Impact Assessment: Binding Occupational Exposure Limits for cobalt metal and cobalt substances

Revised Final report

Cobalt Institute (CI)

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Executive summary

Purpose

This report is prepared to support the Cobalt Institute's industry-wide advocacy efforts concerning the introduction of a European Union (EU) wide Binding Occupational Exposure Limit (BOEL) for cobalt metal and inorganic cobalt compounds.

This project assessed the costs and benefits of implementing four potential BOELs for the cobalt substances that are in scope (see below) in the EU-27 over the next 40 years, compared to the baseline of current manufacturing, import and uses, and the health impacts of the current exposure levels. The information on costs and benefits is gathered from existing data, previous studies and a new questionnaire eftec prepared for this purpose.

Scope of assessment

The scope of the impact assessment covers 40 substances of which 14 are directly in scope and 26 are indirectly in scope (the full list is presented in Section 1.4.1). 24 broad uses of cobalt substances have been assessed, and the geographical scope spans the EU-27. The analysis has been carried out for a period of 40 years from 2022 to 2061.

Baseline

The key results derived in this report regarding the baseline are as follows, particularly those that are important in determining the costs and benefits of BOEL options:

- Estimated current market value of substances in scope manufactured in the EU-27 is around €7.6 billion.
- Across all analysed broad uses (including manufacture and recycling), there are around 7,000 companies in the EU-27, operating an estimated ~9,000 sites, and employing ~641,000 (FTE) workers of which ~72,000 are potentially exposed to cobalt.
- An estimated ~177,000 tonnes per year of cobalt substances are used in downstream uses in the EU.
- Current compliance levels with each of the four BOELs analysed range from 27% for the most stringent BOEL of 1 µg/m^3 to 84% for the least stringent BOEL of 30 µg/m^3.

Alternatives

Cobalt substances serve different functions depending on their uses; therefore, alternatives could be viable substitutes for some of these functions in some uses but not others. Respondents noted that no R&D activities for the substitution of cobalt substances over the last five years have been fully successful. Some substances, such as iron, nickel, ruthenium, other precious metals, vanadium pentoxide, molybdenum and sulphate are potential alternatives for specific applications, but they are not drop-in replacements (i.e., like-for-like) as they have shortcomings either in technical or economic feasibility, availability, or risk reduction (i.e., hazard profile).

Analysis of policy options

There are four BOEL Policy Options assessed in this report – all inhalable fractions: 30 µg/m^3, 20 µg/m^3, 10 µg/m^3, and 1 µg/m^3.

Three possible behavioural responses to each BOEL are assessed:

- Implement risk management measures (RMMs) required to comply with the BOELs;
- Substitute substance or process; or
- Cease affected production in the EU, e.g., close product lines, relocation or complete site closure.

Costs are based on the expected behavioural responses to each BOEL. Costs are estimated using data gathered through an industry questionnaire. Following advice from the Cobalt Institute, it is also assumed that every company that continues to use in-scope substances must implement biological monitoring and respiratory exposure monitoring programmes to demonstrate their compliance with the relevant BOEL, unless they already have this in place. Since it is not known whether companies will have to use PPE to comply with a BOEL, costs with and without PPE have been calculated separately.

Benefits of a BOEL comprise the adverse health impacts avoided by reducing exposure levels below the exposure levels of the baseline (no BOEL). Three health endpoints are assessed: Lung cancer, respiratory irritation and restrictive lung disease. The benefits are calculated using exposure levels per broad use and dose response functions for each of the respective health endpoints. All avoided cases associated with the three health endpoints are valued using appropriate (proxy) valuation factors found in literature.

Results

Chapters 7 – 10 present detailed results of the impact assessment for each the four Policy Options (BOELs), including costs of compliance, social costs (lost jobs) and benefits. A comparison of the impacts across the policy options can be found in Chapter 12. A summary of the key results is presented in **Table ES 1**, which shows that none of the Policy Options has a benefit-cost ratio (BCR) greater than 1, i.e., they all result in net cost to society. The BOEL with the most favourable benefit-cost ratio is the least stringent BOEL of 30 µg/m^3 and the least favourable option is a BOEL of 1 µg/m^3.

Table ES 1: Total costs, benefits, and BCR of each Policy Option

BOEL	Total annual costs (PV € million/year)			Total annual benefits (PV € million/year)			Benefit-Cost Ratio (BCR)		
	Low	Mid	High	Low	Mid	High	Low B/ High C	Mid B / Mid C	High B / Low C
30 µg/m³	180	240	300	10	13	17	0.034	0.056	0.093
20 µg/m³	270	400	530	11	14	18	0.020	0.036	0.066
10 µg/m³	430	570	700	11	15	19	0.016	0.026	0.044
1 µg/m³	700	920	1,140	12	15	19	0.010	0.017	0.027

Table notes:

- "Low" cost estimates are with PPE and use the lower bound number of sites, "High" cost estimates are without PPE and use the upper bound number of sites, and "Mid" cost estimates are the average of "Low" and "High".
- "Low" benefit estimates use the lower bound number of workers exposed, "High" benefit estimates use the upper bound number of workers exposed and Mid" cost estimates are the average of "Low" and "High".
- The total present values (i.e., PVs: sum of discounted future costs) were derived using the recommended rate by the European Commission at 3%, are given in € 2022. Costs and benefits are rounded to the nearest €10 million and € million, respectively.

There is no single most significant cost driver across BOELs. For the most stringent BOEL the lost profit and jobs from companies choosing to cease production in the EU are key drivers, and for less stringent BOELs the costs of monitoring are more important. The sensitivity analysis shows that if no biomonitoring is carried out and the air monitoring costs are halved, the costs of the least stringent BOEL will be reduced by two thirds.

The benefits estimates are highly sensitive to whether PPE is used to demonstrate compliance as well as strongly dependent on the valuation factors. The results from the sensitivity analysis carried out are presented in Section 12.5, which revealed that even under extremely conservative assumptions of maximum benefits and minimum costs, the benefit-cost ratio is significantly below 1 for all Policy Scenarios. Across all combinations of sensitivities tested, the costs are found to be a minimum of three and a maximum of 250 times higher than the benefits.

Uncertainties are still prevalent in the analysis and associated results, in particular related to the representativeness of the data gathered through an industry questionnaire at the EU level, the levels and distribution of exposure for each broad use, and the omission of further health endpoints. However, considering the large differences between the costs and the benefits, it is deemed unlikely that the overall conclusions would change based on any of the identified uncertainties, as is demonstrated in the sensitivity analysis.

A BOEL may also cause wider economic impacts, including supply risks of cobalt as a critical raw material (CRM), energy production and storage may be adversely affected, and wide-reaching knock-on effects may occur if a large number of companies relocate outside the EU. These non-quantified impacts are therefore of particular concern for the more stringent BOEL, where ~1,550 sites are expected to cease EU production with a corresponding 110,000 jobs lost with a BOEL of 10 µg/m^3, and these numbers will double with a BOEL of 1 µg/m^3.

Contents

Tables

Figures

Abbreviations & Acronyms

ACSH	Advisory Committee on Safety and Health at Work
AlNiCo	Aluminium-Nickel-Cobalt
BGV	Biological Guidance Value
BLV	Biological Limit Value
BOEL	Binding Occupational Exposure Limit
CAGR	Compound Annual Growth Rate
CI	Cobalt Institute
CMRD	Carcinogens, Mutagens and Reprotoxic Substances Directive
Co	Cobalt
Co_3O_4	Cobalt (II, III) Oxide
CRM	Critical Raw Material
DG EMPL	Directorate-General for Employment Social Affairs and Inclusion
DNEL	Derived No Effect Level
DRC	Democratic Republic of Congo
EC	European Commission
ECHA	European Chemicals Agency
EEA	European Economic Area
EIC	Environment-Induced Cracking
EoL	End of Life
EU	European Union
EV	Electric Vehicles
FRP	Fiberglass Reinforced Plastics
GTL	Gas-to-Liquid
HD	Hydrodesulphurisation
HDDs	Hard Disk Drives
IPA	Isophthalic Acid
IPC	Inorganic Pigments Consortium
IVD	Invitro Diagnostic Devices
LCO	Lithium Cobalt Oxide
LED	Light Emitting Diode
Li	Lithium

Li-ion	Lithium-Ion
MI	Manufacturers and Importers
MoS_2	Molybdenum Disulphide
NCA	Lithium Nickel Cobalt Aluminium Oxide
NdFeB	Neodymium-Iron-Boron
Ni	Nickel
Ni-Cd	Nickel-Cadmium
Ni-MH	Nickel-Metal Hydride
NMC	Lithium Nickel Manganese Cobalt Oxide
OEL	Occupational Exposure Limit
PBT	Polybutyl Terephthalate
PE	Polyester
PEDs	Portable Electronic Devices
PET	Polyethylene Terephthalate
PPE	Personal protective equipment
PTA	Purified Terephthalic Acid
PTT	Polytrimethylene Terephthalate
PV	Present Value
RAC	Committee for Risk Assessment
REACH	Registration, Evaluation, Authorisation and Restriction of Chemicals
RMM	Risk Management Measure
RTP	Ready to Press
SEA	Socio Economic Analysis
SEAC	Committee for Socio-Economic Analysis
SEIA	Socio-Economic Impact Assessment
SmCo	Samarium Cobalt
SME	Small to Medium Sized Enterprise
STEL	Short Term Exposure Limit
TWA	Time-Weighted Average
UK	United Kingdom
WPC	Working Party on Chemicals
WTP	Willingness to pay

1. Introduction

1.1. Background

Cobalt metal and inorganic cobalt compounds are hazardous substances frequently used in a wide variety of products. Their use is likely to grow in future given their importance to renewable energy technologies and battery production, which are crucial to the green transition (European Commission, 2022a). Cobalt is a critical raw material (CRM), meaning it has significant strategic economic importance and is a key material in the EU's plan for greater resource autonomy (European Commission, 2023a).

Cobalt substances are hazardous in various ways: the Risk Assessment Committee (RAC) states that "cobalt metal and several cobalt compounds may cause cancer and damage fertility. Furthermore, many of them have harmonised classifications as suspected of causing genetic effects, and they may cause an allergic skin reaction and may cause allergy or asthma symptoms or breathing difficulties if inhaled[1] (ECHA, 2022a). Approximately 80,000 workers across the European Union (EU) are exposed to cobalt metal and cobalt substances (European Commission, 2022a). There is thus a need to consider reducing workplace exposure and incidents related to cobalt metal and cobalt compound exposure.

Cobalt substances have been a subject of interest for the EU's regulatory bodies since five cobalt salts were listed on European Chemicals Agency's (ECHA) third prioritisation list for Authorisation in 2011 (ECHA, 2018a). This eventually led to the initiation of a Restriction process under the Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH) legislation for these five cobalt salts in 2017 with ECHA preparing a restriction on the manufacturing, placing on the market and use of: cobalt sulphate, cobalt dichloride, cobalt dinitrate, cobalt carbonate and cobalt diacetate, culminating in an Annex XV dossier published in November 2018 (ECHA, 2018a).

The restriction process was terminated in April 2022 by the European Commission a year or so after the Committee for Socio-Economic Analysis' (SEACs) opinion – which was published in 2020. The SEAC opinion proposed that a restriction was not the most appropriate Union-wide measure (ECHA, 2020a). Instead, it was suggested by SEAC that it may be more appropriate for the European Commission (EC) to set an EU-wide Binding Occupational Exposure Limit (BOEL) for cobalt metal and inorganic cobalt compounds. In their opinion, RAC stated that while they thought the restriction on five cobalt salts would be appropriate, a BOEL should also be implemented for cobalt metal and its compounds (ECHA, 2020a). There is currently no binding or indicative Occupational Exposure Limit (OEL) value for cobalt or inorganic cobalt compounds under Directives 98/24/EC or 2004/37/EC (ECHA, 2022a).

The EC decided that while the restriction on cobalt salts was not the most appropriate policy too, it was necessary to reduce the exposure of workers to cobalt metal and inorganic cobalt compounds. Therefore, it is investigating the implementation of a BOEL for cobalt metal and inorganic cobalt compounds, which would be implemented under the Carcinogens, Mutagens and Reprotoxic substances Directive (CMRD) (European Commission, 2022b). The goal of CMRD is to minimise workplace exposure to toxic substances. One tool to achieve this is a BOEL, which places an EU-wide limit on the permissible airborne concentration of toxic substances in workplaces (ECHA, 2022b). The fourth revision of CMRD, from 2020, stated that the

[1] The legal hazard classifications relating to cobalt metal and the 5 cobalt salts are carcinogenicity (Carc. 1B), mutagenicity (Muta. 2), reproductive toxicity (Repr. 1B), skin sensitisation (Skin Sens. 1), and respiratory sensitisation (Resp Sens. 1).

EC must set a BOEL for cobalt metal and inorganic cobalt compounds and it must be implemented no later than 31st December 2024 (European Commission, 2020).

As such, the EC mandated ECHA to evaluate exposure risks for cobalt metal and inorganic cobalt compounds to assess the option of an airborne BOEL (ECHA, 2022c), and to provide an opinion on the appropriate levels of a BOEL. This was published by the RAC in February 2023 (ECHA, 2022d). Meanwhile, the EC has consulted on its BOEL recommendation for cobalt metal and inorganic cobalt compounds (ECHA, 2022e) and is expected to publish an Impact Assessment (IA) of the different BOEL value options in 2023 (European Commission, 2022a).

The RAC opinion will also be discussed in the context of OEL policy options in the Working Party "Chemicals at the Workplace" (WPC) of the Advisory Committee on Safety and Health at Work (ACSH). This committee supports the EC by giving opinions on EU initiatives in the area of occupational safety and health. A formal opinion on any BOEL will be adopted by the ACSH in 2023, though the ACSH opinion has not yet been published (European Commission, n.d.).

1.2. RAC opinion

The latest RAC opinion on the scientific evaluation of BOEL for cobalt metal and inorganic cobalt compounds was published on 1 February 2023 (ECHA, 2022d). The report found that lung cancer observed in animal-based studies, and non-cancer respiratory effects observed in exposed workers are the main critical toxicities of cobalt metal and inorganic cobalt compounds (ECHA, 2022d).

The RAC derived the values, summarised in **Table 1.1** which includes all limits that were derived by RAC. Some, including a Biological Limit Value (BLV) or a Short-Term Exposure Limit (STEL) were either not relevant or not established by the report. The RAC determined that as different cobalt substances cannot be differentiated (speciated) in workplace air, it was recommended that these limit values should be applied to cobalt metal and all inorganic cobalt compounds.

Table 1.1: RAC derived limit values for cobalt metal and inorganic cobalt compounds from the RAC opinion

Exposure limit	Value	Notes
Inhalable fraction BOEL	1 µg/m^3	8-hour time-weighted average, Endpoint: Respiratory impairment (threshold)
Respirable fraction BOEL	0.5 µg/m^3	8-hour time-weighted average, Endpoint: Lung cancer (non-threshold)
Derived No Effect Level (DNEL)	4 µg/m^3	Relates to male fertility effects only
Biological guidance value (BGV) for females	2 µg/L urine	
Biological guidance value (BGV) for males	0.7 µg/L urine	
Biological limit value (BLV)	*Not established*	
Short-term exposure limit (STEL)	*Not relevant*	

Table note: The RAC opinion is a proposal, not a final decision.

As mentioned above, OELs are implemented to reduce worker exposure to hazardous substances in the workplace. The limits are set based on information of the hazard profile of the substance (e.g., carcinogenicity, mutagenicity, and toxicity to reproduction) and the acute effects of exposure. For more information on each of the limit value types contained in **Table 1.1**, see **Table 1.2**.

Table 1.2: Definition of limit values

Exposure Limit	Description
Occupational Exposure Limits (OEL) and Binding Occupational Exposure Limits (BOELs)	Occupational Exposure Limits (OELs) are regulatory values which indicate levels of exposure for which chemical substances in the air of a workplace to which exposure is considered safe (health-based) - in relation to a reference period of 8 hours (time-weighted average, TWA). These limits are based on the most recent evidence with respect to carcinogenicity, mutagenicity and toxicity to reproduction and on the acute effects of exposure and are set by regulatory authorities at the European Union and national levels) (ECHA, 2023). The Carcinogens and Mutagens Directive (Directive 2004/37/EC) states that these limit values should be revised periodically in light of more recent scientific data (European Union, 2004). ECHA distinguishes between two types of OELs. Binding OELs (BOELs) are those which are set by the EU, and which cannot be exceeded by the Member States when establishing a national limits. This ensures a minimum level of protection for all workers in the EU. OELs, on the other hand, are set by Member States which only need to take the EU value into account (ECHA, 2022f). OELs are usually expressed as milligram per cubic meter (mg/m3) of air (OSH Wiki, 2022), though units of a different order of magnitude (e.g., micron) may be used depending on the exposure volumes required to cause adverse effects.
Short-Term Exposure Limit (STEL)	Short-Term Exposure limits (STELs) were developed to protect workers where the use of 8-hour OELs is not sufficiently effective in the case of short-term exposure situations, such as in the case of irritating compounds (ECHA/RAC-SCOEL Joint Task Force, 2017). These set a limit value above which exposure should not occur and which is related to a 15-minute period unless otherwise specified (European Union, 2004). There are also “Ceiling STELs” which set the limit which concentrations cannot exceed at any time of the workday (OSH Wiki, 2022).
Biological Limit Values (BLVs)	Biological Limit Values (BLVs) focus on the impact on humans and define the maximum levels of substances in humans, their metabolite, or indicator of effect, e.g., in blood, urine or breath (OSH Wiki, 2022). These can be used when air monitoring alone may “seriously underestimate the total uptake of certain substances” (ECHA/RAC-SCOEL Joint Task Force, 2017).
Biological Guidance Values (BGVs)	Where toxicological data cannot support a health based BLV, a Biological Guidance Value (BGV) might be established. This value represents the upper concentration (e.g., 95th percentile) of the substance corresponding to a certain percentile in a defined reference population (e.g., the general EU population). If background levels cannot be detected, the BGV may be equivalent to the detection limit of the biomonitoring method (Scientific Committee on Occupational Exposure Limits, 2014).
Derived No Effect Level (DNEL)	Derived no effect levels (DNELs) are exposure levels below which there are no adverse exposure effects. These can be interpreted as maximum recommended levels for exposure to chemicals and do not consider technical feasibility or costs. These are provided by industry under registration dossiers, and RAC also adopts Opinions on appropriate DNELs (ECHA, n.d.).

