Engines and gear boxes (new)	8 197	3.6
Iron and steel (new)	8 146	3.6
Aluminium components (new)	3 736	1.7
Tires and rims (regulated)	3 255	1.4
Lead batteries (regulated)	1 692	0.8
Catalytic converters (regulated, new)	1 454	0.6
Fluids (regulated)	1 174	0.5
Window shields (regulated)	825	0.4
Cables (new)	*(375) excluded*	-
Copper components (new)	*(220) excluded*	-
Oil filters (regulated)	*(52) excluded*	-
Lead weights (regulated)	*(41) excluded*	-
Other metal components (new)	*(19) excluded*	-
Plastics	*(12) excluded*	-
Hazardous components (regulated)	*(3) excluded*	-
Magnesium components (new)	*(0) excluded*	-
Sum, outputs to recycling, energy recovery or disposal	29 201	-
Reuse (spare parts)	28 000	12.1

2.2. Processing of dismantled components and materials

Details on the type of processing used by receiving parties of wastes stream from dismantling is not publically declared and needs to complement by additional data. An exception is reporting year 2008, for which some data is publically declared by Swedish EPA.[15] Accordingly, energy recovery reported under dismantling originates from incinerated tires and fluids, and disposal from treatment of lead batteries. This is assumed to be valid also for 2012 and the model.

Processing of material flows of regulated components and materials, with the exception of catalytic converters, are not modelled in detail as they are not expected to contain scarce metals. The mass of these flows is estimated to 6 946 tonnes (Table 3). Aided by aforementioned assumptions related to tires, fluids and batteries, transfer coefficients can be calculated, see Table 4.

Table 4. Material transfer coefficients used for modelling Processing of regulated components (excluding catalytic converters).

Process types/process outputs	Quantity [tonnes]	Transfer coefficients used for modelling [%]	Source
Processing of regulated components (excluding catalytic converters)			
Recycled materials	4 468	64.3	Calculated
Output from energy recovery (incinerated tires and fluids)	2 326	33.5	Table 2
Slags (landfilled remains from battery treatment)	152	2.2	Table 2
Sum, processing of regulated components (excluding catalytic converters)	6 946	-	Table 3

Catalytic converters are collected and treated at one Swedish facility.[16] Treatment consists of decanning and smelting the interior at an EAF plant, followed by PGM separation at dedicated facilities.[16] Decanning produces steel going to steel production.[17] Analogous to shredding operations (Section 2.3), 35% of steel output is assumed to be exported. EAF smelting outputs an iron collector holding PGMs, and slags used for construction purposes.[16] The collector is exported and treated by means of PGM refining where individual PGMs are isolated and slags are produced, typically involving numerous refining processes.[16, 18] Catalytic converters can weigh up to 7 Kg.[17] Typically 1 Kg per converter is used in EAF smelting, of which 2.5% enter metal output where essentially all incoming PGMs (more than 99%) are contained at individual concentrations of 1-4%.[16] Typical commercial PGM refining yields roughly 95% of PGM input.[19] Aforementioned data serves as basis for modelling. The concentration of Pd and Pt in the collector is assumed at 5%, and PGM refining yield at 95%. Additionally, as PGMs are the main output of PGM refining, remaining mass is modelled as slags. See Table 5 for transfer coefficients.

It can be noted that the estimated input of Pd and Pt, 1.2-1.5 g Pd/car and 5.5-8.1 g Pt/car (Table 1), is significantly higher than the sum used for modelling metal collector content, 1.25 g/catalytic converter. The data used for modelling PGM refining is based on industry estimates for processing currently discarded catalytic converters, while estimated car content represents the total content in three recently produced diesel-powered cars. The level of PGM in catalytic converters has increased over time, varies between specific brands and designs, and is higher in diesel than petrol applications.[20] Also, Pt, and in particular Pd, occur in other car applications.

Table 5. Material transfer coefficients used for modelling Domestic converter smelting and foreign PGM refining.

