INTERNATIONAL STANDARD

ISO 21106

First edition
2019-11

Railway applications — Recyclability and recoverability calculation method for rolling stock

Applications ferroviaires — Méthode de calcul de recyclabilité et valorisabilité pour matériel roulant

Reference number
ISO 21106:2019(E)

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Published in Switzerland

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Foreword

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This document was prepared by Technical Committee ISO/TC 269, *Railway applications*, Subcommittee SC 2, *Rolling stock*.

Any feedback or questions on this document should be directed to the user's national standards body. A complete listing of these bodies can be found at www.iso.org/members.html.

Introduction

Rolling stock products are generally designed for operational safety, availability and reliability with the consideration to minimize any impact on society and environment. The treatment and environmentally sound disposal of end-of-life products are the desirable environmental priority of railway industry. This needs a common method to describe the end-of-life treatment of rolling stock products.

In order to benchmark the theoretical recyclability and recoverability of rolling stock, common calculation rules have been introduced in this document, which has been developed considering the work of UNIFE Life Cycle Assessment topical group between 2009 and 2011[5].

The calculation approach is based on common recycling practice. Throughout a life cycle perspective, the method adopts railway specific requirements for necessary material information.

End-of-life treatment processes are divided into three stages; pre-treatment, dismantling and shredding. Pre-treatment and dismantling calculations consider recycling and recoverability properties of the materials specific to these stages. At each stage, individual material flows are split into materials for recycling and materials for recoverability, depending on the availability of appropriate technology for recycling and/or recoverability. Therefore, knowledge of materials and dismantling of rolling stock or equipment is essential. The entire supply chain needs to be involved because material information is crucial when using this calculation method. This harmonized calculation method for recyclability and recoverability for rolling stock is intended to prevent misleading data gaps and contradictions.

The primary aim of this calculation method is for the rolling stock domain and other related interfaces with other subsystems.

The calculation method introduced by this document considers different end-of-life paths such as reuse, recycling and recoverability as well as treatment efficiencies at each stage. This means that this method is developed in order to take into account the efficiencies of recycling and recoverability technologies with regard to each material at the different end-of-life treatment stages. The recyclability and recoverability rates of rolling stock are each expressed as a percentage by mass (mass fraction in percent) after applying efficiency factors for each material of the rolling stock, which can potentially be reused, recycled or recovered.

Railway applications — Recyclability and recoverability calculation method for rolling stock

1 Scope

This document specifies a calculation method of recyclability and recoverability rates for rolling stock.

The method defined in this document applies to the design of new rolling stock. However, it can be applied to other existing rolling stock depending on available information. If calculation of recyclability or recoverability is applied to separate parts and/or products used in rolling stock and a specific calculation standard or method exists for the part and/or product, such standard or method can be applied, if relevant.

This calculation method is applicable regardless of any geographical concern.

This calculation method is applicable to any stage of life cycle of rolling stock. The calculated recyclability and recoverability rates are valid at the point of delivering the rolling stock products or equipment. Future recycling technologies or predicted trends with respect to the recycling industry are excluded from any consideration for this calculation method.

This calculation method considers the four main treatment processes, which are reuse, recycling, energy recovery and disposal (Figure 1). Process losses of recycling are treated in the disposal stage. The residue substances of the energy recovery stage (mostly ash and slag) and the residue of the incineration process of the disposal stage are most likely landfilled.