1.3. Purpose of this report

This report will support the Cobalt Institute's (CI) industry-wide advocacy efforts, highlighting the potential impacts induced by the introduction of an EU-wide BOEL for cobalt metal and inorganic cobalt compounds. The report will feed into the EC contractor report assessing BOEL values for cobalt metal and inorganic cobalt compounds for the Directorate-General for Employment Social Affairs and Inclusion (DG EMPL). Therefore, the BOEL value options analysed in this report (30, 20, 10 and 1 µg/m^3) are designed to provide information that can be directly used by the EC contractor for their impact assessment. This report is a Socio-Economic Impact Assessment (SEIA) based on the EU's Impact Assessment Guidance (European Commission, 2021).

1.4. Project scope

The scope of the project is defined below in terms of substances, broad use, geography, time period and impacts, respectively.

1.4.1 Substances in scope

The substances in scope are cobalt metal and all cobalt compounds listed in **Table 1.3**, this includes cobalt metal, 43 inorganic cobalt compounds and 16 organic[2] cobalt compounds. The starting point was the list of substances noted in ECHA's background document (ECHA, 2022a), eftec's initial data collection (i.e., the industry questionnaire) considered all 60 substances in **Table 1.3**. This is because at the time of starting the project, there was no "better" information. Since then, the EC contractor released their questionnaire with 15 substances. Consequently, in this report substances have been split into: "directly in scope", "indirectly in scope", and "out of scope". These groupings are organised to mirror the EC contractor's scope as closely as possible and are influenced by responses to the industry questionnaire.

Henceforth, this report will refer to the cobalt substances in scope (i.e., listed below in **Table 1.3**) collectively as "cobalt metal and cobalt substances". This is different to the language used by the EC Contractor ("cobalt and inorganic cobalt compounds"). The different terminology is used to underline the wider scope of this assessment, as **the impacts of the potential BOEL will go beyond that of the 15 substances included in the EC Contractor's questionnaire**. Where "cobalt and inorganic cobalt compounds" is used it refers to the 15 substances included in the EC Contractor's assessment.

The substances have been grouped into five consortia to avoid reporting volumes for each of the substances separately: Red, Blue and Green (as per the CI consortia), the Inorganic Pigments Consortium (IPC) and "Other" cobalt containing substances which are not part of any of the other consortia listed (see Section 2.2).

Substances that are completely out of scope are those which are included in ECHA's scientific report but are not directly in scope of the EC contractor's report or used alongside directly in scope substances.

The self- and harmonised CMR classifications of substances were taken from the respective ECHA brief

[2] In this report, cobalt substances in the CI's Green Consortium are referred to as organic compounds, due to their organic ligands. These are distinct/different from organometallic substances.

profile webpages. Substances that are self-classified are also included within scope based on the discussion with the EC contractor. This is because self-classified substances can also meet the criteria under CMRD (that is, the substance is believed to have a CMR classification category of either 1A or 1B[3]). The self-classifications for these substances are indicated by an asterisk (*). "Reaction mass of cobalt olivine and crystalline silicon dioxide" is not included in the table below and has a Reprotoxic 1B self-classification.

[3] Substances with a category 1A are substances that are known to be CMR mainly according to human evidence. Substances with a category 1B are substances presumed to be CMR based on data from animal studies.

Table 1.3: Cobalt metal and cobalt substances directly in scope, indirectly in scope and entirely outside of the scope

Substance name	EC no.	Cobalt consortia group	Organic[2] / inorganic substance	CMR 1A/1B classification	Directly in scope of BOEL?	Indirectly in scope	Entirely outside the scope
Cobalt metal	231-158-0	Blue Consortium	Metal	Muta. 2 Repr. 1B*	Yes	N/A	No
Cobalt carbonate	208-169-4	Red Consortium	Inorganic	Carc. 1B Muta. 2 Repr. 1B	Yes	N/A	No
Cobalt dichloride	231-589-4	Red Consortium	Inorganic	Carc. 1B Muta. 2 Repr. 1B	Yes	N/A	No
Cobalt dinitrate	233-402-1	Red Consortium	Inorganic	Carc. 1B Muta. 2 Repr. 1B	Yes	N/A	No
Cobalt sulphate	233-334-2	Red Consortium	Inorganic	Carc. 1B Muta. 2 Repr. 1B	Yes	N/A	No
Cobalt sulphide	215-273-3	Red Consortium	Inorganic		No	Yes	No
Cobalt oxide	215-154-6	Red Consortium	Inorganic	Carc. 1B Repr. 1B*	Yes	N/A	No
Tricobalt tetraoxide	215-157-2	Red Consortium	Inorganic		No	Yes	No
Dicobalt trioxide	215-156-7	Red Consortium	Inorganic		No	Yes	No
Cobalt trihydroxide	215-153-0	Red Consortium	Inorganic		No	No	Yes
Cobalt dihydroxide	244-166-4	Red Consortium	Inorganic	Carc. 1B Repr. 1B*	Yes	N/A	No

Substance name	EC no.	Cobalt consortia group	Organic[2] / inorganic substance	CMR 1A/1B classification	Directly in scope of BOEL?	Indirectly in scope	Entirely outside the scope
Cobalt hydroxide oxide	234-614-7	Red Consortium	Inorganic		No	Yes	No
Reaction mass of cobalt, copper and iron	912-664-7	Red Consortium	Inorganic	Carc. 1B* Muta. 2* Repr. 1A*	No	Yes	No
Cobalt lithium dioxide	235-362-0	Red Consortium	Inorganic	Repr. 1B*	Yes	N/A	No
Reaction mass of cobalt sulphide, nickel sulphide and trinickel disulphide	910-663-6	Red Consortium	Inorganic	Muta. 2* Carc. 1A*	No	Yes	No
Fatty acids, tall-oil, cobalt salts	263-065-6	Green Consortium	Organic		No	No	Yes
Cobalt (II) 4-oxopent-2-en-2-olate	237-855-6	Green Consortium	Organic	Repr. 1B*	No	Yes	No
Cobalt oxalate	212-409-3	Green Consortium	Organic	Repr. 1B*	No	No	Yes
Cobalt, borate 2-ethylhexanoate complexes	295-032-7	Green Consortium	Organic	Repr. 1B*	No	Yes	No
Cobalt, borate propionate complexes	295-033-2	Green Consortium	Organic	Repr. 1B*	No	Yes	No
Resin acids and Rosin acids, cobalt salts	273-321-9	Green Consortium	Organic		No	Yes	No
Naphthenic acids, cobalt salts	263-064-0	Green Consortium	Organic		No	No	Yes
Cobalt diacetate	200-755-8	Green Consortium	Organic	Carc. 1B Muta. 2 Repr. 1B	No	Yes	No

Substance name	EC no.	Cobalt consortia group	Organic[2] / inorganic substance	CMR 1A/1B classification	Directly in scope of BOEL?	Indirectly in scope	Entirely outside the scope
Cobalt bis(2-ethylhexanoate)	205-250-6	Green Consortium	Organic	Repr. 1B*	No	Yes	No
Cobalt isononanoate	282-603-0	Green Consortium	Organic	Repr. 1B*	No	No	Yes
Neodecanoic acid, cobalt salt	248-373-0	Green Consortium	Organic		No	Yes	No
Stearic acid, cobalt salt	237-016-4	Green Consortium	Organic		No	Yes	No
Oleic acid, cobalt salt	238-709-4	Green Consortium	Organic		No	No	Yes
Cobalt propionate	216-333-1	Green Consortium	Organic	Repr. 1B*	No	Yes	No
Cobalt, borate neodecanoate complexes	270-601-2	Green Consortium	Organic		No	Yes	No
Cobalt titanite green spinel	269-047-4	IPC	Inorganic	Carc. 1A*[4]	Yes	N/A	No
Cobalt zinc aluminate blue spinel	269-049-5	IPC	Inorganic		No	Yes	No
Iron cobalt chromite black spinel	269-060-5	IPC	Inorganic		No	Yes	No
Cobalt chromite blue green spinel	269-072-0	IPC	Inorganic		No	Yes	No
Olivine, cobalt silicate blue	269-093-5	IPC	Inorganic	Repr. 1B*	Yes	N/A	No
Cobalt chromite green spinel	269-101-7	IPC	Inorganic		No	Yes	No
Iron cobalt black spinel	269-102-2	IPC	Inorganic		No	No	Yes

[4] Cobalt titanite green spinel is self-classified as a Carc. 1A due the presence of a nickel substance (not a cobalt substance) as an impurity. However, there are some grades of the substance which are pure (i.e., do not contain nickel substance impurity) and as such are not self-classified as a Carc. 1A.

Substance name	EC no.	Cobalt consortia group	Organic[2] / inorganic substance	CMR 1A/1B classification	Directly in scope of BOEL?	Indirectly in scope	Entirely outside the scope
Cobalt zinc silicate blue phenacite	270-208-6	IPC	Inorganic		No	No	Yes
Cobalt aluminate blue spinel	310-193-6	IPC	Inorganic		No	Yes	No
Cobalt wolframate	233-254-8	Other	Inorganic		No	No	Yes
Aluminum cobalt oxide	235-762-5	Other	Inorganic	Carc. 1B* Muta. 2* Repr. 1B*	No	No	Yes
Cobalt molybdate	237-358-4	Other	Inorganic	Carc. 1B Muta. 2* Repr. 1B*	Yes	N/A	No
Tripotassium hexacyanocobaltate	237-742-1	Other	Inorganic		No	No	Yes
Leach residues, zinc ore-calcine, zinc cobalt	273-769-5	Other	Inorganic	Repr. 1A	No	No	Yes
Cobalt lithium nickel oxide	442-750-5	Other	Inorganic	Carc. 1A	Yes	N/A	No
Cobalt lithium manganese nickel oxide	480-390-0	Other	Inorganic	Carc. 1A* Repr. 1B*	Yes	N/A	No
Dipotassium hexacyanocobalt(II)-ferrate(II)	603-073-2	Other	Inorganic		No	No	Yes
Cobaltate(1-), tetracarbonyl-, sodium (1:1), (T-4)-	696-062-7	Other	Inorganic		No	No	Yes
Lithium nickel cobalt aluminium oxide	700-042-6	Other	Inorganic	Carc. 1A Repr. 1B*	Yes	N/A	No
Nickel cobalt manganese hydroxide	839-353-8	Other	Inorganic	Repr. 1B* Carc. 1A*	No	Yes	No

Substance name	EC no.	Cobalt consortia group	Organic[2] / inorganic substance	CMR 1A/1B classification	Directly in scope of BOEL?	Indirectly in scope	Entirely outside the scope
Reaction product of soluble nickel salt, cobalt salt, manganese salt with alkalines	931-895-4	Other	Inorganic		No	No	Yes
Trizinc bis[hexacyanidocobaltate] dodecahydrate	942-358-9	Other	Inorganic		No	No	Yes
Alumina doped with cobalt	945-045-5	Other	Inorganic		No	No	Yes
Matte, precious metal	308-506-6	Other	Inorganic	Repr. 1A Carc. 1B*	No	No	Yes
Cement copper	266-964-1	Other	Inorganic	Carc. 1A* Muta. 1B* Repr. 1A*	No	No	Yes
Leach residues, cadmium cake	293-309-7	Other	Inorganic	Carc. 1A* Muta. 1B* Repr. 1A*	No	No	Yes
Slags, precious metal refining	308-515-5	Other	Inorganic	Carc. 1A* Repr. 1A*	No	Yes	No
Slimes and sludges, precious metal refining	308-516-0	Other	Inorganic	Repr. 1A	No	Yes	No
Waste solids, precious metal refining	308-526-5	Other	Inorganic	Carc. 1A* Repr. 1A*	No	Yes	No
Octacarbonyldicobalt	233-514-0	Other	Organic		No	No	Yes

Table notes:

- Substances directly in scope are bolded.
- *Classifications with this asterisk (*) are self-classified.
- “Carc” = Cancer. “Muta” = Mutagenic. “Repr” = Reprotoxic.
- Source: ECHA brief profile webpages (2023).

Directly in scope

Of the 60 substances that were included in ECHA's Scientific Report (ECHA, 2022a), 14 were included in the EC Contractor's questionnaire – thus, being viewed as "directly in scope". These substances are bolded in **Table 1.3**, and are all inorganic substances and substances with a self- or harmonised classification as carcinogenic, mutagenic or reprotoxic (CMR). One substance was included in the EC Contractor's questionnaire but not in the ECHA report: "Reaction mass of cobalt olivine and crystalline silicon dioxide" (EC no.: 701-439-7). This substance was registered in 2022 having previously been registered in REACH as Olivine, cobalt silicate blue[5] (EC no.: 269-093-5). This is because analysis revealed compositional differences in certain grades of this pigment, and it was decided to split the original dossier and submit a separate Registration dossier under the name of "Reaction mass of cobalt olivine and crystalline silicon dioxide" – which is self-classified as Repr. 1B (oral route). As this substance was not included in the industry questionnaire (2023), it is not included in this report. Total substances directly in scope are 14.

Indirectly in scope

This category is used for substances that are outside the scope but are used alongside substances that are directly in scope. This is because the use of such substances may be indirectly affected as is believed that any company using different (i.e., both organic[2] and inorganic) cobalt substances in the same workplace will need to ensure that their total cobalt exposure level is below the BOEL for the overall volume of cobalt substances potentially present in that workplace. Therefore, both directly and indirectly in scope substances are included in this report. Total substances indirectly in scope are 26.

Out of scope

Substances that are out of scope are those cobalt compounds that do not have the relevant hazard classifications and are not used alongside the directly in scope substances according to responses to the industry questionnaire. Total substances out of scope are 20.

1.4.2 Broad uses of cobalt metal and cobalt substances

Following 24 broad uses are included in the scope:

- Manufacture and import of cobalt metal and cobalt substances;
- Manufacture of other chemicals;
- Manufacture of precursor chemicals for batteries;
- Manufacture of pigments and dyes;
- Manufacture of driers / paints;
- Manufacture of catalysts;
- Use as catalyst - Use as catalyst or catalyst precursor;
- Use as catalyst - Use as oxidation catalysts for purified terephthalic acid (PTA) and isophthalic acid (IPA);
- Use in surface treatment – Formulation of surface treatment;

[5] Olivine, cobalt silicate blue is included in the ECHA Scientific Report and is a substance "directly in scope" of this assessment.

- Use in surface treatment – Passivation or anti corrosion treatment;
- Use in surface treatment – Metal or metal alloy plating;
- Use in biotechnology – Formulation and industrial use of mixtures in biogas production;
- Use in biotechnology – Professional use in biogas production;
- Use in biotechnology – Use in fermentation, fertilizers, biotech, scientific research, and standard analysis;
- Use in biotechnology – Formulation and use in animal feed grade materials;
- Bespoke uses – Use in humidity indicators, cards, plugs, and/or bags with printed spots;
- Bespoke uses – Formulation of water treatment chemicals, oxygen scavengers, corrosion inhibitors;
- Bespoke uses – Use of water treatment chemicals, oxygen scavengers, corrosion inhibitors;
- Adhesion (incl. rubber adhesion);
- Use in electronics;
- Use in magnetic alloys;
- Use in metallurgical alloys;
- Use in cemented carbide / diamond tools and;
- Recycling of materials containing cobalt substances

For more information on each broad use please see Section 2.2.

1.4.3 Geographical scope

The geographic scope of this project is the EU-27. The rest of the European Economic Area (EEA), Switzerland, the United Kingdom and Russian Federation are not included in the geographical scope.

1.4.4 Temporal scope

The temporal scope for the analysis (that is, the period over which costs and benefits were considered) is 40 years, from 2022 to 2061. The industry questionnaire asked companies to provide data that was a representative annual average based on the last three years. However, respondents were given the choice of providing data older than this if they were so adversely affected by Covid-19 as to render last three years outliers.

1.4.5 Impacts

This report assesses the impacts of four policy options, corresponding to four different binding occupational exposure limit values (BOELs): 30 µg/m^3, 20 µg/m^3, 10 µg/m^3 and 1 µg/m^3. Impacts from exposures to cobalt at the workplace of use are in scope, while potential impacts following consumer exposure is not. Impacts due to potential limits in current analytical methods to monitor cobalt, has not been assessed.

The approach used to derive the different types of impacts are set out in their respective sections, and more details can be found in Appendix 1.

1.5. Structure of the report

Following this introduction, the report is structured as follows:

- **Chapter 2** provides an overview of the methodology used;
- **Chapter 3** summarises the baseline scenario, including a description of the existing uses of relevant substances and their functions, the volumes used and information on the value chain, such as the number of companies and workers;
- **Chapter 4** presents the information on the current exposure levels and existing Risk Management Measures (RMMs) in place, and the associated costs to human health if a BOEL is not implemented;
- **Chapter 5** provides an assessment of alternatives to cobalt metal and cobalt substances;
- **Chapter 6** outlines the four policy options that are analysed;
- **Chapters 7, 8, 9, 10** are Socio Economic Analysis (SEAs) of each of the four policy options including estimates of their costs, benefits and feasibility;
- **Chapter 11** assesses the wider economic impacts of implementing a BOEL;
- **Chapter 12** compares the costs and benefits of the policy options and provides a proportionality assessment; and
- **Chapter 13** concludes and summarises the key findings.

The report is also supported by the following appendices:

- **Appendix 1** provides more details on the methodology used in this report.
- **Appendix 2** provides more details on the stakeholder engagement carried out for this report.

2. Approach

2.1. Introduction

This chapter discusses the high-level approach used to gather and analyse the necessary data for the purposes of this impact assessment.

In Section 2.2 the development of the impact assessment's scope is discussed. Section 2.3 presents the data collection process, including past studies, existing data sources and the company level questionnaire, whilst Section 2.4 describes the data cleaning and validation process. The grouping of cobalt metal and cobalt substances and their uses are set out in Section 2.5.

2.2. Development of scope

The scope of this analysis is designed to be as closely aligned as possible with the scope of the EC contractor's project for a potential BOEL. Therefore, the scope presented in Section 1.4 is the result of adaptation throughout this project to maintain this alignment given that the EC contractor's project was being developed at the same time as this project.

The geographical scope for the broad uses and impact assessment was decided to be EU-27 in line with the EC contractor's work.

The substances in scope can be found in **Table 1.3.** The starting point for this was the list of substances noted in ECHA's background document (ECHA, 2022a), but this was modified to align with the substances included in the EC contractor's questionnaire defined as "directly in scope". Through the industry questionnaire carried out for this project (see Section 2.3 for more information), it was also found that some cobalt substances that are *not* directly in scope (e.g., cobalt substances with organic ligands) are used alongside substances directly in scope. The use of such substances may be indirectly affected as is assumed that any company using different cobalt substances in the same workplace will need to ensure that their total cobalt exposure level is below the BOEL. Therefore, these substances that are directly and indirectly in scope are included in this report.