Process types/process inputs and outputs	Quantity [g]	Transfer coefficients used for modelling [%]
Decanning		
Domestic steel from decanning	3 900	55.7
Exported steel from decanning	2 100	30.0
Input to EAF	1 000	-
Sum, decanning	7 000	-
EAF smelting		
EAF slag	975	13.9
Metal collector	25	-
Other materials	23.75	-
Pd and Pt content	1.25	-
Sum, EAF smelting	1 000	-
PGM refining		
PGM refining slags	23.81	0.38
Pd and Pt	1.19	0.02
Sum, PGM refining	25	-

Dismantled engines, gear boxes, aluminium plating and rims are typically recovered for aluminium content.[21] These components are assumed to represent the entire amount of unregulated components and materials reported under *engines and gear boxes*, and *aluminium components* (Table 3), and are modelled as going to shredding and aluminium production, which is typical for such components.[22] Analogous to post-shredding operations (Section 2.4), 50% of aluminium output is assumed to be exported. Iron and steel (Table 3), are typically generated as a consequence of dismantling desired components or materials, are commonly shredded and sent to steel production,[13, 22] which is the modelled case. As for other shredding operations (Section 2.3), 35% of steel and iron is assumed to be exported. The collection of the steel and aluminium occurs separately, shredding is therefore assumed to also occur separately, resulting in dedicated outputs, see Table 6 for transfer coefficients.

Table 6. Material transfer coefficients used for modelling Shredding of dismantled components/materials.

Process types/process outputs	Quantity [tonnes]	Transfer coefficients used for modelling [%]
Shredding of dismantled components/materials		
Domestic aluminium	5 966.5	29.7
Exported aluminium	5 966.5	29.7
Domestic iron and steel	5 294.9	26.4
Exported iron and steel	2 851.1	14.2
Sum, shredding of dismantled components/materials	20 079	-

2.3. Shredding operations

Shredding occurs at seven facilities across Sweden. The market is dominated by one Swedish actor, operating four facilities, shredding 70% of dismantled ELVs.[23] To meet ELV reporting requirements, shredding facilities perform annual shredding trials on ELVs and report the share of material that is recycled, incinerated for energy recovery, or disposed of through landfilling.

Average results from shredding trials on ELVs of model years 1999-2002, 2004 and 2006 at the largest Swedish shredding facility are used as basis for modelling Swedish shredding operations. Results show an average production of 64.7% ferrous fraction, 9.5% NF fraction and 25.8% light fraction.[24] Of the light fraction share, it is assumed based on Edeblom et al.,[24] and Forton et al.,[25] that light fraction processing outputs 1.5 percentages as an aluminium rich fraction. Furthermore, based on Jensen et al.,[23] it is assumed that 17 percentages are output as shredder fluff, resulting in 7.3 percentages of fines.

Statistics on domestic use of ferrous fractions from shredding is not nationally collected and therefore not publically available,[26] but exports of Swedish shredder ferrous fractions amount to 30-40% of the annual production, based on estimates by the Swedish procurement association for the Swedish steel industry, JBF.[27] The average of 35% is assumed. Consequently, 22.6% of shredder input is assumed to be exported ferrous fraction, leaving 42.1% as domestic. Similar to post-shredding operations (Section 2.4), 50% of aluminium from light fraction processing is assumed to be exported.

Shredder fluff is incinerated at municipal solid waste incineration (MSWI) facilities or landfilled on dispensation from the Swedish ban on landfilling of organic and combustible waste.[23] It is assumed that quantities reported under disposal and energy recovery from shredding and post-shredding (Table 2), constitute both shredder fluff and residues from heavy media separation (Section 2.4). Based on the 174 016 tonnes reported as shredder input and estimated shredder efficiencies, roughly 30 000 tonnes of fluff is produced. As disposal is reported at 21 626 tonnes, even if the full amount would constitute fluff, 8 374 tonnes of fluff would have to be incinerated. If instead the full 10 654 tonnes reported as energy recovery would constitute fluff, 19 346 tonnes of fluff would be landfilled. Consequently, the share of fluff being incinerated lies in the range 28-36%. The average of 32% is assumed. Assumptions give that 5.4 percentages of the 17% of input assumed as shredder fluff is modelled as incinerated, leaving

11.6 percentages to be landfilled. See Table 7 for an overview of all material transfer coefficients used for modelling ELV shredding operations.