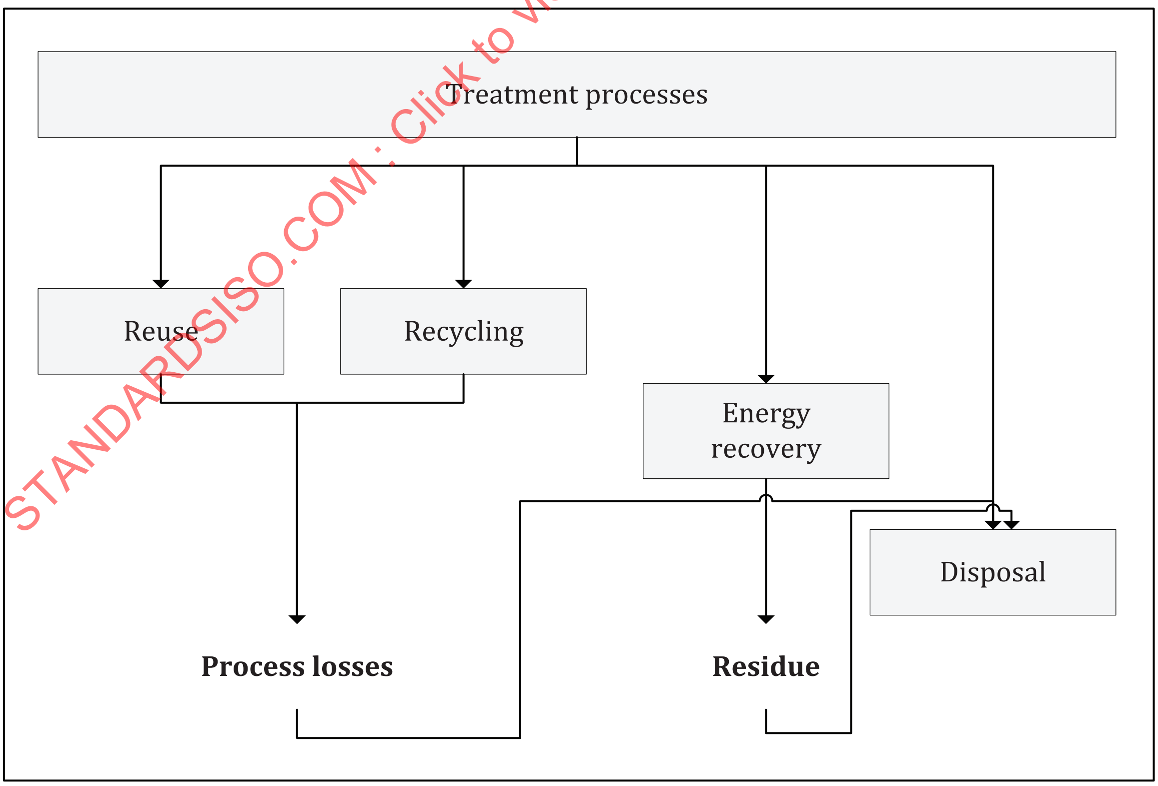

Figure 1 — End-of-life treatment

The application of this calculation method considers the rolling stock or equipment as delivered. Spare parts and/or maintenance parts necessary to keep the rolling stock in service over the entire life cycle, e.g. brake pads, are not taken into account. Also, infrastructure systems like stations, electrification, signal and control units, etc. are excluded from the calculation (Figure 2).

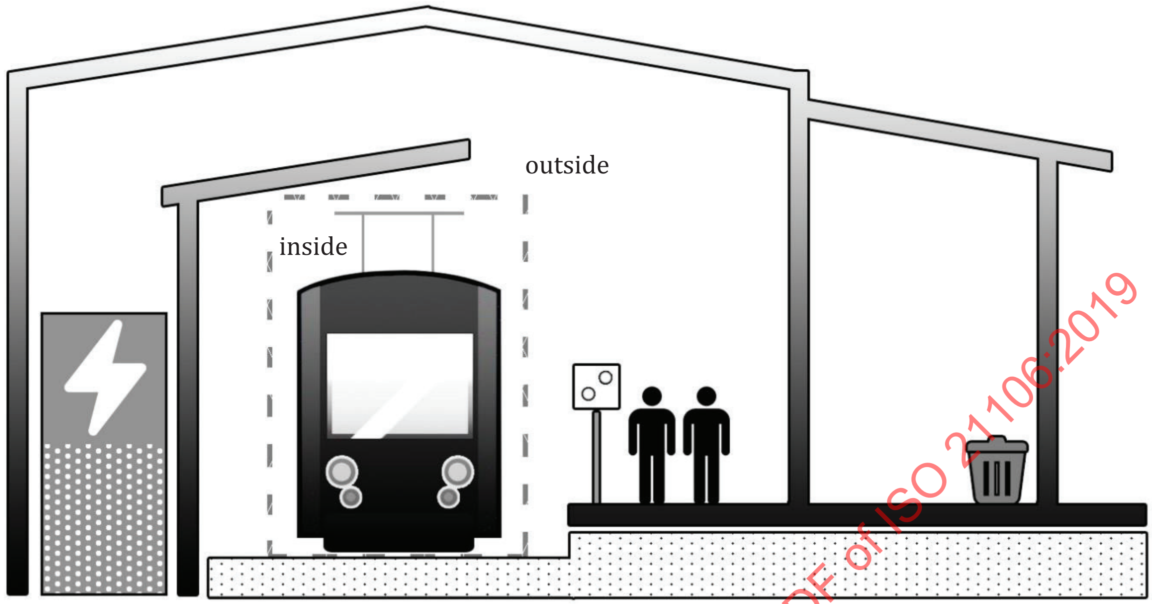

Figure 2 — Scope of the calculation

2 Normative references

There are no normative references in this document.