Out of scope are the remaining cobalt compounds that are not in, or used alongside, the EC contractor's list of substances directly in scope. It should be noted that the substances out of scope were identified through responses to the industry questionnaire. It can therefore not be excluded that some companies (that did not respond to the questionnaire) use some of the "out of scope" substances alongside substances directly in scope.

Five substance groupings are used in line with previous work by eftec (2019a). The substances were grouped into consortia to simplify the data presented and to ensure the anonymity of reporting while discussing as many substances as possible. Three of these consortia of substances (Red, Blue, and Green) were established in line with the grouping of substances by the Cobalt Institute for the purpose of preparing registration dossiers for cobalt metal and cobalt substances. The fourth group is the Inorganic Pigments Consortium (IPC), and the final group, "Other", contains all substances which are included in ECHA's background document but not in the other four consortia.

The broad uses considered in this analysis builds upon previous work by eftec on the cobalt value chain (eftec, 2019a). The 24 broad use categories used in the past report have been duplicated across the Broad Use notes, Headline Results report that was shared with the EC contractor and this report for consistency.

The only exception is “Manufacture of pigments, frits and dyes” which has been adapted to “Manufacture of pigments and dyes” as “frits, chemicals” (EC number: 266-047-6) is not listed within the substances believed to be directly or indirectly in scope (see Section 1.4.1 for discussion on substances within scope).

Table 2.1 shows the number of respondents classifying each broad use according to their use of directly and indirectly in scope and out of scope substances. “Insufficient responses” indicates that there were less than three responses, and information is therefore either not available or cannot be reported due to confidentiality reasons. For information on types of substances typically used per broad use (based on other sources) see Section 3.3.

Table 2.1: Cobalt substances by broad use based on respondent data

Broad use category	Is a cobalt substance that is directly in scope used?	Is a cobalt substance that is indirectly in scope used?	Is a cobalt substance that is completely outside the scope used?
Manufacture of cobalt metal and/or cobalt substances	Yes n=9	Yes n=22	No
Manufacture of other chemicals	Yes n=2	Yes n=4	No
Manufacture of precursor chemicals for batteries	Insufficient responses	Insufficient responses	Insufficient responses
Manufacture of catalysts	Yes n=4	Yes n=1	No
Manufacture of pigments and dyes	Yes n=3	Yes n=6	No
Manufacture of driers/paints	Insufficient responses	Insufficient responses	Insufficient responses
Use as catalysts - used as a catalyst or catalyst precursor	Yes n=1	Yes n=2	No
Use as catalysts - used as oxidation catalyst/for PTA and IPA	Insufficient responses	Insufficient responses	Insufficient responses
Use in surface treatment - Formulation of surface treatment	Yes n=4	No	No
Use in surface treatment - passivation or anti-corrosion treatment processes	Yes n=3	No	No
Use in surface treatment - metal or metal alloy plating	Yes n=2	Yes n=1	No

Broad use category	Is a cobalt substance that is directly in scope used?	Is a cobalt substance that is indirectly in scope used?	Is a cobalt substance that is completely outside the scope used?
Use in biotechnology – formulation and industrial use of mixtures in biogas production	Insufficient responses	Insufficient responses	Insufficient responses
Use in biotechnology – professional use in biogas production	Insufficient responses	Insufficient responses	Insufficient responses
Use in biotechnology – Use in fermentation, fertilizers, biotech, scientific research, and standard analysis	Insufficient responses	Insufficient responses	Insufficient responses
Use in biotechnology – formulation and use in animal feed grade materials	Yes n=2	Yes n=1	No
Bespoke uses – use in humidity indicators cards, plugs and/or bags with printed spots	Insufficient responses	Insufficient responses	Insufficient responses
Bespoke uses – formulation of water treatment chemicals, oxygen scavengers, corrosion inhibitors	Insufficient responses	Insufficient responses	Insufficient responses
Bespoke uses – use of water treatment chemicals, oxygen scavengers, corrosion inhibitors	Insufficient responses	Insufficient responses	Insufficient responses
Adhesion (inc. rubber adhesion agent)	No	Yes n=8	No
Use in electronics	Insufficient responses	Insufficient responses	Insufficient responses
Use in magnetic alloys	Insufficient responses	Insufficient responses	Insufficient responses
Use in metallurgical alloys	Yes n=1	No	No
Use in cemented carbide/diamond tools	Yes n=1	Yes n=1	No
Recycling of materials containing cobalt substances	Yes n=3	Yes n=2	No

Table notes:

- *n* indicates the number of substances used in the category. The numbers of substances directly and indirectly in scope are additive.
- Source: *eftec industry questionnaire* (eftec, 2023).

2.3. Data collection

2.3.1 Use of existing data / previous studies

For the purposes of this impact assessment, a combination of existing data and past studies were used to supplement information collected through a company level, cross industry questionnaire. Past studies used included previous work by eftec for the Cobalt Institute on the cobalt value chain, potential cobalt restrictions and BOELs, and a study by RPA assessing compliance costs of BOELs for cobalt metal and its compounds (eftec, 2021, 2020, 2019a, 2019b; RPA, 2020).

2.3.2 Online survey

In September and October 2022, eftec circulated an online survey amongst companies with several broad uses for cobalt metal and/or cobalt substances. This survey was designed to gather contact information from manufacturers, importers, recyclers, and downstream users of cobalt metal and/or cobalt substances and understand the scope of broad uses that potential participants represented.

2.3.3 Excel™-based cost of compliance questionnaire

In October 2022, a company level Microsoft Excel™ based questionnaire was developed to collect cross-industry information on:

- Broad uses of cobalt substances in the EU-27, rest of the EEA, and the UK;
- Number of employees exposed to cobalt metal and/or cobalt substances in the workplace;
- Volume and value of cobalt substances manufactured, imported as well as used in the EU and exports;
- Recycling processes and volumes of cobalt metal and/or cobalt substances recycled;
- Downstream uses (volumes, functionality, and end-products) of cobalt metal and/or cobalt substances;
- Substitution attempts of cobalt metal and/or cobalt substances (including functions that led to success, partial success, or failure of substitution);
- Existing and planned workplace exposure monitoring processes;
- Existing Risk Management Measures (RMMs) associated with workplace exposure to cobalt; and
- Level of compliance, RMMs needed, and cost of implementation associated with the BOEL levels: 30 µg/m^3, 20 µg/m^3, 10 µg/m^3, and 1 µg/m^3.

This questionnaire was distributed via email to the contact list developed from eftec's survey, as well as other companies and industry organisations who later engaged with eftec and/or the Cobalt Institute.

In total, the questionnaire was circulated to over 150 companies and industry stakeholders. Sixty-two responses were received by late January 2023.

To protect the confidentiality of company-level information, all data was anonymised, and data points were aggregated during the analysis stage.

2.4. Data validation

2.4.1 Excel™-based questionnaire

This section discusses the methodology used in validating the data from the 62 responses received by eftec.

Of these 62 responses, three responses were excluded either because the data was considered limited and unreliable or because they were outside of the geographical and substance scope. These respondents were not included when data was aggregated, leaving a total of 59 responses.

Data relating to operations in the UK, Switzerland, or countries in the European Economic Area (EEA) but outside of the EU-27 was only included in the analysis where relevant, for example when calculating the unit costs of monitoring programme. Ten respondents had at least some operations outside the EU-27, five of which had no operations within the EU-27 and were only considered for these calculations.

The steps taken to validate the respondent data included sanity checking and correcting logical inconsistencies, ensuring formatting was consistent, and producing a list of points for clarification for each respondent. Points for clarification were sent to 53 of the 59 included respondents, of which 30 replied [6].

2.4.2 Broad use notes & webinars

A set of 14 broad use notes, which collectively covered all 24 broad uses, were produced summarising the headline results of the industry questionnaire. The notes were used to collect feedback on the data from the questionnaire and other sources to ensure that it is representative of the industry at large.

The data analysis for the broad use notes covered the following topics:

- **Company data,** including information on the number of companies, workers, sites and the proportion of small to medium sized enterprises (SMEs) in each broad use;
- **Volumes used,** including information on the substances used by each company and their respective volumes;
- **Available alternatives,** including information on the availability, cost and barriers associated with using alternative substances; and,
- **Regulatory compliance,** including information on RMMs and monitoring systems used by each company, and the possibilities of compliance with the BOELs options.

Webinars were held for each of these broad use notes, which were attended by industry representatives and used as an opportunity to ask questions on the results and provide feedback on any issues.

2.4.3 Additional data validation

Headline results from broad use notes were also submitted to the EC contractor for use in their socioeconomic assessment of the implementation of a BOEL. Meetings were also held with the contractor to facilitate a two-way exchange of data and validation of preliminary results. Lastly, drafts were provided to CI Members for comments at several stage during the process, for additional quality assurance.

2.5. Impact assessment framework

An impact assessment is an analytical framework used by policy makers (both at the Member State level

[6] The remaining 23 respondents did not respond to their points for clarification.

and at the EU level) to support public decision-making. An impact assessment seeks to:

- Systematically account for all relevant costs and benefits associated with a policy decision relating to economic, social, human health or environmental impacts; and
- Quantify and monetise the most important costs and benefits to all members of society resulting from the policy decision.

The EC has provided a best practice guideline on how to conduct an impact assessment through their Better Regulation Toolbox (European Commission, 2021). The approach used in this study adheres to this guideline. ECHA has also published their own socioeconomic analysis guidance, which was used here where relevant (ECHA, 2008).

We also assessed the tender published by the EC to provide their own impact assessment, ensuring that the approach taken for this impact assessment is aligned with that of the EC contractor's assessment as far as possible. As explained in Section 6.3, the Policy Options in this SEIA were agreed with the CI, but are not the same as those analysed by the EC Contractor as the details of their analysis was unavailable at the data gathering stage for this project.

The Better Regulation Toolbox sets out the steps of an impact assessment, which are followed in this report (European Commission, 2021):

- **Step 1**: Establish the baseline (Chapters 3 and 4 of this report);
- **Step 2**: Define the scenarios (Chapter 6 of this report);
- **Step 3 - 4**: Identify affected actors, and describe, quantify and monetise impacts (Chapters 7 to 11 of this report);
- **Step 5**: Compare societal costs and benefits of options against the baseline (Chapters 7 to 11 of this report); and,
- **Step 6**: Conduct sensitivity analysis (Chapter 12 of this report).

The present value (PV) of monetised impacts were derived over an appraisal period of 40-year, using a 3% discount rate as recommended in the Better Regulation Toolbox (European Commission, 2021), and all values have been uplifted to 2022 values using GDP deflators from (World Bank, 2023).

Further details on the approach and key assumptions used to estimate impacts are described in Chapter 4, Chapter 7-10 and Appendix 1.

3. Baseline scenario

3.1. Introduction

Baseline scenario defines the situation in the absence of the proposed EU level BOEL for cobalt metal and cobalt substances. It covers the EU-27 and serves to assess the impacts of the BOEL options on the 24 broad uses that would be either directly or indirectly impacted. The baseline contains the following information for these broad uses:

- Description of manufacturing and import of cobalt metal and cobalt substances, and uses of cobalt by downstream users;
- Function of cobalt metal and cobalt substances;
- Value added;
- Employment;
- Number of companies; and,
- Volumes of cobalt metal and cobalt substances manufactured, used, and recycled.

3.2. Manufacture and import of cobalt metal and cobalt substances

The manufacture and/or import of cobalt metal and/or cobalt substances includes the production of cobalt metal and 59 cobalt substances[7], which may be impacted by the introduction of an EU-wide BOEL. Inorganic cobalt compounds can be manufactured using various methods such as precipitation, thermal decomposition, and hydrothermal synthesis. Cobalt salts, including cobalt chloride, cobalt sulphate, and cobalt nitrate, are commonly produced by reacting cobalt metal or cobalt oxide with the corresponding acid or salt (Gupta and Krishnamurthy, 2004). Stakeholders stated that among these salts, cobalt sulphate is a key intermediate produced during the refining process, primarily derived from crude cobalt dihydroxide. These raw materials are traded between mines and refiners as part of the production chain.

3.2.1 REACH registration and CMR harmonised classifications

Forty-two substances are registered under REACH[8] for cobalt metal and inorganic cobalt compounds and 16 for organic[2] substances. As discussed in Sections 1.4 and 2.2, the list of substances included as directly or indirectly in scope is based on the ECHA's background document (ECHA, 2022a), in which cobalt metal and inorganic cobalt compounds are cited from REACH registration data and in discussion with the EC contractor – in large part due to their application under the CMRD. This analysis also includes organic cobalt compounds that are indirectly in scope.

[7] Further details on the selection of these substances are provided in Section 1.4.1.

[8] Regulation (EC) No 1907/2006 of the European Parliament and of the Council of 18 December 2006 concerning the Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH), establishing a European Chemicals Agency, amending Directive 1999/45/EC and repealing Council Regulation (EEC) No 793/93 and Commission Regulation (EC) No 1488/94 as well as Council Directive 76/769/EEC and Commission Directives 91/155/EEC, 93/67/EEC, 93/105/EC and 2000/21/EC (OJ L 396 of 30 December 2006, p. 1; corrected by OJ L 136, 29.5.2007, p. 3)

3.2.2 Manufacture and import of cobalt metal and cobalt substances

The manufacture and/or import of cobalt metal and/or cobalt substances include the production of cobalt metal and 59 cobalt substances, which are the potential substances impacted by the introduction of an EU-wide BOEL (See **Table 3.1**). Cobalt substances (e.g., cobalt dihydroxide) are used to make other cobalt substances (e.g., cobalt metal) and as a result, total tonnages should not be added across or within the manufacture and import categories or different broad uses.

Manufacturers of cobalt substances in the EU-27 primarily use cobalt-containing materials extracted from white alloy, nickel matte, ferro-alloy, and unrefined cobalt to make cobalt metal (eftec and wca, 2015). Approximately 93% of raw materials used are imported from non-EU countries and the remaining 7% are produced within the EU-28[9] (eftec and wca, 2015). Cobalt is mainly mined as a by-product of copper and nickel mining, using both underground and surface mining technologies (ECHA, 2022d). Cobalt is separated from nickel or copper using pyrometallurgical and hydro-metallurgical techniques. (The majority of refined cobalt imported to the EU is from China (60%) while 17% is refined within the EU (Finland, Belgium, and France) (Grohol and Veeh, 2023).

Information on tonnage of cobalt metal and cobalt substances manufactured and imported is presented in Section 3.5.2.

3.2.3 A critical raw material

Cobalt metal is classified by the EC as a critical raw material (CRM) (European Commission, 2023b). Such classification requires determining the criticality of raw materials by assessing two criteria:

1. The economic importance of the substance, which refers to the role and usage of the material in question within the EU economy; and
2. The supply risk of a substance, which focuses on the security of global supply (primary and secondary) taking into account the availability of feasible substitutes for a given material.

Cobalt is one of 27 CRMs in the latest update published in 2017[10]. **Figure 3.1** (below) shows how cobalt (the blue dot) and the remaining 26 CRMs relate against the two criteria: with economic importance on the x-axis and supply risk on the y-axis. As can be seen in the figure, cobalt is one of the raw materials of highest economics importance in the EU.

[9] The EU-28 refers to the EU-27 plus the United Kingdom.

[10] A new update was published after the drafting of this report was completed, which includes cobalt as one of 34 CRMs (European Commission, 2023).

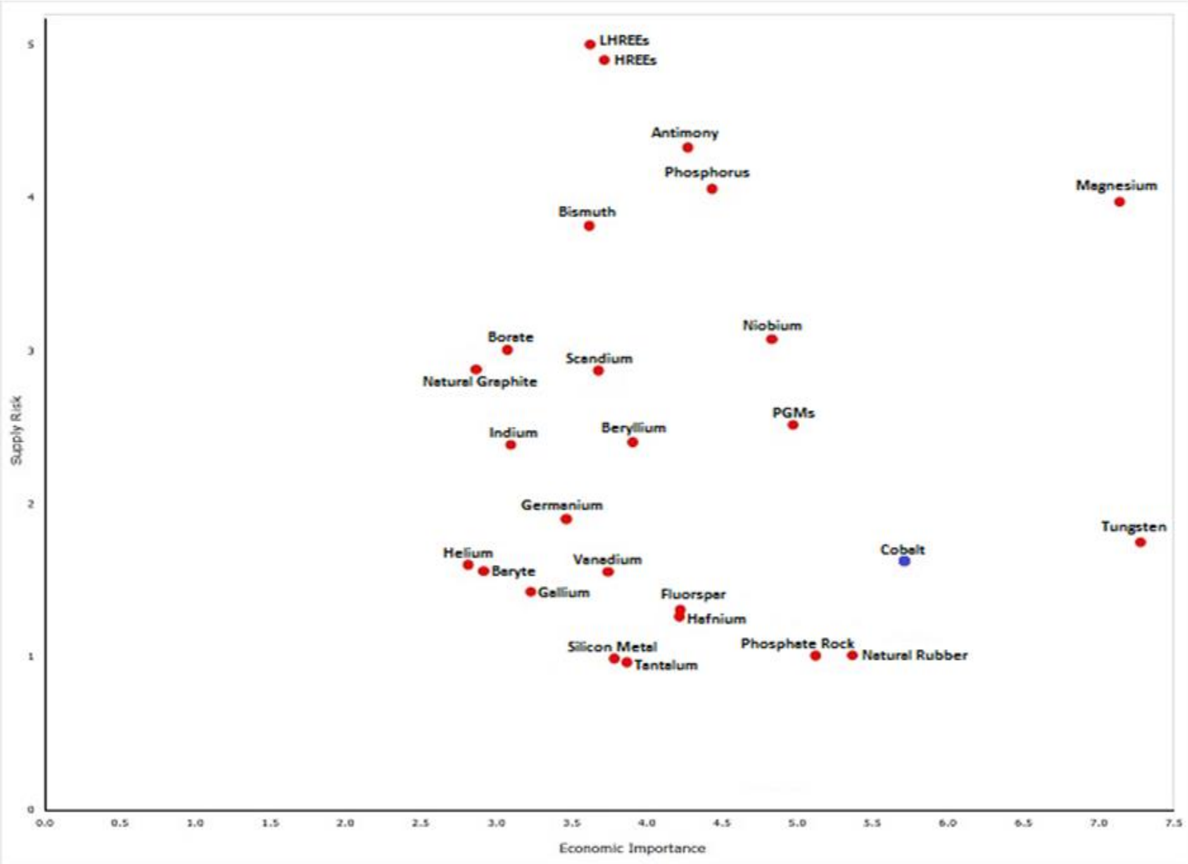

Figure 3.1: Criticality of the 27 CRMs, identified in 2017[10], with cobalt marked in blue

Source: (European Commission, 2022c)

The supply of CRMs is an important issue to consider, as they can only be sourced from a small number of countries (CRM Alliance, n.d.). Cobalt is considered less at risk from supply interruptions compared to others in **Figure 3.1**, with cobalt lying in the lower right quadrant. The Democratic Republic of Congo (DRC) is the world's largest cobalt supplier and is expected to remain the predominant supplier, at 60-75% of global mine output, for at least the next decade (Baars et al., 2021). Other producing countries such as Australia, Cuba, Indonesia, and Russia have significantly lower shares of the global market. According to Baars et al. (2021), the supply of cobalt is constrained by three major factors:

1. Reliance on the copper and nickel market to incentivise increased cobalt mining since cobalt is a by-product of nickel and copper mining;
2. Global dependence on the DRC and the political, geographic, and economic context within the country; and
3. Difficulty, cost and time needed to substitute cobalt for many uses.