Table 7. Material transfer coefficients used for modelling Hammer milling and air separation, Magnetic separation, and Light fraction processing

Process types/process outputs	Share of input to ELV shredding [%]	Transfer coefficients used for modelling [%]
Hammer milling and air separation		
Heavy fraction	74.2	74.2
Light fraction	25.8	25.8
Sum, hammer milling and air separation	100	-
Magnetic separation		
Domestic ferrous fraction	42.1	56.7
Exported ferrous fraction	22.6	30.5
Non-ferrous fraction	9.5	12.8
Sum, magnetic separation	74.2	-
Light fraction processing		
Shredder fluff, landfilled	11.6	45.0
Fines	7.3	28.3
Shredder fluff, incinerated	5.4	20.9
Domestic aluminium fraction	0.75	2.9
Exported aluminium fraction	0.75	2.9
Sum, light fraction processing	25.8	-

2.4. Post-shredding operations

Post-shredding capabilities for treating NF fractions in Sweden range from eddy current separation of primarily aluminium to utilising heavy media separation.[28] The largest Swedish actor deals with an estimated 70% of Swedish ELVs,[23] and ships NF fractions from shredding operations to a heavy media separation plant,[28, 29] which is the technology used to model Swedish national capabilities.

Detailed flow studies of heavy media facilities for ELV treatment are rarely found in literature, as most is concerned with the production and management of shredder fluff. The only, to our knowledge, detailed descriptions are provided by Hoberg et al., and Wolf.[30, 31] Wolf,[31] studied a German ELV heavy media facility where NF input contained 45% metals. Based on descriptions of Swedish ELV heavy media operations provided by Rosdahl and Åkvist,[29, 32] the technical setup studied by Wolf,[31] is estimated as equivalent to Swedish conditions of 2012. However, according to Rosdahl and Åkvist,[29, 32] Swedish NF fractions typically contain 50% metals. The distribution of metal outputs of similar kind, identified by Wolf,[31] are categorised and used for modelling Swedish metal output. Other identified outputs are categorised as residues that be may landfilled, recycled as construction materials or incinerated for energy recovery. See Table 8 for categorisation. To simplify modelling, *copper wires* are categorised as mixed fraction, as it typically contains copper.[24] According to Rosdahl,[32] *magnesium* is typically output together with aluminium, and *metals from fines* are typically aluminium, both outputs are hence categorised accordingly.

Table 8. Typical outputs of heavy media separation of ELV materials, as identified by Wolf.[31]

Process outputs	Share of output, by Wolf [31] [%]	Categorisation
Rubber	28	Residues
Aluminium fractions	19.6	Aluminium fractions
Residues from fines fraction	19.3	Residues
Mixed fraction	16.3	Mixed fraction
Residues from washing	5	Residues
Metals from fines fraction	3.2	Aluminium fractions
Stones	2.7	Residues
Stainless steel	2.3	Ferrous fractions
Various ferrous metals	1.8	Ferrous fractions
Various ferrous metals with aluminium content	1.2	Ferrous fractions
Copper wires	0.5	Mixed fraction
Magnesium	0.1	Aluminium fractions

Trade statistics on aluminium from shredding and post-shredding is not centrally complied,[33] but roughly half of aluminium outputs from Swedish heavy media is used by the domestic aluminium industry according to Åkvist,[29] 50% is assumed. The mixed fraction output is exported outside Europe for hand sorting and metal refining due to being too heterogeneous for economically viable domestic processing.[24, 29] Ferrous output is assumed to be exported to foreign steel production, as typically only aluminium fractions from heavy media separation have a domestic market.[29] The distribution of residues is constrained by energy recovery, and disposal reported under shredding and post-shredding (Table 2), and estimated distribution of shredder fluff (Section 2.3). In order for mass balance to hold for reported quantities, 1 519 tonnes of residues must be landfilled and 1 315 must be incinerated, corresponding to 18% and 16% of residues. Remaining mass is assumed to be recycled as various construction materials. See Table 9 for final transfer coefficients used for modelling.

Table 9. Material transfer coefficients used for modelling Heavy media separation.

Process outputs	Transfer coefficients used for modelling [%]
Residues, recycled	33
Exported mixed fractions	19
Domestic aluminium fractions	12.5
Exported aluminium fractions	12.5
Residues, landfilled	9
Residues, incinerated	8
Exported ferrous fractions	6

2.5. Energy recovery and slag treatment

Waste incineration facilities are required to annually report amount of incinerated fuel and connected outputs, e.g. slags and extracted ferrous and non-ferrous metals. The reported data serves as basis for estimating how shredder fluff and residues from heavy media separation is distributed when incinerated.