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

ISO and IEC maintain terminological databases for use in standardization at the following addresses:

— ISO Online browsing platform: available at https://www.iso.org/obp

— IEC Electropedia: available at http://www.electropedia.org/

3.1
design mass of rolling stock in working order
m_V
state of the complete mass of rolling stock equipped with all the consumables (e.g., fuel, oil, water, etc.) and without staff, passengers, and payload

[SOURCE: EN 15663:2017, 2.1.2.1, modified — The symbol has been amended and the mass of the staff is not included in the definition.]

3.2
reuse
use components of end-of-life rolling stock for the same purpose as that for which they were designed

Note 1 to entry: See ISO 22628.

3.3
recycle
process the waste materials for the original purpose or for other purposes, excluding processing as a means of generating energy

3.4
recover
process the waste materials for the original purpose or for other purposes, including processing as a means of generating energy

Note 1 to entry: "energy recovery" differs from recovery in that it does only include processing the waste materials with the aim to generate energy.

3.5
reusable
<of a component> suitable to be diverted from an end-of-life treatment to be *reused* (3.2)

3.6
recyclability
suitability of components, materials or both to be diverted from an end-of-life treatment to be *recycled* (3.3)

Note 1 to entry: See ISO 22628.

3.7
recyclability rate
R_{cyc}
percentage by design mass (mass fraction in percent) of the rolling stock potentially able to be *recycled* (3.3), *reused* (3.2) or both

Note 1 to entry: See ISO 22628.

3.8
recoverability
suitability of components or materials to be diverted from an end-of-life treatment to be *recovered* (3.4)

Note 1 to entry: See ISO 22628.

3.9
recoverability rate
R_{cov}
percentage by design mass (mass fraction in percent) of the rolling stock potentially able to be *recovered* (3.4), *reused* (3.2) or both

Note 1 to entry: See ISO 22628.

3.10
residue
mixture of materials remaining from the end-of-life treatment that is not *reused* (3.2), *recycled* (3.3) or *recovered* (3.4)

3.11
shredding loss factor
F_{SL}
shredder process efficiency indicating material mass losses during the process

3.12
shredder heavy fraction
metal fraction from the shredding process that can be further divided into ferrous metal fraction or ferrous fraction composed of pure ferrous materials like steel and iron and its alloys and a non-ferrous metal fraction or non-ferrous fraction containing different metals like aluminium, copper, brass, etc.

3.13
shredder light fraction
non-metallic *residue* (3.10) from the shredding process composed of plastics, rubber, foam, residual metal pieces, paper, fabric, glass, sand, etc.

3.14
material recycling factor
MRF
F_{MR}
suitability of material to be *recycled* (3.3) as materials for secondary products depending on the availability of recycling processes

3.15
energy recovery factor
ERF
F_{ER}
efficiency of process based on material weight to be recovered as usable energy

Note 1 to entry: Energy recovery from material is the conversion of materials into usable heat, electricity, or fuel through a variety of processes, including combustion, gasification, pyrolysis, anaerobic digestion and landfill gas recovery.

Note 2 to entry: As shown in Table 1, the *recyclability rate* (3.7) embraces the percentage by design mass of the rolling stock that can potentially be reused and recycled, while the *recoverability rate* (3.9) includes the percentage by design mass of the rolling stock that can potentially be reused, recycled and recovered as energy.

Table 1 — Overview of key terms

	Recovery		**Residue**
(Components) Reuse	(Materials) Recycling	(Materials) Energy recovery	(Materials) Disposal
Recyclability rate[a]			
Recoverability rate[a]			
Design mass of rolling stock			

[a] As a percentage of rolling stock mass.

4 Symbols and abbreviated terms

Table 2 describes the symbols of the mass variables used in calculating the recyclability and recoverability rates.