3.3. Broad uses of cobalt metal and cobalt substances

3.3.1 Manufacture of other chemicals

Cobalt metal and cobalt substances are widely used to manufacture other chemicals, such as cobalt carboxylates, resinates and other inorganic cobalt substances[11] (ECHA, 2022a). Cobalt is also used as an intermediate in the manufacture of ceramic ware and glass. A non-exhaustive list of substances manufactured in this broad use includes:

- Unsaturated polyester and vinyl ester resins;
- Mixtures containing cobalt substances;
- Cobalt-containing decolourisers (to suppress yellow tints caused by the presence of iron) (Darton Commodities Limited, 2023); and,
- Cobalt soaps (widely used to accelerate the drying process in oil-based paints, varnishes, and inks (eftec and wca, 2015).

In addition, some cobalt substances, mainly cobalt sulphate and cobalt chloride, are used in the production of cobalt-alloy films by electro-deposition and electro-less plating (Tebbakh et al., 2020). Cobalt alloy coatings provide several advantages to the substrate (coated material), including corrosion and wear resistance, high temperature resistance, magnetic properties, and low friction.

3.3.2 Manufacture of precursor chemicals for batteries

The material at the final step before becoming a cathode[12], or an ingredient from which a cathode is formed, is referred to as a battery precursor material (LG Energy Solution - Battery Inside, 2022). Cobalt is used to produce the cathode in lithium-chemistry batteries such as, Lithium Cobalt Oxide (LCO) – which are used in portable electronic devices (PEDs) – and Lithium Nickel Cobalt Aluminium Oxide (NCA) and Lithium Nickel Manganese Cobalt Oxide (NMC) chemistry batteries – which are used in electric vehicles (EVs).

The metal (material) used to produce the cathode determines most of the performance characteristics of the battery (Clemens, 2023). Cobalt increases the battery life and energy density[13] which makes them ideal for uses such as mobile electronics (smartphones, laptops, smart watches – for example in LCO batteries), and any compact device that needs to emit power over long periods (Braun et al., 2012; Dragonfly Energy, 2022). With respect to NCA/NMC batteries used in EVs, cobalt substances improve the stability of the battery; thus, enabling higher power density (i.e., higher delivery rate of energy[14]) (Clemens, 2023).

Cobalt, nickel, and lithium are key metals used in modern active cathode materials and the chemistries deployed in high energy density EV batteries (Clemens, 2023). Cobalt sulphate is combined with other metal sulphates, most commonly manganese sulphate and nickel sulphate as in NMC battery cells, to produce the active cathode material for lithium-ion batteries. Cobalt sulphate is not directly present in the final cathode composition but it is used in the production of cathode materials. Instead, it is the cobalt component within the cathode material, such as NMC, that imparts the desired properties. The addition of cobalt ensures that the battery does not overheat by compensating for changes in charge when a lithium ion arrives (during use) or departs (when not in use) (Clemens, 2023). Moreover, cobalt is used in lithium-

[11] Cobalt substances that are not included in the 60 substances which are within the scope of this report.

[12] A cathode is the electrode from which a conventional current leaves a polarised electrical device.

[13] Energy Density (Wh/kg) is a measure of how much energy a battery can hold compared to its weight and size. The higher the energy density, the longer the runtime will be (Braun et al., 2012).

[14] This is useful for performance such as heavy acceleration, where more current is required.

ion (Li-ion) batteries to minimise the degradation of the cathode structure.

Despite the prevalence of Li-ion batteries, rechargeable Nickel-Cadmium (Ni-Cd) and Nickel-Metal Hydride (Ni-MH) batteries continue to have specific applications where they continue to be used. Cobalt is also used in the manufacturing process of Ni-Cd and Ni-MH batteries to improve the oxidation of nickel in the battery. eftec & wca (2015) details that Ni-Cd batteries are used in standby applications including:

- Telecommunications;
- Aviation for energy backup systems and engine starting;
- Motive power for specialist vehicles such as forklifts;
- Railways (e.g., emergency systems);
- Two-way radios;
- Emergency medical equipment; and
- Power tools.

Stakeholders noted that while Ni-MH batteries are mainly used for portable electronic applications such as laptops, hybrid electric vehicles, and satellite applications, LCO battery chemistries were used in almost all portable consumer electronic devices. In the Ni-MH batteries, cobalt alloys enhance the cells' lifespan by increasing hydride thermodynamic stability and inhibiting corrosion (eftec and wca, 2015). The use of cobalt in these batteries allows them to charge more quickly and hold charge for a longer period. Whilst cobalt is still used in Ni-Cd and Ni-MH batteries, over 90% of current consumption in the battery industry is linked to the production of Li-ion batteries (Alves Dias P. et al., 2018).

3.3.3 Manufacture of pigments and dyes

Pigments and dyes are types of colourants used in various industries, such as textiles, cosmetics, and printing. Pigments are solid colour particles that are insoluble in the medium they are mixed with and are added to materials to change their appearance. Dyes are colourants that dissolve in the medium they are mixed with and are used to colour materials such as fabrics, plastics, and paper. Cobalt is a very strong colourant; therefore, only very small quantities need to be used for the manufacture of pigments and dyes. By altering the concentration of cobalt oxide and adding other metal oxides different colours can be created.

Cobalt oxides (i.e., cobalt oxide and tricobalt tetraoxide) are the primary cobalt compounds used as a pigment. They are used in a variety of applications, mainly ceramics and glass, but also in artistic paints, inks, and plastics (eftec & wca, 2015a). Additionally, according to feedback from the industry, tricobalt tetraoxide is the primary raw material utilised in the manufacturing of cobalt-containing inorganic pigments specifically for ceramic applications. IPC members confirmed that the tricobalt tetraoxide used is REACH substance "profile 1" – which has no hazardous impurities.

Cobalt compounds such as cobalt diacetate, cobalt dichloride, and cobalt sulphate are used as dyes for the textile leather, wood, and paper industry. Cobalt metal and cobalt substances are key components of inks used in digital printing (RPA, 2022). Cobalt pigments are also used in several ceramic applications (eftec and wca, 2015). Cobalt pigments include (but are not limited to) the following colours: blue, yellow and green (of various shades) (Kremer Pigmente, 2023). Additionally, stakeholders noted that cobalt substances can be used to provide a combination of functions; colour being just one of them. For example, cobalt substances may be used as it is particularly compatible with various matrices/materials and these matrices/materials' requirements. Therefore, cobalt substances can be used in the manufacture of pigments and dyes as a technical solution to several requirements (including colour).

3.3.4 Manufacture of driers / paints

Driers are chemical additives used to decrease the drying time of the paint or coating (Goldstab, 2023). Driers work by promoting the oxidation process in the paint, which causes the paint to harden and dry more quickly. These additives are particularly useful for corrosive paints that require enhanced drying characteristics in humid environments and at low temperatures. Driers typically consist of stabilised metal carboxylate solutions in mineral spirit, with the most common metals used in their production being cobalt, manganese, iron, or lead. The organic compounds consist of a positively charged metal cation bonded to a negative charged carboxylate functional group (SpecialChem, 2023). The metal cation is the active part of the metal carboxylate drier (SpecialChem, 2023).

Cobalt is used in the paints and coatings industry as a drying agent (solvent catalysts) and a hardener (in the form of unsaturated polyester resin) (RPA, 2022). Cobalt sulphate and cobalt carboxylates accelerate the drying of coatings, paints and/or inks and are used as drying agent in inks, paints, varnishes, and linoleum (US Department of Health and Human Services, 1998). Unlike the lead and manganese alternatives, cobalt driers made from cobalt bis(2-ethylhexanoate) (also referred to as cobalt octoate) or cobalt naphthenate[15] have minimal effect on darkening and loss of flexibility of the paint (Langridge Artist Colours, n.d.).

3.3.5 Manufacture of catalysts

The manufacture of catalysts involves the production or synthesis of catalyst materials. A catalyst is a substance which accelerates the rate of a chemical reaction without undergoing any permanent chemical change itself (Hamers, 2017). By reducing the activation energy required for a reaction, catalysts promote faster reaction rates while requiring less energy input (eftec and wca, 2016). Additionally, catalysts can be recovered and reused as they are not consumed in the reaction (eftec and wca, 2016).

Cobalt dinitrate and cobalt carbonate are often used as raw materials or intermediates in the production of cobalt-based catalysts (DHI, 2018). Cobalt-based catalysts are known for their excellent catalytic activity, stability, and selectivity, making them well suited for a wide range of applications. Cobalt compounds like cobalt nitrate are widely used in the manufacture of catalysts for hydrotreating/desulphurisation processes, which are utilised in the oil refining sector, and in the production of Fischer-Tropsch catalysts that facilitate the conversion of natural gas to synthetic hydrocarbon fuels through the Gas-to-Liquid (GTL) reaction (Jeske et al., 2021). Cobalt is also used in the manufacture of catalysts that are used to manufacture other chemical substances; such as, (cobalt-containing) amination catalysts[16] which are used in ammonia production (DHI, 2018). Additionally, as explained in below in Section 3.3.6, cobalt substances are used in

[15] Cobalt naphthenate is an organic cobalt compound which is not in the scope of the report.

[16] Amines are derivatives of ammonia in which one or more of the hydrogens has been replaced by an alkyl or aryl group (Michigan State University Department of Chemistry, 2013).

polymerisation reactions to produce polymers.

3.3.6 Use as catalysts

The use of catalysts involves employing the manufactured catalyst materials in chemical reactions to enhance their rates or selectivity. Cobalt has valuable catalytic properties and is used as a catalyst in various applications such as use as a catalyst or catalyst precursor and used as oxidation catalyst for Purified terephthalic acid (PTA) and Isophthalic acid (IPA).

Use as catalyst or catalyst precursor

A catalyst precursor is a substance that requires further activation or reaction to produce the active catalyst[17] (Catalysts Europe, 2022). Cobalt has valuable catalytic properties, and it is used as a catalyst or catalyst precursor for many applications (eftec & wca, 2015). Cobalt nitrate and cobalt carbonate are vital precursors in the production of a range of catalysts described below.

Cobalt catalyst precursors are used in the hydrodesulphurisation (HDS) process, which is responsible for 80% of gasoline specifications (Calixto, 2016). Most HDS units in refineries use catalysts based on cobalt-modified molybdenum disulphide (MoS_2) together with small amounts of other metals (RPA, 2020). Moreover, the Fischer-Tropsch (GTL technology) process, which creates liquid hydrocarbons from carbon monoxide and hydrogen using metal catalysts, is often based on cobalt catalyst precursors (requiring cobalt nitrate, cobalt acetate and cobalt chloride salts). Cobalt is also used as part of fluid catalytic cracking catalysts which assist oil refining for extracting specific substance fractions from raw materials, particularly lower olefin categories. It was noted in eftec & wca (2015) that cobalt-containing catalysts (which require catalyst precursor materials) are used in various smaller applications, such as steam reforming, benzoic acid manufacture, fluorination of hydrocarbons and polymerisation of butadiene and oxidation of xylenes.

Use as oxidation catalysts for purified terephthalic acid (PTA) and isophthalic acid (IPA)

Purified terephthalic acid (PTA) is terephthalic acid with 99% purity and is one of the largest-volume commodity chemicals in the world (S&P Global, 2023). PTA is used as a raw material in making polyester (PE) and multi-purpose plastics such as polybutyl terephthalate (PBT), polyethylene terephthalate (PET), and polytrimethylene terephthalate (PTT) (MarketWatch, 2023). Some products made with PTA include polyesters used in fibres, textiles, film, and PET bottles (INEOS, 2022).

Isophthalic acid (IPA), is an isomer of phthalic acid and terephthalic acid (thechemicalcompany, 2023). Similarly, to PTA, IPA is used to produce coatings, polyester resins, unsaturated polyester resins, special fibres, hot melt adhesives, printing inks, polyester fibre dyeing modifiers, and resin plasticisers (OECON, 2021). Isophthalic acid is a key ingredient in fiberglass reinforced plastics (FRP). Isophthalic acid reduces the crystallinity of PET, which serves to improve clarity and increase the productivity of bottle-making (S&P Global, 2022).

Cobalt diacetate is used as an oxidation catalyst to produce PTA and IPA (ECHA, 2017a). More specifically, PTA is produced by the oxidation of p-xylene, oxidation is completed in the presence of the cobalt, manganese and bromide salts catalyst (Big Chemical Encyclopedia, 2019). IPA is produced via oxidising m-

[17] An active catalyst is a substance that increases the rate of reaction. During reaction, the catalyst species reacts with a substrate and then returns to the original species.

xylene in the presence of oxygen which requires a catalyst – for example, a cobalt-manganese catalyst. Stakeholders also stated that some cobalt carboxylates, such as cobalt neodecanoate or 2-ethylhexanoate, are used as catalysts for this application.

3.3.7 Use in surface treatment

Surface treatment is an additional finishing treatment process that involves modifying the condition and properties of the surface of a component and optimising its combination with the core material (Zhang, 2023). Surface treatment can be applied to improve a material's performance, such as adhesion and surface wetting characteristics, and also for cosmetic reasons (to improve appearance) such as polishing (tantec, 2021). Some surface treatments applied during the manufacturing process also provide enhanced mechanical or electrical properties that contribute to the overall functionality of the component (Keller Technology Corporation, 2019). Cobalt is widely used for the surface treatment due to its corrosion resistance, physical appearance (i.e., colour), catalytic properties and mechanical strength. Cobalt is used in a variety of surface treatment applications including formulation of surface treatment, passivation or anti-corrosion treatment processes and metal or metal alloy plating.

Formulation of surface treatment

According to eftec (2023), cobalt is used for the formulation of surface treatment due to its corrosion resistance, physical appearance (i.e., colour), and catalytic properties. Stakeholders also stated that cobalt is used in corrosion protection coatings because it increases the corrosion resistance of chromium (III). Some of the specific applications of cobalt in the formulation of surface treatment include its use in surface coating, aqueous mixtures, and sanitary, automotive and mechanical engineering.

Passivation or anti-corrosion treatment processes

Passivation is a metal finishing treatment process applied to prevent corrosion (BestTechnology, 2023). Cobalt substances are used in the generation of "conversion layers" (also called passivation), typically on zinc or zinc alloy-coated metallic products for corrosion protection. Conversion layers reduce the deterioration of materials caused by their reaction with the environment and delay the initial attacks on the metallic protective layer, leading to longer service life and operating time of metal components. Passivation makes the surface inactive, or less reactive, through a chemical treatment (Wegman and Van Twisk, 2013) and it increases the lifespan of materials by improving their corrosion-resistant properties.

Cobalt substances are used for surface treatment where there are high end performance requirements for corrosion protection and resistance to high temperatures (e.g., car bonnets) (wca, 2012). Cobalt substances are added to the application solutions of chromium (III) oxide-based conversion coatings, which are alternative surface treatments for the use of chromium (VI). In this process, the galvanised components are dipped in a treatment solution containing chromium (III) compounds and a proportion of cobalt substances. The cobalt ions are integrated into the surface as oxides or as spinels. The addition of cobalt substances is necessary if corrosion protection is required in warm or hot environments (e.g., engine spaces, brakes, gearboxes, and electrical parts in housings). According to eftec (2023), cobalt is used in corrosion protection coatings because it increases the corrosion resistance of chromium (III)-containing components.

Metal or metal alloy plating

Metal or metal alloy plating is a surface treatment process that enhances corrosion resistance and hardness, reduces friction, and improves decorative appeal which is mostly achieved through electroplating[18] (Thomasnet, 2023a). Cobalt is used in metal or metal alloy plating (mainly gold-cobalt and tin-cobalt plating) to enhance hardness and corrosion resistance and/or for metal colouring (ECHA, 2020). Plating is a similar process to passivation, but metal or metal alloy plating uses an electrical current to form the surface.

Cobalt salts are added to solutions of other metals (e.g., nickel, tungsten, iron, molybdenum, chromium, zinc, and precious metals) to form alloys in electroplating. During the plating process, the cobalt substances are transformed into cobalt metal. For example, during gold-cobalt electroplating, gold and cobalt are formed and deposited concurrently, building a surface coating of gold alloy. These alloys have improved properties (e.g., hardness, wear resistance) compared to gold on its own (ECHA, 2022b). Cobalt-gold alloy plating is used in electronics and computers and hard-wearing applications, such as jewellery and instruments (eftec & wca, 2015). According to eftec (2023), cobalt is used in the metal or metal alloy plating because of its mechanical strength, corrosion resistance and physical appearance.

3.3.8 Use in biotechnology and animal feed, formulation and use

Cobalt has important biotechnology applications including formulation and industrial use of mixtures in biogas production, professional use in biogas production; use in fermentation, fertilizers, biotech, scientific research, and standard analysis and formulation and use in animal grade material and biogas production.

Formulation and industrial use of mixtures in biogas production

Biogas production is a technology based on the degradation of complex organic materials (such as energy crops, waste, sewage sludge and manure) to produce energy-rich, methane-based gas, called biogas (ECHA, 2017a). The residues are placed in a biogas digester in the absence of oxygen and with the help of a range of bacteria, organic matter breaks down. This primarily releases methane (between 45 - 85%) and carbon dioxide (25 - 50%) which can be used for multiple applications (European Biogas Association, 2023).

The addition of small amounts of cobalt sulphate, cobalt chloride, cobalt carbonate, or cobalt diacetate improves the fermentation involved in biogas production (Cobalt Institute, 2021). Cobalt salts are used as a nutrient additive necessary for bacterial cell growth and reproduction in biogas production from energy crops (ECHA, 2017a). More specifically, cobalt is believed to catalyse fermentation reactions by acting as an acetate digester, leading to an increase in production of biogas (Gofetamang Ditalelo, 2016).

