TEXTE
39/2025

Final report

Optimisation potential with regard to the processing and recycling of waste oil

Evaluation of the collection categories with regard to their suitability for regeneration and the effects of changes in mobility and technology on the distribution and composition of the collection categories

by:

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On behalf of the German Environment Agency

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Abstract: Optimization Potentials in the Reprocessing and Recycling of Waste Oil

The national and EU legislation prioritizes the recycling of waste oil to base oil over other forms of end-of-life treatment. On the German national level, the waste oil flows are periodically analyzed using a calculation model that incorporates statistical input data and return rates specific to different lubricant types. In this project, this calculation model was reviewed and updated. Additionally, the existing collection categories were examined to determine which waste oils are suitable for reprocessing, specifically whether waste oils in collection category 2 are suitable for recycling to base oil. For this purpose, waste oils were analyzed in Avista's laboratories regarding their composition, particularly concerning contaminants (from additives and usage), to determine whether the classification into the collection categories of Annex 1 of the Waste Oil Ordinance Act (AltölV) corresponds to the current technical possibilities for waste oil recycling. Furthermore, the potential impacts of current and anticipated future changes in mobility and technology (different lubricants, changed additive compositions, increasing share of e-mobility, etc.) on the distribution and quality of the collection categories were considered.

Kurzbeschreibung: Optimisation potential with regard to the processing and recycling of waste oil

Die nationale und EU-Gesetzgebung priorisiert die Aufbereitung von Altöl vor anderen Verwertungsarten. Auf deutscher nationaler Ebene werden die Altölmengenströme anhand eines Berechnungsmodells periodisch unter Nutzung statistischer Eingangsdaten und Erkenntnissen zu sortenspezifischen Rücklaufquoten untersucht. In diesem Forschungsvorhaben wurde dieses Berechnungsmodell geprüft und aktualisiert. Daneben wurden die bestehenden Sammelkategorien dahingehend geprüft, welche Altöle zur Aufbereitung geeignet sind, insbesondere, ob auch Altöle der Sammelkategorie 2 zur stofflichen Verwertung geeignet sind. Hierfür wurden Altöle in Hinblick auf ihre Zusammensetzung insbesondere bzgl. Störstoffe (aus Additiven sowie aus der Nutzung) mittels Laboranalysen untersucht und geprüft, ob die Zuordnung zu den Sammelkategorien der Anlage 1 AltölV den aktuellen technischen Möglichkeiten zur stofflichen Verwertung entspricht. Darüber hinaus wurde eine Betrachtung der Auswirkungen der aktuellen und in naher Zukunft zu erwartenden Mobilitäts- und Technikveränderungen (andere Öle, veränderte Additivzusammensetzung, steigender Anteil der E-Mobilität, …) auf die Verteilung und Qualitäten der Sammelkategorien vorgenommen.

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List of abbreviations

A	Suitable for regeneration (Aufbereitbar)
AltölV	Altölverordnung / German Waste Ordinance Act
ASTM	American Society for Testing and Materials
ATF	Automatic Transmission Fluid
AVV	Waste Code Regulation
BA	Partially suited for regeneration (bedingt aufbereitbar)
BAFA	Federal Office for Economic Affairs and Export Control
BREF	Best Available Techniques
BMUV	Federal Ministry for the Environment, Nature Conservation and Nuclear Safety
BVA	Federal Association for Waste Management
CC	Collection Category
COM	Commission
DAT	German Automobile Trust
DEFRA	Department for Environment, Food & Rural Affairs
DIN	German Institute for Standardization
ELV	End-of-Life Vehicle
FAME	Fatty Acid Methyl Ester
GE	Simulated Distillation Temperatures
ISO	International Organization for Standardization
KBA	Federal Motor Transport Authority (Kraftfahrtbundesamt)
KrWG	Circular Economy Act
NA	Not suited for regeneration
NI	No Information
PAH	Polycyclic Aromatic Hydrocarbons
PAO	Polyalphaolefins
PCB	Polychlorinated Biphenyls
PMCC	Pensky-Martens Closed Cup (a method for determining flash point)
RFA	X-ray Fluorescence Analysis
t	Tonnes
UBA	German Environment Agency
UNEP	United Nations Environment Programme
VSI	Association of the Lubricant Industry
WC	Waste Code
WEEE	Waste Electrical and Electronic Equipment
WFD	Waste Framework Directive
Wmb	water miscible
XRF	X-ray Fluorescence Analysis

Summary

The EU's Waste Framework Directive (WFD)[1] defines "*measures to protect the environment and human health by preventing or reducing the adverse impacts of the generation and management of waste and by reducing overall impacts of resource use and improving the efficiency of such use.*" (Art. 1.).

Article 21 of the WFD refers specifically to waste oils and includes:

- Separate collection, where technically feasible.
- Treatment in accordance with Articles 4 (waste hierarchy, i.e. in order of priority) and 13 (protection of human health).
- The separation of waste oils with different properties (mixing ban), as far as technically feasible and economically justifiable.

The reference to the waste hierarchy therefore prioritises material treatment over energy recovery and disposal, unless other types of treatment lead to an equivalent or better result for environmental protection.

The transposition of Article 21 of the Waste Framework Directive into national German law takes place, among other things, via the Waste Oil Ordinance (AltölV). § 2 AltölV regulates the priority of recycling and regeneration: "*The recycling of waste oils shall take precedence over energy recovery and disposal, insofar as this is technically possible and economically reasonable. In the context of material treatment, regeneration shall take precedence over alternative recycling processes in accordance with Section 6 (2) of the Circular Economy Act.*"[2]

The Waste Oil Ordinance distinguishes between four collection categories for waste oil, to which different types of waste oil are assigned (Annex 1 Waste Oil Ordinance). According to Section 2 (2), waste oils in collection category 1 are suitable for regeneration.

Article 21 (4) of the WFD states: "*By 31 December 2022, the Commission shall examine data on waste oils provided by Member States in accordance with Article 37(4) with a view to considering the feasibility of adopting measures for the treatment of waste oils, including quantitative targets on the regeneration of waste oils and any further measures to promote the regeneration of waste oils. To that end, the Commission shall submit a report to the European Parliament and to the Council, accompanied, if appropriate, by a legislative proposal.”*

In addition, the Commission announces in the Circular Economy Action Plan[3] that it will examine the most effective measures to ensure the collection and environmentally sound treatment of waste oils.

This research project serves to prepare and monitor these measures at the national level and to review the calculation model used by the UBA to analyse material flows.

Against the background of progressive technical changes and changes in the composition of the waste oil, the following considerations were made:

[1] Directive 2008/98/EC of the European Parliament and of the Council of 19 November 2008 on waste and repealing certain Directives

[2] Own translation, original text: “Die stoffliche Verwertung von Altölen hat Vorrang vor der energetischen Verwertung und der Beseitigung, soweit dies technisch möglich und wirtschaftlich zumutbar ist. Im Rahmen der stofflichen Verwertung hat die Aufbereitung Vorrang vor alternativ in Frage kommenden Recyclingverfahren nach Maßgabe von § 6 Absatz 2 des Kreislaufwirtschaftsgesetzes”

[3] "A new circular economy action plan for a cleaner and more competitive Europe."

- Review of the existing collection categories/determination of which waste oils are suitable for treatment; in particular examination of whether waste oils in collection categories 2 and 3 are suitable for regeneration. For this purpose, waste oils were examined concerning their composition, in particular concerning impurities (from additives and from use), and checked whether the assignment to the collection categories of Annex 1 AltölV corresponds to the current technical possibilities for regeneration.
- Review of the calculation model (back-calculation model) for determining waste oil flows and updating the calculations.
- Analysing and forecasting the effects of current and expected future changes in mobility and technology (different oils, changed additive composition, increasing share of e-mobility, ...) on the distribution and qualities of the collection categories.
- Examination of possible need for action with regard to a revision of the Waste Oil Ordinance (e.g. tailoring of collection categories, definition of categories suitable for reprocessing, target quotas).

Zusammenfassung

Die Abfallrahmenrichtlinie (ARRL)[4] der EU legt „*Maßnahmen zum Schutz der Umwelt und der menschlichen Gesundheit*" fest, „*indem die schädlichen Auswirkungen der Erzeugung und Bewirtschaftung von Abfällen vermieden oder verringert, die Gesamtauswirkungen der Ressourcennutzung reduziert und die Effizienz der Ressourcennutzung verbessert werden*" (Art. 1.).

Artikel 21 der ARRL bezieht sich konkret auf Altöl und beinhaltet:

- Die Getrenntsammlung, soweit technisch durchführbar.
- Die Behandlung gemäß Artikel 4 (Abfallhierarchie, d. h. entsprechend der Prioritätenfolge) und 13 (Schutz der menschlichen Gesundheit).
- Die Getrennthaltung von Altölen mit unterschiedlichen Eigenschaften (Vermischungsverbot), soweit technisch durchführbar und wirtschaftlich vertretbar.

Aus dem Bezug auf die Abfallhierarchie ergibt sich also eine Priorität der stofflichen Verwertung gegenüber energetischer Verwertung und Beseitigung, sofern nicht andere Verwertungsarten zu einem gleichwertigen oder besseren Ergebnis für den Umweltschutz führen.

Die Umsetzung des Artikels 21 der ARRL in nationales, deutsches Recht erfolgt u. a. über die Altölverordnung (AltölV). § 2 AltölV regelt den Vorrang von stofflicher Verwertung und Aufbereitung: „*Die stoffliche Verwertung von Altölen hat Vorrang vor der energetischen Verwertung und der Beseitigung, soweit dies technisch möglich und wirtschaftlich zumutbar ist. Im Rahmen der stofflichen Verwertung hat die Aufbereitung Vorrang vor alternativ in Frage kommenden Recyclingverfahren nach Maßgabe von § 6 Absatz 2 des Kreislaufwirtschaftsgesetzes*."

Die AltölV unterscheidet zwischen vier Sammelkategorien für Altöl, denen unterschiedliche Altölarten zugeordnet sind (Anlage 1 AltölV). Gemäß § 2 Absatz 2 sind Altöle der Sammelkategorie 1 zur Aufbereitung geeignet.

In Artikel 21 Absatz 4 der ARRL heißt es: „*Die Kommission prüft bis zum 31. Dezember 2022 die von den Mitgliedstaaten im Einklang mit Artikel 37 Absatz 4 zur Verfügung gestellten Daten zu Altöl, um festzustellen, ob Maßnahmen zur Behandlung von Altöl getroffen werden können, darunter auch die Festlegung von quantitativen Zielvorgaben für die Aufbereitung von Altöl und alle anderen Maßnahmen zur Förderung der Aufbereitung von Altöl. Zu diesem Zweck legt die Kommission dem Europäischen Parlament und dem Rat einen Bericht vor, der gegebenenfalls von einem Gesetzgebungsvorschlag begleitet wird*."

Darüberhinausgehend kündigt die Kommission im Aktionsplan für die Kreislaufwirtschaft[5] an, zu prüfen, mit welchen Maßnahmen die Sammlung und die umweltgerechte Behandlung von Altölen am wirksamsten gewährleistet werden können.

Dieses Forschungsvorhaben dient der Vorbereitung und Begleitung dieser Maßnahmen auf nationaler Ebene sowie der Überprüfung des im UBA verwendeten Berechnungsmodells zur Stoffstromanalyse.

Vor dem Hintergrund fortschreitender technischer Veränderungen und vor Veränderungen in der Zusammensetzung des Altöls wurden folgende Betrachtungen durchgeführt:

[4] Richtlinie 2008/98/EG des Europäischen Parlaments und des Rates vom 19. November 2008 über Abfälle und zur Aufhebung bestimmter Richtlinien

[5] „Ein neuer Aktionsplan für die Kreislaufwirtschaft für ein saubereres und wettbewerbsfähigeres Europa."

- Überprüfung der bestehenden Sammelkategorien/Bestimmung, welche Altöle zur Aufbereitung geeignet sind, insbesondere Prüfung, ob Altöle der Sammelkategorien 2 und 3 zur stofflichen Verwertung geeignet sind. Hierfür wurden Altöle in Hinblick auf ihre Zusammensetzung insbesondere bzgl. Störstoffe (aus Additiven sowie aus der Nutzung) untersucht und geprüft, ob die Zuordnung zu den Sammelkategorien der Anlage 1 AltölV den aktuellen technischen Möglichkeiten zur stofflichen Verwertung entspricht.
- Überprüfung des Berechnungsmodells (Rückrechenmodell) zur Bestimmung der Altölmengenströme und Aktualisierung der Berechnungen.
- Analyse und Prognose der Auswirkungen der aktuellen und in naher Zukunft zu erwartenden Mobilitäts- und Technikveränderungen (andere Öle, veränderte Additivzusammensetzung, steigender Anteil der E-Mobilität, …) auf die Verteilung und Qualitäten der Sammelkategorien.
- Prüfung möglicher Handlungsbedarfe hinsichtlich einer Überarbeitung der AltölV (z. B. Zuschnitt der Sammelkategorien, Festlegung der aufbereitungsgeeigneten Kategorien, Zielquoten).

1 Background and problem definition

The Waste Framework Directive (WFD) sets out "*measures to protect the environment and human health by preventing or reducing the adverse impacts of the generation and management of waste and by reducing overall impacts of resource use and improving the efficiency of such use.*" (Art. 1.).

Article 21 of the WFD refers specifically to waste oils and includes:

- Separate collection, where technically feasible.
- Treatment in accordance with Articles 4 (waste hierarchy, i.e. in order of priority) and 13 (protection of human health).
- The separation of waste oils with different properties (mixing ban), as far as technically feasible and economically justifiable.

Definition of waste oil according to WFD
any mineral or synthetic lubrication or industrial oils which have become unfit for the use for which they were originally intended, such as used combustion engine oils and gearbox oils, lubricating oils, oils for turbines and hydraulic oils

The waste hierarchy emphasizes the importance of material recovery / recycling over energy recovery and disposal, unless other treatment methods offer equivalent or better outcomes for environmental protection.

Regeneration which is to be prioritised (following article 3 (18) and article 4) is defined according to Article 3 (18) of the Waste Framework Directive as "*any recycling operation whereby base oils can be produced by refining waste oils, in particular by removing the contaminants, the oxidation products and the additives contained in such oils*".

The overarching implementation of the Waste Framework Directive into German law is carried out by the Circular Economy Act (KrWG). The transposition of Article 21 of the WFD into national German law goes beyond the KrWG and includes the Waste Oil Ordinance Act (AltölV). The definition of regeneration in this context closely aligns with that of the WFD.[6]

The AltölV presents a slightly different definition of waste oils:

Definition of waste oil according to AltölV
Waste oils within the meaning of this Ordinance are oils that accumulate as waste and consist wholly or partly of mineral oil, synthetic or biogenic oil.[7]

§ 2 of the Waste Oil Ordinance outlines the priorities for recycling and regeneration: "*The recycling of waste oils shall take precedence over energy recovery and disposal, insofar as this is technically possible and economically reasonable. In the context of material treatment, regeneration shall take precedence over alternative recycling processes in accordance with Section 6 (2) of the Circular Economy Act.*"

[6] "Refining is any process in which base oils are produced from waste oils by refining processes and in which in particular the separation of pollutants, oxidation products and additives in these oils takes place."

[7] Own translation, original text: „Altöle im Sinne dieser Verordnung sind Öle, die als Abfall anfallen und die ganz oder teilweise aus Mineralöl, synthetischem oder biogenem Öl bestehen.“

The Waste Oil Ordinance distinguishes between four collection categories for waste oil, to which different types of waste oil are assigned (Annex 1 Waste Oil Ordinance):

Table 1: Allocation of waste codes to a collection category

Collection category	Waste code	Description
1	13 01 10*	Mineral based non-chlorinated hydraulic oils
	13 02 05*	Mineral-based non-chlorinated engine, gear and lubricating oils
	13 02 06*	Synthetic engine, gear and lubricating oils
	13 02 08*	Other engine, gear and lubricating oils
	13 03 07*	Mineral-based non-chlorinated insulating and heat transmission oils
2	12 01 07*	Mineral-based machining oils free of halogens (except emulsions and solutions)
	12 01 10*	Synthetic machining oils
	13 01 11*	Synthetic hydraulic oils
	13 01 13*	Other hydraulic oils
3	12 01 06*	Mineral oil-based machining oils containing halogens (except emulsions and solutions)
	13 01 01*	Hydraulic oils, containing PCBs
	13 01 09*	Mineral-based chlorinated hydraulic oils
	13 02 04*	Mineral-based chlorinated engine, gear and lubricating oils
	13 03 01*	Insulating or heat transmission oils containing PCBs
	13 03 06*	Mineral-based chlorinated insulating and heat transmission oils other than those mentioned in 13 03 01
4	13 01 12*	Readily biodegradable hydraulic oils
	13 02 07*	Readily biodegradable engine, gear and lubricating oils
	13 03 08*	Synthetic insulating and heat transmission oils
	13 03 09*	Readily biodegradable insulating and heat transmission oils
	13 03 10	Other insulating and heat transmission oils
	13 05 06	Oils from oil/water separators
	13 07 01	Fuel oil and diesel

Source: Waste Oil Ordinance

According to § 2, paragraph 2, waste oils classified under collection category 1 are suitable for regeneration.

Article 21, paragraph 4 of the WFD states: "*By 31 December 2022, the Commission shall examine data on waste oils provided by Member States in accordance with Article 37(4) with a view to considering the feasibility of adopting measures for the treatment of waste oils, including quantitative targets on the regeneration of waste oils and any further measures to promote the regeneration of waste oils. To that end, the Commission shall submit a report to the European Parliament and to the Council, accompanied, if appropriate, by a legislative proposal.*" This report was published in October 2023 (COM 2023).

Additionally, the Commission announced in the Circular Economy Action Plan (COM 2020) that it would explore the most effective measures to ensure the collection and environmentally sound treatment of waste oils.. In this context, a study commissioned by the European Commission, titled "*Study to support the Commission in gathering structured information and defining of reporting obligations on waste oils and other hazardous* waste" (European Commission: Directorate-General for Environment et al. 2020), has been conducted.

Aims of the research project

The aim of this research project is to prepare and monitor measures at the national level and to review the calculation model used by the Federal Environment Agency (UBA) to analyze waste oil flows.

In light of ongoing technical advancements and changes in the composition of waste oils, the following considerations have been made:

- Assess which waste oils are suitable for regeneration, particularly focusing on whether waste oils in collection categories 2 and 3 are appropriate for treatment. This involves examining the composition of waste oils, particularly regarding impurities from additives and usage, and verifying whether the classification into the collection categories of Annex 1 of the Waste Oil Ordinance (AltölV) aligns with current technical capabilities for material treatment.
- Review of the calculation model (back-calculation model) for determining waste oil flows and updating the calculations.
- Analyze and forecast the implications of current and expected future changes in mobility and technology (including the introduction of different oils, modifications in additive composition, and the increasing share of electric mobility) on the distribution and quality of collection categories.Investigate the potential need for revisions to the Waste Oil Ordinance Act, such as adjusting collection categories, defining categories suitable for reprocessing, and establishing target quotas.

2 Determination of the types of waste oil suitable for regeneration

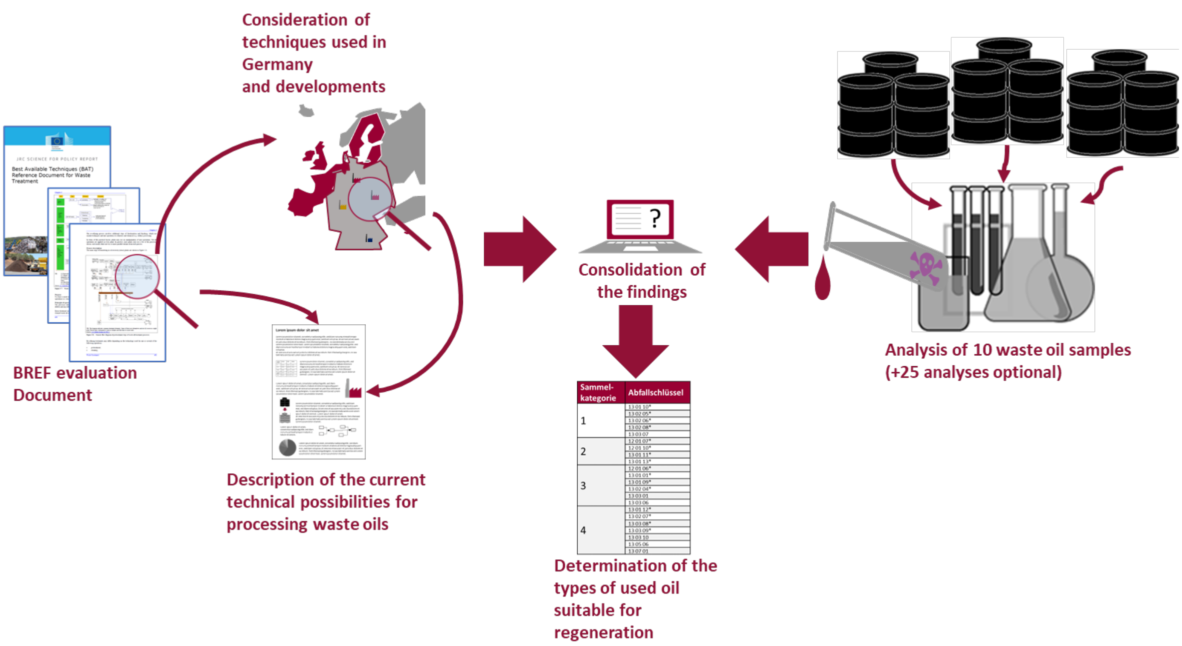
The first work package aims at analysing and determining the types of waste oils suitable for regeneration with consideration of Annex 1 of the Waste Oil Ordinance Act (cf. Table 1).

The procedure for this is divided into three main steps:

- Research and evaluation of technical possibilities
  - Based on an examination of the BREF document
  - Based on a stakeholder survey
  - Analysis of the quantities of waste oil collected and the waste oil collection situation
- Laboratory analytics
- Summarising the findings and determining the types of waste oil suitable for regeneration

These individual work steps are structured as shown in Figure 1 illustrated in Figure 1.

Figure 1: Procedure for determining the types of waste oils suitable for regeneration



Source: Ökopol

2.1 Research and evaluation of the technical possibilities for processing waste oils

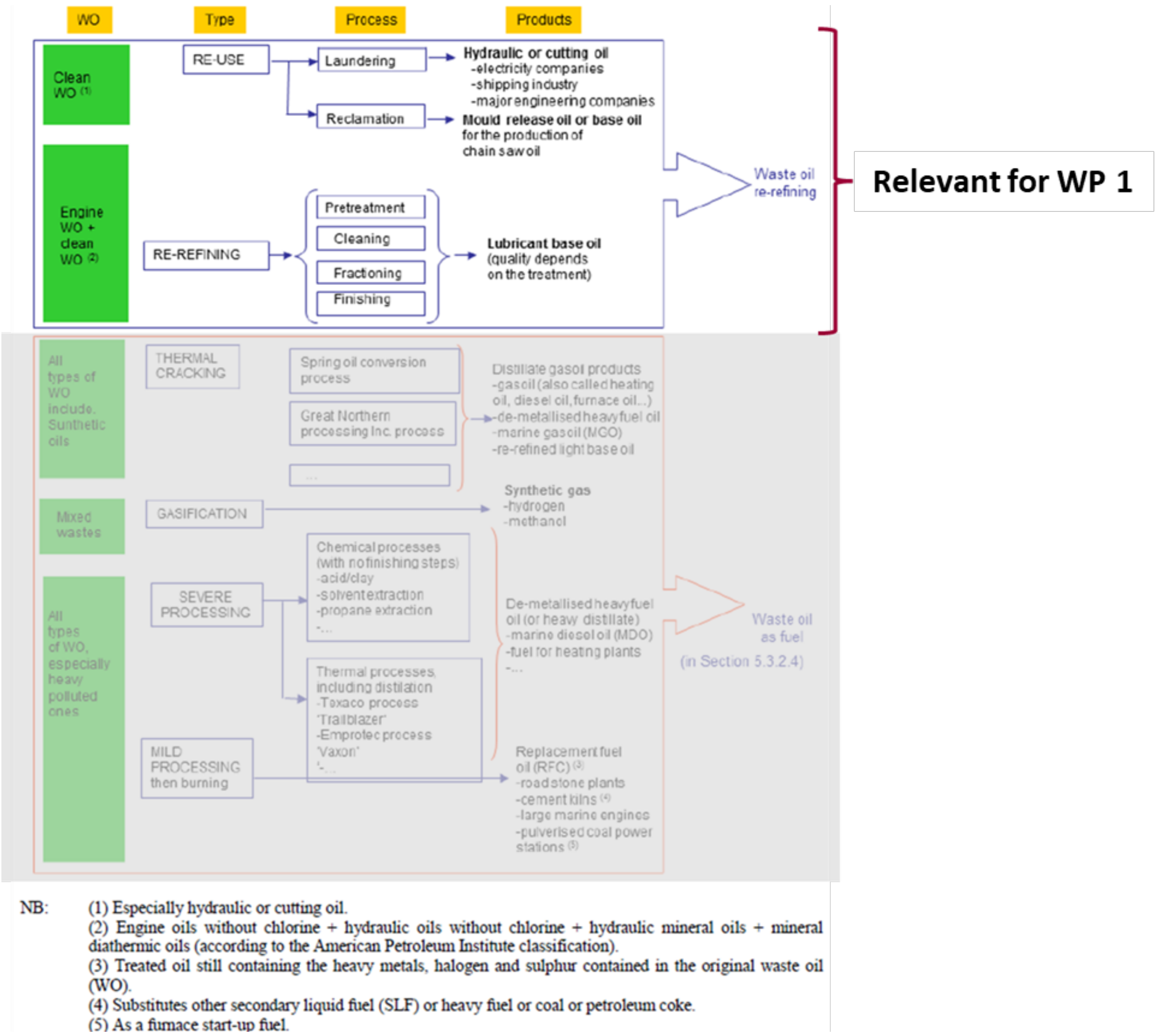
Two methodological approaches are employed to research and assess the technical options for processing waste oils.

First, we review and analyze relevant content from the BREF reference document on waste treatment (Pinasseau et al. 2018). Second, we conduct a survey of waste oil regeneration companies located in Germany to gather their evaluations regarding the technical reprocessability of various types of waste oils, categorized by different waste codes.

2.1.1 Evaluation of BREF document on waste treatment

In principle, the BREF document on waste treatment (Pinasseau et al. 2018) distinguishes between re-refining (processing into base oil) and processing into fuels. The processes of re-refining are relevant to this study (cf. Figure 2).

Figure 2: Classification of waste oil utilisation processes according to the BREF document



Source: (Pinasseau et al. 2018)

Within re-refining, a further distinction is made between the cleaning of waste oil and the actual re-refining process. The steps that are differentiated here – without consideration of pre-treatment - and described below are the cleaning, fractionation and finishing of waste oil.

2.1.1.1 Cleaning of waste oils - "Cleaning of waste oils"

Cleaning involves deasphalting or the removal of asphalt residues such as heavy metals, polymers, additives and other degradation products. This is usually done by distillation, solvent extraction and the addition of acids (Pinasseau et al. 2018).

2.1.1.2 Fractionation

During fractionation, the base oils are separated according to their slightly different boiling temperatures to produce two or three cuts (distillation fractions).

2.1.1.3 Finishing: Re-Refining waste oil

This primarily involves the final purification of the various fractions (distillation fractions) to achieve certain product specifications (e.g. improvement of colour, odour, thermal and oxidation stability, viscosity). The final treatment can also include the removal of PAHs in the case of a strong hydrofinishing treatment (high temperature and high pressure) or solvent extraction (low temperature and low pressure).

The BREF document lists five refinement techniques: alkali treatment, bleaching earth, clay polishing, hydrotreatment and solvent cleaning (Pinasseau et al. 2018). The first three techniques improve the colour properties of the oil, among other things, but there is no comprehensive removal of pollutants.

In **hydrotreatment**, chlorine and sulphur are removed from the waste oil fraction at high temperatures in a hydrogen atmosphere and contact with a catalyst and converted into HCl and H_2S. Phosphorus, lead and zinc are also removed in this process. PAHs can be removed by strong hydrofinishing (high temperature and with hydrogen under high pressure) (Pinasseau et al. 2018). The quality of the distillates is very high and the mineral oil fractions are immediately marketable.

Solvent cleaning removes PAHs from the base oils by extracting them into the solvent. Solvent cleaning also improves the colour and viscosity index (Pinasseau et al. 2018). For extraction, the input oil must already be freed of all heavy metals etc. and fractionated as desired. The product is a high-quality base oil (Pinasseau et al. 2018).

2.1.1.4 Components of waste oil

In addition to a description of the waste oil treatment steps, the BREF document provides an overview of intentionally added components (additives) and typically contained impurities (Pinasseau et al. 2018). These are listed in Table 2 and Table 3 respectively. In addition, the BREF document provides information specifically on components contained in industrial waste oils. These are listed in Table 4 reproduced.

Table 2: Types of waste oil additives and components

Type of additive	Connections used
Anti-corrosion/ Corrosion protection	Zinc dithiophosphates, metal phenolates, fatty acids and amines
Anti-foam agent	Silicone polymers, organic copolymers
Antioxidant	Zinc dithiophosphates, hindered phenols, aromatic amines, sulphurised phenols
Anti-wear/ Wear protection	Zinc dithiophosphates, acid phosphates, organic sulphur and chlorine compounds, sulphurised fats, sulphides and disulphides
Detergent	Organometallic compounds of sodium, calcium and magnesium phenolates, phosphonates and sulphonates

Type of additive	Connections used
Dispersant/ Dispersing agent	Alkylsuccinimides, alkylsuccinic esters
Friction modifier	Organic fatty acids, lard oil, phosphorus
Metal deactivator	Organic complexes containing nitrogenous and sulphurous amines, sulphides and phosphites
Pour-point depressant	Alkylated naphthalene and phenolic polymers, polymethacrylates
Seal swell agent	Organic phosphates, aromatic hydrocarbons
Viscosity modifier	Polymers made from olefins, methacrylates, dienes or alkylated styrenes

Source: Pinasseau et al. 2018

Table 3: Indicative list of possible waste oil components

Waste oil components	Concentration range (ppm, unless otherwise stated)	Origin/comments
Al	4-1112	Bearing wear or engine wear
Alkylbenzenes	900	Petroleum-based oils
Aromatic compounds	14-30 w/w-%	In the case of used engine oil, these result from the base oil of the lubricant
Aliphatic compounds	65.4 w/w-%	N-alkanes make up about 0.4% of the waste oil, but the distribution is shifted in favour of the longer molecules, which are less likely to evaporate: Tetralin 0.0012 % Dodecane 0.014 % Tridecane 0.014 % Octadecane 0.07 % Nonadecane 0.2 %
Antifreeze	NI	NI
As	< 0.5-67	NI
Ash content	0.4-0.64 ( )[1]	NI
Ba	50-690	Detergent additives[8] , additive package

[8] Barium is used in the industrial sector as a detergent additive (ECHA 2023) and has historically been frequently detected in waste oils (Eurofins 2017).