Table 2 — Symbols and definitions for masses

Symbol	Description
$m_{AE,i}$	mass of material category *i* available for energy recovery
$m_{AR,i}$	mass of material category *i* available for recycling
$m_{D,E}$	sum of masses of materials considered as energy recoverable at the dismantling stage considering F_{ER} for material category *i*, $\sum m_{D,iE}$
$m_{D,R}$	sum of masses of materials considered as recyclable at the dismantling stage considering F_{MR} for material category *i*, $\sum m_{D,iR}$
$m_{D,Reuse}$	sum of masses of materials which can be considered as reusable at the dismantling stage for material category *i*, $\sum m_{D,iReuse}$
$m_{E,i}$	mass of material category *i* recovered as energy
$m_{P,E}$	sum of masses of materials considered as energy recoverable at the pre-treatment stage considering F_{ER} for material category *i*, $\sum m_{P,iE}$
$m_{P,R}$	sum of masses of materials considered as recyclable at the pre-treatment stage considering F_{MR} for material category *i*, $\sum m_{P,iR}$
$m_{P,Reuse}$	sum of masses of materials which can be considered as reusable at the pre-treatment stage for material category *i*, $\sum m_{P,iReuse}$
$m_{R,i}$	mass of material category *i* recycled
$m_{S,E}$	sum of masses of materials considered as energy recoverable at the shredding stage considering F_{ER} for material category *i*, $\sum m_{S,iE}$
$m_{S,iS}$	mass of material category *i* after applying shredding loss factor at the shredding stage for material category *i*, $m_{S,iS} = m_{S,i} \times (1 - F_{SL})$
$m_{S,R}$	sum of masses of materials considered as recyclable at the shredding stage considering F_{MR} for material category *i*, $\sum m_{S,iR}$
$m_{S,S}$	sum of masses of materials available for the next process after shredding stage considering F_{SL}, $\Sigma\, m_{S,iS}$
m_V	design mass of rolling stock in working order
m_W	sum of masses of materials considered as residue for material category *i*, $\sum m_{iw}$
$m_{Y,i}$	mass of material category *i* [a] before treatment process Y
$m_{Y,iE}$	mass of material category *i* after applying energy recovery efficiency values of material category *i* at treatment process Y, $m_{Y,iE} = m_{Y,i} \times F_{ER,i}$ [c]
$m_{Y,iR}$	mass of material category *i* after applying material recycling efficiency values of material category *i* at treatment process Y, $m_{Y,iR} = m_{Y,i} \times F_{MR,i}$ [b]

NOTE All masses are expressed in kilograms.

[a] Material category is defined as a group of materials having similar chemical properties, classified in 5.4.

[b] $F_{MR,i}$ is defined as the output of the recycling process divided by the input; it gives an indication of the proportion of the materials actually recycled, which thus provides a more adequate indicator for recycling performance. $F_{MR,i} = \dfrac{m_{R,i}}{m_{AR,i}}$.

[c] $F_{ER,i}$ for specific material can be obtained from the amount of material actually recovered divided by the total amount of the material available for energy recovery. $F_{ER,i} = \dfrac{m_{E,i}}{m_{AE,i}}$.

5 End-of-life treatment process

5.1 General

5.1.1 Overview

The calculation of the recyclability and recoverability rates is carried out through the following three stages of a rolling stock, for which all materials, components or both should be taken into account at each stage as described in Figure 3 and 5.1.2 to 5.1.4:

1) pre-treatment stage;

2) dismantling stage;

3) shredding stage.

All three stages are in fact applicable to the end-of-life treatment process, for which all materials, components or both can be reused, recycled or recovered at each stage. Based on the understanding of these stages, preliminary design for disassembly and recyclability shall be considered in the design and development of rolling stock, to thus improve its recyclability and recoverability.