Professional use in biogas production

Cobalt salts are used as a nutrient additive necessary for bacterial cell growth and reproduction in biogas production from energy crops (ECHA, 2017a). Professional use in biogas production refers to the use of chemicals in the workplace, by trained individuals, such as scientists, technicians, and engineers. This broad use category involves dosing solid material into the reactors (ECHA, 2017a). Professional users often carry out their work outside a single base of operations (an industrial site). They are therefore less likely to be

[18] Electroplating is the coating of an electrically conductive object with a layer of metal using electrical current. The result is a thin, smooth, even coat of metal on the object (Doug Taylor Metal Finishing Co, 2016).

able to use sophisticated RMMs so exposure may be higher (ECHA, 2020b).

Use in fermentation, fertilizers, biotech, scientific research, and standard analysis

Cobalt is used as a trace element in industrial fermentation and biotechnological processes in the biopharmaceutical industry. The fermentation process involves the decomposition of micro-organisms to produce molecules of interest that are subsequently used in various end products, including in-vitro diagnostic devices (IVD), in situ hybridisation assays (using terminal transferase) and medicines (ECHA, 2017a).

Some other end products of industrial fermentation and biotechnological processes include food and technical enzymes, vaccines, proteins, and vitamins (eftec & wca, 2015). Cobalt is a component of vitamin B12 which is an important vitamin for cell growth in both fermentation and cell tissue culture (eftec & wca, 2015).

Formulation and use in animal feed grade materials

Cobalt is required in the animal feed sector as it is the core element in vitamin B12 (eftec & wca, 2015). Vitamin B12 helps to prevent associated deficiencies such as anaemia, ill thrift, and loss of appetite (European Food Safety Authority (EFSA), 2009). Cobalt sulphate, cobalt dichloride, cobalt diacetate, and cobalt carbonate are essential in animal feed pre-mixtures used as supplementation to diets for ruminants, horses, and rabbits (ECHA, 2022b). Within the feed supply chain cobalt is present in four stages of preparation: chemical preparation, the formulation of premixes, the development of compound feed, and end-use by farmers (RPA, 2022).

According to European Food Safety Authority (EFSA) cobalt is used in animal feed exclusively for the production of vitamin B12 by microorganisms in the rumen (EFSA, 2009). Only animals with the capacity of synthesising vitamin B12 in the intestinal tract like ruminants, horses and rabbits can utilise cobalt. The animals which are not capable of producing B12 receive B12 supplementation instead, and there is no need for cobalt supplementation of feed for these animals. Cobalt also aids in the production of glucose in the liver and also participates in the cellulolytic activity of rumen bacteria. Cobalt is one of the most poorly represented essential mineral elements in the animal body and it plays important roles in animal metabolism (eftec, 2023).

3.3.9 Bespoke uses

Cobalt has several bespoke uses, including use in humidity indicators and formulation of water treatment chemicals, oxygen scavengers, corrosion inhibitors and use of water treatment chemicals, oxygen scavengers, and corrosion inhibitors.

Use in humidity indicators, cards, plugs, and/or bags with printed spots

Humidity indicator cards and plugs are designed to indicate the relative humidity level within a sealed container without the user having to access it (James Dawson Enterprises, 2023). Humidity indicators indicate changes in humidity by changing colour. Humidity indicators can be supplied to the market in a number of formats including plugs, cards and indicating silica gel sachets and canisters (ECHA, 2022b).

Cobalt dichloride is used in humidity indicators because it has the property of changing colour at differing humidity levels (ECHA, 2017a) and indicating that the environment has become too moist or humid, which can damage to the product being stored. This makes it a useful indicator for moisture in various applications such as military, food packaging, storage of electronics, and pharmaceutical products.

Formulation of water treatment chemicals, oxygen scavengers, corrosion inhibitors

An oxygen scavenger is a chemical substance that removes oxygen from an environment or substance via chemical reaction. More specifically, they are added for the purpose of adsorbing oxygen molecules to prevent oxygen-induced corrosion, which can lead to the formation of toxic or undesired by-products (EcoLink, 2022). Additionally, they function by preventing the degradation of materials and the growth of microorganisms that require oxygen to survive. They are commonly used in food packaging and boiler water treatment to extend shelf life and in the petroleum industry to protect against corrosion. Corrosion inhibitors often work by adsorbing themselves on the metallic surface, protecting the metallic surface by forming a film (Lenntech, 2023).

The formulation of oxygen scavenger solutions involves handling of cobalt salts (including opening of containers, dosing, loading/unloading weighing, mixing, re-packaging, and sampling) in powder form. Trace amounts of cobalt sulphate and cobalt dichloride are used in oxygen scavenger mixtures to increase the rate of oxygen removal in boiler feed water applications.

Use of water treatment chemicals, oxygen scavengers, corrosion inhibitors

As mentioned above, an oxygen scavenger is a chemical substance that removes oxygen from an environment or substance via chemical reaction. Corrosion inhibitors work by adhering themselves to the metallic surface, protecting the metallic surface by forming a film (Lenntech, 2023). Oxygen scavengers and corrosion inhibitors are used across various industries including food and beverage, pharmaceutical, oil and gas, electronics, and water treatment industries.

The primary use of cobalt as a catalyst in oxygen scavengers helps to reduce the amount of hydrazine[19] needed in the process, making it more efficient and cost-effective (ECHA, 2017a). Cobalt-catalysed oxygen scavengers are added to multi-layered PET bottles to maintain freshness and extend shelf life. Cobalt sulphate, cobalt carboxylates, cobalt dichloride, cobalt dinitrate and cobalt carbonate are used as oxygen scavengers in water treatment applications to remove dissolved oxygen from the water, which can cause rust and corrosion in pipes and other equipment (ECHA, 2022a). Additionally, the food and beverage, electronics, and pharmaceutical industry use oxygen scavengers to prolong shelf life by preventing oxidation. Similarly, the oil and gas industry uses oxygen scavengers to protect pipelines, storage tanks, and other equipment from corrosion caused by oxygen exposure.

3.3.10 Adhesion (inc. rubber adhesion agent)

Cobalt salts are widely used in the tyre industry as bonding agents between rubber and steel cord (including bead wires[20]). Cobalt improves the bonding of rubber to steel in steel-belted radial tyres and steel-reinforced conveyor belts and hoses (Mandal et al., 2005). Cobalt carboxylates provide a highly rubber-

[19] According to the harmonised classification and labelling (CLP), hydrazine is toxic if swallowed, is toxic in contact with skin, causes severe skin burns and eye damage, is toxic if inhaled, may cause cancer, is very toxic to aquatic life, is very toxic to aquatic life with long lasting effects, is a flammable liquid and vapour and may cause an allergic skin reaction. The specific harmonized classifications for hydrazine are Aquatic Chronic 1, Aquatic Acute 1, Skin Corr 1B, Carc. 1B and Skin Sens. 1 (ECHA, 2023c).

[20] Bead wire is a hard-drawn high carbon wire made from quality steel rods, which adheres to the rubber and secures the tyre to the bead. They are used in tyre beads to prevent tyres from changing shape due to air pressure or external forces and safely lock the tire onto the rim to prevent vibration while driving.

soluble form of cobalt that serves as a chemical adhesive, bonding with sulphur in both the vulcanised rubber[21] and the sulphided brass coating of steel (eftec and wca, 2016).

eftec (2023) notes that cobalt salts are vital for adequate steel cord adhesion, and thus are crucial for the production of steel cord conveyor belts. Cobalt salts are present in hundreds of millions of tyres, including all passenger car, commercial vehicle, truck, motorcycle, off-road vehicle, and aircrafts tyres (eftec, 2023). Cobalt rubber adhesion promoters also offer good adhesion between the brass coated steel wire in radial tyres and the rubber upon vulcanisation.

3.3.11 Use in electronics

Cobalt is an important material used in electronic devices and technologies due to its unique magnetic and thermal properties. Although the volumes used in electronics are very small, use of cobalt in electronics has a very high value added for the electronic products (eftec and wca, 2015). Some end products that are produced using cobalt include integrated circuits[22], (contacts, metal leads, packages) semiconductors, magnetic recording thin films, magnetic storage devices, medical devices, and medical imaging devices.

Cobalt is used as a magnetic recording material[23] present in videotapes and thin films for video recording as well as in metal leads (which are part of integrated circuit and are used for mechanical electrical contacts). Although gold is the most common metal used in metal leads for integrated circuits, the gold is deposited with (15%) cobalt which provides improved wear resistance (eftec and wca, 2015). Cobalt is also used to manufacture high-performance magnetic storage devices such as hard disk drives (HDDs) and magnetic tapes. The magnetic property of cobalt enables HDDs to store vast amounts of data in a small space, making them essential for data centres, servers, and computers.

Cobalt is required to create wear-resistant coatings for electronic components, such as printed circuit boards and semiconductors. The coating helps to protect the components from wear and tear, corrosion, and high-temperature environments, thus increasing their lifespan and reliability. Cobalt is used in the production of blue light emitting diodes (LEDs), which are used in a variety of electronic devices, including smartphones, TVs, and lighting fixtures.

3.3.12 Use in magnetic alloys

Cobalt metal is used in magnetic alloys due to its strong magnetic properties. Cobalt is one of the three naturally occurring magnetic metals (iron and nickel being the other two) and has the highest Curie Point[24] of all metals, i.e., retains its magnetism at a higher temperature (1100°C) than any other metal (eftec and wca, 2015). While cobalt is predominantly used in hard magnets[25] it also has some soft magnet applications (eftec and wca, 2015). Soft magnets only hold magnet qualities temporarily, conversely hard magnets can be permanently magnetised by applying a magnetic field. The main applications for soft magnetic materials

[21] Vulcanised rubber refers to rubber which has undergone vulcanisation (where rubber is heated with sulphur to change its structure into cross-linked polymers - which are harder and more resistant).

[22] A device which consists of several circuit elements formed on the surface of a chip made of semi-conductor material.

[23] Magnetic recording materials use the magnetic properties of solids to store and retrieve information.

[24] The Curie Point is the temperature at which rocks lose their permanent magnetisation (GNS, 2020).

[25] Hard metal magnets include: Aluminium-Nickel-Cobalt (AlNiCo) magnets, Samarium (SmCo) and rare earth metal magnets and Neodymium-Iron-Boron (NdFeB) magnets (Poolphol et al., 2017).

are in rotating machines – generators, motors and in static transformers.

Cobalt metal is used in different cobalt-nickel alloys such as nickel-chromium-cobalt alloys and aluminium-nickel-cobalt (AlNiCo) alloys for the production of magnets and varistors (Nickel Institute, 2023). Nickel-chromium-cobalt alloys are used in industrial furnace components, gas turbines, catalyst grid supports to produce nitric acid, and fossil fuel production facilities (Thomasnet, 2023b). As a hard magnet, the AlNiCo alloy can become a permanently magnetic material which has high coercivity[26], Curie Point, magnetic strength, and temperature stability.

Cobalt metal is used in Samarium (SmCo) and rare earth metal magnets. Cobalt is an essential component of these magnets, as it helps to improve the magnetic properties of the material. Rare earth metal magnets are used in specialist high temperature environment applications, such as precision guided missiles and "smart bomb" military equipment. SmCo magnets are also ideal for very low temperature applications and can be used at a few Kelvins above absolute zero, making them a first-choice magnet for cryogenic applications (Roskill, 2014).

Cobalt metal is used in the production of neodymium-iron-boron (NdFeB) magnets. NdFeB magnets are a type of hard magnet that has the highest theoretical maximum energy capacity of any permanent magnet. The use of cobalt is essential in these magnets as the addition of cobalt into iron increases the magnet's magnetic saturation[27]. NdFeB magnets are widely used in a range of industrial and commercial applications, such as electric motors and generators, magnetic sensors, and magnetic storage devices. Its greatest demand is in the production of speakers for audio equipment, and for use in small motors and sensors (eftec and wca, 2015). These applications require quite small magnets weighing 20-50 grams (or even less in the case of sensors) (Roskill, 2014).

3.3.13 Use in metallurgical alloys

Cobalt metal is used in many different metallurgical alloy applications such as heat resistant alloys, wear/corrosion resistant alloys (see Section 3.4), superalloys, controlled expansion alloys, high speed steel, stellite® and vitallium alloys. Cobalt gives these alloys increased resistance to wear, corrosion, and heat, proving them with a longer service life and enhancing reliability.

Cobalt is one of the base elements used in superalloys. Superalloys are high-performance alloys which exhibit exceptional mechanical strength and creep resistance at high temperatures, good surface stability, and corrosion and oxidation resistance. They are developed for use at elevated temperatures where severe mechanical stressing is encountered, and high surface stability is frequently required (Cobalt Institute, 2021). A key sector for cobalt-containing superalloys is aerospace where these properties are vital for reliable and efficient turbines, which helps to ensure passenger safety. Cobalt based superalloys are also used in space vehicles, rocket motors, nuclear reactors, power plants and chemical equipment (Cobalt Institute, 2021). Cobalt-Nickel alloys are used in jet engines, gas turbines, chemical processing, petroleum refining, marine, electronics, and other industrial applications where common stainless steels may not

[26] Coercivity is the resistance of a magnetic material to changes in magnetisation and is commonly referred to as the magnetic field required to demagnetise a material.

[27] The unit beyond which magnetic flux density in a magnetic area does not increase sharply further with increase of magnetomotive force (Electrical4U, 2023).

provide adequate performance.

Cobalt used in the form of an alloy can also be found in surgical instruments, prosthetics/orthopaedic implants (e.g., knee and hip replacements, nails, plates, and screws for trauma applications), cardiac implants (e.g., stents, stylets, and guidewires), syringe products, and catheter products. The durability and strength of cobalt mean it is unrivalled in its ability to help produce long-lasting medical instruments (eftec, 2021). Cobalt alloys are common in orthopaedic and dental applications due to their greater resistance to fatigue and good wear resistance to corrosion compared to alternatives such as stainless steel (Wilson, 2018). Cobalt-chrome alloys (e.g., Stellite®) are widely used in coatings for prosthetics such as artificial knee and hip joints due to their wear resistance (eftec and wca, 2015), and in dental applications such as inlays, crowns, and bridges where the dental restorations are produced in laboratory settings by casting. Vitallium alloys, which consist of cobalt-chrome-molybdenum, are also commonly used in dentistry and artificial joints due to their biocompatibility, strength, and corrosion/wear resistance.

Some other examples of the use of cobalt in metallurgical alloys include controlled expansion alloys (Super Invar and Kovar) which are used in the electronic packaging industry (eftec and wca, 2015). Electronic packaging applications require materials with minimum thermal expansivity in the presence of silicon-based semiconductor devices and good thermal conductivity. Kovar is one of the most popular controlled expansion alloys for hermetic sealing applications and its expansion characteristics match both borosilicate (or Pyrex) glasses and alumina ceramics. Kovar alloy applications include vacuum tubes (valves), x-ray tubes, microwave tubes, power tubes, light bulbs, transistors, diodes, and hybrid packages. Kovar also has specific applications in the aeronautic, space, and defence industries (eftec and wca, 2015).

Cobalt metal is also used as an alloying agent in metallurgical processes for the production and industrial use of cobalt-containing alloys, steels, and tools - namely hard facing alloys, and high-speed steels. While not all high-speed steels contain cobalt, the addition of cobalt strengthens and imparts high temperature resistance to those that do (eftec and wca, 2015). Cobalt is also used for welding in industrial settings (brazing). Cobalt is an important element in some high temperature brazing alloys for aero applications, and effective joint strength is essential to the safe operation of critical high temperature plant (eftec and wca, 2015).

According to eftec (2023), cobalt is used in metallurgical alloys due to its temperature resistance, mechanical strength ductile and malleable, corrosion resistance, biocompatibility, bending strength and wear resistance properties. Some of the specific applications of cobalt's use in metallurgical alloys include production of ball pen tips, cartridge and pens; manufacture of alloys used in abrasive applications and use as alloying element in steel powder (eftec, 2023).

3.3.14 Use in cemented carbide/diamond tools

Cobalt is commonly used in the production of cemented carbide (hard metal) and diamond tools as one of the primary metal hardening substances (RPA, 2020). The addition of cobalt gives the tool its mechanical strength, corrosion resistance, magnetic properties, cohesion properties, wetting properties, ductility and malleability, and temperature resistance (eftec, 2023).

Although cobalt is used as one of the primary substances in the production of both cemented carbide tools and diamond tools, its function, and the way it is incorporated into these products are different. Diamond tools consist of 2% to 5% of diamond and the rest as binder material (e.g., cobalt or bronze). Cobalt is used to hold the diamond (within the diamond tool) by mechanical lock (caused by crystal-structure (i.e., lattice) change). While diamond tools containing cobalt are long lasting, they are also more expensive than alternatives that contain cheaper (but less durable) binder materials. Thus, cobalt is used in those diamond tool applications where superior performance is required. Diamond tools may be used for cutting of natural stone in quarries, for drilling and cutting concrete or other construction materials, and for cutting and grinding glass and other abrasive materials.

On the other hand, in the production of cemented carbides/hard metals, cobalt is typically used as a binder for tungsten carbide (the hard material) in a range of 6% to 25% by weight. Carbide material in isolation is brittle but with the addition of cobalt (in powder form) the material's resistance to wear, hardness, and mechanical strength increases – which is required for cutting tools, machine tools, engine components and other industrial applications. Respondents to eftec (2023) stated that when cobalt is used as a binder it increases the mechanical performance of cemented carbide tools and ensures a unique combination of mechanical strength and ductility. Moreover, the wetting properties of cobalt towards tungsten carbide make the sintering process window bigger (where no brittle carbon deficient form of tungsten carbide or free carbon are formed); the chemistry (carbon balance) is relatively easier to control, and the fully dense materials have excellent mechanical properties. The use of cobalt as a metal-binding agent in carbide tools is also a result of specific characteristics, such as its high melting point, high temperature resistance, ability to dissolve tungsten carbide and form a liquid phase medium at a suitable temperature (i.e., 1250°C) and its ability to be ground very finely to mix with the carbide particles (eftec and wca, 2015). Respondents also shared that at moderate temperatures cemented carbides made of tungsten carbide and cobalt achieve the best combinations of hardness and toughness which helps to achieve fully dense materials which is required for superior mechanical performance (eftec, 2023). Stakeholders noted that products made from cemented carbide or hard metal, like drill bits, have superior performance, lifespan and durability than those made from alternative materials, such as high-speed steel.

In the first step of the production process, fine tungsten carbide and fine cobalt powder with particle sizes ranging from 0.5 to 20 μm are blended together along with minor additives. This mixture is then milled in a liquid medium to ensure a uniform distribution of all components. Once the mixture is dried, it forms a granulated powder known as Ready-to-Press (RTP) powder. The subsequent steps, which can take place either at the same facility or at a different site further down the supply chain, involve pressing, extrusion, and/or forming the RTP powder, followed by sintering at temperatures of up to 1400 °C to melt the cobalt. The sintered parts are typically further processed, either at the same facility or downstream in the supply chain, through grinding and finishing to create various tools and parts. Due to the use of powder materials, the first process steps, i.e., the production and use of RTP powder are the operations with the highest exposure to dust in the whole cemented carbide/hard metal supply chain.