Waste oil components	Concentration range (ppm, unless otherwise stated)	Origin/comments
BTEX	300-700	A composite analysis shows a high level of short-chain hydrocarbons (benzene (0.096–0.1 %), xylenes (0.3–0.34 %), toluene (0.22–0.25 %)), with boiling points below 150 °C..
Ca	900-3000	Additive, mainly in engine oils and hydraulic oils containing zinc, to dissolve impurities and keep them in suspension
Cd	0.4-22	NI
Cl	184-1500 ( )[2]	Chlorine in waste oils arises from: - contamination (either accidental or deliberate) with chlorinated solvents and transformer oils, both of which are now more closely controlled; - lubricating oil additives; - the lead scavengers added to leaded gasoline. - cold-flow additives.
Chlorinated hydrocarbons	37 6300 18-2800 18-2600 3-1300	Dichlorodifluoromethane, Trichlorotrifluoroethane, Trichloroethanes, Trichloroethylene, Perchloroethylene Waste oils can have a significant but variable chlorine content, including organochlorine compounds such as PCBs, dichlorodifluoromethane, trichlorotrifluoroethane, 1,1,1-trichloroethane, trichloroethylene and tetrachloroethylene. They may be formed chemically during the use of contaminated oil..
Cr	2-89	Engine wear
Cu	< 11-250	Bearing wear
Engine blowback	8-10 w/w-%	Absorbed gas, petrol and diesel fuel. A large number of "thermal degradation products" are also contained in the composition of waste oil.
Fe	100-500	Motor wear
Halides	up to 500	NI
Heavy hydrocarbons		They arise from polymerisation and from the incomplete combustion of the fuel. .
Hg	0.05- < 11	NI

Waste oil components	Concentration range (ppm, unless otherwise stated)	Origin/comments
Light hydrocarbons	5-10 w/w-%	A certain amount of unburnt fuel (gasoline or diesel) dissolves in the oil and also arises from the breakdown of the oil.
Lubricant base oil	Up to 95 w/w-%	Major components are aliphatic and naphthenic hydrocarbons and/or olefin polymers (e.g. polybutenes and poly-alpha-olefins in some lube base oils). Smaller amounts of aromatic and polyaromatic hydrocarbons are also present. The heavy metal content is less than 500 ppm. Phenols may be present at a few ppm.
Metals such as Al, As, Ba, B, Ca, Cd, Co, Cr, Cu, Fe, Hg, K, Mg, Mn, Na, Ni, P, Pb, Sb, Si, Sr, Ti, V, Zn	Up to 10000 combined	They originate from lubricating oil additives, engine wear and from external sources. They occur in waste oils as additives in the lubricating oil, through engine wear and in machining oils. The additives (especially the metals) usually remain in the oil after use.
Mg	100-500	Detergent additives
Ni	10	Motor wear
Naphthalene	9.7-470-2300 (4)	From base oils
Nitrogen compounds	NI	Due to the addition of nitrogen compounds
Non-lubricant-related compounds	NI	Waste oil is often contaminated by all sorts of substances, usually due to poor collection/segregation. This includes brake fluid and antifreeze, vegetable oils, cigarette packets, solvents, etc.
P	6-1000	Antioxidants/anti-wear additives
PAHs	30.3-204- < 1000 (3) The sum of the 26 individual PAHs accounted for 0.17 % of the oil or 1.2 % of the aromatic fraction.	Aromatics also include a wide range of PAHs in concentrations of up to 700 ppm for a single species. They are formed in base oils and during incomplete combustion. Examples are benzo(a)anthracene (0.87-30 ppm), benzo(a)pyrene (0.36-62 ppm), pyrene (1.67-33 ppm), naphthalene (47 ppm), biphenyl (6.4 ppm) and also chlorinated polyaromatics.
PCB	<0.5-11- < 50	Under the Waste Oil Directive, the maximum content of PCB allowed in used oils to be treated for disposal is 50 ppm. It occurs due to contamination with transformer oils.

Waste oil components	Concentration range (ppm, unless otherwise stated)	Origin/comments
Pb	8-1200 Up to 14000 when using leaded petrol	Leaded gasoline/ bearing wear
S	0.1-2.8 % by weight	From base oil and combustion products.
Sediments	0.5-2 % by weight	Soot and sediment from the combustion chamber, free metals and dirt. Sediment formation is aggravated by the mixing of used oils from several manufacturers' additive packages, and collection sources.
Si	50-100	Additives/water
Sn	Small quantities	Bearing wear
Tl	0,1	NI
V	300	From base oil
Water	5-10 w/w-% (4)	Combustion
Zn	6-4080	Antioxidants/anti-wear additives

(1) Both parameter limits are average values.
(2) Up to 8,452 ppm in collected waste oil due to contamination with chlorinated solvents and sea salt from marine waste.
(3) If three numbers appear in a range, the middle number is the average.
(4) Up to 30 %.
NB: The additions of the numbers cannot be perfectly matched as they correspond to different data sets.
NI = No information.
Source: Pinasseau et al. 2018

Table 4: Indicative list of possible components of industrial waste oils

Waste oil component	Concentration*	Reason
Cadmium	50 % of the concentration in lubricating oil or 0.000155 %.	Cadmium is currently being phased out from the manufacture of lubricating oil.
Chrome	100 % of the concentration in the lubricating oil or 0.0028 %.	Common: typically used at the same level as in engine oil.

Waste oil component	Concentration*	Reason
Copper	100 % of the concentration in lubricating oil or 0.025 %	Common: typically used at the same level as in engine oil
Naphthalene	0.0042 %	No data at all, naphthalene is in all oils, but one would expect the formulation to have the lowest amount possible (taken from fuel oil no6 content) because it would be a solid at room temperature and does not seem to add anything chemically useful to the formulation.
Nickel	0.0028 %	No data for lubricating oils
PCB	NI	Found in transformer coolant oils
Xylole	0.22 %	NI
Zinc	50 % of the concentration in lubricating oil or 0.029 %	A common component in machining, but zinc appears to be an important additive in lubricating oils.

*) For percentage data on the concentration in lubricating oils, see Table 3

NI = No information.

Source: Pinasseau et al. 2018

2.1.2 Conclusion

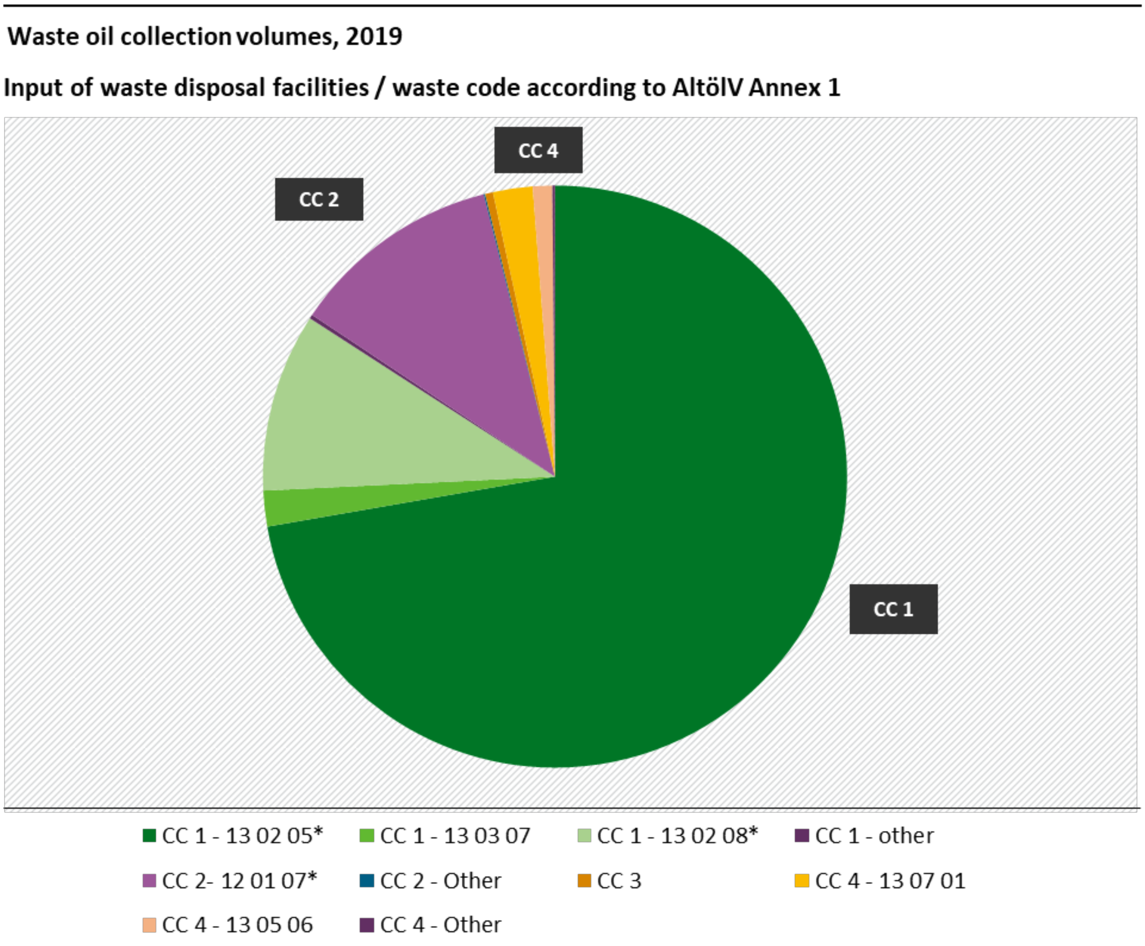
The BREF document offers fundamental descriptions of waste oil regeneration processes and provides an overview of the typical components found in waste oils. However, it is not possible to draw direct conclusions about other types of waste oils suitable for regeneration based on waste codes (beyond those listed in collection category 1). This limitation arises because the BREF does not adequately categorize components by waste oil types, nor does it comprehensively describe the "tolerance" of various processes or technologies regarding different components or impurities. Nevertheless, the tables detailing the typical constituents in waste oils (specifically Table 2 to Table 4) serve as a valuable foundation for planning waste oil analyses.

2.2 Waste oil collection situation

Waste statistics on the annual quantities of waste oil that are sent to waste disposal facilities as input are available from the Federal Statistical Office (table number 32111-0004)[9]. The amounts for the waste codes associated with the waste oil collection categories, as outlined in the Waste Oil Ordinance Act Annex 1, can be found in Table 5 and Figure 3. It should be noted that these quantities include water, whereas the calculation model for waste oil flows (back-calculation model) works with water-free waste oil quantities (dry quantities). Imports and exports from abroad are also included in these quantities.

[9] Database genesis online

Figure 3: Waste oil collection volumes



Source: Destatis, waste disposal surveys

Table 5: Collection quantities of CC1-4 waste oils in 2019

Collection category	Waste code	Description	Quantity (input from waste disposal plants) [1000 tonnes]
1	13 01 10*	Mineral based non-chlorinated hydraulic oils	1
	13 02 05*	Mineral-based non-chlorinated engine, gear and lubricating oils	450,9
	13 02 06*	Synthetic engine, gear and lubricating oils	0,4
	13 02 08*	Other engine, gear and lubricating oils	61,9
	13 03 07*	Mineral-based non-chlorinated insulating and heat transmission oils	12,4
2	12 01 07*	Mineral-based machining oils free of halogens (except emulsions and solutions)	73
	12 01 10*	Synthetic machining oils	0,4
	13 01 11*	Synthetic hydraulic oils	0

Collection category	Waste code	Description	Quantity (input from waste disposal plants) [1000 tonnes]
	13 01 13*	Other hydraulic oils	0,1
3	12 01 06*	Mineral oil-based machining oils containing halogens (except emulsions and solutions)	0,2
	13 01 01*	Hydraulic oils, containing PCBs	0,1
	13 01 09*	Mineral-based chlorinated hydraulic oils	-
	13 02 04*	Mineral-based chlorinated engine, gear and lubricating oils	1
	13 03 01*	Insulating or heat transmission oils containing PCBs	1,4
	13 03 06*	Mineral-based chlorinated insulating and heat transmission oils other than those mentioned in 13 03 01	-
4	13 01 12*	Readily biodegradable hydraulic oils	0
	13 02 07*	Readily biodegradable engine, gear and lubricating oils	0
	13 03 08*	Synthetic insulating and heat transmission oils	0,3
	13 03 09*	Readily biodegradable insulating and heat transmission oils	0
	13 03 10	Other insulating and heat transmission oils	0,6
	13 05 06	Oils from oil/water separators	6,7
	13 07 01	Fuel oil and diesel	13,7

Source: Destatis, waste disposal surveys

Waste oils in collection category 1 represent the largest proportion at approximately 83%. Within this category, waste code 13 02 05* (non-chlorinated mineral oil-based machinery, gear, and lubricating oils) comprises 97% of the total quantity. Collection category 2 accounts for 13% of the overall quantity, with 99% of this category attributed to waste code 12 01 07* (halogen-free mineral oil-based machining oils). waste oils in collection category 3 account for less than 1% of the total quantity, while waste oils in collection category 4 make up just over 1%. Within this category, waste code 13 05 06* (oils from oil/water separators) is particularly significant, representing 88% of the volume.

In addition to the waste codes associated with collection categories 1-4 as per the Waste Oil Ordinance, waste containing oil is also collected under other waste codes. These include emulsions (WC 120108*, 120109*, 130104*, 130105*), bilge oils (WC 130401*, 130402*, 130403*), and other oily waste with high water content (WC 120119*, 130507*). Other waste types include greases and waxes (WC 12 01 12*), fuels and combustibles (WC 130702*, 130703*, 190207*), and mixed waste containing at least one hazardous substance (WC 190204*).

Table 6: Other waste containing (waste) oil

Type / Typing	Waste code	Description	Quantity (input from waste disposal plants) [1000 tonnes]
Emulsions	120108*	Machining emulsions and solutions containing halogens	1,6
	120109*	Machining emulsions and solutions free of halogens	602,9
	130104*	Hydraulic oils: chlorinated emulsions	-
	130105*	Hydraulic oils: Non-chlorinated emulsions	7,3
Bilge oils	130401*	Bilge oils from inland navigation	5,2
	130402*	Bilge oils from jetty sewers	-
	130403*	Bilge oils from other navigation	107,2
Other oily waste with a high water content	120118*	Metal sludge (grinding, honing and lapping sludge) containing oil	50,8
	130507*	Oily water from oil/water separators	38,3
Greases and waxes	120112*	SPent waxes and fats	5,5
Fuels and combustibles	130702*	Petrol	0,9
	130703*	Other fuels (including mixtures)	19,2
Other mixed waste	190207*	Oil and concentrates from separation	161,1
	190204*	Premixed wastes composed of at least one hazardous waste	994

Reference year: 2019

Source: Destatis

2.3 Stakeholder survey

In addition to analysing the BREF document, a survey was conducted among stakeholders involved in waste oil regeneration. This survey gathered data on input and output quantities, which is used to update the back-calculation model (see section 3.3). Questions were also included regarding the types of waste oil that may be suitable for regeneration.

This part of the survey revealed that potential for reprocessing is seen for various waste codes from collection categories 2 and 4.

Collection category 2

Within collection category 2, waste code 12 01 07*—halogen-free mineral oil-based metalworking oils—was frequently cited as potentially suitable for reprocessing. Stakeholders specified that these oils must be purely mineral oil-based, without any added fatty acids, and should not be excessively contaminated from use. Currently, stakeholders do not see any reprocessing potential for ester oils. Two stakeholders also identified potential for reprocessing waste codes 12 01 10* (synthetic machining oils) and 13 01 11* (synthetic hydraulic oils), provided that these oils are polyalphaolefins (PAO) and not esters. Additionally, two stakeholders mentioned waste code 13 01 13* (other hydraulic oils) as suitable for reprocessing. Overall, a regeneration potential is recognized for various waste oils within collection category 2.

Collection category 3

Waste oils in collection category 3 were not identified as suitable for regeneration now or in the future.

Collection category 4

Specific stakeholders have identified waste oils in collection category 4 as suitable for reprocessing, both currently and in the future. The following waste codes were mentioned:

- 13 03 09* readily biodegradable insulating and heat transmission oils
- 13 03 10 other insulating and heat transmission oils
- 13 05 06 oils from oil/water separators
- 13 07 01 fuel oil and diesel

For waste code 13 03 10 (insulating and heat transfer oils), established collection and recycling pathways already exist through fixed collaborations between users and waste oil reprocessors.

2.4 Conducting waste oil analyses

The analyses of waste oil were conducted in several phases. The first phase took place from November 2021 to February 2022, during which 10 analyses were performed. The selection of the types of waste oil sampled and the parameters for analysis were based on the criteria outlined in section 2.1 to 2.3 and in consultation with the German Environment Agency. Following the results from this initial phase, two additional analysis phases were conducted.

2.4.1 Phase 1

Ten analyses were carried out in this first phase of waste oil analysis: three analyses of CC1 waste oils from different collections and seven analyses of CC2 waste oils.

Analysis of CC1 waste oils

CC1 waste oils constitute the majority of waste oils generated in Germany. The requirements for lubricants used in this category, which are primarily produced for the automotive sector, are continuously increasing. This results in a consistent change in their composition, potentially introducing new ingredients. Additionally, substances such as chlorine compounds and PCBs are likely to play a diminishing role due to their gradual elimination from the market.. Regular analysis of the composition and its changes is therefore essential, especially regarding modifications that could impair or hinder the reprocessing of these oils. It is also necessary to gather relevant data to establish a basis for comparing the potential suitability of CC2 waste oils for regeneration. Representative average samples can be collected from the typically large input tanks of regeneration plants, or alternatively from interim storage facilities used in the collection process.

Analysis parameters:

- PCB, chlorine
- Esters (proportion of added "bio-oils" as FAME content)
- Element screening (abrasion, additive elements, sulphur, additionally As, Cd, Hg)
- Water content
- Standard parameters typical of mineral oils (density, viscosity, ash content)
- Flash point
- Boiling range analysis GC (SIMDEST)

Analysis of CC2 waste oils

Waste oils of waste code 12 01 07* (halogen-free mineral oil-based machining oils) play a special role within CC2 waste oils. On the one hand, this is due to the high volume relevance of this waste code (around 99 % of the quantity of CC2 waste oils are assigned to this waste code, cf. section 2.2); on the other hand, the results of the stakeholder survey to date have also shown that a possible potential for reprocessing is seen with regard to WC 12 01 07*.

Following on from this, 40 safety data sheets on lubricants assigned to WC 12 01 07* were analysed. On this basis, it was decided to sample and analyse 3-4 waste oils from different types of metalworking (grinding, machining of low to medium alloyed steels, machining of high alloyed steels) at the point of origin.

The evaluation of the safety data sheets has also shown that various lubricants are assigned to waste code 12 01 07* that are not used in metalworking. These include, for example, heat transmission oils, release agents for polyether/polyurethane and mould release agents. These oils may differ from metalworking oils in terms of additives and impurities from the application. To take this into account, it was decided to take 3-4 samples of mixed CC2 waste oils and analyse them.

<u>Analysis parameters:</u>

- PCB, chlorine
- Esters (proportion of added "bio-oils" as FAME content)
- Element screening (abrasion, additive elements, sulphur, additionally As, Cd, Hg)
- Water content
- Standard parameters typical of mineral oils (density, viscosity, ash content)
- Flash point
- Boiling range analysis GC (SIMDEST)

2.4.1.1 Sample procurement procedure

Sampling of the 10 waste oil samples

1) 3 x CC1

2a) 4 x AVV 12 01 07*

2b) 3 x CC2-4

took place in the period from 23 November 2021 to 16 February 2022.

The samples for 1) and 2b) were each taken from tanker deliveries at the Dollbergen refinery in the form of qualified sampling in accordance with DIN 51750-2 by laboratory employees of AVISTA OIL Deutschland GmbH using a cap sampler. The sample quantity was 1 litre in each case. The waste oils from the tanker deliveries originate from larger tank farms for the temporary storage of waste oils of the respective collection category from the nationwide collection.

The samples for 2a) were taken directly from the waste producer in the form of a side stream sample in accordance with DIN 51750-2 when the waste oil was transferred to the tank truck. The type of metalworking from which the sample originated was also noted in the sampling protocol. The sample quantity was 0.5 litres in each case.

The samples were transferred to suitable sample containers immediately after sampling and labelled with clear, traceable identification. The samples 2a) from the collection points were immediately forwarded to the laboratory of AVISTA OIL Deutschland GmbH for further analyses.

2.4.1.2 Sample preparation

The samples were prepared according to the requirements of the individual analysis methods.

2.4.1.3 Information on laboratory analysis

All analyses were carried out by the laboratory of AVISTA OIL Deutschland GmbH.

The following analysis methods were used for the individual, defined parameters:

- PCB content: DIN EN 12766-1; DIN EN 12766-2
- Chlorine content: DIN 51577-4
- Ester content: DIN EN 14078
- Element screening: X-ray fluorescence analysis (XRF) according to AVISTA test instruction PA_109
- Total sulphur: DIN EN ISO 8754
- Water content: DIN ISO 3733
- Density at 15°C: DIN EN ISO 3675
- Viscosity at 40°C: ASTM D7279
- Oxide ash content: DIN EN ISO 6245
- Flash point PMCC: DIN EN ISO 2719
- Boiling range GC: DIN 51435

2.4.1.4 Laboratory report / results

The results of the investigations are summarised in the following tables:

Table 7: Summary of the analysis results of the waste oil samples

			1) Altöle Sammelkategorie 1			2a) Altöle Sammelkategorie 2 - AVV 12 01 07				2b) Altöle Sammelkategorie 2 - 4		
Probe-Nr. AN-			0810944-02	0810946-02	0810995-02	0816205-01	0816684-01	0816686-01	0817434-01	0808889-02	0809844-02	0810095-02
Probenahmedatum			13.12.2021	13.12.2021	14.12.2021	18.01.2022	01.02.2022	01.02.2022	16.02.2022	23.11.2021	02.12.2021	06.12.2021
Probenahmeort			Altöleingang			Betrieb				Altöleingang		
Art der Bearbeitung 2a)						Tiefziehen Aluminium	Kaltumformung	Hartdrehen - High Speed Cutting	Drehen - Zerspanen			
Einstufung *			A	A	A	NA	NA	NA	BA	NA	NA	NA
Parameter	**Einheit**	**Methode**										
Dichte 15°C	kg/l	EN ISO 3675	0,882	0,878	0,873	0,896	0,837	1,04	0,875	0,860	0,887	0,861
Viskosität bei 40 °C (kin)	mm^2/s	ASTM D7279	72,1	54,4	55,7	83,8	10,4	n.b.	37	19,2	17,0	12,7
FAME - Gehalt	Vol.%	DIN EN 14078	0,3	1,2	1,8	23,7	3,0	n.n.	2,0	14,8	11,0	8,2
Flammpunkt PMCC	°C	DIN EN ISO 2719	> 100	78	91	> 70	84	75	> 90	> 90	68	76
Wasser, destillativ	Gew.%	DIN ISO 3733	2,7	6,9	4,5	< 0,1	0,1	69	< 0,1	< 1,0	14,5	2,4
Oxid-Asche	Gew.%	DIN EN ISO 6245	0,56	0,50	0,56	< 0,01	0,35	n.b.	1,68	0,47	0,09	0,09
Polychlorierte Biphenyle	mg/kg	DIN EN 12766-1,2(B)	n.n.	n.n.	n.n.	n.n.	2,0	0,5	n.n.	n.n.	1,5	13
Chlor, RFA	Gew.%	DIN 51577-4	0,0100	0,0042	0,0043	0,0020	0,0046	0,0295	0,0008	0,0100	0,0034	0,0458
Gesamtschwefel, RFA	mg/kg	DIN EN ISO 8754	3.090	2.530	2.980	13.300	1.700	1.689	5.940	6.270	5.976	1.410
Elementscreening RFA		AOD PA_109										
Aluminium	mg/kg		73	56	58	365	29	37	71	119	133	78
Antimon	mg/kg		n.n.	n.n.	n.n.	n.n.	n.n.	n.n.	n.n.	n.n.	n.n.	n.n.
Arsen	mg/kg		1	1	2	n.n.	n.n.	n.n.	n.n.	n.n.	n.n.	n.n.
Barium	mg/kg		6	4	4	n.n.	n.n.	1	n.n.	n.n.	n.n.	2
Bismut	mg/kg		n.n.	1	1	n.n.	n.n.	n.n.	n.n.	1	n.n.	n.n.
Blei	mg/kg		3	3	4	n.n.	n.n.	n.n.	3	4	1	1
Brom	mg/kg		1	3	2	n.n.	n.n.	n.n.	n.n.	n.n.	n.n.	n.n.
Cadmium	mg/kg		n.n.	n.n.	n.n.	n.n.	n.n.	n.n.	n.n.	n.n.	n.n.	n.n.
Calcium	mg/kg		1.380	1.110	1.430	18	136	423	5.140	2.490	91	132
Chrom	mg/kg		1	2	3	n.n.	n.n.	1	1	n.n.	n.n.	1
Eisen	mg/kg		45	99	77	1	31	155	45	10	26	46
Kobalt	mg/kg		n.n.	1	n.n.	n.n.	n.n.	n.n.	n.n.	n.n.	n.n.	n.n.
Kupfer	mg/kg		15	18	25	1	5	1	3	4	3	7
Magnesium	mg/kg		25	24	66	n.n.	n.n.	84	n.n.	n.n.	n.n.	n.n.
Mangan	mg/kg		2	3	3	n.n.	n.n.	7	17	5	2	2
Molybdän	mg/kg		20	26	33	n.n.	n.n.	n.n.	n.n.	1	1	5
Nickel	mg/kg		4	4	4	3	3	1	3	3	3	3
Phosphor	mg/kg		545	546	649	163	52	526	38	180	264	207
Quecksilber	mg/kg		n.n.	n.n.	n.n.	n.n.	n.n.	n.n.	n.n.	n.n.	n.n.	n.n.
Silicium	mg/kg		31	42	24	n.n.	7	25	8	19	14	3
Thallium	mg/kg		n.n.	n.n.	n.n.	n.n.	n.n.	n.n.	n.n.	n.n.	n.n.	n.n.
Titan	mg/kg		n.n.	n.n.	1	n.n.	n.n.	n.n.	n.n.	n.n.	n.n.	n.n.
Vanadium	mg/kg		n.n.	n.n.	n.n.	n.n.	n.n.	n.n.	n.n.	n.n.	n.n.	n.n.
Wolfram	mg/kg		1	2	2	n.n.	n.n.	1	n.n.	1	1	1
Zink	mg/kg		543	587	659	5	24	60	107	58	33	86
Zinn	mg/kg		n.n.	n.n.	n.n.	n.n.	n.n.	n.n.	n.n.	n.n.	n.n.	n.n.

Table 8: Summary of the analysis results of the waste oil samples (continued)

			1) Altöle Sammelkategorie 1			2a) Altöle Sammelkategorie 2 - AVV 12 01 07				2b) Altöle Sammelkategorie 2 - 4		
Probe-Nr. AN-			0810944-02	0810946-02	0810995-02	0816205-01	0816684-01	0816686-01	0817434-01	0808889-02	0809844-02	0810095-02
Probenahmedatum			13.12.2021	13.12.2021	14.12.2021	18.01.2022	01.02.2022	01.02.2022	16.02.2022	23.11.2021	02.12.2021	06.12.2021
Probenahmeort			Altöleingang			Betrieb				Altöleingang		
Art der Bearbeitung 2a)						Tiefziehen Aluminium	Kaltumformung	Hartdrehen - High Speed Cutting	Drehen - Zerspanen			
Einstufung *			A	A	A	NA	NA	NA	BA	NA	NA	NA
Parameter	Einheit	Methode										
Simulierte Destillation GC		DIN 51435										
Simdest Siedebeginn	°C		175	179	119	185	177	n.b.	157	216	135	136
Simdest 5%	°C		352	380	370	201	191	n.b.	229	324	186	197
Simdest 10%	°C		383	399	392	417	199	n.b.	246	343	211	223
Simdest 15%	°C		398	410	403	445	203	n.b.	286	354	241	239
Simdest 20%	°C		409	419	410	459	211	n.b.	332	363	270	260
Simdest 25%	°C		417	426	416	469	225	n.b.	362	370	287	279
Simdest 30%	°C		424	433	422	478	317	n.b.	384	377	303	295
Simdest 35%	°C		430	441	426	487	340	n.b.	392	382	319	311
Simdest 40%	°C		437	449	431	496	357	n.b.	401	386	339	335
Simdest 45%	°C		444	457	436	505	371	n.b.	409	390	357	365
Simdest 50%	°C		452	467	442	514	385	n.b.	415	395	374	389
Simdest 55%	°C		461	476	448	524	396	n.b.	421	401	388	404
Simdest 60%	°C		470	485	455	535	410	n.b.	426	408	407	415
Simdest 65%	°C		480	494	463	547	423	n.b.	432	419	439	424
Simdest 70%	°C		491	504	471	560	437	n.b.	438	433	465	432
Simdest 75%	°C		503	514	480	575	453	n.b.	445	454	486	442
Simdest 80%	°C		517	526	490	592	471	n.b.	453	475	510	454
Simdest 85%	°C		534	538	503	609	490	n.b.	465	494	540	466
Simdest 90%	°C		556	554	521	616	510	n.b.	489	540	578	476
Simdest 95%	°C		592	579	547	626	539	n.b.	535	596	610	499
Simdest Siedeende	°C		638	635	632	642	609	n.b.	630	632	638	558

* A - aufbereitbar
BA - bedingt aufbereitbar
NA - nicht aufbereitbar

No English version of these tables was available. The tables report physical, chemical, and elemental analysis data for different waste oil samples, each representing a specific type of metal processing, such as "grinding," "cutting," "drilling," "milling," and "turning." The samples are labelled with "Probe Nr." (sample number) and have corresponding test dates and processing types. The table is divided into several key sections:

Physical and Chemical Parameters: Includes measurements of: Density at 15°C (g/ml): Ranges between 0.83 and 0.86 for most samples, indicating slight variations in fluid composition. Viscosity at 40°C (mm²/s): Shows differences in viscosity, important for assessing how the fluid behaves under heat. For example, viscosity values range from around 29 to 146 across the samples. FAME Content (% m/m): Fatty acid methyl esters (FAME), found in biodiesel, are measured here, with values around 0.8–1.5%. Water Content (% v/v): Ranges from 0.1% to 0.5%, indicating the presence of water in the fluids, important for understanding their stability and effectiveness in lubrication. Acid Value (mg KOH/g): Varies between 0.4 and 0.9, indicating the level of acidity, which affects fluid reactivity and corrosion potential. Polyolester and Chlorine Content (g/kg): These are presented in lower concentrations (usually less than 0.1–0.5 g/kg), relevant for assessing environmental and operational safety, as some elements can be harmful. Elemental Analysis (RFA): Provides concentrations of metals like: Aluminum (mg/kg): Detected in some samples, ranging from around 10 to 350 mg/kg. Iron, Copper, and Zinc (mg/kg): Levels range across samples (e.g., iron: up to 320 mg/kg, copper: less than 1 to 15 mg/kg, zinc: up to 4 mg/kg), which helps assess potential contamination and wear. Other elements: Includes metals like barium, calcium, lead, nickel, and others, which vary between being detected (e.g., calcium at 700–2200 mg/kg) and being below the detection limits (noted as "n.n.").