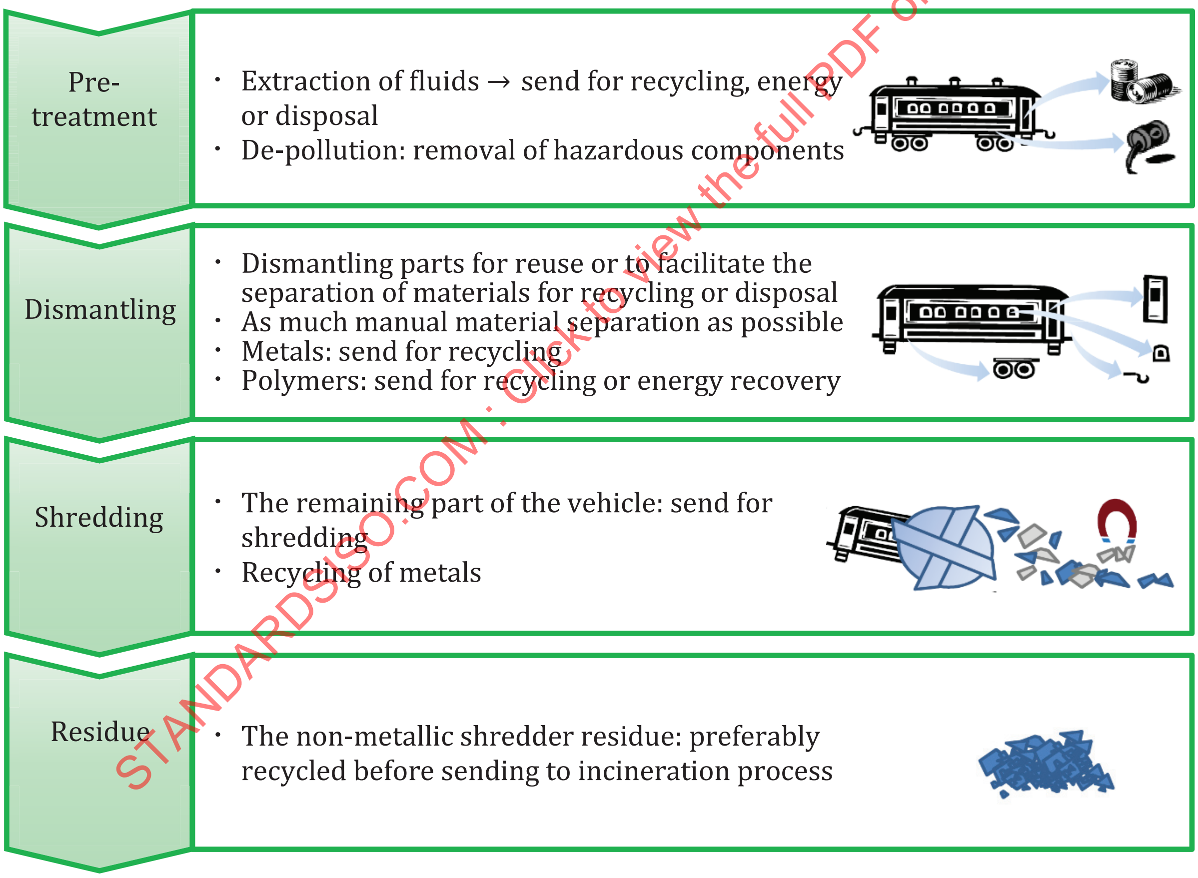

Figure 3 — Illustration of the end-of-life treatment stages for rolling stock

For all three stages, partial masses, $m_{\text{P,Reuse}}$, $m_{\text{P,R}}$, $m_{\text{P,E}}$, $m_{\text{D,Reuse}}$, $m_{\text{D,R}}$, $m_{\text{D,E}}$, $m_{\text{S,R}}$, or $m_{\text{S,E}}$ can be determined. Annex A provides a data sheet in accordance with these stages and the schematic representation of the method.

5.1.2 Pre-treatment

The objective of pre-treatment stage is to remove hazardous gases, fluids, materials, components and parts which can be harmful to both humans and the environment from the end-of-life rolling stock before subsequent stages such as dismantling and shredding.

Table B.1 shall be fully assessed for the end-of-life rolling stock to be considered as part of the pre-treatment stage.

From this stage, it is possible to calculate the masses of materials and components available for reuse, recycling, or recovery, corresponding to $m_{\mathrm{P,Reuse}}$, $m_{\mathrm{P,R}}$ and $m_{\mathrm{P,E}}$ in Figure 4.

After the pre-treatment stage, no substances which can harmfully affect any recycling process shall remain inside the rolling stock so that the next treatment stage can be safely applied.

5.1.3 Dismantling

The objective of this stage is to dismantle materials and components from the end-of-life rolling stock using the checklist in Table B.2 prior to commencing the shredding process. During the dismantling stage, parts and materials are separated and sorted for appropriate and dedicated recycling processes. Therefore, the availability of recycling processes for the dismantled parts and components is a precondition for the efficient dismantling. The efficiency of recycling processes of materials and components is generally higher when these are removed and sorted out.

Various issues shall be taken into account when determining the eligibility for dismantling of the end-of-life rolling stock, such as safety, economic feasibility (e.g. value of material, time necessary for dismantling, etc.), component accessibility, fastening technologies and any other proven dismantling processes.

Specific criteria in Table B.2 shall be applied in accordance with any process related to environmental impacts, economic risks and opportunities simultaneously. Windows, seats, floors, cables and electronic parts, HVAC units are typical examples of components to be dismantled at this stage.

The non-qualified parts and components shall be processed in the shredding stage.

From this stage, it is possible to calculate the masses of all parts available for reuse, recycling, or recovery, corresponding to $m_{\mathrm{D,Reuse}}$, $m_{\mathrm{D,R}}$ and $m_{\mathrm{D,E}}$ in Figure 4.