The reported data is primarily the result of incineration of household and industrial waste other than ELV material flows. Assuming incinerated residues from heavy media separation to be rubber, as that is a major residue constituent (Table 8), known to be utilised as fuel,[29, 32] results from studies of ash, ferrous and non-ferrous content of incinerated typical Swedish MSWI fuel, shredder fluff and rubber are compared. Subsequently, assuming that MSWI process efficiencies for each content type is the same regardless of fuel, reported data on outputs may be scaled accordingly. The main element of ferrous and non-ferrous output is iron and aluminium respectively, which are used as indicators for ferrous and non-ferrous fuels content.

The share of shredder fluff and rubber in the model fuel is set to 88% and 12% respectively in accordance with modelled quantities being produced (Sections 2.3-2.4). See Table 10 for fuel comparisons and resulting scaling factors applicable to reported data. Furthermore, see Table 11 and Table 12 for application of scaling factors and resulting transfer coefficients for energy recovery and slag treatment respectively. The ratio between MSWI bottom ash and evaporated water of reported statistics is assumed to hold after scaling (Table 12).

Note that MSWI facilities likely transfer the majority of iron and aluminium input to slags,[34-36] while slag treatment operations may partially recover these elements but also transfers them to remaining bottom ash.[37] Typically, some of the aluminium rich non-ferrous output is used by the domestic aluminium industry,[38] as for post-shredding operations (Section 2.4), 50% is assumed. Produced ferrous fractions are typically exported as they do not meet quality demands of Swedish steel plants,[39] which is the assumed case for modelling.

Table 10. Fuel compositions of MSWI fuel, shredder fluff, rubber and model fuel, as well as resulting scaling factor used for modifying reported data.

Fuel composition	MSWI fuel (A) [%][40, 41]	Shredder fluff [%][42-49]	Rubber [%][50]	Model fuel (88% shredder fluff, 12% rubber) (B) [%]	Scaling factor, B/A
Ash content	14	32	9.2	29	2.1
Ash composition	MSWI fuel (A) [% of ash]	Shredder fluff [% of ash]	Rubber [% of ash]	Model fuel (B) [% of ash]	Scaling factor, B/A
Ferrous	2.7	16.4	0	14.4	5.3
Non-ferrous	5.3	2.9	0	2.6	0.5

Table 11. Application of scaling factors and resulting transfer coefficients used for modelling Energy recovery.

Process types/process inputs and outputs	Reported share for MSWI fuel, 2012 [%][51]	Scaling factor	Transfer coefficients used for modelling [%]
Energy recovery			
Incinerated materials to flue gas (calculated)	80.9	-	59.8
Slags	14.6	2.1	30.7
Flue gas residues (assumed exported)	4.5	2.1	9.5
Sum, energy recovery	100	-	-

Table 12. Application of scaling factors and resulting transfer coefficients used for modelling Slag treatment.

Process types/process inputs and outputs	Reported share for MSWI fuel, 2012 [%][51]	Scaling factor	Transfer coefficients used for modelling [%]
Slag treatment			
MSWI bottom ash	58.9	-	44.2
Ferrous fraction (assumed exported)	5.5	5.3	29.2
Evaporated water (calculated)	34.9	-	26.2
Non-ferrous fraction (domestic use assumed at 50%)	0.7	0.5	0.4
Sum, slag treatment	100	-	-

2.6. Metal refining

Transfer coefficients for metal refining processes are based on common commercial technologies. Steel production is based on typical European EAF production with scrap input,[52] see Table 13. Aluminium production is based on typical rotary furnace technology,[53] see Table 14.

Table 13. Material transfer coefficients used for modelling steel production.

Process outputs	Transfer coefficient [%]
Crude steel	88
Slags	11
Dusts/Sludge	1

Table 14. Material transfer coefficients used for modelling aluminium production.

Process outputs	Transfer coefficient [%]
Cast aluminium	93
Slags	7

As mixed fractions are exported to hand sorting and subsequent metal refining, transfer coefficients are difficult to assess and modelling is not done in detail. Instead, it is assumed that the fractions are processed fully by common technologies related to the metals of the mixed fraction, i.e. mainly copper, precious metals, steel and lead. Based on transfer coefficients for steel and aluminium production, metal yields commonly lie at roughly 90% of input, while remains are output to slags, dusts or sludge. This is used as a transfer coefficient to provide a very rough representation of metal and residual output, the latter assumed to be landfilled or used as construction materials.

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