Each sample is classified based on its recyclability:

- A (aufarbeitbar): Suitable for recycling.
- BA (bedingt aufarbeitbar): Conditionally recyclable.
- NA (nicht aufarbeitbar): Not recyclable.

Table 8 focuses on simulated distillation data, which gives insight into how the fluids evaporate at different temperature points, a crucial factor for understanding thermal stability and performance under operational conditions. The key parameters here are: Boiling Point Temperatures: Data is provided for various boiling fractions, from 5% to 95% of the fluid evaporated. For example, at the 50% distillation point, temperatures range from approximately 300°C to 430°C, which indicates how different samples behave under heat. This is critical in evaluating whether the fluids will maintain their lubricating properties at high temperatures or break down. Simulated Distillation GE (°C): Each percentage point of evaporation (e.g., 5%, 10%, 30%, up to 95%) has an associated temperature reading. For instance, sample 12-08 reaches 95% distillation at 651°C, whereas sample 12-12 does so at 614°C. This second table also applies the same recyclability classification system ("A", "BA", "NA") to assess the reusability of the fluid samples after use in metalworking processes. Overall, the two tables together present a detailed analysis of the fluid samples in terms of their composition, potential contaminants, physical properties, and their behaviour during heating, all of which contribute to decisions about whether these fluids can be recycled or reused after their initial use.

2.4.1.5 Interpretation and presentation of results

The results of the analyses of the 10 waste oil samples are shown in Table 7 and Table 8 are summarised. The fifth row (classification) indicates whether the respective waste oil is to be classified as suitable for regeneration (A), or conditionally recyclable (BA) or not recyclable (NA) based on the analysis results. The data that led to the NA or BA classification are highlighted in red.

1) Waste oils CC1:

As expected, the samples from the collection of CC1 waste oils show no abnormalities. They show typical data and thus confirm their suitability for processing into base oils.

2a) Waste oils WC 12 01 07*:

Of the WC 12 01 07* samples taken directly during waste generation, 3 (metal processing: deep drawing aluminium / cold forming / hard turning - high speed cutting) are to be classified as unsuitable for reprocessing, while the sample from the processing type "turning - machining" is to be assessed as conditionally recyclable.

Explanations of the evaluation criteria:

- **Ester content**: High proportions of esters, especially natural fatty acid esters, lead to the massive formation of residues ("fouling") in the processing plants, which can lead to frequent plant shutdowns and high cleaning costs. In addition, components that cannot be separated in the first processing stages and are found in the end product base oil can lead to quality losses (many of the esters used are sensitive to hydrolysis and thermally unstable). The determination of the ester content in the waste oils is therefore part of the routine analysis at the entrance to the processing plants. Traditionally, the so-called "Luxprobe" is used here, but this leads to a relatively unspecific yes/no statement (present - not present). Alternatively, infrared spectroscopic methods can be used to determine the FAME content in mineral oil products (here DIN EN 14078), which allows a somewhat more specific assessment. A generally applicable limit value cannot be specified, but it can be said that contents of >3 % ester content determined as FAME should lead to the exclusion of suitability for regeneration.

  The origin of the ester content can be so-called readily biodegradable lubricants that use ester oils as base oils from the outset. Waste oils resulting from these lubricants are therefore correctly categorised in collection category 4.

  In the case of metalworking considered here, however, the origin is usually due to a specific additivation. Sulphurised fatty acid esters are very often used as EP (extreme pressure)/AW (anti-wear) additives in certain types of machining, whereby the additivation is usually quite high. In the waste oil from the "deep-drawing aluminium" process considered here, this can be seen from the values for FAME (23.7% by volume) and sulphur (13,300 mg/kg).

- **Viscosity**: Very "thin" oils are often used, particularly in metalworking applications where the lubricant is primarily used for cooling. These are based on base oils with comparatively very low viscosities. When processing waste oils of this origin, the majority of the base oil would be produced as a gas oil component in the by-product stream. This leads to yield losses and possibly (with higher contents) to impairments in process control. CC1 waste oils generally have viscosities in the range between 40 and 70 mm^2/s at 40°C (V40). The waste oil from cold forming has a V40 of 10.4 mm^2/s, which corresponds to a gas oil or very thin base oil (the low density corresponds with this finding).

- **Water content**: The waste oil from hard turning has an unusually high water content of 69% by weight. This is unexpected, as it should be a water-immiscible lubricant (meaning it should not form an emulsion). It is possible that water was introduced during operation or originated from a cleaning process, leading to mixing with the used lubricant. In general, waste oils of CC1 should have a maximum water content of around 7% for regeneration. It's difficult to specify a clear limit, as the effects of higher water content are mainly economic—resulting in yield losses, increased wastewater production, and higher energy input. Typically, additional economic costs are calculated for water contents exceeding 10% in CC1 waste oils. However, water contents above 20% are likely to lead to rejection, as it cannot be ruled out that other impurities were also introduced with the added water. Rejections due to unauthorized mixtures render the oil unsuitable for the base oil train and usually result in the blocking and separation of the delivery. If it is possible to process the non-compliant goods elsewhere in the refinery or dispose of them externally, the original supplier is informed, and negotiations commence regarding cost assumption or non-payment. If no agreement is reached, the supplier must take back the goods and initiate a new disposal process.
- **Additivation**: The fourth WC 12 01 07* waste oil from the turning and machining sector appears to have a higher additivation, as indicated by the ash content and the sulphur and calcium contents. Higher additive contents can lead to correspondingly higher proportions of these components in certain by-products of regeneration but are generally not necessarily an exclusion criterion in individual cases. Therefore, this waste oil, in conjunction with the slightly lower viscosity, was categorised as conditionally recyclable.
- **Metal contents**: In principle, waste oils from metalworking can also contain higher contents of the respective processed metals (see aluminium content of the waste oil "deep-drawing aluminium"). These are then usually present in solid form as particles or dispersed in solution. If such oils are used in processing plants, it must be ensured that these metal components are separated as completely as possible during use in the plant, as otherwise abrasive effects are to be feared. In any case, there will be an increased formation of residues. Defined limit values cannot be specified here.

2b) Waste oils CC2-4:

All three waste oils from the mixed collection of CC2-4 were (as expected) categorised as non-suited for regeneration. All samples have high ester contents of 14.8 vol.%, 11.0 vol.% and 8.2 vol.%, which lead to their exclusion. The sulphur content of the first two samples is also elevated, which indicates a proportion of sulphurised fatty acid esters, while the ester content of the third sample is more likely to be due to the presence of CC4 waste oils (readily biodegradable oils). In addition, all oils are also in a low viscosity range (for explanations see comments on 2a). An increased PCB content (13 mg/kg) was also measured in the third sample.

2.4.2 Phase 2

The analysis results of the first analysis phase showed that waste oils from metalworking, especially from machining with geometrically defined cutting edges (drilling, turning, milling) - except for the machining of aluminium and non-ferrous metals - tend to be suitable for regeneration.

Waste oils from machining with geometrically indeterminate cutting edges (honing, grinding, lapping), on the other hand, as well as waste oils from forming processes (deep drawing, wire drawing, high-pressure forming, cold forming), do not appear to be suitable for regeneration according to the results of the first analysis phase.

The focus for the next 15 analyses in the second analysis phase was determined accordingly: On the one hand, the potential suitability for regeneration of waste oils from machining with a geometrically defined cutting edge is to be confirmed. On the other hand, the non-suitability of waste oils from forming processes and machining with geometrically indeterminate cutting edges is to be confirmed.

2.4.2.1 Sample procurement procedure

As the samples from the application for certain types of metalworking were to be provided for the second round of analyses, the problem arose that waste oil had to be disposed of during this period. To ensure this, support was requested from the BVA. Coordinated by the BVA, various companies provided waste oil samples from the different manufacturing processes for analysis. The samples were taken directly from the respective waste producer in the form of a side stream sample in accordance with DIN 51750-2 when the waste oil was transferred to the tank truck. The samples were transferred to suitable containers immediately after sampling and labelled with clear, traceable identification. The type of metal processing was noted in the sampling protocol according to the producer's specifications. The sample volume was 0.5 litres in each case. The samples were taken between July and November 2022 and forwarded directly to the laboratory of AVISTA OIL Deutschland GmbH for analysis. The following samples were available:

Table 9: Overview of samples from the second analysis phase

Sample number	Sampling date	Postcode of the company	Type of metalworking
1.2 - 01	07.07.2022	35XXX	Deep drawing of light metals
1.2 - 02	07.07.2022	38XXX	Machining oil, metalworking Forging Crankshafts
1.2 - 03	12.07.2022	35XXX	Machining oil for screw machining
1.2 - 04	04.08.2022	12XXX	Cutting oils Metal forming Fittings, hinges
1.2 - 06	31.08.2022	89XXX	Machining oil cooling + lubrication
1.2 - 07	24.08.2022	77XXX	Thread cutting
1.2 - 08	07.09.2022	70XXX	Cutting oil
1.2 - 09	27.09.2022	85XXX	Grinding
1.2 - 10	17.10.2022	91XXX	Drilling
1.2 - 11	27.10.2022	90XXX	Turning
1.2 - 12	07.11.2022	70XXX	Turning
1.2 - 13	28.11.2022	87XXX	Grinding, turning
1.2 - 14	29.11.2022	89XXX	Grinding oil

Sample number	Sampling date	Postcode of the company	Type of metalworking
1.2 - 15	12.2022	09XXX	Milling / Drilling
1.2 - 16	11.11.2022	47XXX	Milling (bolts, screws)

Source: Avista

2.4.2.2 Sample preparation

The samples were prepared following the requirements of the individual analysis methods.

2.4.2.3 Information on laboratory analysis

The analyses were carried out by the laboratory of AVISTA OIL Deutschland GmbH in the same way as the first analysis phase.

The following analysis methods were used for the individual, defined parameters:

- PCB content: DIN EN 12766-1,2(B)
- Chlorine content: DIN 51577-4
- Ester content: DIN EN 14078
- Element screening: X-ray fluorescence analysis (XRF) according to AVISTA test instruction PA_109
- Total sulphur: DIN EN ISO 8754
- Water content: DIN ISO 3733
- Density at 15°C: EN ISO 3675
- Viscosity at 40°C: ASTM D7279
- Oxide ash content: DIN EN ISO 6245
- Flash point PMCC: DIN EN ISO 2719
- Boiling range GC: DIN 51435

2.4.2.4 Laboratory report/ results

The results of the investigations are summarised in the following tables:

Table 10: Summary of the analysis results of the waste oil samples phase 2

			Altöle Metallbearbeitung														
Probe-Nr.			1.2 - 01	1.2 - 02	1.2 - 03	1.2 - 04	1.2 - 06	1.2 - 07	1.2 - 08	1.2 - 09	1.2 - 10	1.2 - 11	1.2 - 12	1.2 - 13	1.2 - 14	1.2 - 15	1.2 - 16
Labor-Nr.			0842434-01	842438-01	842439-01	842440-01	842442-01	23-002116-01	23-002121-01	23-002122-01	23-002157-01	23-002158-01	23-002159-01	23-002160-01	23-002163-01	23-002164-01	23-002165-01
Probenahmedatum			07.07.2022	07.07.2022	12.07.2022	04.08.2022	31.08.2022	24.08.2022	07.09.2022	27.09.2022	17.10.2022	27.10.2022	07.11.2022	28.11.2022	29.11.2022	12.2022	11.11.2022
Probenahmeort Betrieb (PLZ)			35XXX	38XXX	35XXX	12XXX	89XXX	77XXX	70XXX	85XXX	91XXX	90XXX	70XXX	87XXX	89XXX	09XXX	47XXX
Art der Bearbeitung			Tiefziehen Leicht-metalle	Bearbeitungs-öl Metall-bearbeitung Schmieden Kurbelwellen	Bearbeitungs-öl Schraubenbe-arbeitung	Schneidöle Metall-umformung Beschläge, Scharniere	Bearbeitungs-öl Kühlen + Schmieren	Gewinde-schneiden	Schneidöl	Schleifen	Bohren	Drehen	Drehen	Schleifen, Drehen	Schleiföl	Fräsen / Bohren	Fräsen (Bolzen, Schrauben)
Einstufung *			NA	A	BA	NA	NA	NA	NA	BA	NA	NA	NA	A	BA	BA	NA
Parameter	**Einheit**	**Methode**															
Dichte 15°C	kg/l	EN ISO 3675	0,895	0,874	0,850	0,857	0,852	0,909	0,843	0,835	0,865	0,870	0,855	0,845	0,853	0,840	0,857
Viskosität bei 40 °C (kin)	mm²/s	ASTM D7279	88,70	46,90	47,00	13,30	14,62	114,00	6,29	10,42	25,30	23,84	18,40	26,47	21,45	18,88	16,45
FAME - Gehalt	Vol.%	EN 14078	8,1	0,8	3,9	14,7	5,4	16,7	14,0	4,3	9,1	10,4	3,5	1,9	2,6	5,1	12,7
Flammpunkt Pensky-Martens	°C	DIN EN ISO 2719	104	> 140	95	81	85	>95	>95	95	87	>95	>95	>95	>95	>140	>140
Wasser, destillativ	Gew.%	DIN ISO 3733	< 0,1	2,1	3,6	< 0,1	< 0,1	0,6	0,1	0,1	0,1	<0,1	0,1	<0,1	<0,1	<0,1	<0,1
Oxid-Asche	Gew.%	DIN EN ISO 6245	0,13	0,07	1,07	1,60	0,85	4,51	0,07	< 0,01	0,21	0,42	0,11	0,11	0,44	0,06	0,12
Polychlorierte Biphenyle	mg/kg	DIN EN 12766-1,2(B)	n.n.	n.n.	n.n.	n.b.	n.n.	n.n	n.n	n.n.	n.n	n.n	n.n	n.n	n.n	n.n	n.n
Chlor, RFA	Gew.%	DIN 51577-4	0,0100	0,0100	0,0100	n.n.	0,0700	n.n	n.n	n.n.	n.n	0,0100	0,3200	n.n	n.n	n.n	n.n
Gesamtschwefel, RFA	mg/kg	DIN EN ISO 8754	11.560	6.610	3.327	17.980	6.128	40.500	529	6.780	2.270	26.210	3.130	4.300	6.250	8.100	7.460
Elementscreening RFA		AOD PA_109															
Aluminium	mg/kg		320	50	41	86	92	213	101	34	6	136	54	21	36	40	45
Antimon	mg/kg		n.n.	n.n.	n.n.	n.n.	n.n.	n.n	2	< 2	2	2	2	2	<2	<2	>2
Arsen	mg/kg		n.n.	n.n.	n.n.	1	n.n.	1	4	<1	1	n.n	2	1	n.n	n.n	n.n
Barium	mg/kg		n.n.	n.n.	n.n.	n.n.	n.n.	3	1	<1	8	2	1	n.n	n.n	n.n	n.n
Bismut	mg/kg		n.n.	n.n.	n.n.	n.n.	1	n.n	1	<1	1	n.n	n.n	n.n	n.n	n.n	n.n
Blei	mg/kg		n.n.	n.n.	n.n.	n.n.	2	2	178	<1	2	n.n	15	72	3	n.n	n.n
Brom	mg/kg		n.n.	n.n.	n.n.	n.n.	n.n.	n.n	1	<1	1	n.n	11	n.n	n.n	n.n	n.n
Cadmium	mg/kg		n.n.	n.n.	n.n.	n.n.	n.n.	n.n	1	1	1	n.n	n.n	n.n	n.n	n.n	n.n
Calcium	mg/kg		7	95	209	483	3.015	12.410	18	<1	137	1.540	100	33	2.210	65	266
Chrom	mg/kg		n.n.	n.n.	n.n.	n.n.	n.n.	4	2	<1	12	5	n.n	n.n	n.n	n.n	n.n
Eisen	mg/kg		2	4	24	197	28	195	119	4	34	37	22	8	19	10	2
Kobalt	mg/kg		n.n.	n.n.	n.n.	1	n.n.	n.n	1	45	1	n.n	n.n	n.n	n.n	n.n	n.n
Kupfer	mg/kg		2	3	2	16	4	48	6	2	224	9	11	49	2	3	1
Magnesium	mg/kg		13	< 10	< 8	n.n.	< 10	n.n	189	< 3	< 6	<3	<3	<7	<3	<3	<3
Mangan	mg/kg		n.n.	n.n.	n.n.	n.n.	7	3	1	<1	5	1	18	2	10	10	n.n
Molybdän	mg/kg		n.n.	n.n.	n.n.	n.n.	n.n.	2	1	<1	9	n.n	n.n	n.n	n.n	n.n	n.n
Nickel	mg/kg		3	3	4	5	4	n.n	1	<1	4	n.n	n.n	n.n	n.n	n.n	n.n
Phosphor	mg/kg		151	72	36	831	68	2.384	736	643	344	680	578	325	77	206	693
Quecksilber	mg/kg		n.n.	n.n.	n.n.	n.n.	n.n.	1	1	<1	1	n.n	n.n	n.n	n.n	n.n	n.n
Silicium	mg/kg		n.n.	n.n.	n.n.	19	15	n.n	39	<1	552	680	6	9	n.n	n.n	12
Thallium	mg/kg		n.n.	n.n.	n.n.	n.n.	n.n.	1	7	<1	1	n.n	1	3	n.n	n.n	n.n
Titan	mg/kg		n.n.	n.n.	n.n.	n.n.	n.n.	n.n	1	<1	3	n.n	n.n	n.n	n.n	n.n	1
Vanadium	mg/kg		n.n.	n.n.	n.n.	n.n.	n.n.	1	8	<1	1	n.n	n.n	n.n	n.n	n.n	n.n
Wolfram	mg/kg		n.n.	n.n.	n.n.	n.n.	n.n.	n.n	1	8	2	n.n	1	2	n.n	n.n	n.n
Zink	mg/kg		4	25	9	869	43	2.992	50	2	345	38	153	346	7	74	11
Zinn	mg/kg		n.n.	n.n.	n.n.	n.n.	n.n.	n.n	1	1	39	n.n	n.n	n.n	n.n	n.n	n.n

Table 11: Summary of the analysis results of the waste oil samples phase 2 (continued)

Probe-Nr.			1.2 - 01	1.2 - 02	1.2 - 03	1.2 - 04	1.2 - 06	1.2 - 07	1.2 - 08	1.2 - 09	1.2 - 10	1.2 - 11	1.2 - 12	1.2 - 13	1.2 - 14	1.2 - 15	1.2 - 16
Labor-Nr.			0842434-01	842438-01	842439-01	842440-01	842442-01	23-002116-01	23-002121-01	23-002122-01	23-002157-01	23-002158-01	23-002159-01	23-002160-01	23-002163-01	23-002164-01	23-002165-01
Art der Bearbeitung			Tiefziehen Leicht-metalle	Bearbeitungs-öl Metall-bearbeitung Schmieden Kurbelwellen	Bearbeitungs-öl Schraubenbe-arbeitung	Schneidöle Metall-umformung Beschläge, Scharniere	Bearbeitungs-öl Kühlen + Schmieren	Gewinde-schneiden	Schneidöl	Schleifen	Bohren	Drehen	Drehen	Schleifen, Drehen	Schleiföl	Fräsen / Bohren	Fräsen (Bolzen, Schrauben)
Einstufung *			NA	A	BA	NA	NA	NA	NA	BA	NA	NA	NA	A	BA	BA	NA
Parameter	**Einheit**	**Methode**															
Simulierte Destillation GC		DIN 51435															
Simdest Siedebeginn	°C		178	248	178	176	156		232	255	164	127	164	214	235	292	212
Simdest 5%	°C		199	375	194	187	236	184	266	324	306	369	337	324	350	359	361
Simdest 10%	°C		356	399	200	195	313	199	275	336	357	394	357	356	365	371	408
Simdest 15%	°C		428	411	208	199	342	337	281	343	357	405	369	380	374	377	412
Simdest 20%	°C		450	419	227	202	356	379	286	349	374	412	377	403	381	383	414
Simdest 25%	°C		464	426	314	208	366	407	291	354	380	417	385	416	387	388	415
Simdest 30%	°C		474	432	334	222	373	422	294	359	402	421	393	424	392	392	416
Simdest 35%	°C		483	439	352	319	379	431	297	364	419	425	400	430	398	396	417
Simdest 40%	°C		492	445	367	356	385	443	301	368	432	429	406	437	403	400	418
Simdest 45%	°C		502	451	381	380	390	453	304	372	444	434	411	443	408	404	419
Simdest 50%	°C		513	458	398	407	395	464	308	376	455	438	416	449	413	408	426
Simdest 55%	°C		527	465	414	426	401	486	312	380	467	44	421	456	418	413	434
Simdest 60%	°C		541	473	428	444	408	498	316	384	476	449	426	463	423	419	444
Simdest 65%	°C		558	480	444	462	415	509	321	389	483	456	431	470	429	427	454
Simdest 70%	°C		574	488	461	479	424	522	326	393	489	462	439	477	435	436	465
Simdest 75%	°C		590	498	478	496	433	538	335	398	496	470	448	485	441	447	475
Simdest 80%	°C		606	508	495	514	447	556	348	403	508	478	458	493	448	459	486
Simdest 85%	°C		614	522	513	537	467	579	363	409	529	489	471	502	457	477	498
Simdest 90%	°C		625	540	538	577	502	606	445	415	546	505	489	513	469	501	516
Simdest 95%	°C		639	571	586	617	566	627	545	424	586	532	518	531	496	537	560
Simdest Siedeende	°C		657	645	647	655	637	651	616	491	636	631	613	608	616	624	625

* A - aufarbeitbar
BA - bedingt aufarbeitbar
NA - nicht aufarbeitbar

No English version of these tables was available. The tables report physical, chemical, and elemental analysis data for different waste oil samples, each representing a specific type of metal processing, such as "grinding," "cutting," "drilling," "milling," and "turning." The samples are labelled with "Probe Nr." (sample number) and have corresponding test dates and processing types. The table is divided into several key sections:

Physical and Chemical Parameters: Includes measurements of: Density at 15°C (g/ml): Ranges between 0.83 and 0.86 for most samples, indicating slight variations in fluid composition. Viscosity at 40°C (mm²/s): Shows differences in viscosity, important for assessing how the fluid behaves under heat. For example, viscosity values range from around 29 to 146 across the samples. FAME Content (% m/m): Fatty acid methyl esters (FAME), found in biodiesel, are measured here, with values around 0.8–1.5%. Water Content (% v/v): Ranges from 0.1% to 0.5%, indicating the presence of water in the fluids, important for understanding their stability and effectiveness in lubrication. Acid Value (mg KOH/g): Varies between 0.4 and 0.9, indicating the level of acidity, which affects fluid reactivity and corrosion potential. Polyolester and Chlorine Content (g/kg): These are presented in lower concentrations (usually less than 0.1–0.5 g/kg), relevant for assessing environmental and operational safety, as some elements can be harmful. Elemental Analysis (RFA): Provides concentrations of metals like: Aluminum (mg/kg): Detected in some samples, ranging from around 10 to 350 mg/kg. Iron, Copper, and Zinc (mg/kg): Levels range across samples (e.g., iron: up to 320 mg/kg, copper: less than 1 to 15 mg/kg, zinc: up to 4 mg/kg), which helps assess potential contamination and wear. Other elements: Includes metals like barium, calcium, lead, nickel, and others, which vary between being detected (e.g., calcium at 700–2200 mg/kg) and being below the detection limits (noted as "n.n.").

Each sample is classified based on its recyclability:

A (aufarbeitbar): Suitable for recycling.

BA (bedingt aufarbeitbar): Conditionally recyclable.

NA (nicht aufarbeitbar): Not recyclable.

Table 11 focuses on simulated distillation data, which gives insight into how the fluids evaporate at different temperature points, a crucial factor for understanding thermal stability and performance under operational conditions. The key parameters here are: Boiling Point Temperatures: Data is provided for various boiling fractions, from 5% to 95% of the fluid evaporated. For example, at the 50% distillation point, temperatures range from approximately 300°C to 430°C, which indicates how different samples behave under heat. This is critical in evaluating whether the fluids will maintain their lubricating properties at high temperatures or break down. Simulated Distillation GE (°C): Each percentage point of evaporation (e.g., 5%, 10%, 30%, up to 95%) has an associated temperature reading. For instance, sample 12-08 reaches 95% distillation at 651°C, whereas sample 12-12 does so at 614°C. This second table also applies the same recyclability classification system ("A", "BA", "NA") to assess the reusability of the fluid samples after use in metalworking processes. Overall, the two tables together present a detailed analysis of the fluid samples in terms of their composition, potential contaminants, physical properties, and their behaviour during heating, all of which contribute to decisions about whether these fluids can be recycled or reused after their initial use.

2.4.2.5 Interpretation and presentation of results

The results of the analyses of the 15 waste oil samples are shown in Table 12 summarised. The third column (classification) indicates whether the respective waste oil is to be classified as suitable for recycling (A), conditionally recyclable (BA) not recyclable (NA) based on the analysis results.

In Table 10 and Table 11 this labelling can be found in the sixth and fourth row respectively. The parameters that led to the NA or BA classification are highlighted in red. In addition, other parameters are highlighted in blue that are conspicuous but do not necessarily lead to a negative assessment of suitability for reprocessing on their own, but can be included in the final assessment.

Table 12: Explanation of the categorisation of the waste oil samples

Sample	Type of metalworking	Comment on categorisation*
1.2 - 01	Deep drawing of light metals	**NA**: Ester / sulphur content too high, probable use of sulphurised fatty acid esters
1.2 - 02	Machining oil, metalworking Forging crankshafts	**A**
1.2 - 03	Machining oil for screw machining	**BA**: ester content slightly too high; the low density indicates a high proportion of low-viscosity components, which is also confirmed by the boiling curve; processable oils usually have a boiling start (start of base oil content) at 320°C below 5 vol% distillate content, here it is 25 - 30 vol%.
1.2 - 04	Cutting oils Metal forming Fittings, hinges	**NA**: ester / sulphur content too high, probable use of sulphurised fatty acid esters; high proportion (approx. 35%) of low-viscosity components; increased oxide ash
1.2 - 06	Machining oil Cooling + lubrication	**NA**: Ester/sulphur content increased, calcium content (3,015 mg/kg) too high
1.2 - 07	Thread cutting	**NA**: Ester / sulphur content too high; ash content (4.51% by weight) and Ca, P, Zn each too high
1.2 - 08	Cutting oil	**NA**: Ester content too high; viscosity (6.29 mm²/s) very low and correspondingly proportion of low-boiling components clearly too high (approx. 60%)
1.2 - 09	Grinding	**BA**: Ester/sulphur content increased; despite low density/viscosity, the boiling curve shows no increased low-boiling content, therefore still classified as conditionally treatable
1.2 - 10	Drilling	**NA**: Silicon content clearly too high at 552 mg/kg; ester content too high
1.2 - 11	Turning	**NA**: Silicon content clearly too high at 680 mg/kg; ester content too high
1.2 - 12	Turning	**NA**: Chlorine content 0.32 % by weight
1.2 - 13	Grinding, turning	**A**: despite low density/viscosity, the boiling curve shows no increased low-boiling content

Sample	Type of metalworking	Comment on categorisation*
1.2 - 14	Grinding oil	**BA**: sulphur content increased; calcium content increased; despite low density/viscosity, the boiling curve does not show an increased low-boiling content, therefore still classified as conditionally treatable
1.2 - 15	Milling / Drilling	**BA**: Ester/sulphur content increased; despite low density/viscosity, the boiling curve shows no increased low-boiling content, therefore just classified as conditionally treatable
1.2 - 16	Milling (bolts, screws)	**NA**: Ester / sulphur content too high

* See also 2.4.1.5 for justification of the respective assessment.

2.4.3 Phase 3

The analysis phases 1 and 2 showed that

- Certain waste oils that are not categorised as CC1 according to the German Waste Oil Ordinance (AltölV) may be suitable for regeneration from individual sources,
- These waste oils in the analysed samples originate mainly from metalworking with geometrically defined cutting edges (drilling, turning, milling);
- However, there is no fundamental suitability of waste oils from these processes for regeneration.

In the third phase of waste oil analysis, an attempt was made to specifically analyse waste oils from individual large sources.

2.4.3.1 Sample procurement procedure

Sample procurement was again supported by the companies in the second round of analyses. It was specified that the samples should be taken from large companies such as car manufacturers or their suppliers. The samples were obtained directly from the respective waste producer in the form of a side stream sample following DIN 51750-2 when the waste oil was transferred to the tank truck. The samples were transferred to suitable containers immediately after sampling and labelled with clear, traceable identification. If available, the type of metal processing was noted in the sampling protocol according to the producer's specifications. The sample quantities were between 250 ml and 4,000 ml. The samples were taken between November 2023 and May 2024 and forwarded directly to the laboratory of AVISTA OIL Deutschland GmbH for analysis. The following samples were available:

Table 11: Overview of samples from the second analysis phase

Sample number	Sampling date	Postcode of the company	Type of metalworking
1.2 - 17	04.2024	94XXX	Grinding oil
1.2 - 18	02.05.2024	70XXX	Hardening oil
1.2 - 19	25.03.2024	91XXX	Punching

Sample number	Sampling date	Postcode of the company	Type of metalworking
1.2 - 20	04.04.2024	34XXX	Cutting oil
1.2 - 21	02.05.2024	70XXX	Forming oil
1.2 - 22	25.03.2024	91XXX	Forming oil
1.2 - 23	01.2024	73XXX	Not specified
1.2 - 24	01.2024	73XXX	Not specified
1.2 - 25	20.11.2023	38XXX	Not specified
1.2 - 26	22.11.2023	70XXX	Not specified
1.2 - 27	24.11.2023	38XXX	Not specified

2.4.3.2 Sample preparation

The samples were prepared following the requirements of the individual analysis methods.

2.4.3.3 Information on laboratory analysis

The analyses were carried out by the laboratory of AVISTA OIL Deutschland GmbH in the same way as the first and second analysis phases.