5.1.4 Shredding

After the pre-treatment and the dismantling stages, the remaining parts and materials enter the shredding process. The intention of the shredding process is to reduce the size and volume of the remaining part of the rolling stock.

After the shredding stage, the smaller pieces of the remaining parts are sorted and separated into different material fractions. The efficiency of the shredding process can be described by the shredding loss factor (F_{SL}). The lower F_{SL} values mean that lesser materials are not sorted and will later be classified as residue. For example, the shredder heavy fraction is effectively separated by using magnetic capabilities and can yield a very low shredding loss factor. Vice versa, the shredder light fraction tends to yield a higher shredding loss factor.

$m_{\mathrm{S,S}}$ are calculated considering F_{SL} as given in Formula (1):

$$m_{\mathrm{S,S}} = \sum m_{\mathrm{S},i} \times (1 - F_{\mathrm{SL}}) \quad (1)$$

Materials considered for the shredding process cannot be classified as reusable. All materials not considered for material recycling or energy recovery shall be considered as residues.

From this stage, it is possible to calculate the masses of all parts available for recycling or recovery, corresponding to $m_{\mathrm{S,R}}$ and $m_{\mathrm{S,E}}$ in Figure 4.

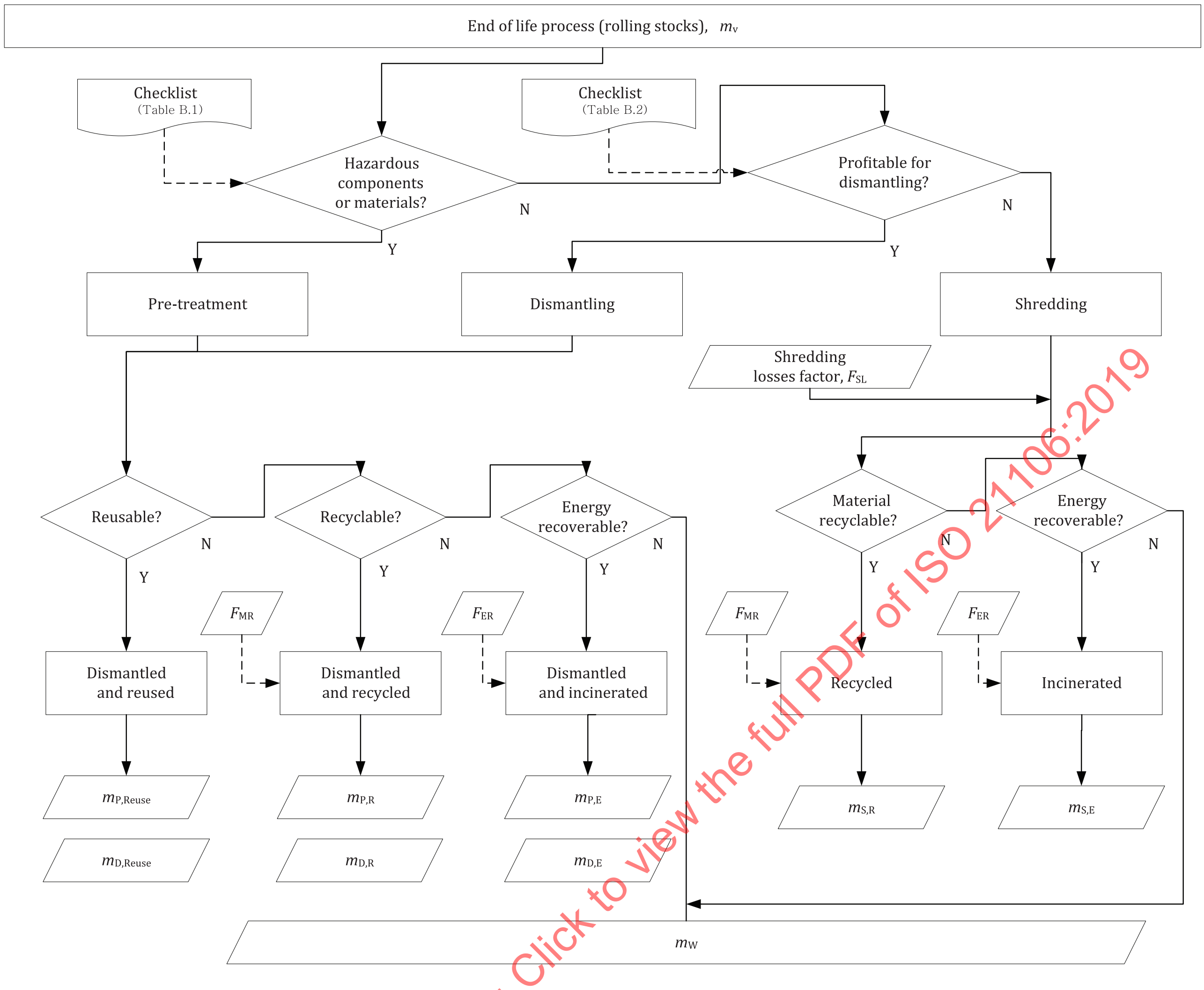

Figure 4 — Three stages of the end-of-life treatment for rolling stock

5.2 Efficiency of recycling process

5.2.1 General

It is important to consider that the amounts of materials suitable for material recycling or energy recovery processes can be different at various stages. The suitable amount of materials extracted at the dismantling stage is in general higher than that of the same materials obtained from the shredding residues.

Factors that shall be considered by the manufacturers of the rolling stock and equipment for their recycling strategies are:

— politics (laws and regulations);

— rolling stock owner (strategy, environmental guideline);

— markets (end users' requirements, trends, fashion);

— materials (ability to be identified, suitability for recycling, recycling compatibility in material compounds, environmentally critical contents which have to be treated);

— ability for dismantling (visual perceptibility, accessibility, connection/bond, dismantling time);

— recycling technologies (availability of economically optimized recycling processes for specific target fractions);

— raw materials consumption;

— emissions (solid, liquid, gaseous);

— cumulative consumption of energy.

The decisions on which components will be extracted at the pre-treatment and dismantling stages can influence the recyclability and recoverability rates.

5.2.2 Material recycling

A material recycling process aims at reducing the demand for primary materials; for example, producing new raw materials that can later be processed into new products. When identifying which materials are optimal for material recycling at the end-of-life stage, the availability of material recycling processes and the efficiency of these processes shall be taken into account. Additional factors can also have an influence, as described in 5.2.1.