The range of applications for cemented carbides and diamonds tools overlap due to their high wear resistance. Diamond tools are often used for the cutting of natural stone in quarries and the cutting, shaping, and polishing of natural stones at production sites. In the construction industry, diamond tools are used for drilling and cutting concrete or other construction materials at site. In addition, diamond tools are used for cutting, grinding, and polishing glass and other abrasive materials, such as ceramics. Moreover, grinding and polishing of cemented carbides/hard metals is mostly done with diamond tools. Cemented carbides or hard metals are the superior materials for all applications requiring high wear resistance, including: the cutting, drilling, or grinding, of metal, wood, paper, or composite material; metal forming; stone drilling; crushing in the oil and mining industry; and waste shredding for recycling.

3.3.15 Recycling of materials containing cobalt substances

The average lifespan for cobalt-containing products is four years, with a 32% recycling rate (Wood Mackenzie, 2022)[28]. Recycling of materials containing cobalt is carried out by utilising the following processes:

- **Direct** recycling starts by extracting cobalt substances without breaking down or changing their chemical structure;
- **Pyrometallurgical** recycling first involves smelting End-of-Life (EoL) materials before the cobalt can be leached[29]. Metal recovery with an impurity management process is then performed and cobalt sulphates are removed (for hard metals an oxidation or "zinc-reclaim"[30] process is first used before leaching), and
- **Hydrometallurgical** recycling uses a different leaching process that does not require smelting. Cobalt sulphates are then removed and recovered. In some cases, materials containing cobalt that go through the pyrometallurgical smelting process can then be passed through the hydrometallurgical leaching process, depending on desired recovered materials (see figure note under **Figure 3.2**).

Pyrometallurgical and hydrometallurgical recycling are similar processes and are used primarily for battery recycling. **Figure 3.2** and **Figure 3.3** show pyrometallurgical and hydrometallurgical recycling processes, respectively, for battery materials that contain cobalt.

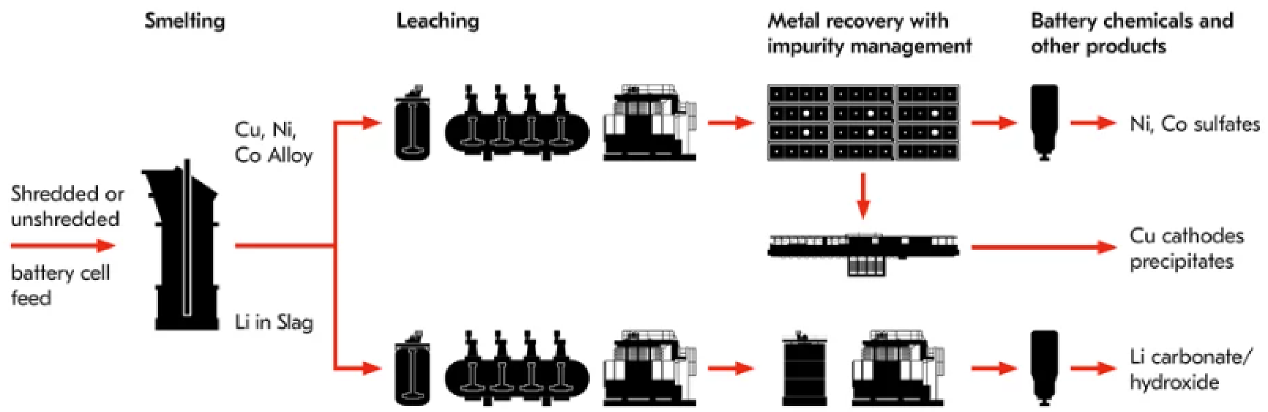

Figure 3.2: Pyrometallurgical recycling process for variable material flows for batteries
Source: (Metso Outotec, 2022)
Figure note: This figure also shows a hydrometallurgical process for recycling lithium, which becomes slag in the pyrometallurgic process (first section of the figure).

[28] Rate includes recycling that occurs outside the EU-27.
[29] Leaching is a process in which the EoL materials are treated with chemicals to convert the valuable metals within into soluble salts while the remaining material remains insoluble.
[30] Zinc-reclaim is a process in which zinc is first removed from the EoL materials and creates a tungsten carbide-cobalt powder.

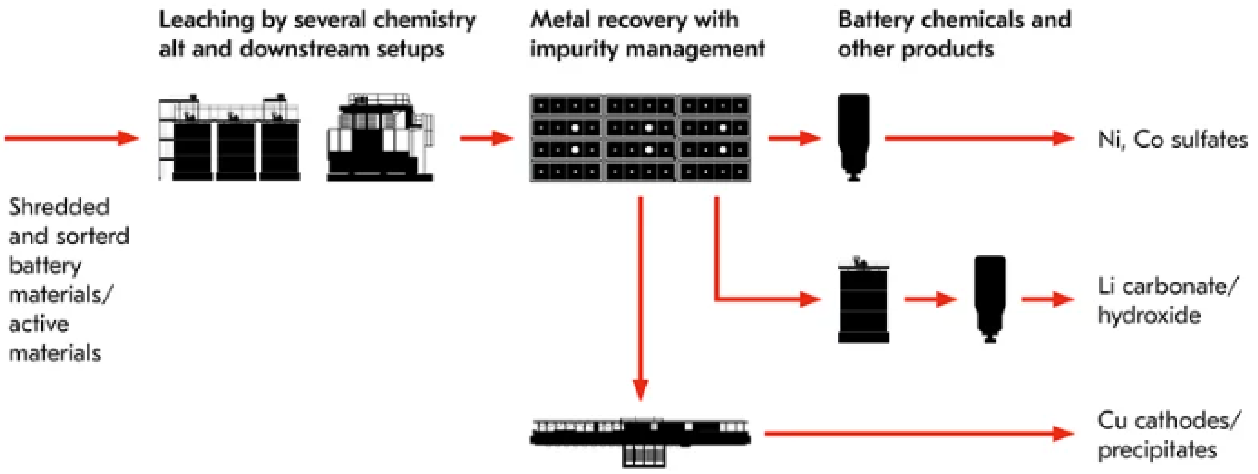

Figure 3.3: Hydrometallurgical recycling process for medium and small homogenous flows for batteries
Source: (Metso Outotec, 2022)

3.4. Function of cobalt metal and cobalt substances

Cobalt metal and cobalt substances exhibit a number of functions which vary depending on their application. Table 3.1 summarises the ten functions of cobalt metal and cobalt substances and the broad use(s) they are used in. More detailed information of the functions is presented in the rest of this section. The most common functions as indicated by respondents in eftec (2023) were catalytic properties, corrosion resistance and mechanical strength.

Table 3.1: Summary table of functions of cobalt metal and cobalt substances and their broad uses

Function	Description	Main broad use(s)
Catalytic properties	Cobalt substances demonstrate good catalytic properties (e.g., selectivity). For example, cobalt nitrate is used for the manufacture of catalysts used in Fisher-Tropsch applications.	• Manufacture and use of catalysts
Chemical stability	Cobalt is added to materials to increase their inertness / resistance to chemical degradation. For example, it is added during the sintering process in cemented carbides production as cobalt shows superior chemical strength.	• Bespoke uses • Use in cemented carbide/diamond tools
Corrosion resistance	Cobalt metal and cobalt substances are used in the hard metal industry due to their ability to provide superior corrosion resistance when combined with other alloys (e.g., Co-Cr-W-C[31]).	• Formulation of and use in surface treatment • Use in metallurgical alloys • Use in cemented carbide/diamond tools • Adhesion
Ductile & Malleable	Cobalt metal is a ductile material which makes it integral to metallurgical alloys and hard metal	• Use in metallurgical alloys • Use in cemented carbide/diamond tools

[31] Cobalt chromium tungsten carbon alloy.

Function	Description	Main broad use(s)
	cutting tools (used as a binder in cemented carbide/diamond tools).	
Cathode / battery functionality	Cobalt compounds (e.g., cobalt sulphate and cobalt oxide) are used to produce cathodes for EV batteries using the predominant NMC and NCA chemistries. Cobalt oxide is used to produce cathodes for LCO batteries which are used in almost all portable consumer electronics.	• Manufacture of precursor chemicals for batteries • Use in electronics
Essential vitamin	Synthesis of vitamin B12 in the rumen (or hindgut) and for fermenting bacteria.	• Use in biotechnology: animal feed, formulation and use
Magnetic properties	Cobalt metal is noted to be used for its magnetic properties (e.g., has the highest Curie point of all metals) when adding magnets to various types of sensors in automotive vehicles[32]. Cobalt containing magnets can retain their magnetic strength at much higher temperatures than other types.	• Use of magnetic alloys • Use in electronics
Mechanical strength	Cobalt metal and cobalt substances are used in a number of different sectors for their mechanical strength. For example, cobalt metal is used in cemented carbide / diamond tools, cobalt sulphate is used in surface treatment for electroplating and brush plating and cobalt metal is used to create cobalt alloys.	• Use of metallurgical alloys • Use in surface treatment • Use in cemented carbide/diamond tools
Physical appearance	Cobalt compounds are used for their physical appearance (i.e., colour). For example, the manufacture of pigments and dyes uses cobalt substances such as cobalt zinc aluminate blue spinel to colour inks.	• Manufacture of pigments and dyes • Bespoke uses
Temperature resistance	Cobalt provides good temperature resistance to nickel and iron-based alloys, which allows them to maintain their required levels of mechanical performance. Additionally, cobalt metal is used in metallurgical alloys to provide high levels of temperature resistance necessary for end-products (such as engine parts) to function adequately in elevated temperatures.	• Use in metallurgical alloys • Use in magnetic alloys • Use in cemented carbide/diamond tools

3.4.1 Catalytic properties

Cobalt metal and cobalt substances have significant catalytic properties due to their ability to form stable complexes with a variety of ligands[33] (Sun et al., 2022). Cobalt metal and cobalt-containing substances also possess excellent catalytic properties due to their ability to exist in different oxidation states, which allows

[32] Cobalt alloys are used (for their magnetic properties) in hard disks, wind turbines, MRI machines and sensors (Eclipse Magnetics, 2021).

[33] Ligands are atoms, ions, or molecules that bind to a central metal ion to form a complex (Huheey et al., 1993).

them to participate in oxidation and reduction (redox) reactions[34] (Haase et al., 2022). Additionally, the unique electronic and structural properties of cobalt complexes make them highly selective and efficient catalysts for specific chemical reactions. Cobalt compounds are used as catalysts in a wide range of industrial processes, including the production of synthetic fibres, plastics, and petrochemicals. Cobalt metal is also used as a catalyst in the refining of crude oil and the production of hydrogen gas.

Cobalt nitrate is a soluble form of cobalt, used in the manufacture of cobalt substance-containing catalysts for Fisher-Tropsch applications. Cobalt is the most suitable substance for this type of catalysis, alternatives to which are significantly more expensive (e.g., ruthenium), or have significantly worse performance (e.g., iron). Cobalt nitrate is the most suitable soluble salt due to its metallurgic properties; low corrosion of plant metalwork and ease of trapping evolved gases during use. Cobalt metal is often used as a raw material in the manufacture of catalysts as alternatives (e.g., nickel) have equivalent of worse hazard profiles or are hundreds of times more expensive and scarcer (e.g., PGMs).

Cobalt dinitrate has been found to be effective in a number of different types of reactions, such as the conversion of certain epoxides into cyclic carbonates, and in the reduction of nitroaromatics to anilines. Additionally, it can help with the oxidation of alcohols to aldehydes and ketones, and with the creation of epoxide chemical bonds from alkenes.

3.4.2 Chemical stability (inertness)

Cobalt is an incredibly strong metal, making it highly sought after for use in many industrial applications. It has a tensile strength of 1550–2080 MPa (megapascals), which means it can withstand considerable stress before breaking or failing. Cobalt's chemical stability comes from its electronic configuration (specifically its full d-shell along with its partially filled s and p orbitals), which make it relatively unreactive towards oxidation or reduction reactions, and thus more stable compared to other transition metals (that have partially filled d-shells) (Atkins et al., 2016).

eftec (2023) notes that chemical stability is a key functional property of cobalt substances in humidity spots in sight glasses, the manufacture of pigments and when used as a binder in cemented carbide / diamond tools.

3.4.3 Corrosion resistance

Cobalt metal and cobalt substances are used in formulation of surface treatment, cemented carbide/diamond tools, metallurgical alloys, passivation or anti-corrosion treatment process, metal or metal alloy plating and adhesion due to their resistance to corrosion. Corrosion resistance refers to a material's ability to resist degradation or deterioration (i.e., retain its electrons) due to chemical reactions with its environment, such as oxidation or rusting (Roberge, 2018).

Cobalt's electronic configuration contributes to the formation of a passive oxide layer on the surface of cobalt (when exposed to oxygen or other oxidising agents), which acts as a protective barrier against further corrosion (Atkins et al., 2016) by preventing the diffusion of corrosive species into the underlying metal.

[34] Redox reaction is a chemical reaction involving both reduction and oxidation, which results in changes in the oxidation numbers of atoms included in the reaction.

The passive oxide layer can also "self-heal" in the presence of oxygen, which further enhances the corrosion resistance of cobalt metal and its alloys. Consequently, cobalt is a moderately reactive metal that is resistant to corrosion. It reacts slowly with oxygen in the air and with water.

eftec (2023) shows that for some uses of cobalt metal and cobalt substances – e.g., formulation of, and use, in surface treatment (more specifically, electroplating) – corrosion resistance is the most important function. When used in surface treatment (passivation and anti-corrosion treatment processes), cobalt sulphate is used to increase the corrosion resistance of chromium (III) in products such as corrosion protection coatings. Similarly, cobalt metal is used in cobalt-chromium-tungsten-carbon alloys which are resistant against corrosion, oxidation and softening at elevated temperatures – which is necessary when producing metallurgical alloys. Cobalt is also commonly used in cemented carbide / diamond tools as a binder required for tools and wear-parts as the corrosion resistance increases the lifespan of the products.

3.4.4 Ductile & Malleable

Cobalt is a ductile and malleable metal, meaning it can be easily formed into various shapes without breaking or cracking. Ductility refers to a material's ability to deform under tensile stress without fracture, while malleability refers to its ability to deform under compressive stress without cracking. These properties are due to the fact that cobalt has a close-packed hexagonal crystal structure, which allows for easy slip and deformation of its crystal planes (Callister and Rethwisch, 2018).

These properties make cobalt metal and cobalt substances ideal for use in cemented carbide/diamond tools and metallurgical alloys. eftec (2023) notes that cobalt metal is used extensively in cemented carbide/diamond tools as an alloying element or binder used in wear resistant powders, semi-finished parts and finished articles.

3.4.5 Cathode / battery functionality

Cobalt is a good conductor of electricity, making it useful in electrical applications such as the production of magnets and rechargeable batteries. eftec (2023) demonstrated that cobalt carbonate and cobalt dihydroxide utilised this property when used to manufacture precursor chemicals for batteries.

Cobalt is used to produce the cathode in lithium-chemistry batteries. Cobalt is used in lithium-ion (Li-ion) batteries to minimise the degradation of the cathode structure. Most importantly, cobalt increases the battery life and energy density[35] which makes them ideal for uses such as mobile electronics (smartphones, laptops, smart watches), electric vehicles (EVs), battery storage power stations and any compact device that needs to emit power over long periods (Dragonfly Energy, 2022).

Cobalt is also used in the manufacturing of rechargeable Nickel-Cadmium (Ni-Cd) and Nickel-Metal Hydride (Ni-MH) batteries to improve the oxidation of nickel in the battery. In the Ni-MH batteries, cobalt alloys enhance the cells' lifespan by increasing hydride thermodynamic stability and inhibiting corrosion – more information on this is presented in Section 3.3.2 (eftec and wca, 2015).

[35] Energy Density (Wh/kg) is a measure of how much energy a battery can hold compared to its weight and size. The higher the energy density, the longer the runtime will be (Braun et al., 2012).

3.4.6 Essential vitamin

Cobalt (in salt form[36]) has essential nutritional properties for ruminants which is explained in Section 3.3.8. Cobalt deficiency can lead to multiple health risks such as dysfunction of ruminal fermentations, progressive reduction in appetite, weight loss, reduction in growth and milk production, anaemia, anorexia, lacrimation, and growth retardation in young ruminants (i.e., large head, small body) (eftec, 2023).

3.4.7 Magnetic Properties

Cobalt is ferromagnetic, which means it can be magnetised and retain its magnetisation in the absence of an external magnetic field. It has a high magnetic permeability and is used in the production of magnetic alloys (magnetic properties) (Kittel, 2004). Cobalt also has a high magnetic anisotropy, which means that its magnetic properties depend on the direction of the applied magnetic field. This property makes cobalt a valuable material for use in magnetic storage devices, such as hard drives and magnetic tapes, as well as in magnetic sensors and magnetic resonance imaging (MRI) systems (Jiles, 2015).

eftec (2023) shows where cobalt's magnetic properties were most valued was when magnetic alloys were required for various types of sensors in automotive industry, DC motors, mechanical kWs meters and safety switches. Other broad uses (e.g., use in cemented carbide / diamond tools) noted magnetic properties as a function of cobalt used, but this was not its primary function.

3.4.8 Mechanical Strength

Mechanical strength refers to the ability of a material or structure to withstand a mechanical load or stress without undergoing significant deformation or failure (Material Properties, 2023). Cobalt can be alloyed with other metals such as chromium, tungsten, and molybdenum to further enhance its mechanical properties (Shukla and Gupta, 2015). For special applications cobalt is needed as the alloying element, making steel more durable and wear resistant.

At moderate temperatures, cemented carbides made of tungsten carbide and cobalt achieve the best combination of hardness and toughness. Cobalt is used as the binder of the carbide as it ensures a unique combination of mechanical strength and ductility. The wetting properties of cobalt towards tungsten carbide make the sintering process window bigger; the chemistry (carbon balance) is easier to control, and the fully dense material has excellent mechanical properties (eftec, 2023).

eftec (2023) noted that galvanisation (i.e., applying a protective coating to steel – commonly to prevent corrosion, such as rusting) requires cobalt metal's mechanical strength and corrosion resistance. Similarly, cobalt metal coating ensures brazeability of the surface of cutting inserts and wear parts. When cobalt is used in metallurgical alloys as the alloying element in metal powder for metal injection moulding, maraging steels containing cobalt are used to print mould tools by laser based additive manufacturing technologies and attain high levels of hardness without the requirement for carbon.