The following analysis methods were used for the individual, defined parameters:

- PCB content: DIN EN 12766-1,2(B)
- Chlorine content: DIN 51577-4
- Ester content: DIN EN 14078
- Element screening: X-ray fluorescence analysis (XRF) according to AVISTA test instruction PA_109
- Total sulphur: DIN EN ISO 8754
- Water content: DIN ISO 3733
- Density at 15°C: EN ISO 3675
- Viscosity at 40°C: ASTM D7279
- Oxide ash content: DIN EN ISO 6245
- Flash point PMCC: DIN EN ISO 2719
- Boiling range GC: DIN 51435

2.4.3.4 Laboratory report/ results

The results of the investigations are summarised in the following tables:

Table 13: Summary of the analysis results of the waste oil samples phase 3

			Altöle Metallbearbeitung										
Probe-Nr.			1.2 - 17	1.2 - 18	1.2 - 19	1.2 - 20	1.2 - 21	1.2 - 22	1.2 - 23	1.2 - 24	1.2 - 25	1.2 - 26	1.2 - 27
Labor-Nr.			24-011478-01	24-012193-01	24-012194-01	24-012195-01	24-012196-01	24-012198-01	24-004000-01	24-004001-01	23-030322-01	24-030521-01	24-030801-01
Probenahmedatum			04.2024	02.05.2024	25.03.2024	04.04.2024	02.05.2024	25.03.2024	01.2024	01.2024	20.11.2023	22.11.2023	24.11.2023
Probenahmeort Betrieb (PLZ)			94xxx	70xxx	91xxx	34xxx	70xxx	91xxx	73xxx	73xxx	38xxx	70xxx	38xxx
Art der Bearbeitung			Schleiföl	Härteöl	Stanzen	Schneidöl	Umformöl	Umformöl					
Einstufung *			NA	A	BA	NA	NA	NA	BA	NA	NA	NA	NA
Parameter	**Einheit**	**Methode**											
Dichte 15°C	kg/l	EN ISO 3675	0,829	0,860	0,860	0,874	0,840	0,919	0,840	0,918	1,035	0,918	0,965
Viskosität bei 40 °C (kin)	mm^2/s	ASTM D7279	14,80	26,24	19,91	28,67	10,37	105,60	18,13	17,50 **	16,30	n.b.	45,10 **
FAME - Gehalt	Vol.%	EN 14078	7,6	< 0,1	<0,1	6,9	10,6	27,0	6,6	n.b.	n.b.	n.b.	n.b.
Flammpunkt Pensky-Martens	°C	DIN EN ISO 2719	> 90	> 90	> 90	> 90	> 90	> 90	> 98	> 98	> 70	> 70	> 70
Wasser, destillativ	Gew.%	DIN ISO 3733	< 0,1	< 0,1	< 0,1	< 0,1	< 0,1	< 0,1	1,8	42,4	46,8	30,0	42,7
Oxid-Asche	Gew.%	DIN EN ISO 6245	0,03	< 0,1	< 0,5	0,25	< 0,1	0,04	0,06	0,30	3,82	1,43	4,66
Polychlorierte Biphenyle	mg/kg	DIN EN 12766-1,2(B)	1,50	n.n.	n.n.	n.n.	n.n.	n.n.	n.n.	n.n.	n.n.	1,50	n.n.
Chlor, RFA	Gew.%	DIN 51577-4	n.n.	n.n.	n.n.	n.n.	n.n.	n.n.	n.n.	n.n.	n.n.	n.n.	n
Gesamtschwefel, RFA	mg/kg	DIN EN ISO 8754	9.900	4.640	6.830	13.160	2.940	45.450	8.570	2.490	3.180	1.760	10
Elementscreening RFA		AOD PA_109											
Aluminium	mg/kg		52	23	135	74	16	263	69	58	63	198	35
Antimon	mg/kg		n.n.	n.n.	n.n.	n.n.	n.n.	n.n.	2	2	2	2	2
Arsen	mg/kg		n.n.	n.n.	n.n.	n.n.	n.n.	n.n.	n.n.	n.n.	n.n.	n.n.	n.n.
Barium	mg/kg		n.n.	n.n.	n.n.	8	n.n.	1	n.n.	n.n.	n.n.	n.n.	n.n.
Bismut	mg/kg		n.n.	n.n.	n.n.	n.n.	n.n.	n.n.	n.n.	n.n.	n.n.	n.n.	n.n.
Blei	mg/kg		n.n.	n.n.	n.n.	n.n.	n.n.	n.n.	n.n.	n.n.	1	n.n.	n.n.
Brom	mg/kg		n.n.	n.n.	n.n.	n.n.	n.n.	n.n.	n.n.	n.n.	n.n.	1	n.n.
Cadmium	mg/kg		n.n.	n.n.	n.n.	n.n.	n.n.	n.n.	n.n.	n.n.	n.n.	n.n.	n.n.
Calcium	mg/kg		n.n.	72	2	389	127	n.n.	58	33	200	178	1
Chrom	mg/kg		1	n.n.	n.n.	n.n.	n.n.	1	n.n.	n.n.	n.n.	n.n.	n.n.
Eisen	mg/kg		184	6	n.n.	986	50	4	47	233	49	379	1
Kobalt	mg/kg		n.n.	n.n.	n.n.	n.n.	n.n.	n.n.	n.n.	n.n.	n.n.	1	n.n.
Kupfer	mg/kg		2	1	1	2	n.n.	2	5	1	13	1	1
Magnesium	mg/kg		n.n.	9	n.n.	n.n.	n.n.	n.n.	11	n.n.	7	7	8
Mangan	mg/kg		12	n.n.	n.n.	52	2	2	6	n.n.	2	8	n.n.
Molybdän	mg/kg		n.n.	n.n.	n.n.	n.n.	n.n.	n.n.	n.n.	n.n.	2	1	n.n.
Nickel	mg/kg		n.n.	n.n.	3	2	n.n.	3	3	3	4	3	9
Phosphor	mg/kg		338	13	36	608	267	702	182	42	257	328	n.n.
Quecksilber	mg/kg		n.n.	n.n.	n.n.	n.n.	n.n.	n.n.	n.n.	n.n.	n.n.	n.n.	10
Silicium	mg/kg		n.n.	n.n.	n.n.	n.n.	33	n.n.	3	16	18	2660	n.n.
Thallium	mg/kg		n.n.	n.n.	n.n.	n.n.	n.n.	n.n.	n.n.	n.n.	n.n.	n.n.	n.n.
Titan	mg/kg		n.n.	n.n.	n.n.	n.n.	n.n.	n.n.	n.n.	n.n.	n.n.	n.n.	n.n.
Vanadium	mg/kg		n.n.	n.n.	n.n.	n.n.	n.n.	1	n.n.	n.n.	n.n.	n.n.	n.n.
Wolfram	mg/kg		n.n.	n.n.	n.n.	n.n.	n.n.	n.n.	1	11	n.n.	n.n.	n.n.
Zink	mg/kg		37	2	n.n.	47	11	3	67	1	25	7	11
Zinn	mg/kg		n.n.	n.n.	n.n.	n.n.	n.n.	n.n.	1	n.n.	1	1	1

Table 14: Summary of the analysis results of the waste oil samples phase 3 (continued)

Probe-Nr.			1.2 - 17	1.2 - 18	1.2 - 19	1.2 - 20	1.2 - 21	1.2 - 22	1.2 - 23	1.2 - 24	1.2 - 25	1.2 - 26	1.2 - 27
Labor-Nr.			24-011478-01	24-012193-01	24-012194-01	24-012195-01	24-012196-01	24-012198-01	24-004000-01	24-004001-01	23-030322-01	24-030521-01	24-030801-01
Probenahmedatum			04.2024	02.05.2024	25.03.2024	04.04.2024	02.05.2024	25.03.2024	01.2024	01.2024	20.11.2023	22.11.2023	24.11.2023
Probenahmeort Betrieb (PLZ)			94xxx	70xxx	91xxx	34xxx	70xxx	91xxx	73xxx	73xxx	38xxx	70xxx	38xxx
Art der Bearbeitung			Schleiföl	Härteöl	Stanzen	Schneidöl	Umformöl	Umformöl					
Einstufung *			NA	A	BA	NA	NA	NA	BA	NA	NA	NA	NA
Parameter	**Einheit**	**Methode**											
Simulierte Destillation GC		DIN 51435											
Simdest Siedebeginn	°C		313	295	302	297	275	333	304	261	223	234	195
Simdest 5%	°C		353	347	332	340	305	387	354	298	294	296	364
Simdest 10%	°C		363	363	346	358	318	403	366	313	314	314	398
Simdest 15%	°C		370	373	356	368	327	414	373	323	329	328	412
Simdest 20%	°C		374	382	364	377	335	422	378	333	342	340	422
Simdest 25%	°C		379	389	371	387	343	429	383	341	352	350	429
Simdest 30%	°C		383	396	377	395	349	436	387	348	363	359	437
Simdest 35%	°C		386	402	384	404	356	444	391	354	370	367	445
Simdest 40%	°C		389	408	390	411	359	451	396	360	381	375	453
Simdest 45%	°C		392	413	397	417	363	453	400	366	393	382	462
Simdest 50%	°C		395	417	404	423	368	467	405	372	406	389	471
Simdest 55%	°C		399	421	411	429	374	476	410	379	417	395	480
Simdest 60%	°C		402	425	418	435	380	486	419	388	426	402	489
Simdest 65%	°C		406	429	425	442	386	493	427	398	435	408	499
Simdest 70%	°C		411	433	433	451	392	506	437	409	447	416	511
Simdest 75%	°C		421	438	444	461	399	517	449	419	461	423	525
Simdest 80%	°C		437	443	456	474	406	528	465	428	477	439	540
Simdest 85%	°C		461	450	471	492	413	540	487	439	497	463	558
Simdest 90%	°C		492	459	489	516	421	557	514	456	522	493	581
Simdest 95%	°C		528	477	515	552	436	600	569	490	568	553	610
Simdest Siedeende	°C		625	628	592	626	542	645	636	626	644	645	649

* A - aufarbeitbar
BA - bedingt aufarbeitbar
NA - nicht aufarbeitbar

** Werte aus der Ölphase

No English version of these tables was available. The tables report physical, chemical, and elemental analysis data for different waste oil samples, each representing a specific type of metal processing, such as "grinding," "cutting," "drilling," "milling," and "turning." The samples are labelled with "Probe Nr." (sample number) and have corresponding test dates and processing types. The table is divided into several key sections:

Physical and Chemical Parameters: Includes measurements of: Density at 15°C (g/ml): Ranges between 0.83 and 0.86 for most samples, indicating slight variations in fluid composition. Viscosity at 40°C (mm²/s): Shows differences in viscosity, important for assessing how the fluid behaves under heat. For example, viscosity values range from around 29 to 146 across the samples. FAME Content (% m/m): Fatty acid methyl esters (FAME), found in biodiesel, are measured here, with values around 0.8–1.5%. Water Content (% v/v): Ranges from 0.1% to 0.5%, indicating the presence of water in the fluids, important for understanding their stability and effectiveness in lubrication. Acid Value (mg KOH/g): Varies between 0.4 and 0.9, indicating the level of acidity, which affects fluid reactivity and corrosion potential. Polyolester and Chlorine Content (g/kg): These are presented in lower concentrations (usually less than 0.1–0.5 g/kg), relevant for assessing environmental and operational safety, as some elements can be harmful. Elemental Analysis (RFA): Provides concentrations of metals like: Aluminum (mg/kg): Detected in some samples, ranging from around 10 to 350 mg/kg. Iron, Copper, and Zinc (mg/kg): Levels range across samples (e.g., iron: up to 320 mg/kg, copper: less than 1 to 15 mg/kg, zinc: up to 4 mg/kg), which helps assess potential contamination and wear. Other elements: Includes metals like barium, calcium, lead, nickel, and others, which vary between being detected (e.g., calcium at 700–2200 mg/kg) and being below the detection limits (noted as "n.n.").

Each sample is classified based on its recyclability:

A (aufarbeitbar): Suitable for recycling.

BA (bedingt aufarbeitbar): Conditionally recyclable.

NA (nicht aufarbeitbar): Not recyclable.

Table 14 focuses on simulated distillation data, which gives insight into how the fluids evaporate at different temperature points, a crucial factor for understanding thermal stability and performance under operational conditions. The key parameters here are: Boiling Point Temperatures: Data is provided for various boiling fractions, from 5% to 95% of the fluid evaporated. For example, at the 50% distillation point, temperatures range from approximately 300°C to 430°C, which indicates how different samples behave under heat. This is critical in evaluating whether the fluids will maintain their lubricating properties at high temperatures or break down. Simulated Distillation GE (°C): Each percentage point of evaporation (e.g., 5%, 10%, 30%, up to 95%) has an associated temperature reading. For instance, sample 12-08 reaches 95% distillation at 651°C, whereas sample 12-12 does so at 614°C. This second table also applies the same recyclability classification system ("A", "BA", "NA") to assess the reusability of the fluid samples after use in metalworking processes. Overall, the two tables together present a detailed analysis of the fluid samples in terms of their composition, potential contaminants, physical properties, and their behaviour during heating, all of which contribute to decisions about whether these fluids can be recycled or reused after their initial use.

2.4.3.5 Interpretation and presentation of results

The results of the analyses of the 11 phase 3 waste oil samples are shown in Table 15 summarised. The third column (classification) indicates whether the respective waste oil is to be classified as suitable for recycling (A), conditionally recyclable (BA) not recyclable (NA) based on the analysis results. In Table 13 and Table 14 this labelling can be found in the sixth and fourth row respectively. The data that led to the NA or BA classification are highlighted in red. In addition, other parameters that are conspicuous and do not necessarily lead to a negative assessment with regard to suitability for reprocessing but can be included in the final assessment are highlighted in blue.

Table 15: Overview of samples from the third analysis phase

Sample	Type of metalworking	Comment on categorisation*
1.2 - 17	Grinding oil	**NA**: Ester / sulphur content too high, probable use of sulphurised fatty acid esters
1.2 - 18	Hardening oil	**A**
1.2 - 19	Punching	**BA**: sulphur content increased; aluminium content increased; despite low viscosity, the boiling curve does not show an increased low-boiling content, therefore still classified as conditionally treatable
1.2 - 20	Cutting oil	**NA**: Ester / sulphur content too high, probable use of sulphurised fatty acid esters
1.2 - 21	Forming oil	**NA**: ester content too high; the low density/viscosity correlates with the later onset of boiling
1.2 - 22	Forming oil	**NA**: Ester / sulphur content clearly too high, probable use of sulphurised fatty acid esters
1.2 - 23	Not specified	**BA**: Ester/sulphur content increased; despite low density/viscosity, the boiling curve shows no increased low-boiling content, therefore just classified as conditionally treatable
1.2 - 24	Not specified	**NA**: very high water content, mixing with other (water-miscible) metalworking fluids to be assumed
1.2 - 25	Not specified	**NA**: very high water content, mixing with other (water-miscible) metalworking fluids to be assumed; high ash content
1.2 - 26	Not specified	**NA**: very high water content, mixing with other (water-miscible) metalworking fluids to be assumed; increased ash content, very high silicon content
1.2 - 27	Not specified	**NA**: very high water content, mixing with other (water-miscible) metalworking fluids to be assumed; high ash content

* See also 2.4.1.5 for justification of the respective assessment.

Samples 1.2-24 to 1.2-27 show the particularity that, especially in very large companies, the respective used metalworking fluids are obviously not stored separately for each machine /

application, but there is only one common waste container at the end. This explains the inability to specify the type of processing and the very high water content of the samples.

2.5 Result: Waste oils suitable for regeneration

The analysis of waste oils from the CC1 collection confirmed their typical characteristics and indicated their suitability for regeneration into base oils. Conversely, the waste oils collected from the mixed categories CC2-4 proved unsuitable for regeneration.The results for the four waste oils analyzed from the targeted sampling of exclusive AVV 12 01 07* waste were less definitive. While three samples clearly met exclusion criteria, the fourth sample, derived from a turning-chipping processing type, showed potential for reprocessing.

Based on these findings, a second round of analyses focused specifically on waste oils from metalworking. This analysis confirmed that certain waste oils, which do not fall under the CC1 classification according to the Waste Oil Ordinance, may still be suitable for regeneration. It was noted that these oils often originate from metalworking processes that utilize geometrically defined cutting edges, such as drilling, turning, and milling. However, waste oils from these processes were generally found to be unsuitable for regeneration.

In the third phase of waste oil analysis, an effort was made to analyze waste oils from specific large sources. However, no clear trends emerged in this phase either. It was particularly evident that used metalworking fluids are typically not stored separately in large companies; instead, they are often disposed of in a common waste container. The remaining samples mainly reflected the composition and additive criteria identified in the second round of analyses, rendering them unsuitable for reprocessing.

In summary, the results indicate that the existing classification and sorting of waste oils into categories outlined in the Waste Oil Ordinance Act have been effective in practice. There appears to be no urgent need for action regarding the requirements of this ordinance.

Among the waste oils categorized as CC2-4, only a few from specific applications under WC 12 01 07* are suitable for reprocessing. However, due to the composition of most used metalworking oils, which would complicate reprocessing, they should not be classified as CC1 by default.

In the interest of sustainable recycling—provided that practical and economic considerations allow—it would be beneficial for waste producers to consult processors on a case-by-case basis to ascertain whether specific waste oils could be suitable for reprocessing and should be disposed of separately. This approach could be particularly advantageous for individual sources generating larger volumes of waste.

Finally, in addition to ongoing efforts to extend the service life through effective cycle management and reducing waste generation directly at the machines, product developers must also consider the suitability for regeneration in the design of future products.

3 Determination of the material flows of waste oils

In this chapter, we analyze the material flows of various types of waste oil. To achieve this, we begin by reviewing the existing calculation model, focusing on return rates and process yields. Following this update, we calculate the material flows for the reference year, which has been designated as 2019 in consultation with the German Environment Agency.

First, Section 3.1 describes the market distribution of lubricants in Germany. In Section 3.2, we examine the return rates for different grade groups and make adjustments as necessary. The update of yield factors for waste oil regeneration is addressed in Section 3.3. Sections 3.4 and 3.5 discuss the volumes resulting from re-refining and energy recovery, respectively.

Finally, Section 3.6 provides a description of waste oil flows in Germany for the year 2019. In Chapter 4, we will assess how the specific material flows can be used for data transmission as outlined in Annex IV of Commission Implementing Decision 2019/1004.

3.1 Lubricants placed on the market

Data on domestic deliveries of lubricants are available from the BAFA statistics (Table 10a of the BAFA Official Mineral Oil Data) (BAFA 2020).

Accordingly, the placing on the market by lubricant category is shown in Table 16. In total, 976,879 tonnes of lubricants were placed on the market in Germany in 2019.

Table 16: Domestic deliveries of lubricants, Germany, 2019

Category	Specification	t	Proportion of lubricants placed on the market
Engine oils	-	245.811	25,2%
Compressor oils	-	8.793	0,9%
Turbine oils	-	1.405	0,1%
Gear oils	total	128.027	13,1%
	MOTOR VEHICLE	47.473	4,9%
	ATF	55.089	5,6%
	Industry	25.465	2,6%
Hydraulic oils	-	62.823	6,4%
Electrical insulating oils	-	12.162	1,2%
Machine oils	-	69.884	7,2%
Other industrial oils not for lubrication	-	62.484	6,4%
Process oils	total	140.293	14,4%
	Technical white oils	26.169	2,7%

Category	Specification	t	Proportion of lubricants placed on the market
	medicinal white oils	45.155	4,6%
Metalworking oils	total	81.417	8,3%
	Hardening oils	2.519	0,3%
	water-miscible	31.693	3,2%
	not water miscible	40.808	4,2%
	Anti-corrosion oils	6.397	0,7%
Lubricating greases	total	32.758	3,4%
	including for motor vehicles	8.442	0,9%
Base oils	-	127.126	13,0%
Extracts from lubricating oil refining	-	3.896	0,4%
In total	**-**	**976.879**	**100,0%**

Source: BAFA 2020

3.2 Review of return rates

Return rates are a key factor in the waste oil material flow model. They are used to calculate the waste oil potential for the different lubricant categories based on domestic sales of lubricants (refer to Table 10a in BAFA's official mineral oil data; cf. Table 16).

These return rates indicate the percentage of the quantities originally sold that are available for collection. They represent a critical point in the calculation model. For large-volume lubricant types, even slight differences of a few percentage points in assumed return rates can lead to significant variations in the estimated volume of waste oil potential. Additionally, the combination of influencing factors can introduce greater uncertainties into the calculations.

3.2.1 Procedure

Among the underlying loss variables, only some are directly influenced by objective variables. For example, discharge loss can be precisely measured in the case of metered loss lubrication. However, other variables, such as those related to handling losses, are much more challenging to quantify and often lack representativeness. To verify and, if necessary, update the assumed return rates, a thorough examination is conducted. This process takes into account the studies by Sander et al; Jepsen et al. (2006; 2016) and the more recent project (Zimmermann und Jepsen 2017) which Ökopol carried out in Belgium. The findings from these studies are first summarised, compared with the previous assumptions in the calculation model and examined concerning the possible need for adjustment - taking into account the quality of the data basis. The return rates assumed in the respective studies are summarised in Table 17.

Table 17: Overview of return rates in various studies

Variety groups	Return rate from (Sander et al. 2006)	Return rate from (Jepsen et al. 2016)	Return rate from (Zimmermann und Jepsen 2017)
Engine oils	59,5 %	51,9 %	59 %
Compressor oils	50 %	50 %	50 %
Turbine oils	70 %	70 %	77,5 %
Gear oils:	64 %	75,8 %	-
- Automotove gear oils	-	76,1 %	79 %
- Automatic transmission fluids (ATF)	-	76,1 %	79 %
- Industrial gear oils	-	75,0 %	77,5 %
Hydraulic oils	75 %	75,0 %	73 %
Electrical insulating oils	90 %	90 %	92,5 %
Machine oils	40 %	50 %	50 %
Other industrial oils not for lubrication	0 %	0 %	0 %
Process oils	0 %	0%	0 %
Metalworking oils:	45 %	45 %	50 %
Lubricating greases	0 %	0 %	0 %
Base oils	50 %	50 %	-
Extracts from lubricating oil refining	0 %	0 %	-

It should be noted that Zimmermann und Jepsen (2017) refers to the situation in Belgium and that there may be deviations due to import and export activities, particularly for lubricants in the automotive sector.
Sources: (Jepsen et al. 2016; Zimmermann und Jepsen 2017; Sander et al. 2006)

Experts are consulted on specific aspects while updating the return rates for individual lubricant categories. In the case of electrical insulating oils, data from waste statistics is analyzed, ensuring that the information outlined in section 3.2.2 is carefully considered. For certain types of lubricants, an update is also carried out taking into account current statistical data. (Interim) results of the analysis are discussed with VSI and BVA, among others.

3.2.2 Possibility of utilising waste statistics data

The use of waste statistics data to analyse waste oil flows or as input for the reverse calculation model is not possible without further ado.

A key obstacle is that the data from the waste statistics contain water components, while the reverse calculation model works with water-free (dry) quantities of waste oil. Therefore, it's necessary to first adjust the waste statistics data to account for water content, which introduces uncertainty into the process..

In addition, with regard to updating the return rates for the individual lubricant types, it should be noted that in many cases - as in Table 18 it is not possible to assign the lubricant category to the waste code(s), nor can it be assumed that disposal will always take place under the appropriate waste code.

Table 18: Allocation of lubricant grade groups to waste codes

Variety groups	Corresponding waste codes	Explanation
Engine oils Compressor oils Gear oils Machine oils Turbine oils	13 02 05*	Mineral-based non-chlorinated engine, gear and lubricating oils
	13 02 06*	Synthetic engine, gear and lubricating oils
	13 02 04*	Mineral-based chlorinated engine, gear and lubricating oils
	13 02 07*	Readily biodegradable engine, gear and lubricating oils
	13 02 08*	Other engine, gear and lubricating oils
Metalworking oils	12 01 06*	Mineral oil-based machining oils containing halogens (except emulsions and solutions)
	12 01 07*	Mineral-based machining oils free of halogens (except emulsions and solutions)
	12 01 10*	Synthetic machining oils
Electrical insulating oils	13 03 01*	Insulating or heat transmission oils containing PCBs
	13 03 06*	Mineral-based chlorinated insulating and heat transmission oils other than those mentioned in 13 03 01
	13 03 07*	Mineral-based non-chlorinated insulating and heat transmission oils
	13 03 08*	Synthetic insulating and heat transmission oils
	13 03 09*	Readily biodegradable insulating and heat transmission oils
	13 03 10*	Other insulating and heat transmission oils
Hydraulic oils	13 01 01*	Hydraulic oils, containing PCBs
	13 01 09*	Mineral-based chlorinated hydraulic oils
	13 01 10*	Mineral based non-chlorinated hydraulic oils
	13 01 11*	Synthetic hydraulic oils
	13 01 12*	Readily biodegradable hydraulic oils
	13 01 13*	Other hydraulic oils

Source: Compilation by Ökopol

As can be seen from the description in the table, the lubricant types engine oils, compressor oils, gear oils, machine oils, hydraulic oils and turbine oils are (partially) collected under the same waste codes. As a result, employing waste statistical data to examine return rates for these lubricants is not feasible.

In contrast, using waste statistical data appears to be feasible for electrical insulating oils (see section 3.2.9).

The first step is to adjust the data from the waste statistics with regard to the water content. The findings from the preliminary report (Jepsen et al. 2016) are used for this purpose (see Table 19).

Table 19: Summary of water contents and derived anhydrous mineral oil contents

Waste code	Designation	Number of analyses	Minimum [%]	Maximum [%]	Mean value [%]
13 03 01*	Insulating or heat transmission oils containing PCBs	7	0,01	2,0	0,3
13 03 06*	Mineral-based chlorinated insulating and heat transmission oils other than those mentioned in 13 03 01	-	-	-	-
13 03 07*	Mineral-based non-chlorinated insulating and heat transmission oils	58	0,003	27,0	1,3
13 03 08*	Synthetic insulating and heat transmission oils	1	0,1	0,1	0,1
13 03 09*	Readily biodegradable insulating and heat transmission oils	-	-	-	-
13 03 10*	Other insulating and heat transmission oils	2	0,1	0,1	0,1

Source: (Jepsen et al. 2016)

Using these water contents, the quantities of waste oil adjusted for water content can be calculated based on Destatis data on waste collection (see Table 20).

Table 20: Waste oils for waste treatment in 2019 and dry quantities

Waste code	Description	Quantity (input from waste disposal facilities) [1000 tonnes]	Assumed water content	Quantity, dry [1000t]
13 03 01*	Insulating or heat transmission oils containing PCBs	1,4	0,3 %	1,4
13 03 06*	Mineral-based chlorinated insulating and heat transmission oils other than those mentioned in 13 03 01	-	-	-
13 03 07*	Mineral-based non-chlorinated insulating and heat transmission oils	12,4	1,3 %	12,2
13 03 08*	Synthetic insulating and heat transmission oils	0,3	0,1 %	0,3

Waste code	Description	Quantity (input from waste disposal facilities) [1000 tonnes]	Assumed water content	Quantity, dry [1000t]
13 03 09*	Readily biodegradable insulating and heat transmission oils	0	-	-
13 03 10*	Other insulating and heat transmission oils	0,6	0,1 %	0,6

Source: Destatis, surveys on waste disposal, water shares from (Jepsen et al. 2016); own calculations

3.2.3 Lubricant types without return

Some lubricant types do not have a return flow. This results either from the type of lubricant application (e.g. loss lubrication) or the use in non-lubricant applications. These include process oils, other industrial oils not for lubrication, hardening oils and corrosion protection oils from the group of metalworking oils, lubricating greases and extracts from lubricating oil refining.

Following the previous reports (Sander et al. 2006; Jepsen et al. 2016) various comparable studies (Kline & Company 2007; Kline & Company 2012; Kuczenski et al. 2014; Zimmermann und Jepsen 2017; Zimmermann und Jepsen 2018a) and the Commission study from 2020 (European Commission: Directorate-General for Environment et al. 2020) it is still assumed that there will be no return of waste oil from process oils, other industrial oils not used for lubrication, hardening oils and anti-corrosion oils. With regard to hardening oils, however, it should be noted that although there is agreement among the stakeholders involved that these are not suitable for reprocessing as waste oils, a quantifiable return flow is also considered possible in some cases. This should be re-examined in future reports.

Table 21: Lubricant types without return

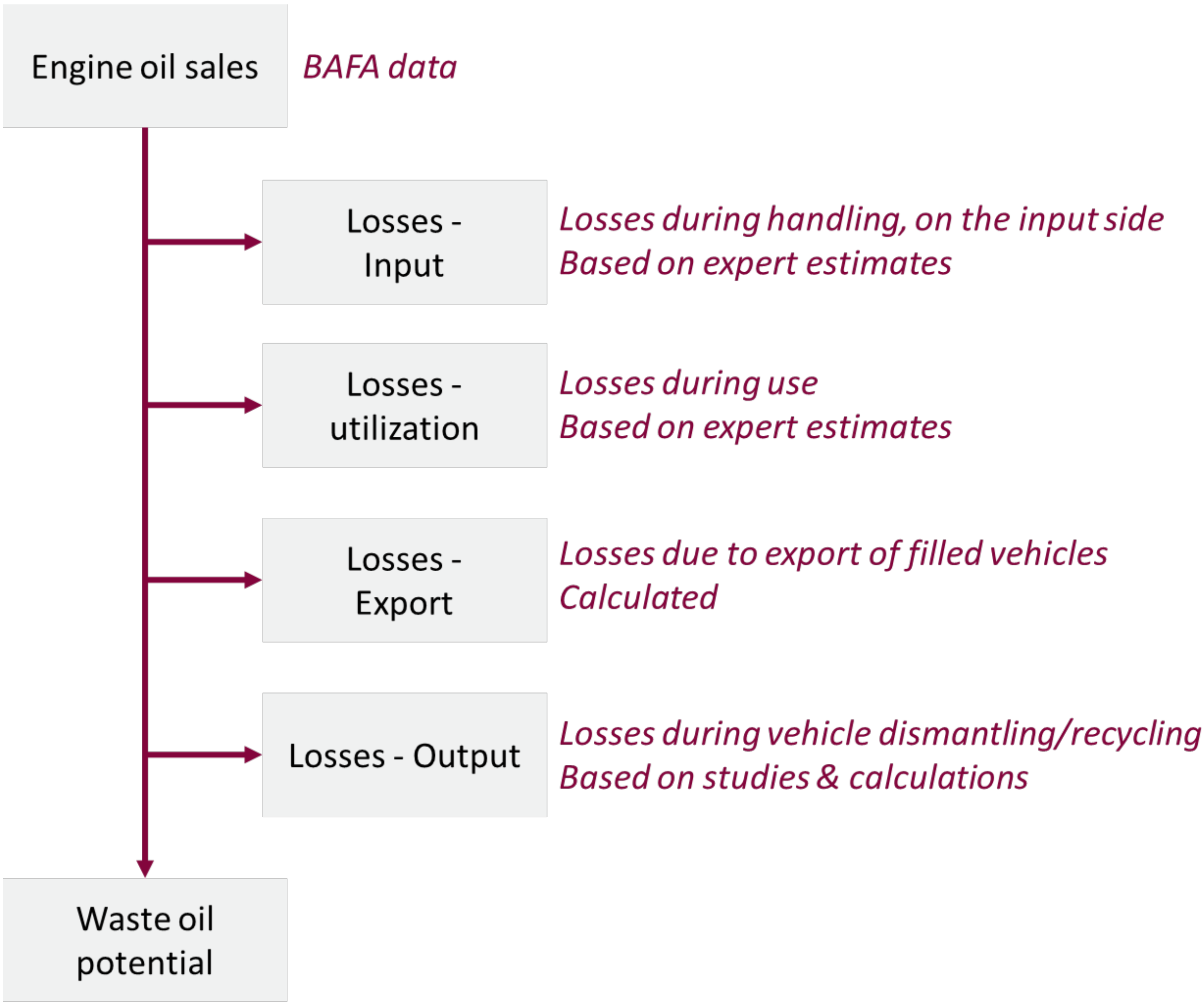
Lubricant grade	Return rate	Reason
Other industrial oils not for lubrication	0 %	No return due to application
Process oil		
Hardening oils		
Anti-corrosion oils		
Lubricating greases		
Extracts from lubricating oil refining		

In future updates of the calculation model, we may consider excluding types of oils that are not used for lubrication, such as process oils, anti-corrosion oils, and others not meant for lubricating purposes. While these oil types are included in the BAFA statistics on domestic lubricant sales, they do not contribute to lubrication or result in any return flow. By excluding these categories, we would maintain a focus solely on lubricant applications. This change would also align with the requirements for data transmission to the EU Commission, which specifies that these oil types should not be included in the reported data. However, it's important to note that this exclusion would lead to some inconsistency with previous calculations based on the existing model.