Material recycling is included in this calculation method by considering the recyclability with respect to commercially available technologies. F_{MR} is a material recycling factor that describes the portion of material available for recycling. The factor is unique for each material and to be applied to the mass of material assigned in the recycling process for rolling stock in order to determine the theoretical recycled mass of material, as per Formula (2).

$$m_{Y,i\mathrm{R}} = m_{Y,i} \times F_{MR,i} \quad (2)$$

5.2.3 Energy recovery

Introducing a material for any energy recovery process has double benefits when considering the end-of-life treatment at a larger scope: decrease of remaining waste and extraction of energy (e.g. heat and electricity). This is a reason why the suitability of a material for energy recovery is highly influenced by its calorific value. A lower calorific value indicates that the material is less appropriate for this process. For example, natural polymers and wood have higher heat values compared to composite materials such as glass fibre reinforces epoxy. Available technologies for energy recovery processes can also affect the possibility to recover a material.

For each material suitable for an energy recovery process, a factor, F_{ER}, is used. A higher factor indicates that a higher feasibility to extract energy from the material can be achieved. The factor is applied to the mass of material subjected to the energy recovery process to illustrate how much material is recovered, as per Formula (3).

$$m_{Y,i\mathrm{E}} = m_{Y,i} \times F_{ER,i} \quad (3)$$

5.3 Documentation of factors

All factors (F_{SL}, F_{MR}, F_{ER}) used in the calculation of the recycling and recovery rate of rolling stock shall be selected depending on available information:

— data based on official values or provided by professional organizations;

— data provided by designated recycling/recovering actors;

— commercially available data.

Reference to the sources shall be included in the calculation.

5.4 Breakdown materials

The breakdown of materials of the rolling stock shall be established by classifying all the materials composing the rolling stock into the following categories:

— metals (ferrous metals or non-ferrous metals);

— elastomers;

— polymers (thermosets or thermoplastics);

— composites (e.g. fibre reinforced polymers or others);

— electric and electronic equipment;

— glass;

— safety glass;

— oil, grease or similar;

— acids, cooling agents or similar;

— other inorganic materials (e.g. ceramics);

— mineral wools;

— modified organic natural materials (MONM), including wood.

The material categories can be expanded or condensed in relation to the above listed material breakdown, based on the available information about materials used as well as available recycling and recoverability technologies. For the material categories used, the corresponding F_{MR} and F_{ER} shall be based on public references and documented.