3.4.9 Physical appearance (i.e., colour)

Cobalt-containing inorganic pigments, such as cobalt chromite green spinel, cobalt aluminate blue spinel

[36] Examples of cobalt salts are cobalt carbonate and cobalt sulphate.

and cobalt chromite blue green spinel, have the function of showing colour. Their colour is due to the ligand field exerted by the oxide on the tetrahedral co-ordinated cobalt2+ ion in the spinel lattice, which splits the originally equivalent d-orbitals of the cobalt (II) anion and permits electron transitions between the split levels as a result of light absorption in the visible range (Dr Andrew Ludlow, 2022).

Inorganic cobalt compounds (e.g., tricobalt tetraoxide) are used in the manufacture of pigments dyes as their physical appearance is used for colouring painting glass and porcelain. In some instances, especially durable (e.g., long lasting) pigments are manufactured with tricobalt tetraoxide as cobalt's other characteristics are beneficial. eftec (2023) shows that cobalt spinels and oxides are primarily used in the manufacture of pigments and dyes for their physical appearance (i.e., colour).

3.4.10 Temperature resistance

Cobalt provides good heat resistance in nickel & iron-based alloys, in order to maintain mechanical performance. Cobalt is a hard, lustrous, silver-grey metal that is magnetic at room temperature. It has a high melting point of 1495°C and a boiling point of 2927°C. Therefore, it maintains its mechanical strength and physical properties (e.g., ductility) at high temperature (Yildiz, 2017). Cobalt alloys, which are formed by adding other metals such as chromium, tungsten, and molybdenum to cobalt, can have even greater temperature resistance.

Its temperature resistance makes cobalt useful in applications that require high-temperature stability such as gas turbines, jet engines, and nuclear reactors. Cobalt-based superalloys are used in gas turbine components, such as blades and vanes, as well as in other high-temperature applications, such as chemical processing and aerospace. eftec (2023) shows that temperature resistance is an important function of cobalt metal when making metallurgical alloys and cemented carbide/diamond tools. Specifically, when creating alloys that are used in combustion engines and binders that are necessary for hard metal cutting tools.

3.4.11 Other

In addition to the abovementioned ten primary functions of cobalt metal and cobalt substances, eftec (2023) noted that cobalt dihydroxide was readily oxidised, both for the pro-oxidation of rubber and also for the formulation of water treatment chemicals and oxygen scavengers. Cobalt alloys are used in medical implants and orthodontic applications (and have been for several decades), due to their inherent biocompatibility. Furthermore, organic[2] cobalt compounds (e.g., cobalt (II) 4-oxopent-2-en-2-olate and cobalt, borate 2-ethlhexanoate complexes) are used as rubber adhesion agents, helping to bond rubber and steel cords which are required to produce automotive tyres.

3.5. Market information and value added

This section summaries the value added by cobalt metal and cobalt substances by manufacturers and/or importers (M/Is) and downstream users (DUs). No market information on recycling is available from the respondent data, hence, only data from other sources is presented below.

3.5.1 Market information from other sources

This section collates market information from other relevant sources to provide context on the EU market for cobalt metal and cobalt substances. It should be noted that previous reports differ in scope from the present report in terms of substances assessed, where no reports that included the full 30 substances were found. The information presented are therefore only intended to be illustrative, as it is not based on respondent data and only include small part of the substance included in this study. eftec and wca (2015) estimated the production value of cobalt metal and cobalt salts[37] manufactured in, or imported into, the EU-28[38] at €758.5 million and €1 billion, respectively, in 2022 prices[39]. The value added (i.e., compensation for labour, capital, non-financial assets, and natural resources used in production) for cobalt metal and cobalt salts was estimated at €111 million and €269 million[40], respectively, in 2022 prices[41]. The report also showed that for both cobalt metal and cobalt salts, the majority of value added can be attributed to production in the EU-28, whilst less than 5% is attributable to imports.

According to the Cobalt Institute's market report (2022), global demand for cobalt metal and cobalt chemicals (see **Figure 3.4**) grew at a compound annual growth rate (CAGR) of 9.2% from 2015 to 2020. From 2020 to 2021, the global demand grew to from 143,000 tonnes to 175,000 tonnes; an unprecedent annual demand growth of 22% (Cobalt Institute, 2022). Growth was led by lithium-ion battery applications, accounting for 63% of annual demand and 85% of y/y growth. It is anticipated that these trends will continue, due to the continuously growing battery market.

Figure 3.4 presents the global share of growth in 2021 by end use and cobalt product[42]. The majority of demand came from Li-ion battery applications, which is reflected in the high share of cobalt sulphates. Information on volumes manufactured/used and recycled in the EU based on respondent data is presented in Section 3.8.

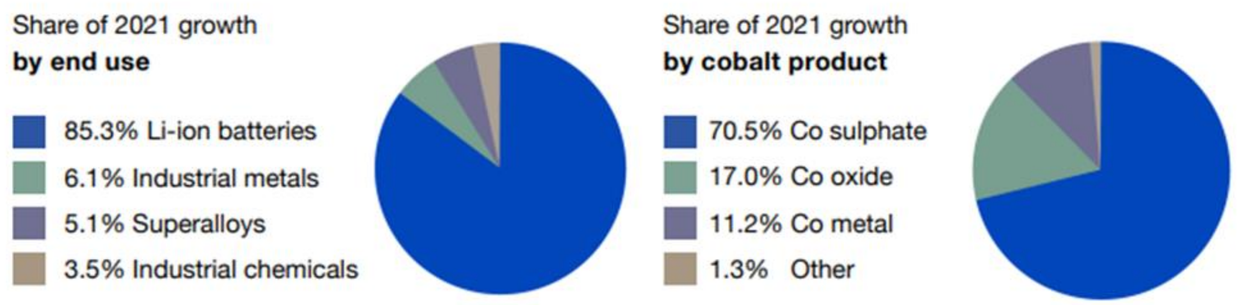

Figure 3.4: Share of growth in 2021 by end use and cobalt product
Source: (Cobalt Institute, 2022)

According to Wood Mackenzie (2022) value added to Europe from the cobalt industry (i.e., both

[37] Cobalt salts refers to: cobalt diacetate, cobalt dichloride, cobalt carbonate, cobalt nitrate and cobalt sulphate.
[38] The EU-28 refers to the EU-27 plus the United Kingdom.
[39] Production value of cobalt metal is €672 million in 2015 prices, and of cobalt salts is €901 million in 2015 prices.
[40] Value added is one component of the production value of cobalt metal and cobalt salts. It is therefore less than the production value as it for example excludes the cost of raw materials.
[41] The value added in 2015 prices is €98 million for cobalt metal and €238 million for cobalt salts.
[42] End uses and cobalt products are not aligned to the substance scope of this analysis. The pie charts are only illustrative of the total cobalt market.

manufacturing and downstream uses) included:

- Value added (the sum of its wages, salaries, profits, and dividends) was €2.83 billion[43] per annum between 2010 to 2021, making up almost 16% of the global value added;
- Almost 50,000 people were employed in cobalt value-chain related positions, and these positions taken together produced €1.28 billion[43] per annum between 2010 and 2021; and
- The cobalt value chain's contributions to taxes in Europe in the same period were €0.64 billion[43] per annum, forecast to increase to €1.15 billion[43] per annum between 2022 to 2023.

The market information provided by Wood Mackenzie includes downstream users (DUs) further down the supply chain[44], and the substances in scope differ[45], meaning figures will not correspond to those based on respondent data in Sections 3.6, 3.7, and 3.8. However, it provides a good indication of the economic importance of cobalt metal and cobalt substances to the EU economy.

Recycling is a rapidly growing industry, driven by the increasing demand for cobalt-containing batteries and production in Europe (Council of the EU, 2022). As of 2021, about 22% of cobalt substances used in Europe are recycled in Europe (CIC energy GUNE, 2021), including from batteries, catalysts, superalloys, and hard metals. Activity in the cobalt recycling industry doubled through 2010 to 2021 (Wood Mackenzie, 2022).

3.5.2 Manufacturers / importers

Table 3.2 presents the market value (price per tonne) of cobalt based on respondent data from the industry questionnaire (eftec, 2023). Market value price was calculated for each substance for each respondent based on their response to the question "*What is the current market value (2022) of each cobalt substance you make/import?*", and the average of these are presented in the **Table 3.2**.

[43] Converted from US dollars using an annual average. Rate 1 USD = 0.9604 EUR. Source: (European Central Bank, 2023).

[44] This is because most DUs further down the supply chain would have minimal cobalt exposure.

[45] Substances in scope of the Wood Mackenzie (2022) study are cobalt metal, cobalt salts, oxides and carboxylates.

Table 3.2: Substance sales prices based on respondent data

Substance	Average price (€ per tonne) rounded	Substance group	Average price per substance group (€ per tonne)
Cobalt metal	87,800	Blue Consortium	87,800
Cobalt dichloride	9,500	Red Consortium	31,900
Cobalt sulphate	8,300		
Tricobalt tetraoxide	41,300		
Cobalt dihydroxide	49,100		
Reaction mass of cobalt, copper and iron	45,000		
Cobalt lithium dioxide	38,000		
Cobalt (II) 4-oxopent-2-en-2-olate	29,500	Green Consortium	26,500
Cobalt, borate 2-ethylhexanoate complexes	29,100		
Cobalt, borate propionate complexes	29,100		
Resin acids and Rosin acids, cobalt salts	26,700		
Cobalt diacetate	40,300		
Cobalt bis(2-ethylhexanoate)	35,800		
Cobalt isononanoate	15,000		
Neodecanoic acid, cobalt salt	17,100		
Stearic acid, cobalt salt	26,800		
Cobalt propionate	13,500		
Cobalt, borate neodecanoate complexes	29,100		
Cobalt zinc aluminate blue spinel	27,500	IPC	27,500
Iron cobalt chromite black spinel	25,000		
Cobalt chromite blue green spinel	24,000		
Olivine, cobalt silicate blue	35,000		
Cobalt aluminate blue spinel	25,800		

Table notes:

- Estimates are given in 2022 € and rounded to the nearest €100.
- No data was received for the substance group "Others".

Table 3.3 presents the estimated market value from substances manufactured using cobalt metal and cobalt substances, which were calculated by multiplying the prices in **Table 3.2**, with the EU volumes presented in Section 3.8. The minimum and maximum values are based on the same substance volumes but using the maximum and minimum prices within each substance group. As shown in **Table 3.3**, the current market value of cobalt metal and cobalt substances directly or indirectly in scope of a BOEL is estimated at €3.3 – €10.9 billion. Respondent data on the expected change in the sales of cobalt metal and cobalt substances was sparse. According to the Cobalt Institute's market report (2022), between 2015 and 2021, demand for metal applications have grown at a CAGR of 3.7% and chemical applications at a CAGR of 14.7% globally. This trend is expected to continue, particularly driven by growth in demand for chemical applications in EVs, which, as reported in Section 3.5.1, drove a 22% y/y growth between 2020 and 2021. In the next five years, demand is forecast to increase at a CAGR of 12.7% (Cobalt Institute, 2022).

Table 3.3: Estimated current market value of substances manufactured in the EU-27

Substance group	Estimated EU volumes (tonnes)	Estimated market value of volume manufactured in the EU - per substance group (€ million)		
		Based on lowest average price across the substances in the group	*Based on average price across the substances in the group*	*Based on highest average price across the substances in the group*
Blue Consortium	13,500	1,200	1,200	1,200
Red Consortium	171,600	1,400	5,500	8,400
Green Consortium	9,400	100	200	400
IPC	25,500	600	700	900
Other	136,900	no data	no data	no data
All	**Cannot be summed**	**3,300**	**7,600**	**10,900**

Table notes:

- Estimates are given in 2022 €
- Volumes are rounded to the nearest 100 tonnes and market value rounded to nearest €100 million.

3.5.3 Downstream Users

Table 3.4 presents sales revenue per tonne of cobalt substance based on respondent data from the industry questionnaire (eftec, 2023). Revenue was calculated by dividing each respondent's sales revenue by their use volume for each substance. These estimates where then grouped into the 5 consortia, to estimate the average revenue per consortia per use to arrive at EU revenue. The average revenue per tonne of cobalt substance used is around 14 times higher for downstream users than for manufacturers and importers. This is an indication of the significant added value of cobalt when applied in downstream uses.

Table 3.4: Current sales revenue per volume used based on respondent data

Use	Current sales revenue per tonne cobalt metal and cobalt substances used (€ per tonne)				
	Blue Consortium	**Red Consortium**	**Green Consortium**	**IPC**	**Other**
Manufacture of other chemicals	No vol.	934,000	5,326,000	48,000	No data
Manufacture of precursor chemicals for batteries	No rev.	2,000	No vol.	No vol.	No data
Manufacture of catalysts	14,000	16,000	No vol.	No vol.	No data

Use	Current sales revenue per tonne cobalt metal and cobalt substances used (€ per tonne)				
	Blue Consortium	Red Consortium	Green Consortium	IPC	Other
Manufacture of pigments and dyes	No vol.	78,000	No vol.	91,000	No data
Manufacture of driers / paints	No rev.	No vol.	No rev.	No vol.	No data
Use as catalysts - used as a catalyst or catalyst precursor	No vol.	516,000	No vol.	No vol.	No data
Use as catalysts - used as oxidation catalyst/for PTA and IPA	No rev.	No rev.	No rev.	No vol.	No data
Use in surface treatment - Formulation of surface treatment	500,000	161,000	No vol.	No vol.	No data
Use in surface treatment - Passivation or anti-corrosion treatment processes	227,000	1,905,000	No vol.	No vol.	No data
Use in surface treatment - Metal or metal alloy plating	No rev.	2,051,000	No vol.	No vol.	No data
Use in biotechnology – Formulation and industrial use of mixtures in biogas production	No vol.	No rev.	No vol.	No vol.	No data
Use in biotechnology – Professional use in biogas production	No vol.	No rev.	No vol.	No vol.	No data
Use in biotechnology – Use in fermentation, fertilizers, biotech, scientific research, and standard analysis	No vol.	No rev.	No vol.	No vol.	No data
Use in biotechnology – Formulation and use in animal feed grade materials	No vol.	2,184,000	965,000	No vol.	No data
Bespoke uses – Use in humidity indicators cards, plugs and/or bags with printed spots	No vol.	No rev.	No vol.	No vol.	No data
Bespoke uses – Formulation of water treatment chemicals, oxygen scavengers, corrosion inhibitors	No vol.	50,000	No vol.	No vol.	No data
Bespoke uses – Use of water treatment chemicals, oxygen scavengers, corrosion inhibitors	No vol.	No rev.	No vol.	No vol.	No data
Adhesion (inc. rubber adhesion agent)	No vol.	No vol.	5,648,000	No vol.	No data
Use in electronics	No vol.	No rev.	No vol.	No vol.	No data
Use in magnetic alloys	277,000	No vol.	No vol.	No vol.	No data
Use in metallurgical alloys	275,000	No vol.	No vol.	No vol.	No data

Use	Current sales revenue per tonne cobalt metal and cobalt substances used (€ per tonne)				
	Blue Consortium	**Red Consortium**	**Green Consortium**	**IPC**	**Other**
Use in cemented carbide/diamond tools	1,624,000	75,000	No vol.	No vol.	No data
Weighted average revenue per tonne	**620,000**				

Table notes:

- Estimates are given in 2022 € and are rounded to the nearest €1,000.
- "No vol." = no volumes data was reported.
- "No rev." = no revenue data was reported.
- "No data" = no data on the sales revenue from relevant substance was reported. No data on the sales revenue from substances in the "Other" substance consortia group was reported.

Table 3.5 presents the estimated revenue linked to products manufactured using cobalt metal and cobalt substances, and the percentage of revenue attributed to substances directly in scope. Revenue was calculated using estimated volumes data in the EU-27 (see Section 3.8 for how figures were calculated per broad use) multiplied by the per tonne revenue as reported by respondents in eftec (2023). The percent directly or indirectly in scope follows that of substances directly and indirectly in scope as reported by respondents in (eftec, 2023).

Based on the limited data available, the total revenue generated by downstream uses of cobalt metal and cobalt substances was estimated at approximately €91.7 billion in 2022. Due to sparse revenue data, around 60,000 tonnes of cobalt substances could not be valued, and the total revenue is therefore believed to be significantly underestimated. Most of the "missing" revenue is associated with use of cobalt substances within the "Other" substance group in manufacture of precursor chemicals for batteries.

Table 3.5: **Current market value of products and share (%) directly in scope**

Use	Current market value of products manufactured using cobalt metal and cobalt substances (€ million)						% directly or indirectly in scope (based on respondent data)
	Blue Consortium	Red Consortium	Green Consortium	IPC	Other	Total revenue generated	
Manufacture of other chemicals	No vol.	1,400	7,990	50	No data	9,440	75%
Manufacture of precursor chemicals for batteries	No rev.	170	No vol.	No vol.	No data	170	100%
Manufacture of catalysts	10	50	No vol.	No vol.	No data	60	100%
Manufacture of pigments and dyes	No vol.	120	No vol.	180	No data	300	97%
Manufacture of driers / paints	No rev.	No vol.	No rev.	No vol.	No data	-	100%
Use as catalysts - used as catalyst precursor	No vol.	1,190	No vol.	No vol.	No data	1,190	100%
Use as catalysts - used as oxidation catalyst/for PTA and IPA	No rev.	No rev.	No rev.	No vol.	No data	-	100%
Use in surface treatment - Formulation of surface treatment	150	20	No vol.	No vol.	No data	170	100%
Use in surface treatment - Passivation or anti-corrosion treatment processes	90	0	No vol.	No vol.	No data	90	100%
Use in surface treatment - Metal or metal alloy plating	No rev.	620	No vol.	No vol.	No data	620	100%
Use in biotechnology – Formulation and industrial use of mixtures in biogas production	No vol.	No rev.	No vol.	No vol.	No data	-	100%
Use in biotechnology – Professional use in biogas production	No vol.	No rev.	No vol.	No vol.	No data	-	100%

Use	Current market value of products manufactured using cobalt metal and cobalt substances (€ million)						% directly or indirectly in scope (based on respondent data)
	Blue Consortium	Red Consortium	Green Consortium	IPC	Other	Total revenue generated	
Use in biotechnology – Use in fermentation, fertilizers, biotech, scientific research and standard analysis	No vol.	No rev.	No vol.	No vol.	No data	-	100%
Use in biotechnology – Formulation and use in animal feed grade materials	No vol.	1,530	100	No vol.	No data	1,630	100%
Bespoke uses – Use in humidity indicators cards, plugs and/or bags with printed spots	No vol.	No rev.	No vol.	No vol.	No data	-	100%
Bespoke uses – Formulation of water treatment chemicals, oxygen scavengers, corrosion inhibitors	No vol.	10	No vol.	No vol.	No data	10	100%
Bespoke uses – Use of water treatment chemicals, oxygen scavengers, corrosion inhibitors	No vol.	No rev.	No vol.	No vol.	No data	-	100%
Adhesion (inc. rubber adhesion agent)	No vol.	No vol.	49,140	No vol.	No data	49,140	77%
Use in electronics	No vol.	No rev.	No vol.	No vol.	No data	-	100%
Use in magnetic alloys	360	No vol.	No vol.	No vol.	No data	360	100%
Use in metallurgical alloys	1,040	No vol.	No vol.	No vol.	No data	1,040	100%
Use in cemented carbide/diamond tools	20,330	7,110	No vol.	No vol.	No data	27,440	100%
Total	**21,980**	**12,220**	**57,230**	**230**	**No data**	**91,660**	**98%**

Table notes:

- Estimates are given in 2022 € and are rounded to the nearest €10, except for figures <€10 which are rounded to the nearest €1.
- "No vol." = no volumes data was reported.
- "No rev." = no revenue data was reported.
- "No data" = no data on the sales revenue from substances in the "Other" substance consortia group was reported.