3.2.4 Engine oils

Engine oils are the most relevant type of lubricant in terms of quantity. The calculation model is correspondingly sensitive to changes in the return rate assumed here. The potential return rate of engine oil depends on several factors, which are summarised in Figure 4 are shown schematically.

Figure 4: Schematic description of the calculation method for the waste oil return for engine oil



Source: Own figure (Ökopol)

The total loss results from handling during oil changes and filling and refilling processes, the specific consumption per kilometre driven and the absolute mileage as well as losses from the net export of filled vehicles.

Handling losses

Handling losses, i.e. during maintenance or oil changes, result from drip losses during the filling/removal process and from residual quantities that remain in the containers.

The quantity whereabouts/transfer is calculated on the basis of the evaluation in (Zimmermann und Jepsen 2017) is assumed to be <0.1 %.

The amount of drip losses during input and output (during oil changes and refilling processes) depends on the professionalism of the implementation. It can be assumed that fewer losses occur when oil changes are carried out professionally in garages than when they are carried out privately. It can be seen here that the private performance of oil changes continues to decline (cf. Table 22). The frequency of oil changes is also continuing to decline. This is due to a move away from fixed oil change intervals. Instead, technologies such as oil quality sensors and cold start counters are being used, which enable more efficient use of engine oil (DAT 2018; DAT 2020).

Table 22: Carrying out oil changes

Process	Performer	2003	2013	2018	2019
Oil change	Workshops and petrol stations	82 %	89 %	90 %	91 %
	Private/ "DIY"	17 %	11 %	9 %	9 %
Refill	Workshops and petrol stations	29 %	34 %	-	-
	Private/ "DIY"	71 %	63 %	67 %*	65 %*

* refers to checking the oil level

Sources: (Sander et al. 2006; Jepsen et al. 2016; DAT 2020; DAT 2018; DAT 2016; DAT 2014)

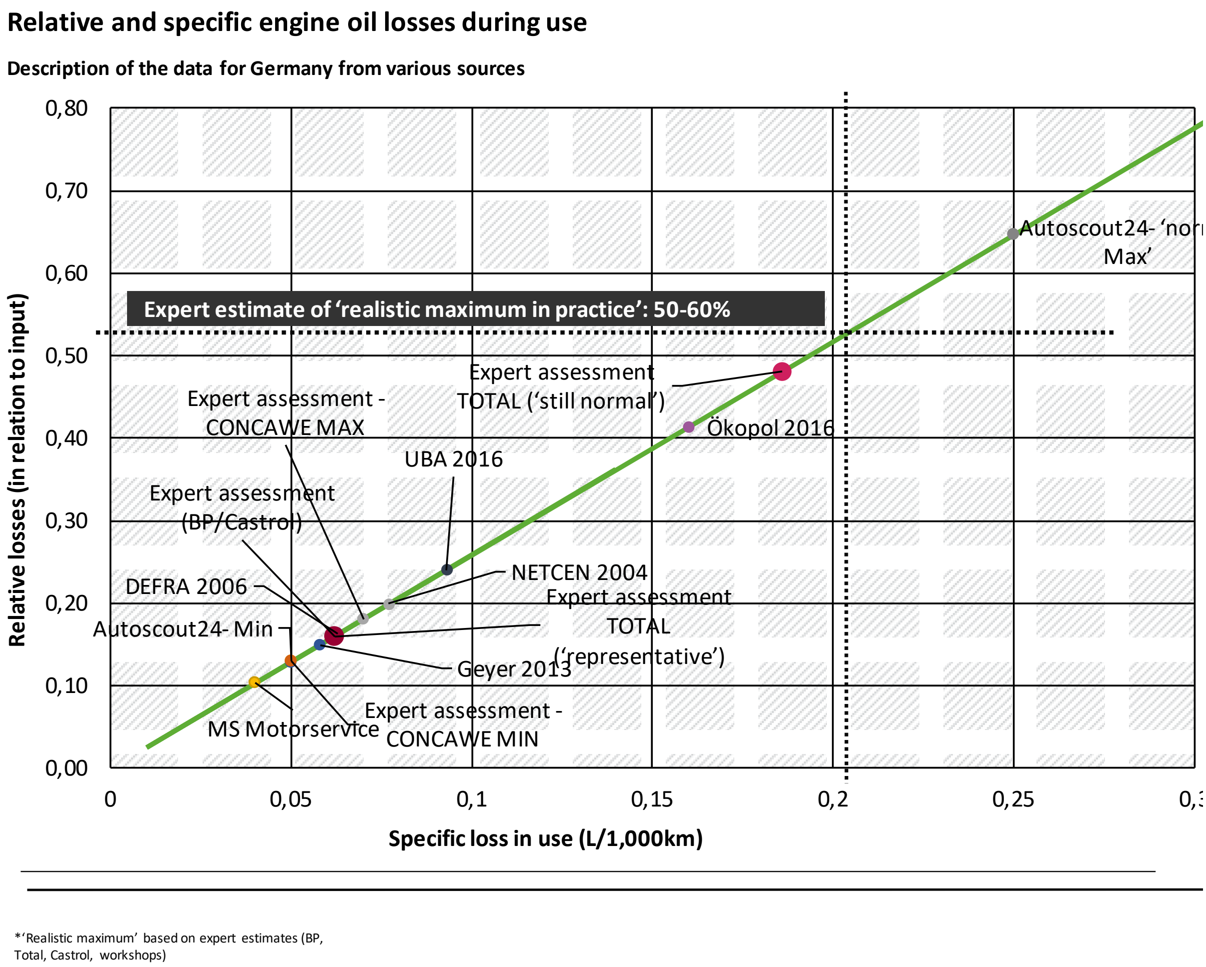
With assumed residual quantities in containers of ~0.1 % and input and output-side drip losses of 0.6 % to 0.7 % (cf. Zimmermann und Jepsen 2017; Zimmermann et al. 2022a), the total loss (handling plus drip losses input and output) is estimated at 0.8 %.

Loss of utilisation

The losses in vehicle utilisation essentially depend on the mileage. Specifically, the loss is calculated using the mileage and a loss factor (l/1000 km).

The information on the specific loss provided by experts or found in the literature varies considerably in some cases. Zimmermann und Jepsen (2017) conducted a broad survey of experts and analysed the literature. The results for passenger cars are shown in Figure 5 described.

Figure 5: Relative and specific engine oil loss - in use (passenger car)



Source: Ökopol on the basis of (Zimmermann und Jepsen 2017)

The figure illustrates the linear relationship between specific loss in use and relative loss (in comparison to the input quantity). It also highlights a maximum limit for "realistic" assumptions regarding relative and specific losses, based on assessments from various lubricant experts, including those surveyed by TOTAL as part of a study (Zimmermann und Jepsen 2017). Slightly above this "realistic maximum" is information provided by Autoscout24 (AutoScout24 26.3.2019) which represents the upper limit for "normal consumption".

Additionally, an absolute maximum is indicated in the figure, representing a complete relative loss in utilization. The majority of the data points fall within the range of 0.05 to 0.07 liters per 1,000 kilometers. Notably, the following should be emphasized::

- The results of a survey of workshops/ garages as part of the study by Jepsen et al. (2016) with a specific loss of 0.05 litres/1,000 km
- CONCAWE's estimates with a specific loss of between 0.05-0.07 litres/1,000 km
- The data from TOTAL and BP/Castrol (collected by Zimmermann und Jepsen (2017) with a specific loss of 0.06 litres/1,000 km
- The data from the two Californian studies (Geyer et al. 2013; Kuczenski et al. 2014) with a specific loss of 0.058 L/1,000 km

Considering this data, a loss factor of 0.07 liters per 1,000 kilometers is assumed for passenger cars. This figure is at the higher end of the majority of data points, while also accounting for a certain proportion of vehicles with higher losses.

Much less information is available on the specific loss in the use of engine oils for lorries and two-wheelers. Based on the survey by Zimmermann und Jepsen (2017) a usage loss of 0.4 litres/1,000 km is assumed for HGVs and 0.3 litres/1,000 km for two-wheelers.

Losses due to exports

Waste oil losses result from the export of filled vehicles. On the one hand, these are exports of filled new vehicles and, on the other, exports of used vehicles.

The data basis used here is data from the foreign trade statistics (Destatis 2022b)data from UBA/BMUV on exports, in particular of used vehicles (UBA and BMUV 2021) as well as data from a recently completed study on end-of-life vehicle utilisation, which partially corrects the assumptions made by UBA and BMUV (2021) contains (Zimmermann et al. 2022b) were used.

Accordingly, net exports of passenger cars amount to around 3.2 million vehicles. Net exports of buses and lorries amount to around 100,000 vehicles. There is a net import of around 40,000 vehicles for two-wheelers.

Engine oil per vehicle

To determine the engine oil loss due to exports, the quantity of engine oil per vehicle must be determined. In the previous report, an engine oil content of 5.5 litres was assumed. However, as the composition of the vehicle population has changed significantly over time, with annual growth rates in the double-digit range for SUVs and off-road vehicles, for example, an update or review appears necessary here.

It should be noted that the average engine oil content per vehicle for passenger cars does not correspond to the average of the vehicle fleet. In the case of used car exports, more durable vehicle segments are particularly relevant, while small cars are significantly underrepresented here (Zimmermann et al. 2022a).

Firstly, data from KBA on the composition of the stock by vehicle segment was used. For each vehicle segment, the quantity of engine oil for 3 to 5 selected representative vehicle types was then researched via the Internet.

On this basis, the quantity of engine oil for export vehicles has been adjusted from 5.5 to 6.1 litres.

Losses - vehicle recycling / waste oil removal during dismantling

A survey of dismantling facilities regarding the practice of dismantling end-of-life vehicles, conducted as part of the study by Zimmermann et al. (2022a), revealed that out of an average total quantity of 9.7 liters of oil per end-of-life vehicle, approximately 700 ml typically remains in the vehicle after it has been drained. This quantity includes not only engine oil but also transmission oils, shock absorber oils, differential oils, and power steering oils. Transmission oils are discussed separately in section 3.2.7.

The relative loss of engine oil is lower compared to that of transmission oils, which is estimated to be between 3-5%. When considering additional handling-related drips of 0.6%, the total output-side loss is estimated at 4.6%. This loss pertains to vehicles treated in Germany. In 2019, this accounted for 461,266 vehicles dismantled in authorized facilities (UBA and BMUV 2021). Additionally, some vehicles are dismantled in non-authorized facilities. Based on findings from

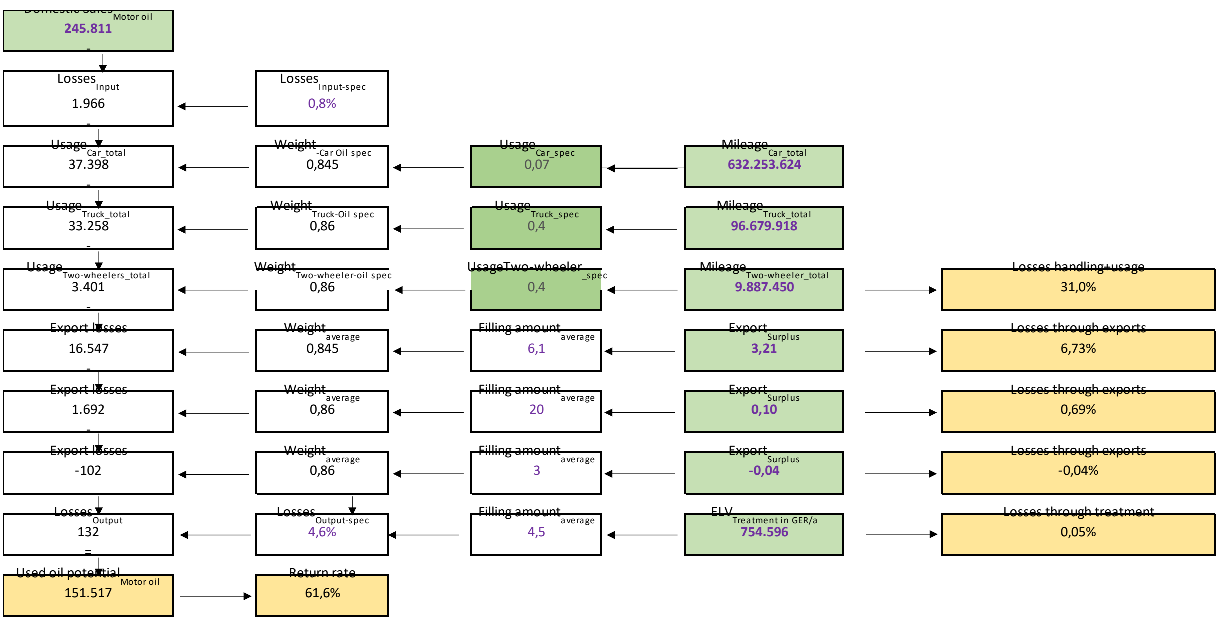
Zimmermann et al. (2022b), the number of vehicles dismantled by unauthorized operators is estimated to be 293,000.

While vehicles with larger engine capacities are more likely to be exported, small cars are underrepresented. The situation is different for vehicles treated in Germany. In the survey of the recycling situation conducted by Zimmermann et al. (2022b), an average of 4.5 liters of waste oil per end-of-life vehicle was reported. As mentioned, an average of 4.6% of this oil either remains in the vehicle or is lost due to handling.

Summary

In summary, the individual calculation steps are illustrated in Figure 6. The overall result shows a return rate for engine oil of 61.6%.

Figure 6: Determination of the updated return rate for engine oil



Source: Ökopol, calculation model for return rates of engine oil

Excursus: Time series of return rates for engine oil

In past studies on the whereabouts of waste oil in Germany (Sander et al. 2006; Jepsen et al. 2016) return rates for waste oil were also determined. These amounted to 59.6 % (in 2006) and 51.9 % (in 2016).

As described above, a return rate of 61.6 % was determined in this study. For the data transmission (see chapter 4), the return rates for 2020 and 2021 were also determined. These amount to 66.2 % and 60.3 %.

However, a comparison of the 2006 and 2016 figures with the current figures is only possible to a limited extent. On the one hand, this is due to the adjustments made to the calculation model, which was further differentiated with regard to export losses and end-of-life vehicle utilisation. Secondly, model parameters were updated. These include, in particular, the factor for calculating the utilisation losses of engine oil and the handling losses for input and output. This break in methodology means that it is not possible to create a consistent time series.

However, an approximate update of the 2006 and 2016 quotas can be made using the updated parameters. The resulting values are listed in the following table. The values for engine oil return range between around 60 and 69 %. If the annually fluctuating factor of engine oil losses due to vehicle exports is also factored out, values between just under 66% and 75.5% are obtained.

Table 23: Engine oil return according to other studies and sources

Return rate	Return rate 2006 (Sander et al. 2006)	Return rate 2016 (Jepsen et al. 2016)	Return rate 2019 (newly determined)	Return rate 2020 (newly determined)	Return rate 2021 (newly determined)
According to the study	59,6 %	51,9 %	61,6%	66,2%	60,3%
Response, parameters from the current study	68,8 %	65,1 %	61,6%	66,2%	60,3%
Without exports	75,5%	72,0%	69,0%	71,4 %	65,7%

3.2.5 Compressor oils

With a share of 0.9 % of the lubricant placed on the market, compressor oils are only of minor volume relevance. Losses of compressor oils occur as a result of evaporation and leaks as well as residual quantities in containers and the compressors themselves.

The various previous studies (Sander et al. 2006; Jepsen et al. 2016; Zimmermann und Jepsen 2017) assume a return rate of 50 %. Older studies with other geographical references sometimes assume a higher response rate (85 % for Kuczenski et al. (2014) and Kline & Company (2012) partly lower (30 % in UNEP (2012).

A consultation of VSI and BVA has indicated an increase in the return rate from the previous 50%. The implementation of better seals in modern machines, along with a stronger focus on minimizing losses due to high compressor oil prices, are significant trends contributing to this improvement. According to the experts surveyed, a return rate of 70% is now considered more realistic for the current situation. Consequently, a return rate of 70% has been adopted in the calculation model.

3.2.6 Turbine oils

With a share of 0.1 % of lubricants placed on the market, turbine oils are only of very minor relevance in terms of volume.

The preliminary reports from Germany (Sander et al. 2006; Jepsen et al. 2016) put the return rate at 70 %, while other studies indicate return rates of between 75 % and 85 % (Zimmermann und Jepsen 2017; Kuczenski et al. 2014; DEFRA 2006; Kline & Company 2012; Kline & Company 2007; UNEP 2012).

In the report by Zimmermann und Jepsen (2017) on waste oil returns in Belgium, a series of stakeholder discussions were held, resulting in an increase in the return rate for turbine oils to 75 %. A consultation with the BVA also revealed that the previously assumed return rate of 70% no longer corresponds to reality and should be corrected upwards. Modern machines with better seals and high prices are factors that have contributed to an increase in the return rate. According to the experts surveyed, a return rate of between 75 and 85% is considered realistic.

On this basis, the assumed return rate is adjusted to 80% for the calculation model.

3.2.7 Gear oils

The group of gear oils can be further subdivided into automotive gear oils, ATF gear oils (automatic transmission fluids, which are used in vehicles with automatic transmissions) and industrial gear oils.

3.2.7.1 Automotive and ATF gear oils

Possible losses of motor vehicle and ATF transmission oils result from handling during filling, losses during use, losses during draining (in end-of-life vehicle recycling) and through the export of vehicles.

Losses during filling are estimated at 1.5 %, and losses during utilisation at 0.5 % (Zimmermann und Jepsen 2018b; Zimmermann und Jepsen 2017). Taking into account the findings from (Zimmermann et al. 2022b) and discussions held with ELV dismantling facilities and workshops, the loss in input is adjusted to 0.5 % and in use to 0.3 %. The losses during drainage in ELV treatment are calculated based on the surveys by Zimmermann et al. (2022b) are estimated at 6 %. The decisive factor here is the number of end-of-life vehicles generated for treatment in Germany each year (see section 0).

The losses resulting from the export of vehicles are determined by the net export figures already described in section 0. In addition to the net export figures, the quantity of transmission oil per exported vehicle is also decisive. In the preliminary report (Jepsen et al. 2016) 3.4 litres of gear oil per vehicle have been assumed. Analogous to the procedure for the engine oil return, validation is carried out here based on the composition of the stock by vehicle segment and specific transmission oil quantities by vehicle type. On this basis, a slightly higher gear oil quantity of 3.7 litres per vehicle was determined.

3.2.7.2 Industrial oils

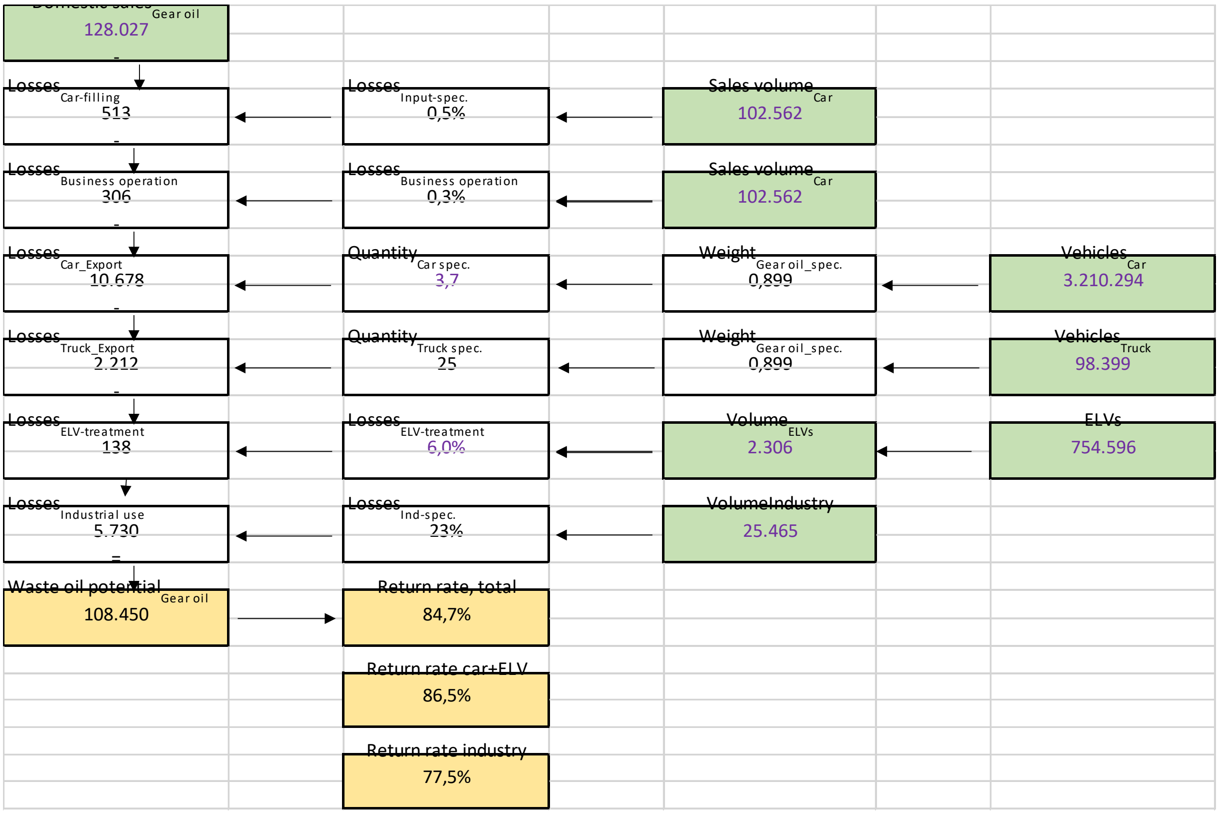
The losses of industrial gear oils result from handling losses (filling, removal), leaks and losses from the export of machines. Previously, an overall loss rate of 25 % was assumed here. There is a broad consensus in the relevant studies regarding the magnitude of the loss rate (Sander et al. 2006; Jepsen et al. 2016; Zimmermann und Jepsen 2017; Zimmermann und Jepsen 2018a; Kuczenski et al. 2012; Kuczenski et al. 2014; DEFRA 2006). In the report by Zimmermann und Jepsen (2017) on waste oil returns in Belgium, a series of stakeholder discussions were held, resulting in an assumed loss rate of 22.5 %. This assumption was fed back to the VSI and BVA and was adopted for the situation in Germany.

3.2.7.3 Recalculation of the return rate

Based on the above explanations (sections 3.2.7.1 and 3.2.7.2), the return rates for transmission oils have been recalculated. The return rate for motor vehicle and ATF gear oils is 86.5 %. For industrial gear oils, it is 77.5 %.

Across all groups of gear oil types, the response rate was 84.7 % (weighted average, calculated based on the responses and quantities of the slightly different types of gear oil).

Figure 7: Calculation of waste oil potential for gear oils



Source: Ökopol, calculation model for return rates of gear oil

3.2.8 Hydraulic oils

Hydraulic oils are utilized across a variety of applications, including both stationary uses (such as in machine tools and hoists) and mobile uses (including construction machinery, loaders, excavators, graders, industrial trucks, agricultural tractors, aircraft, and marine hydraulics). These oils account for approximately 6.4% of the lubricants marketed. In previous reports regarding Germany, the assumed return rates for hydraulic oils were set at 75% (refer to Table 24 for an overview). This figure was derived from specific return rates for mobile and stationary applications.

Table 24: Return rates assumed for hydraulic oil in various studies

Return rate from (Sander et al. 2006)	Return rate from (Jepsen et al. 2016)	Return rate from (Zimmermann und Jepsen 2017)	Return rate from (DEFRA 2006)
75 %	75 %	73 %	80 %

For mobile applications (excavators, tractors, mobile cranes, etc.), the loss rates were adjusted from an earlier estimate of 40% to 50% down to 32.5%, as determined by expert consultations (Sander et al. 2006; Jepsen et al. 2016). A recent consultation with experts from BVA and VSI indicated that the earlier assumed loss range of 40% to 50% was too high, with the loss rate now estimated to be between 20% and 30%. Consequently, the loss rate has been revised to 25%.

In stationary applications, losses were initially estimated at 20% (Zimmermann and Jepsen 2017). However, the latest consultations by BVA and VSI suggest a loss rate of 10% to 20%. As a result, the estimated loss rate has been adjusted to 15%.

The key factor in determining the total loss rate is the distribution of hydraulic oil usage between stationary and mobile applications. In Sander et al. (2006), the ratio was determined to be 60:40 in favor of stationary applications, a finding that was confirmed in Jepsen et al. (2016). However, an analysis of production and foreign trade statistics suggests that the actual proportion of mobile applications may be higher. Therefore, this ratio has been adjusted to 50:50, which has been communicated back to BVA and VSI.

Additionally, closer examination of the studies and statistical data, along with an initial survey of stakeholders, has highlighted that the export of complete products (devices and machines) may represent an underappreciated loss pathway. An evaluation of foreign trade statistics for various products utilizing hydraulic fluids indicates a significant export surplus for cranes, excavators, and presses (see Table 25). It is important to note that the foreign trade statistics only provide data in terms of weight (tonnes) and value (euros), making it challenging to determine the exact quantity of machines or vehicles involved.

Table 25: Import-export balance for hydraulic oil applications

WA	Explanation	Import-export balance [tonnes]
WA841382	Lifting equipment for liquids (except pumps)	36
WA842541	Lifting platforms, stationary, motor vehicle workshops	-907
WA842611	Bracket cranes or wall travelling cranes	-6.522
WA842619	Overhead travelling cranes, gantry cranes, loading bridges	-11.863
WA842620	Tower cranes	-10.764
WA842630	Portal slewing cranes	-5.747
WA842641	Cranes, self-propelled, with pneumatic tyres	-43.410
WA842649	Mobile cranes and crane trucks	-65.191
WA842691	Cranes for mounting on road vehicles	11.894
WA842699	Derrick cranes, cable cranes and other cranes n.e.c.	-8.148
WA842951	Front shovel loader, self-propelled	-33.735
WA842952	Excavator, self-propelled, with rotating uppercarriage	-152.144
WA842959	Excavators, scrapers and other shovel loaders	10.692
WA843031	Sloping machines and other mining machines, self-propelled	138
WA843039	Cutter and other mining machines	-34.937
WA843340	balers for hay or straw, pick-up balers	-18.769
WA843510	Presses, mills, etc. for wine, must, etc.	-524
WA843590	Parts of presses, mills, etc. for wine, must, etc.	664
WA844140	Machines for compression moulding of paper goods	-810
WA846291	Presses, hydraulic, for metalworking	-12.077
WA846299	Presses, for metalworking	-4.589

WA	Explanation	Import-export balance [tonnes]
WA846711	Tools, pneumatic, hand-held, rotating	1.127
WA846719	Tools, pneumatic, hand-operated	40
WA846789	Tools, hand-held, with hydraulic motor	-2.329
WA847480	Machines for pressing mineral fuels	-22.881
WA847930	Presses for the production of wooden panels	-27.926
WA860400	Rail vehicles for track maintenance, etc.	-3.217
WA870110	Single-axle bagger tractors and tractors	114
WA870510	Crane lorries (mobile cranes)	-228.017
WA890510	Dredger	-6.005
WA930310	Muzzleloader	3

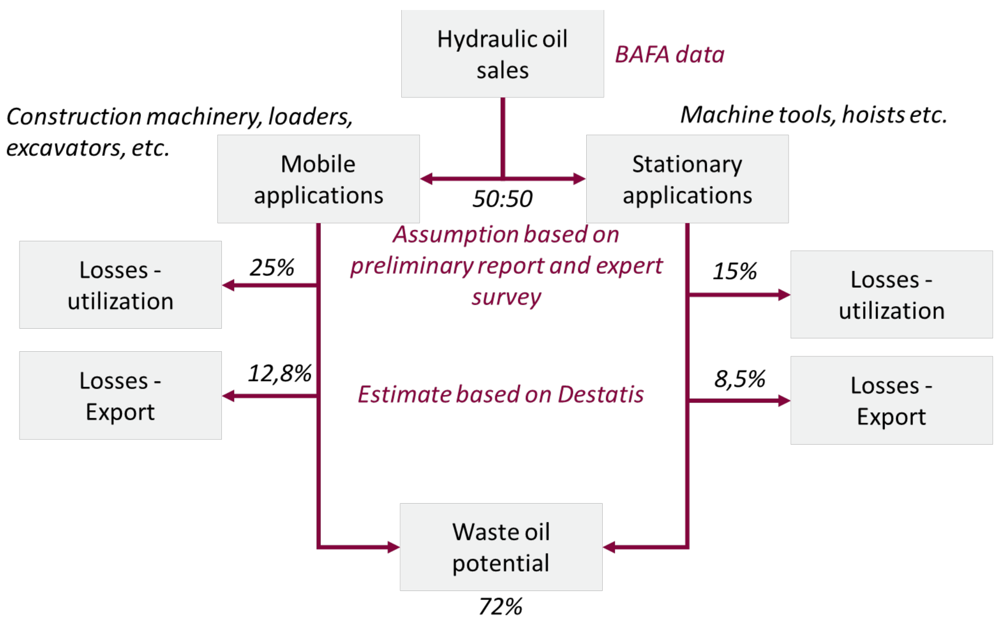
Source: Destatis, foreign trade statistics; negative values indicate an export surplus

A survey of manufacturers has shown that mobile applications in particular are typically exported in a filled state. In the case of stationary applications (presses, etc.), there are both ready-to-use (filled) and unfilled export.