The total mass of each category can be presented using the template given in Annex A. The same table can also be used to present the F_{MR}, F_{ER}, F_{SL} for the material categories as well as the results of recyclability and recoverability calculations. The breakdown of materials of rolling stock into categories shall be applied at each stage of the calculation for each partial mass mentioned in Clause 6.

6 Calculation methods

6.1 Recyclability rate

The recyclability rate, R_{cyc}, of the rolling stock is calculated as a mass fraction using Formula (4):

$$R_{cyc}\,(\%) = \frac{m_{P,Reuse} + m_{P,R} + m_{D,Reuse} + m_{D,R} + m_{S,R}}{m_V} \times 100 \quad (4)$$

where all masses are expressed in kilograms.

6.2 Recoverability rate

The recoverability rate, R_{cov}, of the rolling stock is calculated as a mass fraction using Formula (5):

$$R_{cov}\,(\%) = R_{cyc} + \frac{m_{P,E} + m_{D,E} + m_{S,E}}{m_V} \times 100 \quad (5)$$

where all masses are expressed in kilograms.

6.3 Limitation

The uncertainty of calculation results depends on the information related to the material type and mass, and the assembly of rolling stock. The more detailed the information, the lower the uncertainty.

Annex A
(informative)

Data sheet

When calculating the recyclability and recoverability rates of rolling stock, this annex can be used to provide the calculation details with a detailed list of the materials applied to each value of F_{MR}, F_{ER} and F_{SL}, with their references in each material categories for the purpose of verification. Some examples are provided in References [4] and [5].

A.1 Data sheet for the pre-treatment stage

Material category		$m_{P,i}$ (kg)	$F_{MR,i}$	$F_{ER,i}$	Reuse	Recycling		Energy recovery		m_{iW} (kg)
					$m_{P,iReuse}$ (kg)	$m_{AR,i}$ (kg)	$m_{P,iR}$ (kg)	$m_{AE,i}$ (kg)	$m_{P,iE}$ (kg)	
		(1)	(a)	(b)	(2)	(3) = (1) − (2)	(4) = (3) × (a)	(5) = (1) − (2) − (4)	(6) = (5) × (b)	(7) = (1) − (2) − (4) − (6)
1) Pre-treatment	Electrics and electronic equipment									
	Oil, grease or similar									
	Acids, cooling agents or similar									
Sub-total (kg)										

A.2 Data sheet for the dismantling stage

Material category		$m_{D,i}$ (kg)	$F_{MR,i}$	$F_{ER,i}$	Reuse	Recycling		Energy recovery		m_{iW} (kg)
					$m_{D,iReuse}$ (kg)	$m_{AR,i}$ (kg)	$m_{D,iR}$ (kg)	$m_{AE,i}$ (kg)	$m_{D,iE}$ (kg)	
		(1)	(a)	(b)	(2)	(3) = (1) − (2)	(4) = (3) × (a)	(5) = (1) − (2) − (4)	(6) = (5) × (b)	(7) = (1) − (2) − (4) − (6)
2) Dismantling	Metal (ferrous)									
	Metal (non-ferrous)									
	Elastomers									
	Polymer (thermosets)									
	Polymer (thermoplastics)									
	Composites									
	Electrics and electronic equipment									
	Glass									
	Safety glass									
	Other inorganic materials (ceramics)									
	Mineral wools									
	NONM									
Sub-total (kg)										

A.3 Data sheet for the shredding stage

Material category		$m_{S,i}$ (kg)	$F_{MR,i}$	$F_{ER,i}$	F_{SL}	Shredding	Recycling		Energy recovery		m_{iW} (kg)
						$m_{S,iS}$ (kg)	$m_{AR,i}$ (kg)	$m_{S,iR}$ (kg)	$m_{AE,i}$ (kg)	$m_{S,iE}$ (kg)	
		(1)	(a)	(b)	(c)	(2) = (1) × (1 - c)	(3) = (2)	(4) = (3) × (a)	(5) = (2) − (4)	(6) = (5) × (b)	(7) = (1) − (2) − (4) − (6)
3) Shredding	Metal (ferrous)										
	Metal (non-ferrous)										
	Elastomers										
	Polymer (thermosets)										
	Polymer (thermoplastics)										
	Composites										
	Electrics and electronic equipment										
	Glass										
	Safety glass										
	Other inorganic materials (ceramics)										
	Mineral wools										
	NONM										
Sub-total (kg)											

A.4 Data sheet for total

Total (kg)	m_V (kg)	
	m_W (kg)	