A rough estimate of the quantitative loss of oil through exports based on a random survey of weights and hydraulic oil quantities per vehicle/machine and supplementary discussions with manufacturers and retailers revealed a total export loss of around 6,600 tonnes for mobile and stationary applications. Concerning the volume of around 63,000 tonnes placed on the market, this corresponds to proportional losses of around 11 %, or around 12.8 % for mobile applications and 8.5 % for stationary applications (cf. Figure 8).

The return rate is adjusted accordingly to 72%.

Figure 8: Losses and returns of hydraulic oils - schematic description



Source: Own description, Ökopol

3.2.9 Electrical insulating oils

Electrical insulating oils account for 1.2 % of the lubricants placed on the market. The previous reports indicate a return rate of 90 % (Jepsen et al. 2016; Sander et al. 2006). Slightly higher return rates can be found in other reports (Zimmermann und Jepsen 2017; DEFRA 2006).

Table 26: Return rates assumed for electrical insulating oil in various studies

Return rate from (Sander et al. 2006)	Return rate from (Jepsen et al. 2016)	Return rate from (Zimmermann und Jepsen 2017)	Return rate from (DEFRA 2006)
90 %	90 %	92,5 %	95 %

Source: Compilation by Ökopol based on the sources mentioned

As described in section 3.2.2 the waste statistics for electrical insulating oils can provide indications for adjustments to the return rate. Table 27 shows the quantities placed on the market and the quantities of waste (dry) for the years 2014 to 2019. The ratio of waste quantities and quantities placed on the market is also shown. Over the period shown, the ratio is around 98.8 %.

Table 27: Electrical insulating oils - Placing on the market and waste quantities

Quantity	2019	2018	2017	2016	2015	2014	2014-2019
Quantity placed on the market [t]	12.162	11.118	12.247	11.628	18.232	14.209	79.596
Amount of waste, dry [tonnes]	13.761	12.474	13.167	12.672	13.464	13.167	78.705
Waste quantity/ Quantity placed on the market	113%	112%	108%	109%	74%	93%	99%

Sources: BAFA, Destatis, dry volume calculated using the water content in Table 19

Against this background, the return rate for electrical insulating oils is adjusted to 98%.

3.2.10 Machine oils

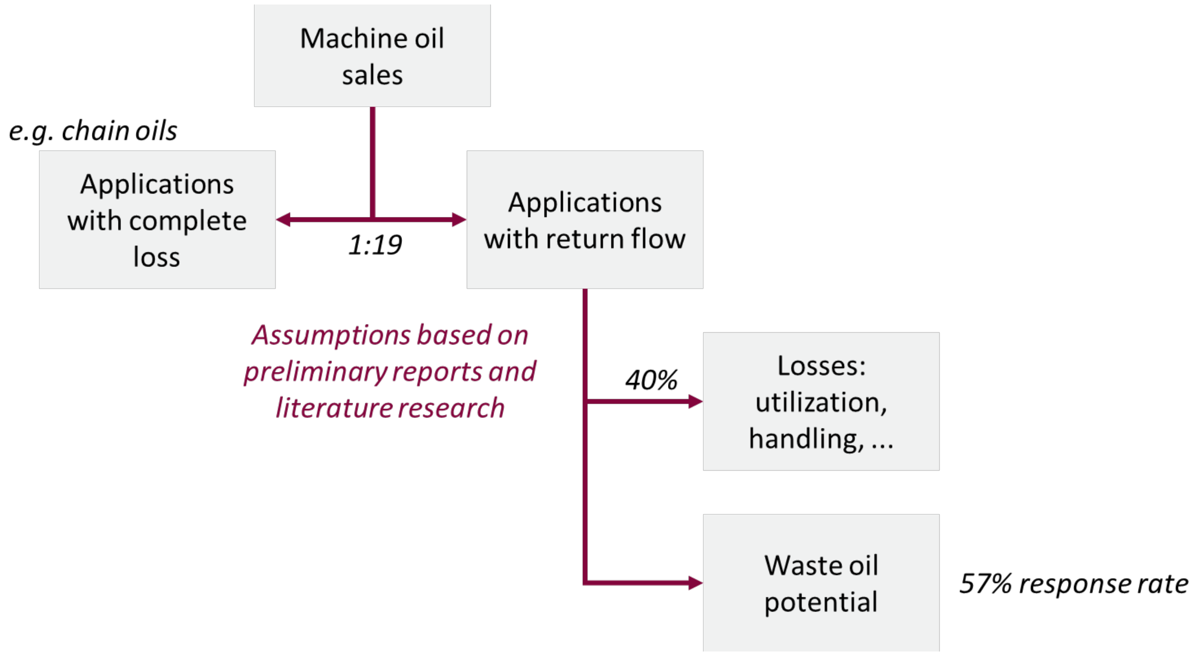
Machine oils are used in a wide range of applications for the lubrication of machines and machine parts. Machine oils include (cf. Sander et al. 2006)

- Cylinder lubricating oils,
- Spindle lubricating oils,
- Machine lubricating oils,
- Adhesive oils,
- Bed/slideway oils,
- All axle oils,
- Textile machine oils,
- Compressed air machine oils and

- Chain oils.

This includes applications with and without waste oil return. A loss rate of 40 % is currently assumed for applications with waste oil return. The breakdown between applications with and without returns is decisive for determining the return rate. The following figure shows the breakdown as determined by expert interviews in the preliminary report.

Figure 9: Losses and returns of machine oils - schematic description



Source: Own description, Ökopol

Consultation with the VSI and BVA has shown that these assumptions are still considered realistic. Accordingly, a return rate of 57 % is assumed for machine oils.

3.2.11 Metalworking oils

The lubricant type group of metalworking oils can be further subdivided into water-miscible (wm) and non-water-miscible (nwm) metalworking oils as well as hardening oils and corrosion protection oils. The latter belong to the lubricant types without waste oil return and have already been described in section 3.2.3 above.

Wm and nwm metalworking oils are used as lubricants and coolants in cutting, grinding, drilling and other operations that generate metal swarf. In these applications, the oil used is usually collected, filtered to remove sludge and metal swarf, and then treated for reuse. Wm and nwm metalworking oils can also be used for forming. In this process, a part is lost as a thin film on the metal object. In both applications, machining and forming, losses can occur due to evaporation, leakage and inefficiencies.

Recirculating lubricants in metal cutting operations reduces oil change frequencies and consumption. While on-site recirculation increases the service life of metalworking oils and reduces annual consumption, it increases losses in relation to lubricant use and reduces the proportion that can be recorded: the longer the lubricants are used, the greater the relative importance of losses due to adhesion to metal chips, handling, etc. Minimum quantity lubrication as a lubricant technology with increasing importance also reduces the absolute consumption, but reduces the relative amount that can be recorded.

The trend towards minimum quantity lubrication has continued (Singh et al. 2020; Herrmann et al. 2017); Discussions with the VSI have revealed that, in addition to the trend towards minimum quantity lubrication, systems with the most extensive recirculation of the lubricant are now the rule, at least for the area of nwm metalworking oils. This results in a low discharge via the workpieces, which makes occasional refilling of the machines necessary. This recirculation means that hardly any waste oil is produced in these systems. This is only the case if, for example, the existing lubricant is completely replaced due to new requirements. For normal operation, this means a very low return rate of <10 %. The frequency of replacing the entire lubricant is more difficult to quantify. In preliminary projects, the return rate of nwm metalworking oils was estimated at 52 % (Jepsen et al. 2016; Zimmermann und Jepsen 2017) Taking into account the trends in lubricant practice, this rate may appear somewhat too high. The consultation with the BVA also resulted in general agreement with this assessment. Against this background, the assumed return rate was slightly adjusted to 50 %.

So far, higher losses have been assumed for wm metalworking oils than for nwm oils. In the various preliminary reports, a return rate of 47 % is assumed for wm oils (Sander et al; Jepsen et al; Zimmermann und Jepsen 2006; 2016; 2017).

A 2017 study by the VDI Centre for Resource Efficiency on wm metalworking oils revealed losses of around 36% due to adhesion to chips and workpieces (Herrmann et al. 2017). The remaining emulsions, which ultimately accumulate as waste and are assigned to waste code numbers 12 01 08* and 12 01 09*, are disposed of as hazardous waste at a cost of around €150/m^3 to disposal companies, which split them into waste oil phase and aqueous phase. The waste oil phase is typically not sent for reprocessing (Destatis 2022a; Herrmann et al. 2017). The waste oils collected by the Herrmann et al. (2017) loss rate of 36 % gives no reason to increase the previously assumed return rate of 47 %, as only a limited selection of manufacturing processes is mapped here. The BVA survey confirmed the previous assumptions in the order of magnitude.

For wm and nwm metalworking oils, the previously assumed return rate will be maintained.

When updating the reverse calculation model, it should be noted that the wm metalworking oils fall under waste code numbers that are not assigned to collection categories 1-4. For future updates, consideration can be given to either setting the return rate to 0 or adding other waste treatment (in thermal plants and physico-chemical treatment plants).

3.2.12 Base oils

With regard to the base oils that are reported when lubricants are placed on the market, it is unclear which end applications they are used for. Discussions with practitioners have not yielded any new findings compared to the previous reports.

Various approaches are conceivable, which can at least provide an orientation for the order of magnitude of the return flow of base oil. Table 28 provides an overview of four corresponding approaches. The returns here range between around 24 % and 67 %.

A return rate of 50% is still assumed for the calculation model.

Table 28: Various orientating calculations on the return of base oils

Calculation approach	return rate
as an average of industrial oils with return	66,6%

Calculation approach	return rate
than the average for industrial oils	23,8%
as an average of all lubricants	34,9%
as an average of all lubricants with return flow	65,8%
Return rate assumed in the calculation model	50,0%

Source: Calculation by Ökopol

3.2.13 Summary: updated return rates

Based on the individual updates of the return rate for each lubricant grade group described above, the results are shown in Table 29.

Table 29: Summary of the update of the return rates

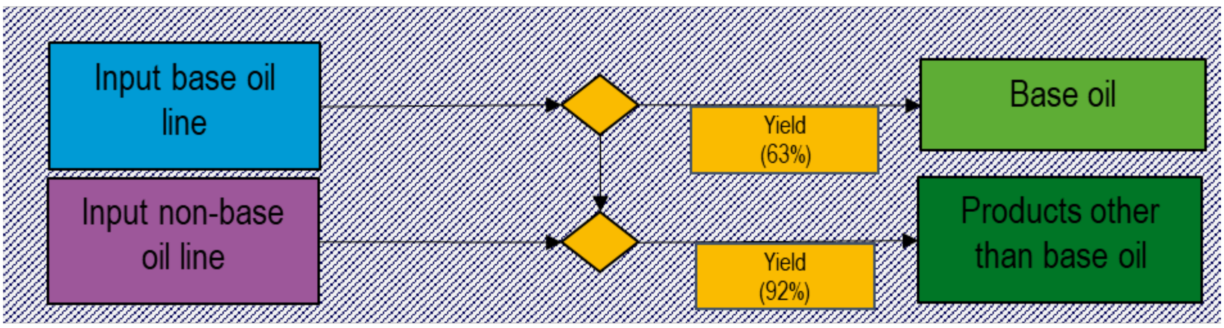
Variety group	Return rate - previous assumption	Return rate - Updated	Remark
Engine oils (see section 0)	51,9%	61,6 %	Assumption updated. Losses due to exports updated based on current data. Model refined concerning export losses. Losses due to handling and utilisation updated.
Compressor oils (see section 3.2.5)	50,0%	70%	Assumption updated. Increase in the return rate based on the expert consultation carried out.
Turbine oils (see section 3.2.6)	70,0%	80%	Assumption updated. Increase in the return rate based on the expert consultation and current studies.
Transmission oils - total (see section 3.2.7)	64,0%	79%	Assumption updated. Losses due to exports updated based on current data. Model refined concerning export losses. Losses due to handling and utilisation updated.
- Motor vehicles (gear oils)	79%	82%	
- ATF	79%	82%	
- Industry (gear oils)	75%	77,5%	
Hydraulic oils (see section 3.2.8)	75%	72 %	Assumption updated. Export losses included in calculation. Breakdown into stationary and mobile applications adjusted.
Electrical insulating oils (see section 3.2.9)	90,0%	98,0%	Updated on the basis of waste statistics data.
Machine oils (see section 3.2.10)	50,0%	57%	Assumption updated. Consideration of mobile:stationary split and losses based on expert consultation.

Variety group	Return rate - previous assumption	Return rate - Updated	Remark
Metalworking oils (see section 3.2.11)		49%	Retention of the assumption.
- Wm	47%	47%	Retention of the assumption.
- Nwm	52%	50%	Updated, minor adjustment.
Base oils (see section 3.2.12)	50,0%	50%	Allocation to applications unclear, therefore no update possible.
Process oils	0,0%	0,0%	Checked / assumption still valid.
Other industrial oils not for lubrication	0,0%	0,0%	Checked / assumption still valid.
Lubricating greases	0,0%	0,0%	Checked / assumption still valid.
Extracts from lubricating oil refining	0,0%	0,0%	Checked / assumption still valid.

3.3 Updating the yield factors

A survey of stakeholders in the waste oil regeneration industry was carried out to collect the yield factors. For this purpose, information was requested on the quantities of waste oils received and the quantities produced (base oil and non-base oil products).
The waste oil regeneration companies covered by the survey report a total base oil production of 215,803 tonnes. This corresponds to about 80% of the production of base oils and lubricants from secondary refining reported by BAFA.The survey showed an overall yield of 63 % in the base oil route and 92 % in the non-base oil route (cf. Figure 10). In each case, this represents a slight increase compared to the figures in the previous report (Jepsen et al. 2016) of 62.9% and 89.2%, respectively.

Figure 10: Yield factors in base oil and non-base oil train



(Figures for 2019)

Source: Calculation by Ökopol based on a survey of waste oil re-refiners

3.4 Regeneration/ Re-refining

The volume from re-refining can be found in the BAFA statistics; it is reported in *Table 5j*, broken down by product. The quantities for 2019 and 2020 are shown in Table 30.

Table 30: **Volume from secondary refining**

Product	2019	2020
Secondary refining (regeneration)	**272.001**	**253.721**
thereof base oil	234.141	217.583
of which other lubricants	37.860	36.138
Products other than base oils and lubricants, total	**200.268**	**193.740**
of which heating oil, light	13.954	15.816
of which middle distillate components	4.393	4.136
of which heating oil, heavy	135.515	131.567
of which heating oil, heavy components	39.332	34.103
of which speciality petrol	7.074	8.118

Source: Secondary refining, BAFA Table 5j

3.5 Energy treatment of waste oils

Established paths for the energy recovery of waste oils in Germany are treatment in the cement industry and treatment in the lime industry.

The German Cement Works Association (VDZ) periodically reports on the treatment of waste oils for energy recovery in the cement industry in the "Environmental data of the cement industry" (vdz 2020). According to this report, 70,000 tonnes of waste oil (50,750 tonnes dry) and 140,000 tonnes of oil sludge and organic distillation residues were treated for energy in the cement industry in 2019.

Data on the lime industry is available from BV Kalk on request. According to this data, waste oil with a calorific value totalling 893,452 GJ was used in the lime industry in Germany in 2019. Assuming an energy content of 40 MJ/kg, this corresponds to around 22,000 tonnes.

The total for 2019 (excluding oil sludge and organic distillation residues) is around 72,000 tonnes of waste oils (dry) that are sent for energy recovery. For 2020, the corresponding quantities for the lime and cement industry total around 65,000 tonnes (dry).

In previous expert reports (Jepsen et al. 2016; Sander et al. 2006) the use of these two data sources as a basis for energy treatment in the material flow model was critically discussed with stakeholders. As a result, the approach was maintained in the calculation model for waste oil flows.

A possible alternative approach is to utilize data from waste statistics. This data includes the reported input quantities of waste oils from various waste streams, including thermal waste treatment plants, incineration plants, and chemical-physical treatment facilities (*Table 32111-0004*).

The input quantities of waste oils in thermal waste treatment plants and combustion plants can be transferred directly to the model as quantities for energy recovery, whereby these quantities must still be adjusted for the water content. In the case of CP plants, it is not the input quantities but the output quantities that must be considered. The outputs of waste oils from the CP plants are mainly sent for energy recovery, with a smaller proportion also going for recovery or disposal, which is reported accordingly in the waste statistics. Operators of chemical-physical treatment plants confirm this (Nehlsen 2023).

Consultation with re-refiner indicated that the oil phases generated from CP treatment are generally unsuitable for recycling. The input materials for CP plants typically consist of oils with high water content, such as emulsions or oil-water mixtures. The goal of the treatment is to separate the oil for energy recovery and the water phases. However, the resulting oil fractions are not suitable for re-refining in most instances.

There are exceptional cases where the input consists almost entirely of waste oils categorized as CC I. In these instances, a suitable oil phase can be produced after a pre-treatment process to reduce the water content. However, this concerns very rare cases, which are negligible.

The statistical quantities for treatment in thermal waste treatment plants, incineration plants and chemical-physical treatment plants contain water as described and must be adjusted accordingly for consideration in the context of the calculation model. For the input quantities for treatment in thermal waste treatment plants and in incineration plants, the values of Table 36 in section 4.3 can be used as an approximation. For the input quantities in CP plants, it can be assumed, based on information from practice, that these have significantly higher water contents, while the output quantities in terms of water content corresponding to the values in Table 36 in section 4.3 are rather close. Accordingly, the output quantities from CP plants are recognised here as quantities including water content.

Table 31: Data on energy recovery from the waste statistics (year: 2019)

Waste code	Description description	Input quantities Thermal waste treatment (1,000 tonnes)	Input quantities com-bustion plants (1,000 tonnes)	Input quantities CP plants (1,000 tonnes)	Output of CP plants for energy recovery (1,000 t)	Total - quantities for energy recovery (1,000 t)	Total (1,000 tonnes, dry)
120106	Mineral oil-based machining oils containing halogens (except emulsions and solutions)	0.10	-	0.10	-	0.10	0.10
120107	Mineral-based machining oils free of halogens (except emulsions and solutions)	0.00	24.70	5.70	6.80	31.50	26.78
120110	Synthetic machining oils	-	-	0.30	-	0.00	0.00

Waste code	Description description	Input quantities Thermal waste treatment (1,000 tonnes)	Input quantities com-bustion plants (1,000 tonnes)	Input quantities CP plants (1,000 tonnes)	Output of CP plants for energy recovery (1,000 t)	Total - quantities for energy recovery (1,000 t)	Total (1,000 tonnes, dry)
130101	Hydraulics Oils containing PCBs	0.10	-	-	-	0.10	0.09
130109	Mineral-based chlorinated hydraulic oils	-	-	-	-	0.00	0.00
130110	Other insulating and heat transmission oils	-	-	0.50	-	0.00	0.00
130111	Synthetic hydraulic oils	-	-	-	-	0.00	0.00
130112	Readily biodegradable hydraulic oils	-	-	-	-	0.00	0.00
130113	Other hydraulic oils	0.00	-	-	-	0.00	0.00
130204	Mineral-based chlorinated engine, gear and lubricating oils	0.60	-	0.30	0.10	0.70	0.66
130205	Mineral-based non-chlorinated engine, gear and lubricating oils	0.60	16.70	85.40	23.90	41.20	37.29
130206	Synthetic engine, gear and lubricating oils	0.10	-	-	-	0.10	0.10
130207	Readily biodegradable engine, gear and lubricating oils	-	-	-	-	0.00	0.00

Waste code	Description description	Input quantities Thermal waste treatment (1,000 tonnes)	Input quantities com-bustion plants (1,000 tonnes)	Input quantities CP plants (1,000 tonnes)	Output of CP plants for energy recovery (1,000 t)	Total - quantities for energy recovery (1,000 t)	Total (1,000 tonnes, dry)
130208	Other engine, gear and lubricating oils	0.60	-	19.40	5.50	6.10	5.52
130301	Insulating or heat transmission oils containing PCBs	1.10	-	0.00	-	1.10	1.10
130306	Mineral-based chlorinated insulating and heat transmission oils other than those mentioned in 13 03 01	-	-	-	-	0.00	0.00
130307	Mineral-based non-chlorinated insulating and heat transmission oils	0.10	-	4.90	3.40	3.50	3.47
130308	Synthetic insulating and heat transmission oils	0.00	-	0.10	-	0.00	0.00
130309	Readily biodegradable insulating and heat transmission oils	-	-	-	-	0.00	0.00
130310	Other insulating and heat transmission oils	0.00	-	-	-	0.00	0.00

Waste code	Description description	Input quantities Thermal waste treatment (1,000 tonnes)	Input quantities com-bustion plants (1,000 tonnes)	Input quantities CP plants (1,000 tonnes)	Output of CP plants for energy recovery (1,000 t)	Total - quantities for energy recovery (1,000 t)	Total (1,000 tonnes, dry)
Total	**for all listed waste codes**	**3.30**	**41.40**	**116.70**	**39.70**	**84.40**	**75.09**
Plus 120109	Machining emulsions and solutions free of halogens	1.20	-	499.20	19.90	200.20	19.90
Total	**for all listed waste codes**	**4.50**	**41.40**	**615.90**	**59.60**	**284.60**	**94.99**

Table 32: Data on energy recovery from waste statistics (year: 2020)

Waste code	Description description	Input quantities Thermal waste treatment (1,000 tonnes)	Input quantities com-bustion plants (1,000 tonnes)	Input quantities CP plants (1,000 tonnes)	Output of CP plants for energy recovery (1,000 t)	Total - quantities for energy recovery (1,000 t)	Total (1,000 tonnes, dry)
120106	Mineral oil-based machining oils containing halogens (except emulsions and solutions)	-	-	0.1	-	0	0
120107	Mineral-based machining oils free of halogens (except emulsions and solutions)	0	20.5	3.9	4	24.5	20.83

Waste code	Description description	Input quantities Thermal waste treatment (1,000 tonnes)	Input quantities com-bustion plants (1,000 tonnes)	Input quantities CP plants (1,000 tonnes)	Output of CP plants for energy recovery (1,000 t)	Total - quantities for energy recovery (1,000 t)	Total (1,000 tonnes, dry)
120110	Synthetic machining oils	-	-	0.3	-	0	0
130101	Hydraulics Oils containing PCBs	-	-	-	-	0	0
130109	Mineral-based chlorinated hydraulic oils	-	-	-	-	0	0
130110	Other insulating and heat trans-mission oils	-	-	0.6	-	0	0
130111	Synthetic hydraulic oils	-	-	-	-	0	0
130112	Readily bio-degradable hydraulic oils	-	-	-	-	0	0
130113	Other hydraulic oils	-	-	-	-	0	0
130204	Mineral-based chlorinated engine, gear and lubricating oils	0.6	-	0.2	0.1	0.7	0.658
130205	Mineral-based non-chlorinated engine, gear and lubricating oils	2.2	10.6	89.3	25.1	37.9	34.3

Waste code	Description description	Input quantities Thermal waste treatment (1,000 tonnes)	Input quantities com-bustion plants (1,000 tonnes)	Input quantities CP plants (1,000 tonnes)	Output of CP plants for energy recovery (1,000 t)	Total - quantities for energy recovery (1,000 t)	Total (1,000 tonnes, dry)
130206	Synthetic engine, gear and lubricating oils	0.1	-	-	-	0.1	0.1
130207	Readily bio-degradable engine, gear and lubricating oils	-	-	-	-	0	0
130208	Other engine, gear and lubricating oils	0.1	-	18.9	5	5.1	4.6155
130301	Insulating or heat trans-mission oils containing PCBs	1	-	0	0	1	0.997
130306	Mineral-based chlorinated insulating and heat trans-mission oils other than those mentioned in 13 03 01	-	-	-	-	0	0
130307	Mineral-based non-chlorinated insulating and heat transmissio n oils	0.1	-	4.4	-	0.1	0.1
130308	Synthetic insulating and heat	0.5	-	0.3	-	0.5	0.5

Waste code	Description description	Input quantities Thermal waste treatment (1,000 tonnes)	Input quantities com-bustion plants (1,000 tonnes)	Input quantities CP plants (1,000 tonnes)	Output of CP plants for energy recovery (1,000 t)	Total - quantities for energy recovery (1,000 t)	Total (1,000 tonnes, dry)
	trans-mission oils						
130309	Readily bio-degradable insulating and heat transmission oils	-	-	-	-	0	0
130310	Other insulating and heat transmission oils	0.1	-	-	-	0.1	0.1
Total	**for all listed waste codes**	**4.70**	**31.10**	**118.00**	**34.20**	**70.00**	**62.19**
Plus 120109	Machining emulsions and solutions free of halogens	1.1	-	437.1	12.8	129.1	12.8
Total	**for all listed waste codes**	**5.80**	**31.10**	**555.10**	**47.00**	**199.10**	**74.99**

For 2019, this results in quantities for energy recovery of around 75,000 tonnes, or around 95,000 tonnes if emulsions are taken into account, compared to 73,000 tonnes based on the reports from the lime and cement industries. For 2020, the quantities for energy recovery amount to around 62,000 tonnes, or around 75,000 tonnes if emulsions are taken into account, compared to 65,000 tonnes based on the reports from the lime and cement industries.

The quantities for energy recovery treatment that can be determined on the basis of the two approaches therefore do not show any significant discrepancy. It should be considered whether the quantities from the waste statistics should be used in the calculation model in the future - analogous to the procedure for EU reporting.

It is important to highlight that there remain unanswered questions concerning the statistical data that could not be definitively resolved within this project:

- How can the high quantities of CC1 waste oils (in particular 130205 and 130208) that are treated in CP plants and treated for energy recovery be explained?
- Are the assumed water contents for the outputs of the CP treatment sufficiently accurate?

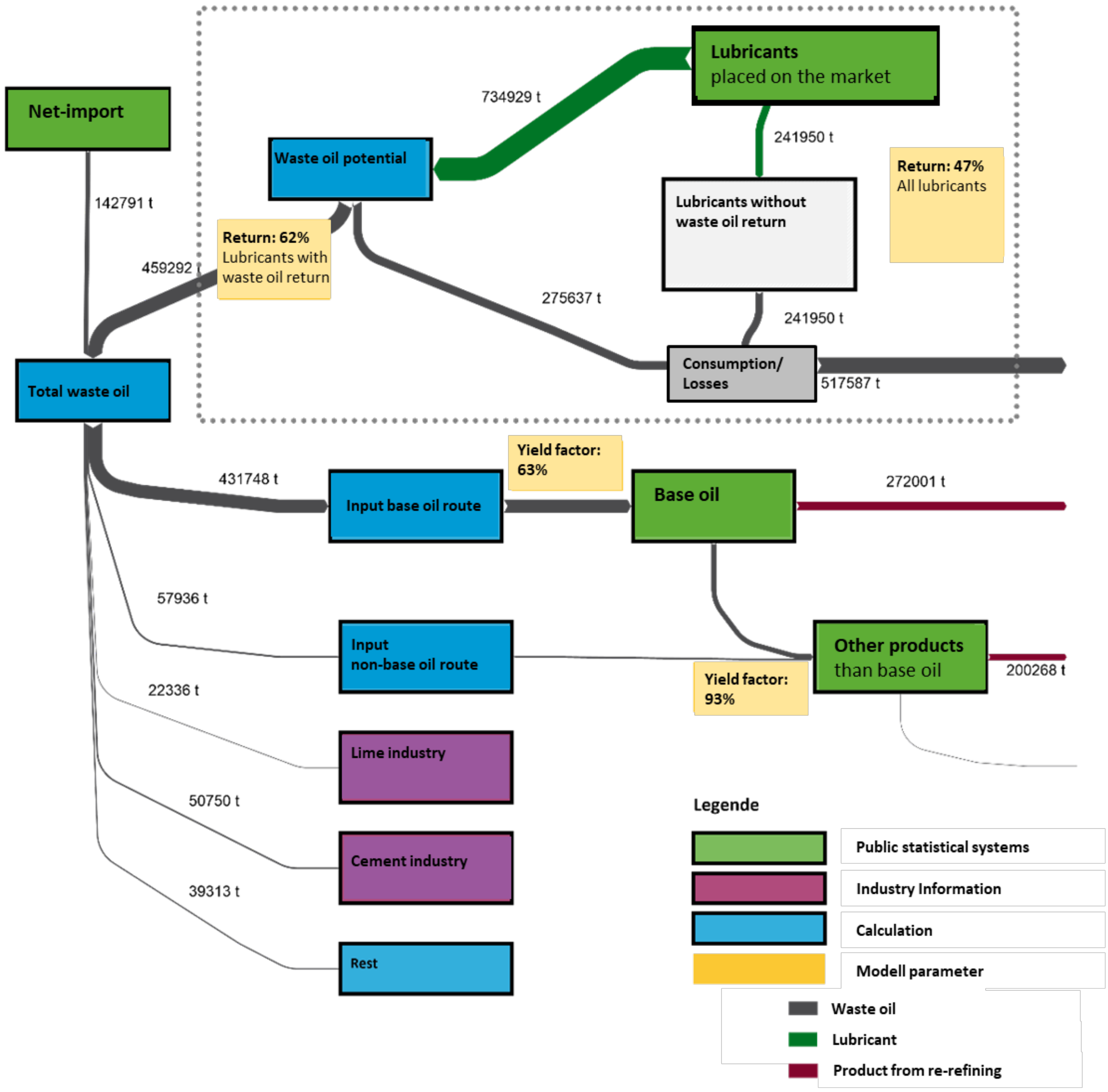
- In addition to the lime and cement industries, what other relevant players in energy treatment are there?

These questions warrant further exploration in future studies.

3.6 Description of waste oil flows in Germany 2019

Based on the information presented in Sections 3.1 to 3.5 the recalculation of waste oil flows for Germany in 2019 is based on the data and considerations described in sections 3.1 to 3.5. Figure 11 shows the material flows of lubricants and waste oils in Germany as a Sankey diagram.

Figure 11: Waste oil flows Germany 2019



Source: Ökopol

According to BAFA statistics, approximately 977 kilotonnes (kt) of various lubricant types were placed on the market in 2019. From this, the potential for waste oil recovery is around 459 kt, which represents about 47%. When considering only the grades that are suitable for return, the recovery rate increases to 62%. In addition to the German waste oil potential, net imports of around 143 kt have to be taken into account. This results in a total volume of 602 kt of waste oil in Germany.

Of this total, 72% is used for processing into base oil, while another 10% is processed for non-base oil applications. Additionally, 12% is utilized for energy recovery, leaving about 7% of the waste oil's final disposition unclear.

4 Checking suitability for data transmission in accordance with Annex VI

With Implementing Decision (EU) 2019/1004 of 7 June 2019 "laying down rules for the calculation, verification and reporting of data on waste in accordance with Directive 2008/98/EC", the EU Commission has issued, among other things, requirements for the reporting of data on the waste oil recovery situation. The specifications provide a foundation for establishing a data set to determine the feasibility of treating waste oil. This includes defining quantitative targets for the regeneration of waste oil, as well as outlining other measures to promote its regeneration (EU 2019/1004).

Annex VI of the implementing decision (EU 2019/1004) specifies the format for the transmission of data on the placing on the market of mineral and synthetic lubricating and industrial oils as well as on the treatment of waste oils.

Two tables are used to specify the format for data transmission. The first table titled “Reporting on data on the placing on the market of mineral and synthetic lubrication and industrial oils and on the treatment of waste oils” covers

1) Engine and gear box oils,
2) Industrial oils,
3) Industrial oils (emulsions only) and
4) Oil and concentrates from separation

For these four categories, the following data needs to be transmitted:

1. Oils placed on the market
2. Waste oil generated (dry oil)
3. Separately collected waste oils (including water and dry)
4. Exported waste oils (including water and dry)
5. Imported waste oils (including water and dry)
6. Regeneration (including water and dry)
7. Other recycling (including water and dry)
8. Energy treatment (including water and dry)
9. Disposal (including water and dry)

The second tabletitled “Reporting on data on the treatment of waste oils” covers
1-4) Regenerated base oil (with differentiation according to Group I to Group IV),
5) Recycled products,
6) "Fuel products for off-site energy recovery - light heating oil",
7) "Fuel products for off-site energy recovery - distillate fuel oil",
8) "Fuel products for off-site energy recovery - heavy fuel oil",
9) "Fuel products for off-site energy recovery treatment - recoverd fueloil",
10) "Fuel products for external energy recovery - processed fuel oil", internal energy recovery and
11) Other

For these categories the following data on quantities must be submitted:

1. Regeneration
2. Other recycling
3. Energy recovery or reprocessing into materials that are to be used as fuels
4. Disposal

In some cases, the information is optional rather than mandatory.

The following section describes which data sources are available for the individual data points, how to proceed for data transmission and which additional aspects may need to be taken into account when entering data.

4.1 Quantities placed on the market

Data on the quantities placed on the market are available for Germany in the official mineral oil statistics published periodically by the BAFA.

The lubricant types differentiated here must be allocated to the categories "engine and gear box oils", "industrial oils" and "industrial oils (emulsions only)" as requested by the data tables. In addition, some categories listed in the BAFA statistics are not to be included here, as these do not correspond to any lubricant application in the narrower sense and are also not reported by other member states. The exclusion of these categories is also consistent with the optional Table 3 of the Commission's submission. Table 33 summarises the classification.

Table 33: Domestic deliveries of lubricants, Germany, 2020

Variety group	Specification	t	Classification
Engine oils	-	264.829	Engine and gearbox oil
Compressor oils	-	9.301	Industrial oil
Turbine oils	-	1.358	Industrial oil
Gear oils	total		
	automotive gear oli	43.364	Engine and gearbox oil
	ATF	49.007	Engine and gearbox oil
	Industrial gear oil	24.373	Industrial oil
Hydraulic oils		80.093	Industrial oil
Electrical insulating oils		11.803	Industrial oil
Machine oils		25.814	Industrial oil
Other industrial oils not for lubrication		57.627	-
Process oils	total	117.334	-
	Technical white oils	20.551	-
	medicinal white oils	41.594	-
Metalworking oils	total		
	Hardening oils	2.460	-

Variety group	Specification	t	Classification
	water-miscible	27.995	Emulsions
	not water miscible	31.902	Industrial oil
	Anti-corrosion oils	5.336	Industrial oil
Lubricating greases	total	30.086	-
	including for motor vehicles	7.841	-
Base oils	-	28.566	Industrial oil
Extracts from lubricating oil refining	-	2.965	-
In total	**-**	**814.213**	**-**

Variety groups marked with "-" in the "Classification" column are not taken into account when reporting the quantities placed on the market.
Source for quantities of domestic deliveries: (BAFA 2020)

Annex VI of the Implementing Decision (EU 2019/1004) outlines adjustments to the quantity placed on the market to account for export losses and import gains, particularly concerning vehicle imports and exports. However, this correction is not applied at the current stage of data transmission.The import-export correction is determined by the return rates described in section 3.2. This applies in particular to engine and automotive gear box oils. Additionally, export losses are considered in the return rate for hydraulic oils, as noted in footnote 1 of the data transmission table. It is important to mention that the proposed "default" return rates, derived from the study by Jepsen et al. (2016), already incorporate this correction. Thus, making further adjustments to the quantities placed on the market would result in double counting. Accordingly, the quantities of domestic deliveries of lubricants from the BAFA statistics are used here without any additional adjustments.

Result

The corresponding data on data transmission and the associated footnote can be found in Figure 12.

Figure 12: Reporting on "1: Oils placed on the market"

	1			
	Oils placed on the market[5]			
	(t)	Standard footnotes	Explanatory footnote	
Engine and gear box oils[1]	357.200		1	Based on
Industrial oils[2]	213.210		1	Based on
Industrial oils (emulsions only)[3]	27.995		1	Based on
Oil and concentrates from separation[4]				

1	Based on BAFA data. The data of amounts placed on the market has not been adapted considering export losses of lubricant oils (e.g. export of lubricant oils within passenger cars) and import gains (e.g. imports of lubricant oils within passenger cars). This correction is included in the return rates which are applied to calculate waste oil return. Also in the provided default values for return rates this correction is included based on the situation in Germany (Ökopol 2016, 2022).

Source: Ökopol. Screenshot of the supplemented Excel template

4.2 Waste oil return

The dry oil quantities of waste oil generation must be reported under point (2). These are calculated on the basis of the quantity placed on the market for 2020 (based on BAFA statistics on domestic deliveries of lubricants) using the updated return rates (see section 3.2 and 3.2.13) (see footnote 2 (Explanatory footnote) in the Commission table).

It should be noted here that the data described in section 3.2 has the reference year 2019 as the reference year for the return rates for the back calculation model. In principle, it can be assumed that the return rates represent a sufficiently accurate basis for calculation for several years after the reference year. However, 2020 in particular is a special year in terms of export and import activities due to the coronavirus pandemic. For engine oils as well as for automotive gear box oils and ATF oils, an update is therefore made based on import and export activities in 2020. As the final statistics on vehicle imports and exports (unit numbers) are not yet available, the monetary euro values are used as an approximation. Due to lower export activities, the corresponding losses are lower and the return rates are higher. The adjusted return rates are shown in Table 34.

Table 34: Adjustment of the return rates for 2020

Lubricant grade	Return rate - basis 2019	Return rate adjusted for 2020
Engine oils	61,6%	66,2%
Automotive and ATF gear oils	86,5%	88,2%

The corresponding data on data transmission and the associated footnote can be found in Figure 13.

Figure 13: Reporting on "2: Waste oil generated"

	2		
	Waste oil generated[6] (dry oil)		
	(t)	Standard footnotes	Explanatory footnote
Engine and gear box oils[1]	256.788		2 Calculated
Industrial oils[2]	140.668		2 Calculated
Industrial oils (emulsions only)[3]	13.158		2 Calculated
Oil and concentrates from separation[4]			

2 Calculated based on amounts placed on the market and return rates specific for the situation in Germany as determined in a study in 2022.

Source: Screenshot of the supplemented Excel template

4.3 Separately collected waste oils

Annex VI of the implementing decision stipulates that for a) engine and automotive gear box oils and b) industrial oils, the quantity collected separately must be reported under (3), and the quantity exported and imported under (4) and (5), in each case including water content and dry.

The data from the Destatis waste statistics are used here[10] . However, these do not differentiate between (used) engine and (automotive) gear box oils and industrial oils, but break them down by waste code.

The Commission's guidance document on data transmission (EU COM 2022) provides for the following assignment of waste codes to the reporting categories (Table 35):

Table 35: Proposed assignment of waste codes to reporting categories

Category	Waste code	Description
Engine and automotive gear oils	13 02 04*	Mineral-based chlorinated engine, gear and lubricating oils
	13 02 05*	Mineral-based non-chlorinated engine, gear and lubricating oils
	13 02 06*	Synthetic engine, gear and lubricating oils
	13 02 07*	Readily biodegradable engine, gear and lubricating oils
	13 02 08*	Other engine, gear and lubricating oils
Industrial oils	12 01 06*	Mineral-based machining oils containing halogens (except emulsions and solutions)
	12 01 07*	Mineral-based machining oils free of halogens (except emulsions and solutions)
	12 01 10*	Synthetic machining oils
	12 01 19*	Readily biodegradable machining oils
	13 01 09*	Mineral-based chlorinated hydraulic oils

[10] Table from genesis online database. Table number 32111-0002.

Category	Waste code	Description
	13 01 10*	Mineral based non-chlorinated hydraulic oils
	13 01 11*	Synthetic hydraulic oils
	13 01 12*	Readily biodegradable hydraulic oils
	13 01 13*	Other hydraulic oils
	13 03 06*	Mineral-based chlorinated insulating and heat transmission oils other than those mentioned in 13 03 01
	13 03 07*	Non-chlorinated insulating and heat transfer oils based on mineral oil
	13 03 08*	Synthetic insulating and heat transfer oils
	13 03 09*	Readily biodegradable insulating and heat transfer oils
	13 03 10*	Other insulating and heat transfer oils
Not assigned	13 01 01*	Hydraulic oils containing PCBs
	13 03 01*	Insulating and heat transfer oils containing PCBs
Industrial oils (emulsions only)	12 01 08*	Processing emulsions and solutions containing halogens
	12 01 09*	Halogen-free processing emulsions and solutions
	13 01 04*	Chlorinated emulsions
	13 01 05*	non-chlorinated emulsions
	13 08 02*	other emulsions
Oils and concentrates	19 02 07*	Oil and concentrates from separation processes

Allocation according to EU COM (2022)

However, this categorisation does not correspond to disposal practice in Germany. Both engine and gear box oils as well as various types of industrial lubricants are assigned to the same waste codes (cf. Figure 14). In particular, numerous groups of types are collected under the waste code 13 02 05*.

Figure 14: Allocation of type groups to waste codes

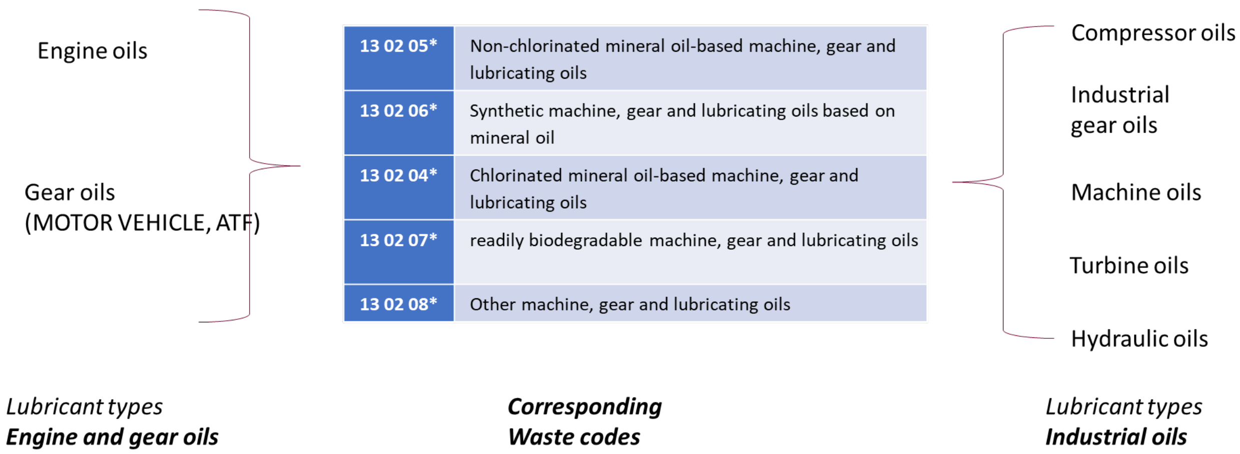


Figure: Ökopol

Based on the insights gained from this report as well as previous ones, and supported by the calculations in the model, it is assumed that the distribution of engine and gear oils to industrial oils is 73:27. This ratio corresponds to the calculated quantity of the lubricant types mentioned, derived from the results of the back-calculation model shown in Figure 14 .

In addition to the waste quantities including water content, a column has been created for the dry quantities. By default, the dry quantities of the separately collected waste oils are not calculated using assumptions about the water content, but are calculated automatically as

Import quantity
+ Quantity in energy treatment
+ Quantity in material treatment/ processing
+ Quantity in disposal
- Exported quantity

This calculation means that the quantities of waste oil collected separately (dry) correspond exactly to the recycling quantities and import/export quantities reported in the table. This suggests an accuracy that is not reflected in practice.

In addition to potential inaccuracies in the statistical data, the assumed proportions of water in other contexts also introduce uncertainties. Moreover, there are additional waste codes that pertain to oily waste, such as bilge oils or oil-contaminated operational materials, that have not been considered.

Given this situation, the standard automatic calculation for the dry quantities of separately collected waste oils is not utilized. Instead, relevant fields are unlocked, and the dry values are manually entered based on waste statistics. The following water contents are applied for each individual waste code:

Table 36: Assumed water contents according to waste codes

Waste code	Explanation	Assumed water content
EAV-120106-G	Mineral-based machining oils containing halogens (except emulsions and solutions)	4,1%
EAV-120107-G	Mineral-based machining oils free of halogens (except emulsions and solutions)	15,0%
EAV-120108-G	Processing emulsions and solutions containing halogens	90%
EAV-120109-G	Halogen-free processing emulsions and solutions	90%
EAV-120110-G	Synthetic machining oils	7,2%
EAV-130101-G	Hydraulic oils containing PCBs	9,4%
EAV-130104-G	Hydraulic oils: Chlorinated emulsions	90%
EAV-130105-G	Hydraulic oils: Non-chlorinated emulsions	90%
EAV-130109-G	Mineral-based chlorinated hydraulic oils	7,1%

Waste code	Explanation	Assumed water content
EAV-130110-G	Mineral based non-chlorinated hydraulic oils	4,00%
EAV-130111-G	Synthetic hydraulic oils	-
EAV-130112-G	Readily biodegradable hydraulic oils	5,5%
EAV-130113-G	Other hydraulic oils	.
EAV-130204-G	Mineral-based chlorinated engine, gear and lubricating oils	6,0%
EAV-130205-G	Mineral-based non-chlorinated engine, gear and lubricating oils	9,5%
EAV-130206-G	Synthetic engine, gear and lubricating oils	0,2%
EAV-130207-G	Readily biodegradable engine, gear and lubricating oils	-
EAV-130208-G	Other engine, gear and lubricating oils	9,5%
EAV-130301-G	Insulating and heat transmission oils containing PCBs	0,3%
EAV-130306-G	Mineral-based chlorinated insulating and heat transmission oils other than those mentioned in 13 03 01	-
EAV-130307-G	Mineral-based non-chlorinated insulating and heat transmission oils	1,0%
EAV-130308-G	Synthetic insulating and heat transmission oils	0,1%
EAV-130309-G	Readily biodegradable insulating and heat transmission oils	-
EAV-130310-G	Other insulating and heat transmission oils	0,1%
EAV-130506-G	Oils from oil/water separators	51,8%
EAV-130701-G	Fuel oil and diesel	23,6%
EAV-130802-G	Oil waste: Other emulsions	90%
EAV-190207-G	Oil and concentrates from separation processes	23,4%

Sources: (Sander et al. 2006; Jepsen et al. 2016; EU KOM 2022) as well as BVA survey and results of the analysis (see section 2.4)

The corresponding data on data transmission and the associated footnote can be found in Figure 15.

Figure 15: Reporting on "3: Separately collected waste oils"

		3					
5		Separately collected[7] waste oils					
6		Including water (t)	Standard footnotes	Explanatory footnote	Dry oil[14] (t)	Standard footnotes	Explanatory footnote
7							
8	Engine and gear box oils[1]	268.165		3 Deviating	242.888		7 Not
9	Industrial oils[2]	188.652		3 Deviating	168.419		7 Not
10	Industrial oils (emulsions only)[3]	509.500		4 Based on	58140		8 Calculated
11	Oil and concentrates from separation[4]	123.600		9 Based on	99361,4		8 Calculated

3	Deviating from the guidance document for waste codes 13 02 04, 13 02 05, 13 02 06, 13 02 07 and 13 02 08, a split of 73:27 for engine and gearbox oils to industrial oils is assumed. This split better reflects the prevailing disposal practice in Germany.
4	Based on Destatis (Federal Statistical Office of Germany) data. In accordance with the guidance document, the following waste codes have been included here: 12 01 08, 12 01 09, 13 01 04, 13 01 05, 13 08 02.
7	Not calculated automatically but balculated based on the separately collected amounts and specific water content per waste code.
8	Calculated automatically.
9	Based on Destatis statistics (Federal Statistical Office of Germany).

Source: Ökopol. Screenshot of the supplemented Excel template

4.4 Export of waste oils

Explanations on the allocation of lubricant categories to waste codes are givenin section 4.3. The quantities (including water content) are available from the statistics on the transboundary shipments of waste.

The dry quantities were calculated on the basis of the water contents as shown in Table 36.

The data for the reporting and the associated footnotes can be found in Figure 16.

4.5 Import of waste oils

Explanations on the allocation of lubricant categories to waste codes are givenin section 4.3. The quantities (including water content) are available from the statistics on the transboundary shipments of waste.

The dry quantities are calculated for "engine and gear box oils" and "industrial oils" using the water contents from Table 36; for "industrial oils (emulsions only)" and "oil and concentrates from separation" using the default water contents from EU COM (2022).

The data for the reporting and the associated footnotes can be found in Figure 16.

Figure 16: Reporting on "4: Exported waste oils" and "5: Imported waste oils"

Country: Germany												
Reference year: 2020												
	4						5					
	Exported[8] waste oils						Imported[9] waste oils					
	Including water (t)	Standard footnotes	Explanatory footnote	Dry oil[14] (t)	Standard footnotes	Explanatory footnote	Including water (t)	Standard footnotes	Explanatory footnote	Dry oil[14] (t)	Standard footnotes	Explanatory footnote
Engine and gear box oils[1]	7.762		9 Based on	7.030		11 Calculated	168.842		9 Based on	152.928		11 Calculated
Industrial oils[2]	12.925		9 Based on	11.539		11 Calculated	67.888		9 Based on	60.606		11 Calculated
Industrial oils (emulsions only)[3]	0		9 Based on	0			1.100		9 Based on	110,00		10 Calculated
Oil and concentrates from separation[4]	0		9 Based on	0			27.100		9 Based on	20.759		10 Calculated

9	Based on Destatis statistics (Federal Statistical Office of Germany).
10	Calculated using default water content.
11	Calculated using specific water content per waste code.

Source: Ökopol. Screenshot of the supplemented Excel template

4.6 Regeneration quantities

Input quantities for regeneration must be reported under point 6. Regenerated waste oil quantities (quantities from secondary refining) are available from the BAFA statistics. Based on these quantities and using the yield factors determined (see section 3.3) the input for processing is calculated. The calculated input again does not differentiate between engine and gear box oils and industrial oils. Here, a distribution analogous to the quantity distribution of engine and gear box oils to industrial oils in the waste oil return is assumed. The corresponding quantity ratio is 1.85:1.

The corresponding data on data transmission and the associated footnote can be found in Figure 17.

Figure 17: Reporting on "6: Regeneration" and "7: Other recycling"

	6						7					
	Regeneration[10]						Other recycling[11]					
	Including water (t)	Standard footnotes	Explanatory footnote	Dry oil[14] (t)	Standard footnotes	Explanatory footnote	Including water (t)	Standard footnotes	Explanatory footnote	Dry oil[14] (t)	Standard footnotes	Explanatory footnote
Engine and gear box oils[1]				260.197		9 Based on				38.320		9 Based on
Industrial oils[2]				142.535		9 Based on				20.992		9 Based on
Industrial oils (emulsions only)[3]	0		9 Based on	0		9 Based on	0		9 Based on	0		
Oil and concentrates from separation[4]	0		9 Based on	0		9 Based on	0		9 Based on	0		

9	Based on Destatis statistics (Federal Statistical Office of Germany).

Source: Ökopol. Screenshot of the supplemented Excel template

4.7 Other recycling

Data on "other recycling" is determined in the same way as in point 6 (regeneration). The corresponding data for data transmission and the associated footnote can be found in Figure 17.

4.8 Energy recovery

The data foundation for energy recovery is based on the waste statistics provided by Destatis (Waste Disposal: Germany, years, facility type, waste types; Table 32111-0004). Relevant variables are described in section 3.5. The input quantities of waste oils from various waste streams into thermal waste treatment plants, incineration plants, and chemical-physical treatment plants are of relevance. For thermal waste treatment plants and incineration plants, the input quantities of waste oils can be directly considered as quantities for energy recovery, although they must be adjusted for water content. In contrast, for chemical-physical (CP) plants, it is the output quantities that need to be taken into account. The outputs of waste oils from CP plants are primarily utilized for energy recovery, with a smaller portion allocated for treatmregeneration ent and disposal, as reported in the waste statistics.

The ratio of 73:27 is used for the breakdown of engine and (automotive) gear box oils and industrial oils, as described in section 4.3 described in section 4.3.

The corresponding data on data transmission and the associated footnote can be found in FigureFigure 18.

Figure 18: Reporting on "8: Energy recovery" and "9: Disposal"

	8					9					
	Energy recovery[12] (R1)					Disposal[13]					
	Standard footnotes	Explanatory footnote	Dry oil[14] (t)	Standard footnotes	Explanatory footnote	Including water (t)	Standard footnotes	Explanatory footnote	Dry oil[14] (t)	Standard footnotes	Explanatory footnote
Engine and gear box oils[1]			28.961						0		9 Based on
Industrial oils[2]			33.232						0		9 Based on
Industrial oils (emulsions only)[3]		9 Based on	11.090		10 Calculated	0		9 Based on	0		9 Based on
Oil and concentrates from separation[4]		9 Based on	69.654		10 Calculated	0		9 Based on	0		9 Based on

9	Based on Destatis statistics (Federal Statistical Office of Germany).
10	Calculated using default water content.

Source: Ökopol. Screenshot of the supplemented Excel template

4.9 Disposal

There was no disposal in the reference year. The corresponding data on data transmission and the associated footnote can be found in Figure 18.

4.10 Treatment of waste oils

Table 2 of the COM table contains data on the treatment of waste oils and output quantities from regeneration and other recycling. Corresponding data is part of the BAFA statistics (official mineral oil data; see the following Table 37).

Table 37: Output quantities from secondary refining

Mineral oil products	Volume from secondary refining in 2020 [tonnes]	Note regarding data transmission
Raw petrol	0	(no quantities to be taken into account)
Petrol	0	(no quantities to be taken into account)
Petrol components	0	(no quantities to be taken into account)
Diesel fuel	0	(no quantities to be taken into account)
Light fuel oil	15.816	Consideration under "Light fuel oil" - "material that are to be used as fuels"
Middle distillate components	4.136	Consideration under "Distillate fuel oil" - "material that are to be used as fuels"
Heavy fuel oil	131.567	Consideration together with "HS components" as "heavy fuel oil" - "material that are to be used as fuels"
HS components	34.103	Consideration together with "Heating oil, heavy" as "Heavy fuel oil" - - material that are to be used as fuels
Liquefied petroleum gas	0	(no quantities to be taken into account)
Refinery gas	0	(no quantities to be taken into account)
Special petrol	8.118	Consideration under "Other material that are to be used as fuels"
White spirit	0	(no quantities to be taken into account)

Mineral oil products	Volume from secondary refining in 2020 [tonnes]	Note regarding data transmission
Aviation petrol	0	(no quantities to be taken into account)
Aero-turbine power unit, light	0	(no quantities to be taken into account)
Aero-turbine power unit, heavy	0	(no quantities to be taken into account)
Other petroleum	0	(no quantities to be taken into account)
Base oil	217.583	Consideration under "Regeneration" as "Other (base oils)"
Other lubricants	36.138	Consideration under "Other recycling" as "other lubricants"
Bitumen	0	(no quantities to be taken into account)
Petroleum coke	0	(no quantities to be taken into account)
Waxes,Paraffins,Vaseline	0	(no quantities to be taken into account)
Other residues	0	(no quantities to be taken into account)
Total quantity	**447.461**	**(total quantity)**

Source for quantities: (BAFA 2020)

Base oils are not differentiated according to groups 1-4 in the BAFA statistics. The quantity of base oils from secondary refining is reported accordingly under "regeneration" - "other". The production of other lubricants from secondary refining is reported under "other recycling". The other products from secondary refining are reported under "material to be used as fuels" as shown in Table 37.

The corresponding data on data transmission and the associated footnote can be found in Figure 19.

Figure 19: Reporting on "Reporting data on the treatment of waste oil" (table 2)

Country: Germany									
Reference year: 2020									
Section 1	2			3			4		
Type of output from recovery	Regeneration[1]			Other recycling			Energy recovery or reprocessing into materials that are to be used as fuels (including regenerated oils used as fuel)		
	(t)	Standard footnotes	Explanatory footnote	(t)	Standard footnotes	Explanatory footnote	(t)	Standard footnotes	Explanatory footnote
Regenerated base oil – group I[2, 3]			12 Different base oil groups						
Regenerated base oil – group II[4]			12 Different base oil groups						
Regenerated base oil – group III[5]			12 Different base oil groups						
Regenerated base oil – group IV[6]			12 Different base oil groups						
Recycled products[7] (specify)									
Fuel products for off-site energy recovery – Light fuel oil							15.816,00		13 Based on BAFA data.
Fuel products for off-site energy recovery – Distillate fuel oil							4.136,00		13 Based on BAFA data.
Fuel products for off-site energy recovery – Heavy fuel oil							165.670,00		13 Based on BAFA data.
Fuel products for off-site energy recovery – Recovered fuel oil							0,00		13 Based on BAFA data.
Fuel products for off-site energy recovery – Processed fuel oil							0,00		13 Based on BAFA data.
On-site energy recovery[8]							0,00		13 Based on BAFA data.
Other	253.721,00		5 Base oil. Based on BAFA	36138			8118		
[specify 'other']				36.138,00		6 Other lubricants. Based on	8.118,00		14 Special fuel
[specify 'other']									
[specify 'other']									

5	Base oil. Based on BAFA data.
6	Other lubricants. Based on BAFA data.
12	Different base oil groups reported aggregated as "base oil" under "others".
13	Based on BAFA data.
14	Special fuel ("Spezialbenzin"). Based on BAFA data.

Source: Ökopol. Screenshot of the supplemented Excel template

4.11 Summarised assessment of data transmission

Using the calculation model and the available statistics from BAFA and Destatis (waste statistics), the data required for transmission can be collected. The detailed procedure for this is outlined in sections 4.1 to 4.10 above. It is important to pay special attention to the following points in the procedure, which may differ from the COM guidelines on data transmission:

- It is important to note (see section 4.2) that when using the updated return rates (refer to section 3.2.13) as well as the default return rates, no import-export correction is necessary for engine oils and automotive gearbox oils, as this is already accounted for in the return rates.
- Additionally, it should be highlighted that, in some cases, it is not possible to clearly assign waste codes to different lubricant typs, which deviates from the requirements set by the Commission.

The default setting in the COM table assumes that all separately collected dry waste oil quantities correspond exactly to the recycling and import/export quantities reported. However, it is recommended to enter the dry values calculated based on waste statistics instead. Overall, the calculated and entered quantities provide a largely consistent picture. However, it is notable that the calculated quantity of 168,410 tonnes of waste industrial oils collected exceeds the quantity of 140,668 tonnes of waste industrial oils produced, as indicated by the calculation model.. This discrepancy can be explained: the calculation model (including the default approach in the COM table) estimates waste based on placing on the market figures. This method provides a rough approximation, as industrial oils actually remain in use for years in many applications. Assuming constant economic development, this approach is sufficiently accurate. Nevertheless, during the year 2020, which faced significant economic challenges due to the coronavirus pandemic, this method reaches its limitations. The waste volume documented in waste statistics reflects waste generated over several previous years, while sales of new industrial oils fell in 2020. This leads to the difference mentioned earlier.

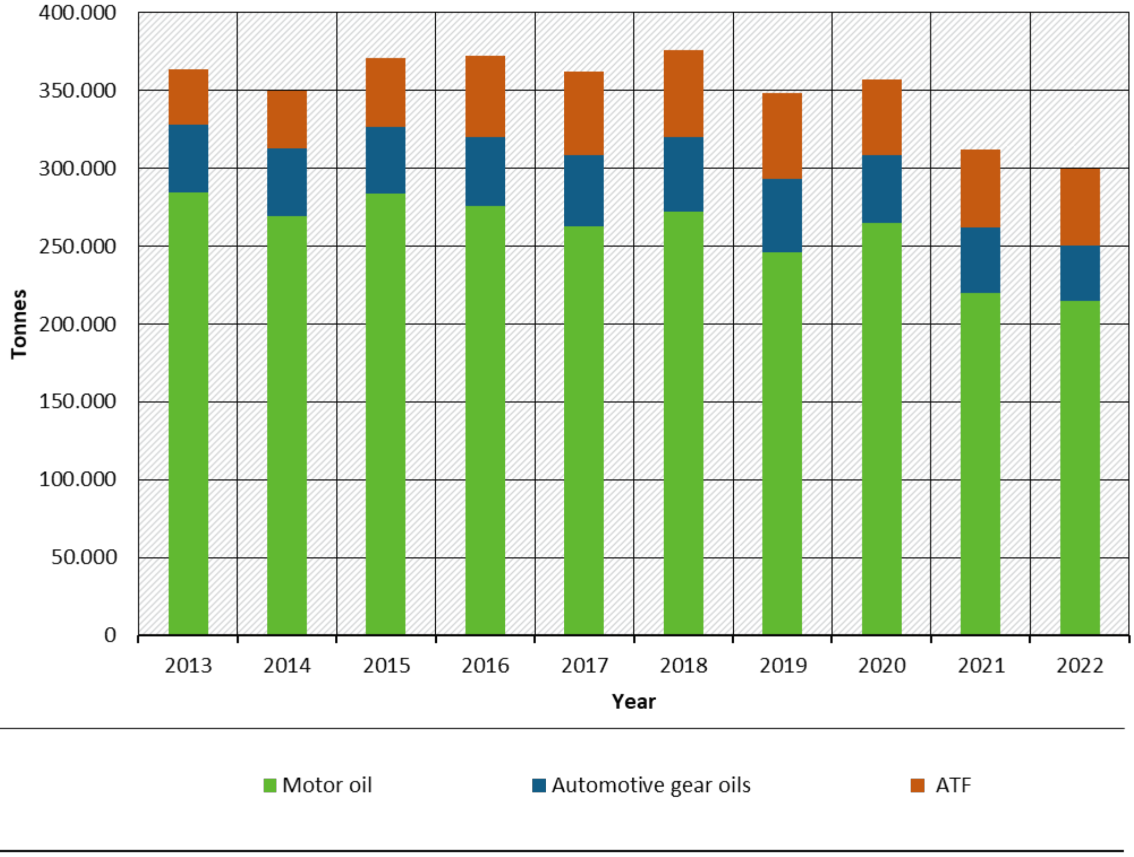
5 Future trends: changes in the volume of waste oil

This work package takes a retrospective look at the changes in the volume of waste oil over the last five years and the prospects for the near future up to 2030. This involves both quantitative trends and changes in waste oil quality (composition, additives, impurities). As in the previous analyses, a basic distinction is made between automotive engines and gear box oils and industrial oils.

5.1 Engine and automotive gear box oils

A key indicator is the quantity placed on the market of used engine and gear box oils. A look at the time series (see Figure 20) shows a downward trend in recent years. However, it should be noted that this includes the coronavirus years 2020 and 2021, in which new vehicle registrations also fell sharply. In the years before that, domestic sales fluctuated around 350,000 tonnes.

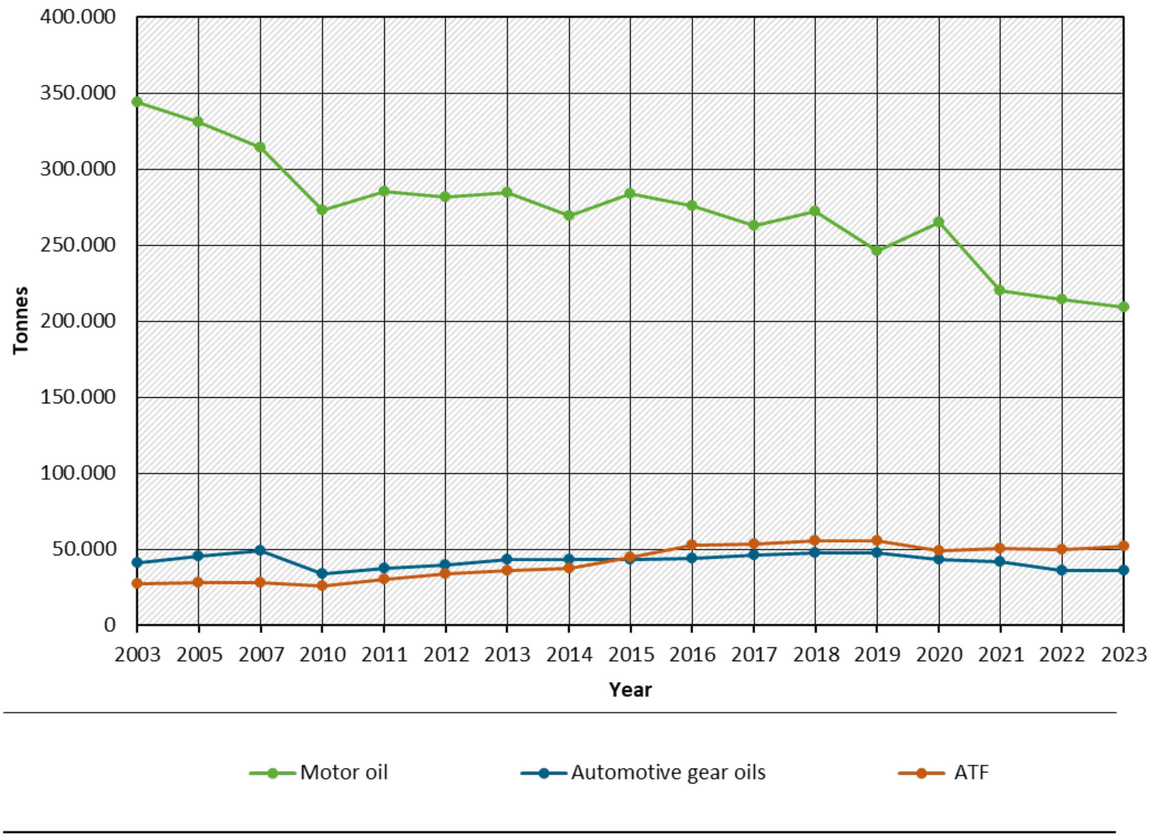
Figure 20: Quantities placed on the market: engine and gear box oils; from 2013



Source: BAFA Official Mineral Oil Data

If a longer time series of placing on the market is used, the downward trend becomes clearer:

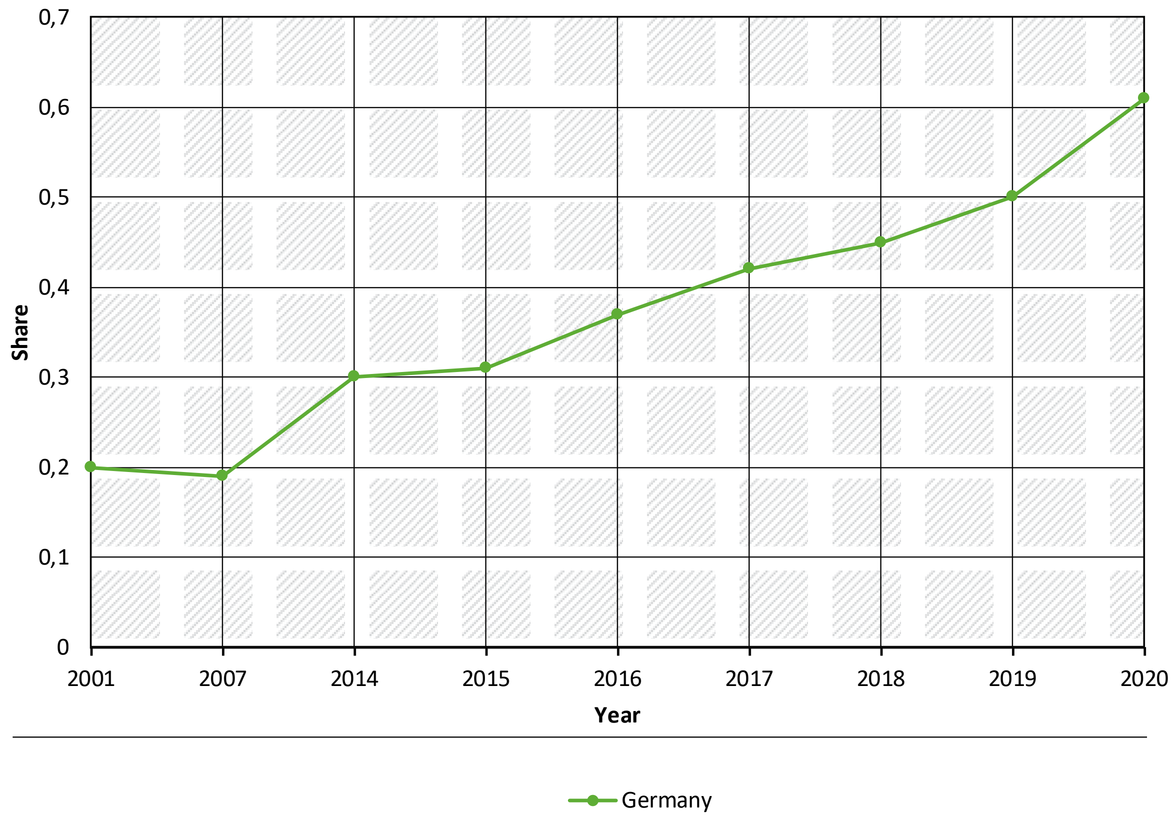
Figure 21: Quantities placed on the market: engine and (automotive) gear box oils; from 2013



Source: BAFA Official Mineral Oil Data

This also reflects the significant increase in sales of automatic transmission fluids (ATF oils). This is the result of the significant increase in the share of automatic transmissions on the market (see Figure 22). The proportion of new cars with automatic transmissions on the German market roughly tripled between 2001 and 2020, from around 20 % to around 60 %. It seems likely that this trend will continue. A continuously growing increase in the proportion of new cars with automatic transmissions can be seen in all EU countries (ICCT 2024). In Sweden, the proportion of new cars with automatic transmissions was already 86% in 2020. As automatic transmissions have a higher filling quantity than manual transmissions, this does not result in a 1:1 replacement of the two types of oil, but - without taking other factors into account - leads to a slight increase in quantity. Compared to engine oil sales, however, this remains of secondary importance.

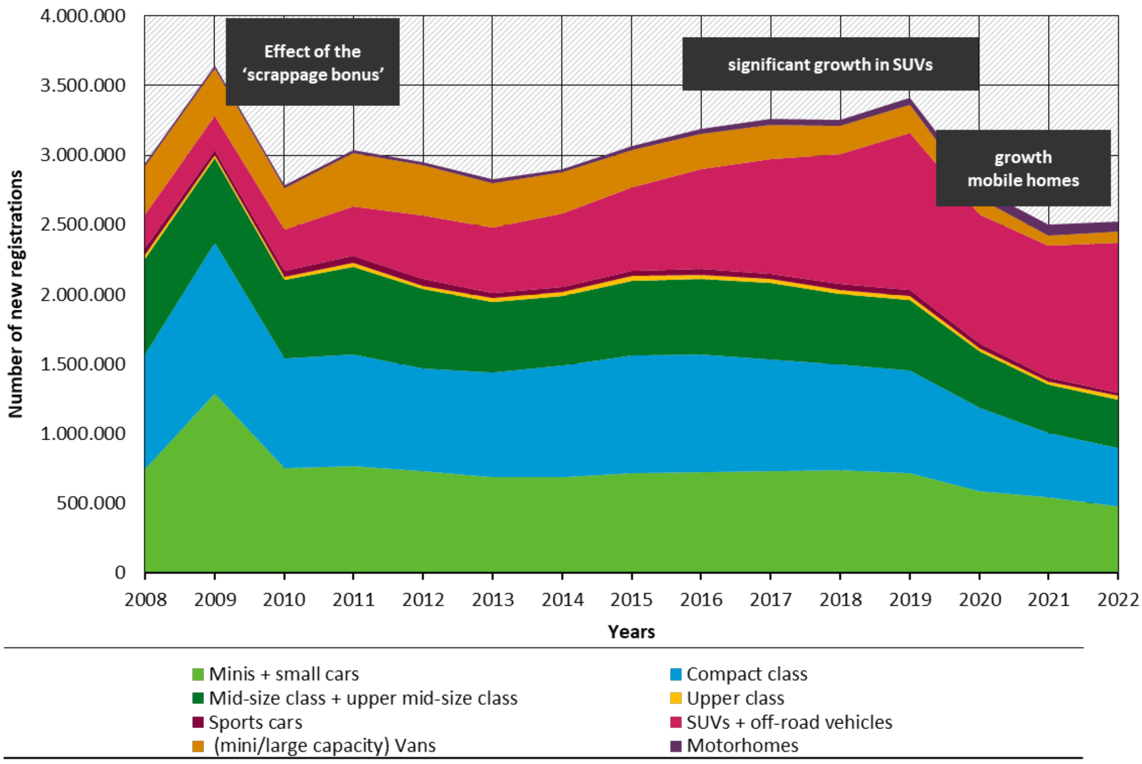
Figure 22: Share of new cars with automatic gearboxes



Source: ICCT; ICCT (2024; 2021)

For a broader perspective on the near future, the developments in the vehicle fleet are considered. The analysis of new registrations shows a significant increase in the proportion of SUVs and off-road vehicles (cf. Figure 23). In 2019, SUVs became the most relevant vehicle segment in terms of volume for the first time. By 2022, approximately 43% of newly registered vehicles were SUVs or off-road vehicles. These types of vehicles require larger quantities of engine and gear box oils (see explanations in sections 0 and 3.2.7.1). As a result, there will be an increasing amount of engine and gear box in use which will eventually become waste oil. However, it is uncertain how this will affect the overall volume of waste oil in Germany. On the one hand, larger filling quantities increase the amount of waste oil produced per vehicle during oil changes. On the other hand longer service intervals may reduce the total amount of waste oil produced.. Additionally,it's important to consider where end-of-life vehicles are treated.. A look at the history shows that luxury vehicles in particular are often exported and not treated in Germany (Sander et al. 2017; Zimmermann et al. 2022b). It remains to be seen whether a similar trend will also develop for the SUV and off-road vehicle segment.

Figure 23: Development of the share of different vehicle segments



Source: KBA

A look at new registrations by motorisation or fuel reveals that electric vehicles, which previously had minimal market presence, have gained significant relevance since2020/21 (see Figure 24). If this trend continues, it could lead to a substantial decrease in the demand for engine and gearbox oil in the near future. The increasing adoption of electric vehicles is likely to have a major impact on the demand for these lubricants (Kamchev 2021).

It is important to notethat electric vehicles still require a reduced amount of lubricants (around 50%) to lubricate moving components such as electric motors, wheel and roller bearings, gearboxes[11] etc. compared to vehicles with combustion engines (Shah et al. 2021; Addinol 2020; Zimmermann et al. 2022a) where no routine oil changes are required, i.e. waste oil is usually only produced when the end-of-life vehicle is dismantled.

Lubricants in electric vehicles play an important role in reducing friction and thus increasing the efficiency of the electric vehicle, particularly in power transmission from the electric motor (Shah et al. 2021). In some cases, there are significantly different requirements compared to the lubricants used in combustion engines.

In the vicinity of motors, for example, low electrical conductivity is a key requirement, as are good heat resistance, good compatibility with copper and strict water separation to avoid

[11] In contrast to conventional combustion engines, electric motors have a wide speed range and offer high torque over a wide range. This means that electric vehicles can manage without a gearbox in most driving situations.

However, some electric vehicles, especially those with powerful motors or special requirements such as off-road capability or towing capacity, are equipped with a gearbox. These transmissions are used to match the power of the electric motor to the wheels and can, for example, enable improved acceleration or a higher top speed. There are also models with two-speed gearboxes, which can offer better efficiency at high speeds.

However, it is important to note that many modern electric vehicles use a so-called "single-stage transmission", which is technically not a traditional transmission. This transmission consists of a single fixed ratio that transfers power from the electric motor to the wheels. It has no shiftable gears like a conventional gearbox. This simple design contributes to the efficiency and reliability of electric vehicles.

electric flashovers (Shah et al. 2021; Addinol 2020). However, certain requirements placed on oils used in combustion engines, such as engine cooling, cleaning of deposits and sealing between piston rings and cylinder walls, do not apply.

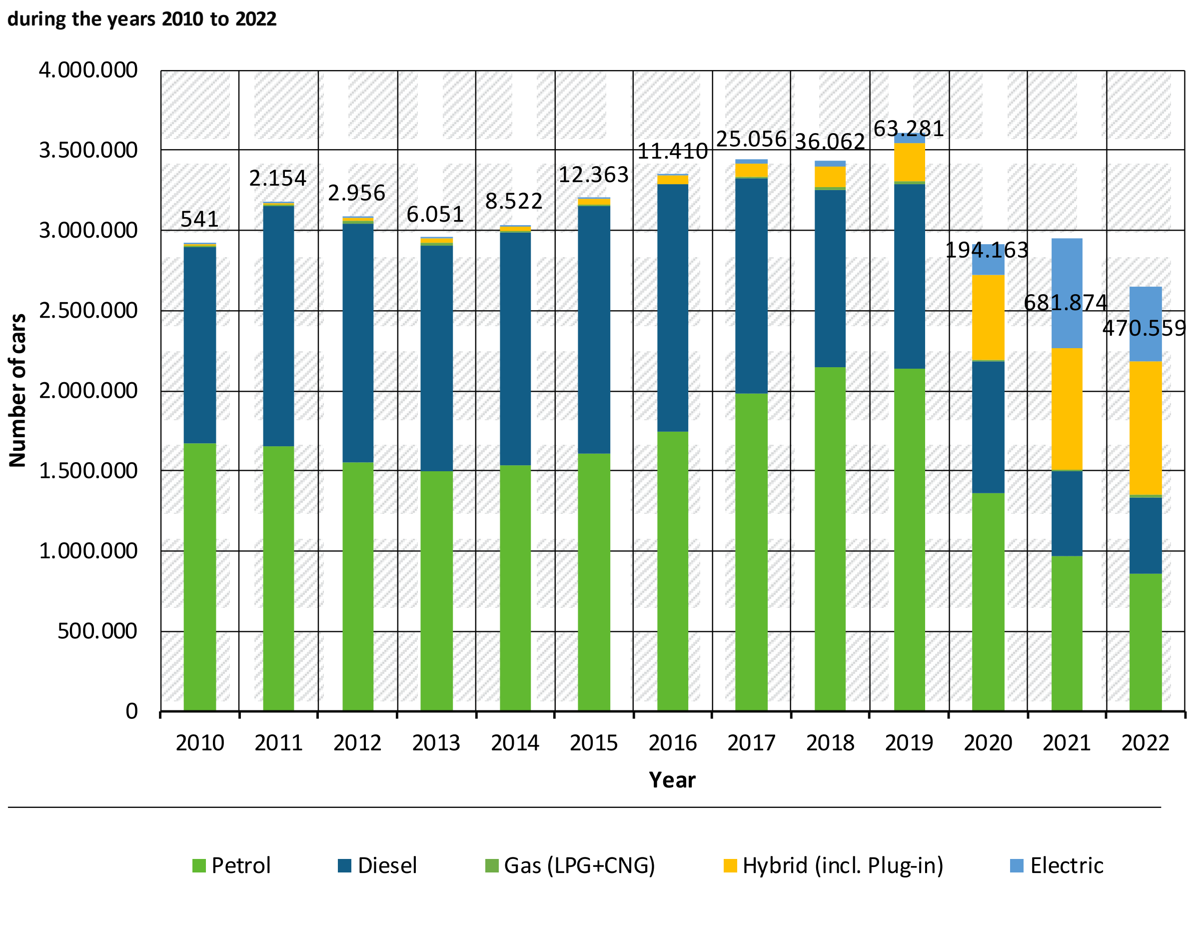
An analysis of the market for gear box oils shows that it is possible to find oils that are approved for vehicles with combustion engines as well as for certain electric vehicles.

In general, the development of lubricants for electric vehicles is still very dynamic and it is currently not possible to predict how lubricant compositions will develop over the next 10 years (Shah et al. 2021).

An evaluation of several safety data sheets for electric vehicle lubricants shows that these oils, classified as waste, fall under waste codes 13 02 05* (non-chlorinated mineral-based engine, gear, and lubricating oils) and 13 02 08* (other engine, gear, and lubricating oils), categorizing them as category 1 waste oils.Despite the dynamic developments described above, there are currently no indications that a different categorisation can be assumed in the future. Nevertheless, it is of course important to monitor the composition as described.

Another development with an impact on the volume of waste oil is the increasing service life of modern engine oils. In addition to engine oil quality, technologies such as oil quality sensors, cold start counters and others also contribute to this (DAT 2018).

Figure 24: New car registrations by fuel type



Quelle: KBA (2023)

The individual trends described for engine and gear box oil are summarised in the following table.

Table 38: Future trends in engine and gear box oils

Development	Impact in the past 5 years	Impact until 2030	Conclusion
Increase in SUVs and off-road vehicles	Higher average engine and gear box oil requirement per vehicle; higher volume of waste oil per vehicle	Increase in the amount of engine and gear box oil in the fleet that will become waste oil in the future. What is relevant here is whether the end-of-life vehicles are destined for treatment in Germany.	Prospective reduction in waste oil quantities from gear box and engine oil.
Increase in electric vehicles	Reduction in average engine and gear box oil consumption per vehicle; reduction in aste oil consumption per vehicle	Continuous reduction of engine and gear box oil quantities and resulting waste oil quantities. Change in the composition of waste oils, but still likely to be allocated to collection category 1.	
Increase engine oil service life	Reduction in engine oil consumption, reduction in waste oil	Reduction in engine oil consumption, reduction in waste oil	

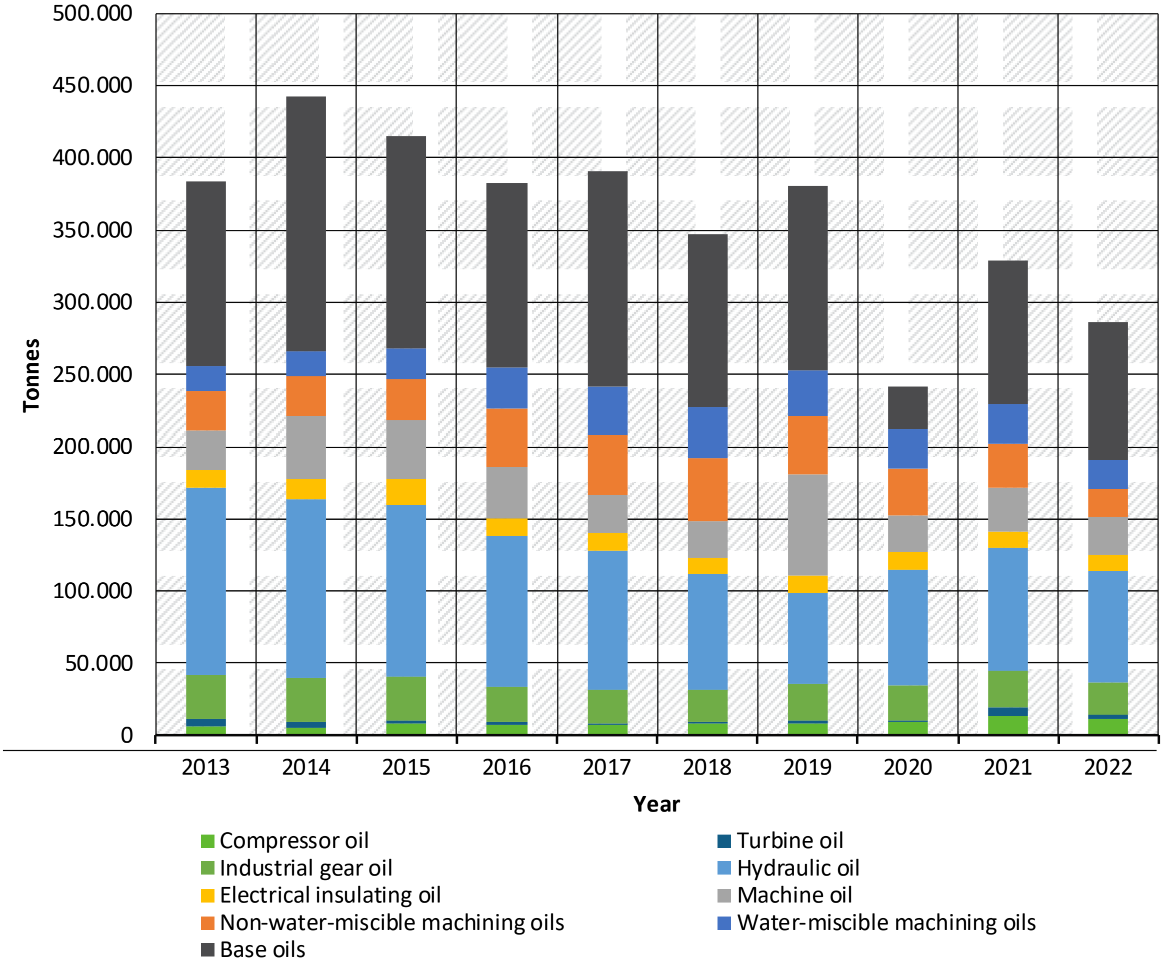
Compilation by Ökopol

The conclusion that volumes will fall in the future is in line with the findings of a recently published Commission study (European Commission: Directorate-General for Environment 2023). The models used here assume that the lubricant requirement of a fully electrified vehicle fleet corresponds to around 10 % of the requirement of a conventional fleet.

5.2 Industrial oils

The following figure shows the development of the placing on the market of industrial oils. Overall, it can be seen that - except for the effects of the coronavirus pandemic - there is no direct link between lubricant consumption and economic growth. Even though GDP generally tends to grow, lubricant consumption is falling overall. The reasons for this are shifts in production, trends towards smaller filling quantities and higher-quality lubricants (Baumgärtel 2020).

Figure 25: Development of the placing on the market of industrial oils



Source: BAFA Official mineral oil data

However, the effects of the coronavirus pandemic in 2020, which, in addition to a significant decline in machine oils, is due in particular to a decline in base oils, can be observed.

The following trends can be observed for the slightly different lubricant grade groups over the period from 2013 to 2022:

- Compressor oil: continuous growth
- Turbine oils: No clear trend. Initially decline from 2013 to 2020, then a significant increase.
- Industrial gear oils: downward trend
- Hydraulic oils: downward trend
- Electrical insulating oils: slight downward trend
- Machine oils: no clear trend
- Machining oils: no clear trend

The demand for compressor oils used in compressed air, gas, or refrigeration compressors is expected to continue growing. Similarly, applications such as heat exchangers, heat pumps, and air conditioning are likely to experience further growth in the coming years..

When it comes to turbine oils, it is challenging to predict future developments. While there is an obvious connection between sales and the installation of new power plant capacities, this link cannot be confirmed based on statistical data (Federal Network Agency power plant list, Fraunhofer ISF 2023).

The downward trend in the area of industrial gear oils, hydraulic oils and electrical insulating oils and the further development in the area of machine oils and machining oils is subject to the following drivers in particular:

- Improvement of lubricant qualities that enable a reduction in application quantities and longer service lives (Möhr 2022; Krethe 2022; Schulz 2022; Baumgärtel 2020; Patnaik et al. 2021).
  - This includes the continuous further development of lubricants and additives following the respective application requirements. Changes in the regulatory environment, which may restrict the use of certain substances/mixtures as additives, must also be taken into account.
  - In the scientific literature, the use of nanoparticles to improve lubricant properties - especially concerning wear protection and friction reduction - plays an important role (Han et al. 2022; Xinghe 2022; Gao et al. 2022).
- Increase in alternative approaches to lubrication, such as minimum quantity lubrication or dry machining in the field of metalworking (Schulz 2022; Herrmann et al. 2017; Weinert 2013).
- Reduction of lubricant consumption through optimised handling (optimisation of use, maintenance, monitoring): Although efforts have been initiated here in recent years, the broad potential is still seen (Cornelius 2022; Baumgärtel 2020; Herrmann et al. 2017; Gosch 2020). In particular also through
  - Further development of approaches to oil purification in operation: The use of operationally integrated approaches to oil purification can in some cases significantly increase service life (Neumann 2022; Krethe 2020; Gosch 2020)
  - The continuous development of oil monitoring: Oil (quality) sensors have been available for several years now. Whilst the spread is faster in some areas, other areas are only penetrating more slowly. Overall, however, the spread is continuously increasing (Krethe 2020; Gosch 2020).

In addition to the points mentioned above, it is clear that it can be assumed that the useful life of industrial oils will continue to increase in the future and that the quantities placed on the market will tend to fall. Concerning changes in additivation, there are currently no indications that this will have a negative impact on suitability for regeneration. These are usually separated from the base oil during re-refining (Bruhnke 2022).

5.3 Summarising future trends

Based on the analyses conducted, it can be expected that the volume of lubricants available on the market, as well as the resulting quantities of waste oil, will decline in the future both categories, engine and gearbox oils, as well as industrial oils.

In both categories, improvements in lubricant quality and technological advancements are significant factors contributing to this trend. Additionally, in the category of engine and gearbox oils, the electrification of the vehicle fleet serves as another important driver of change.

6 Conclusions and outlook

The review of the allocation of waste oils of different waste codes to collection categories carried out in the study based on the evaluation of the BREF document on waste treatment (Pinasseau et al. 2018), a stakeholder survey and, in particular, the waste oil analyses carried out, showed that waste oils outside collection category 1 are not systematically suitable for regeneration. Accordingly, there is no need to adjust the allocation of waste codes to collection categories in the Waste Oil Ordinance Act.

Waste oils from collection category 2, in particular WC 12 01 07*, showed suitability for regeneration in individual cases. However, since the majority of waste oils in this waste code would interfere with regeneration, no general sorting into category 1 can be recommended. It seems more appropriate for waste producers to contact the re-refiners to determine whether a specific waste oil (CC2-4, but especially CC2, WC 12 01 07*) is suitable for regeneration and should be collected separately. This appears to be particularly useful for sources of waste with comparatively large volumes.

The back-calculation model for determining waste oil flows has undergone revisions. Model parameters were updated and in some cases, the model has been expanded with more detailed sub-models, for example in the models for calculating the return flow of engine and gear oils. The return rates of all different types of lubricants were reviewed and updated as necessary.

In addition to analysing waste oil flows using the updated back-calculation model, the new requirements for reporting to the EU Commission were examined and the necessary data inputs from the back calculation model and available statistics, in particular waste statistics, were identified. It has been found that the EU data transmission and the calculation using the calculation model result in some synergies, but that there are also different requirements or differences in the model structure and approach (e.g. concerning the lubricants placed on the market or the determination of the quantities of energy recovery). Corresponding differences were identified in this project, but initially both approaches were still pursued.

Future studies can examine the extent to which further adjustments to the calculation model are useful concerning further synchronisation with EU reporting. One of the questions to be discussed in this context concerns the (non-)consideration of oils in non-lubricant applications such as "other industrial oils not for lubrication", process oils, extracts from lubricating oil refining and hardening oils as well as lubricating greases that do not result in a return. These are not included in the EU reporting system but are included in the German back-calculation model. Concerning this aspect, the question of the extent to which a return can be categorically excluded based on the application rather than the use as a lubricant should be considered in future. Concerning hardening oils, for example, it was determined that a renewed examination of possible returns should take place in the next report.

In the course of examining the suitability of the available data for EU reporting, it has been shown on the one hand that a calculation of solid quality appears possible in Germany using the existing data and parameters. Nevertheless, conceivable improvements can be identified concerning the statistical data basis. These include the lack of clarity in the allocation of lubricant types to waste codes and, in some cases, the quantities reported in the waste statistics.

Nevertheless, it can be assumed that the data quality in Germany is significantly higher than in some other EU member states. This would have to be taken into account if binding quantitative targets for waste oil collection and treatment were to be introduced.

Given the foreseeable changes in mobility and technology, it can be stated that the increasing importance of electromobility and changes in the composition of lubricants and additives can be expected to result in lower quantities of lubricants being placed on the market and correspondingly lower quantities of waste oil being returned.

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