3.6. Number of companies and sites

This section summarises the estimated number of companies, the number of sites, and the share of companies that are SMEs in the EU-27, across manufacturers and/or importers, downstream users, and recyclers of cobalt substances.

As mentioned in Section 1.4.1, eftec's industry questionnaire collected information on a wider range of substances. The substances "directly in scope", "indirectly in scope" and "outside the scope" were identified from the respondent data. The respondent data revealed that at some sites, only substances outside the scope were manufactured and/or used; these sites would therefore not be impacted by a BOEL. However, since the data collected through the industry questionnaire was sparse, it is unclear to what extent this is representative for the wider EU-27 market. The proportion of sites outside the scope in the respondent data is therefore reported separately.

The responses to the industry questionnaire revealed that some companies carry out activities related to more than one broad use, sometimes also at the same site. This means that summing companies and sites across the broad uses will lead to potentially significant double-counting. Note that this is not an issue with the data, but how the data is interpreted and used; Some companies do in fact operate within more than sector (broad use), which means that they will be counted more than once when summing companies across sectors. This will also occur if estimates from other sources are used, unless this is already corrected for in the underlying sources, which is not the case for the sources used within this report.

The overlap (double-counting) has been estimated amongst the questionnaire respondents, however, these are not fully representative for EU-27. In particular, it is believed that there were insufficient SMEs represented amongst the respondents, which means that the overlap between the broad uses is likely to be smaller at the EU level than amongst the respondent. For transparency, two estimates are therefore reported: (i) "Upper bound", which includes overlap with other broad uses, which means that summing across multiple uses will lead to double counting, and (ii) "Lower bound", which was estimated by using the overlap factor derived from the respondent data to proportionally reduce the EU-level estimates. See Appendix A 1.1 for further details on double counting, and the interpretation of the lower and upper bound values.

No one source was found to reliably predict the number of companies, SMEs, and sites for all the uses included in this report. A broader set of sources have therefore been used in combination to approximate these key numbers, including eftec (2021, 2020, 2019a, 2019b) and RPA (2020), stakeholder webinars, other stakeholder communication (e.g., calls) and communication with the EC contractor.

Due to data limitations, it has not been possible to estimate the number of companies in each of the substance consortia without using further assumptions and creating considerable uncertainty. The number of companies in each substance consortia could be estimated based on the share of volumes in each consortium, but this would require an assumption that substance volumes are equally distributed between companies.

3.6.1 Manufacturers / Importers

Table 3.6 presents an estimate of the number of companies and sites in the EU-27 manufacturing and/or importing cobalt substances, as well as the share of companies that are SMEs. The number of companies manufacturing and/or importing cobalt substances was initially taken from eftec (2021) and was later modified based on feedback provided during webinars that presented the initial baseline results (eftec, 2023). The number of sites was calculated by multiplying the ratio of companies to sites from the respondent data with the total number of companies in the EU-27. The share of SMEs is mostly based on information provided by respondents in the questionnaire (eftec, 2023).

Table 3.6: Number of companies and sites and percent SME in Manufacture and/or import of cobalt metal and/or cobalt substances

	Total number of companies	Total number of sites in the EU-27	Share of companies that are SMEs	% of sites directly or indirectly in scope (based on respondent data)
Total upper bound	**80**	**145**	**38%**	**89%**
Total lower bound	**45**	**85**	**38%**	**89%**

Table notes:

- This data refers to companies and sites that manufacture and/or import cobalt metal and/or cobalt substances or supporting business within the EU-27 only.
- Figures are rounded to the nearest 5.
- "Upper bound" includes overlap with other broad uses, which means that summing across multiple uses will lead to double counting.
- "Lower bound" was estimated by using the overlap factor from the respondent data to proportionally reduce the EU-level estimates.

3.6.2 Downstream Users

Table 3.7 provides an overview of the estimated number of companies and sites in the EU-27 for each of the downstream broad uses, as well as the estimated share of companies that are SMEs. The majority of the estimates for total number of downstream user companies and SMEs are based on information from RPA (2020). However, the uses are not defined in the same way in RPA (2020) as in this report. Descriptions of the RPA uses (e.g., within section 2.5.1 in RPA (2020)) was therefore utilised to map uses from one report to the other. For example, *Manufacture of precursor chemicals for batteries* corresponds well with the combination of two uses reported in the RPA report, namely, *Batteries* and *Fuel cells*. The total number of companies within *Manufacture of precursor chemicals for batteries* was therefore estimated as the sum of companies within the corresponding categories in RPA (2020). Across all broad uses, around 93% of companies are SMEs and 81% of the sites belongs to SMEs.

In some instances, older eftec reports (i.e., eftec (2021, 2020, 2019a, 2019b)) were used to adjust the RPA estimates. For example, RPA only has one surface treatment use, whilst the current report has three. The RPA estimate was then split into the three sub-categories, by using the relative size of these uses from eftec (2019a). Information from the stakeholder survey (eftec, 2023), webinar feedback, calls and input from the EC contractors was primarily used for quality checks and adjustments of the first proposed numbers. In some cases, such adjustments resulted in a significantly lower number of companies, as can be seen for

Use in cemented carbide/diamond tools. For most of the uses, the number of sites was estimated by multiplying the average ratio of sites to companies from the respondent data with the estimated number of companies in the EU-27. For some of the broad uses, the number of sites was adjusted based on stakeholder feedback. In some cases, no site information was found, in which instance the ratio was assumed as one site per company to reflect the overall high share of SMEs.

Based on the respondent data, the vast majority of the companies and sites use at least one of the substances directly in scope, as can be seen in **Table 1.3**. The only exemption is the broad use “Adhesion (inc. rubber adhesion agent)”, for which most of the companies reported that they only use substances outside the scope on their sites (>70% of the sites within the respondent data). Impacts associated with a BOEL may therefore be less pronounced for this industry.

Table 3.7: Estimated number of companies and sites in the EU-27 and percent SME across downstream user broad uses[46]

Broad use	Total number of companies in the EU-27	Total number of sites in the EU-27	Share of companies that are SMEs	% of sites directly or indirectly in scope (based on respondent data)
Manufacture of other chemicals	30	50	67%	88%
Manufacture of precursor chemicals for batteries	20	70	0%	100%
Manufacture of catalysts	15	15	0%	100%
Manufacture of pigments and dyes	15	30	33%	91%
Manufacture of driers / paints	100	100	35%	100%
Use as catalysts - used as a catalyst or catalyst precursor	80	80	0%	100%
Use as catalysts - used as oxidation catalyst/for PTA and IPA	40	40	0%	100%
Use in surface treatment - Formulation of surface treatment	10	15	90%	100%
Use in surface treatment - Passivation or anti-corrosion treatment processes	750	1,350	89%	100%
Use in surface treatment - Metal or metal alloy plating	190	530	89%	100%
Use in biotechnology – Formulation and industrial use of mixtures in biogas production	310	310	98%	100%

[46] This table was outdated in the report sent to the European Commission contractors. This has now been corrected.

Broad use	Total number of companies in the EU-27	Total number of sites in the EU-27	Share of companies that are SMEs	% of sites directly or indirectly in scope (based on respondent data)
Use in biotechnology – Professional use in biogas production	2,790	2,790	98%	100%
Use in biotechnology – Use in fermentation, fertilizers, biotech, scientific research and standard analysis	100	100	90%	100%
Use in biotechnology – Formulation and use in animal feed grade materials	3,300	4,000	99%	100%
Bespoke uses – Use in humidity indicators cards, plugs and/or bags with printed spots	5	5	100%	100%
Bespoke uses – Formulation of water treatment chemicals, oxygen scavengers, corrosion inhibitors	5	30	100%	100%
Bespoke uses – Use of water treatment chemicals, oxygen scavengers, corrosion inhibitors	5	5	100%	100%
Adhesion (inc. rubber adhesion agent)	20	100	50%	27%
Use in electronics	200	200	70%	100%
Use in magnetic alloys	30	30	47%	100%
Use in metallurgical alloys	170	395	40%	100%
Use in cemented carbide/diamond tools	630	720	95%	100%
Total upper bound	**8,815**	**10,965**	**93%**	**99%**
Total lower bound	**4,960**	**6,240**	**93%**	**99%**

Table notes:

- The number of companies and sites only relates to the use of cobalt metal and/or cobalt substances or supporting business within the EU-27. The results indicate that companies typically have more than 1 site in the EU-27 relevant to the use of cobalt metal and/or cobalt substances.
- Figures are rounded to the nearest 5 companies/sites.
- "Upper bound" includes overlap with other broad uses, which means that summing across multiple uses will lead to double counting.
- "Lower bound" is estimated by using the overlap factor from the respondent data to proportionally reduce the EU-level estimates.

3.6.3 Recyclers

Table 3.8 presents an estimate of the number of companies and sites in the EU-27 recycling cobalt substances, as well as the proportion of those companies that are SMEs.

There is limited previous data on the number of companies related to the recycling of cobalt containing substances. Using Eurostat data, RPA (2020) estimated there are 1,900 companies related to “materials recovery”. However, this was deemed too broad and is likely to significantly overestimate the number of companies in the EU-27.

Around half of the manufacturer respondents indicated that they also recycle cobalt containing material. This was therefore used as a starting point for estimating the number of cobalt recyclers in the EU-27. Based on stakeholder feedback provided during webinars presenting the initial baseline results (eftec, 2023) and communication with industry specialists, there are only a few specialist recycling companies. In the absence of further information, it was assumed that there are five companies that specialise in the recovery of a variety of metals but do not manufacture/refine the cobalt substances. The number of sites was calculated by multiplying the ratio of sites to companies from respondent data with the total number of companies. The proportion of SMEs is the same as provided by respondents to the eftec questionnaire (eftec, 2023).

Table 3.8: Number of companies and sites and percent SME in recycling of materials containing cobalt substances

	Total number of companies in the EU-27	Total number of sites in the EU-27	Share of companies that are SMEs	% of sites directly or indirectly in scope (based on respondent data)
Total upper bound	45	65	44%	100%
Total lower bound	25	35	33%	100%

Table notes:

- This data refers to companies that recycle cobalt substances within the EU-27 only.
- The number of sites only relates to sites relevant to the recycling of cobalt metal and/or cobalt substances or supporting business.
- Figures are rounded to the nearest 5.
- “Upper bound” includes overlap with other broad uses, which means that summing across multiple uses will lead to double counting.
- “Lower bound” is estimated by using the overlap factor from the respondent data to proportionally reduce the EU-level estimates.

3.7. Employment

This section summarises the total number of workers and the number of workers potentially exposed in the manufacture and/import, use, and recycling of cobalt metal and/or cobalt substances.

As mentioned in Section 3.6, some sites only manufacture and/or use substances outside the scope. Workers on these sites, would not be exposed to any of the BOEL-relevant substances, and should be excluded from further assessment. However, given the paucity of data collected through the industry questionnaire, the extent to which this is representative for the wider EU-27 market is unclear. The share of workers exposed only to substances outside the scope (based on respondent data) is therefore reported separately.

Similarly, to the number of companies and sites, adding workers and workers exposed across the broad uses will lead to potentially significant double-counting, because many companies and sites are involved in activities associated with more than one broad use. The overlap (double-counting) has been estimated amongst the questionnaire respondents, however, they are not fully representative for the EU-27. In particular, it is believed that there were insufficient SMEs represented amongst the respondents, which means that the overlap between the broad uses is likely to be smaller at the EU-27 level than amongst the respondents to the industry questionnaire. For transparency, two estimates are reported: (i) "Upper bound", which includes overlap with other broad uses, which means that summing across multiple uses will lead to double counting, and (ii) "Lower bound", which is estimated by using the overlap factor derived from the respondent data to proportionally reduce the EU-27 level estimates.

3.7.1 Manufacturers / Importers

Table 3.9 presents employment data for companies in the EU-27, as well as the number and proportion of employees potentially exposed to cobalt substances. The estimated number of workers exposed in the EU-27 related to manufacture of cobalt substances is based on eftec (2019a) and number of exposed per site from eftec (2023). The total number of employees was subsequently derived by back-calculating from the share of workers exposed from eftec (2023).

Table 3.9: Numbers of employees (total and exposed to cobalt) in manufacture of cobalt metal and/or cobalt substances (manufacturers / importers)

	Number of FTE workers employed	Number of FTE workers potentially exposed	% potentially exposed relative to total employment	% of workers exposed in scope (based on respondent data)
Total upper bound	89,600	8,000	9%	89%
Total lower bound	56,900	4,800	8%	89%

Table notes:

- Employment is presented as full-time equivalents (FTEs), which considers part-time employment as a percentage of 1 FTE employee. Figures are rounded to the nearest 100 FTE.
- Potentially exposed refers to employees who work in and/or visit the production site where cobalt substances are present (e.g., staff working in buildings far away from the production process may not be exposed to cobalt in the same way as those workers involved in the production process).
- "Upper bound" includes overlap with other broad uses, which means that summing across multiple uses will lead to double counting.
- "Lower bound" was estimated by using the overlap factor from the respondent data to proportionally reduce the EU-level estimates.
- The share of those potentially exposed relative to employment differ between the upper and lower bound estimates due to rounding.

3.7.2 Downstream Users

Table 3.10 presents the total number of employees and the number and share of employees potentially exposed to cobalt, for companies in the EU-27 in each of the downstream broad uses.

For most uses, the total number of workers potentially exposed in the EU-27 was derived based on a combination of existing information from eftec (2020) and eftec (2023). An average of number of workers exposed per site was derived from the two sources, which was subsequently multiplied with the estimated number of sites in the EU-27 for each broad use to arrive at the total number of workers potentially exposed in the EU-27 based (see **Table 3.7** for the estimated number of sites in the EU-27).

In cases where the respondent data for a broad use was insufficient to estimate the number of workers potentially exposed per site, the number of workers potentially exposed was based solely on eftec (2020). In a few instances, the broad uses in eftec (2020) represented more than one broad use defined in the current report. For these broad uses, the total number of workers exposed was split across the "sub uses" according to the relative number of sites.

In cases where the number of workers potentially exposed within a particular broad use was not reported in eftec (2020) and there was insufficient survey data, the median number of workers potentially exposed per site across the broad uses from eftec (2020) was used instead.

Feedback provided by stakeholders during webinars presenting the initial baseline results (eftec, 2023) on the number or the share of workers potentially exposed presented in **Table 3.10** for the relevant broad uses. Feedback was integrated in cases where it broadly aligned with existing data from the industry questionnaire and existing reports.

There was limited information on the total number of employees in other reports, as the focus was solely on workers exposed. The total number of all workers employed in the EU-27 was therefore derived by "back calculating" using the number of workers exposed. The share of the total workforce potentially exposed was collated from the respondent data and stakeholder feedback, and the total number of employees was derived using these shares[47].

Based on the respondent data, the vast majority of the workers exposed are directly or indirectly in scope, with exemption of "Adhesion (inc. rubber adhesion agent)", for which more than 70% of the workers may not be exposed to substances in scope.

Table 3.10: Numbers of employees (total and potentially exposed to cobalt) using cobalt metal and/or cobalt substances (downstream users)

Broad use	Number of FTE workers employed	Number of FTE workers potentially exposed	% potentially exposed relative to total employment	% of workers exposed directly or indirectly in scope (based on respondent data)
Manufacture of other chemicals	5,200	2,200	42%	88%
Manufacture of precursor chemicals for batteries	7,400	2,000	27%	100%
Manufacture of catalysts	3,600	600	17%	100%
Manufacture of pigments and dyes	8,700	2,400	28%	91%

[47] Workers exposed = Share of worker exposed / Total employed → Total employed = Workers exposed / Share of workers exposed.

Broad use	Number of FTE workers employed	Number of FTE workers potentially exposed	% potentially exposed relative to total employment	% of workers exposed directly or indirectly in scope (based on respondent data)
Manufacture of driers / paints *	3,600	600	17%	100%
Use as catalysts - used as a catalyst or catalyst precursor	3,000	500	17%	100%
Use as catalysts - used as oxidation catalyst/for PTA and IPA	1,200	200	17%	100%
Use in surface treatment - Formulation of surface treatment	2,100	200	9%	100%
Use in surface treatment - Passivation or anti-corrosion treatment processes	221,500	5,900	3%	100%
Use in surface treatment - Metal or metal alloy plating	13,500	4,500	33%	100%
Use in biotechnology – Formulation and industrial use of mixtures in biogas production	3,000	500	17%	100%
Use in biotechnology – Professional use in biogas production	29,000	4,900	17%	100%
Use in biotechnology – Use in fermentation, fertilizers, biotech, scientific research and standard analysis	5,300	900	17%	100%
Use in biotechnology – Formulation and use in animal feed grade materials	50,000	2,500	5%	100%
Bespoke uses – Use in humidity indicators cards, plugs and/or bags with printed spots	40,000	100	0%	100%
Bespoke uses – Formulation of water treatment chemicals,	5,300	1,500	28%	100%

Broad use	Number of FTE workers employed	Number of FTE workers potentially exposed	% potentially exposed relative to total employment	% of workers exposed directly or indirectly in scope (based on respondent data)
oxygen scavengers, corrosion inhibitors				
Bespoke uses – Use of water treatment chemicals, oxygen scavengers, corrosion inhibitors	600	100	17%	100%
Adhesion (inc. rubber adhesion agent)	150,000	11,300	8%	27%
Use in electronics *	7,700	1,300	17%	100%
Use in magnetic alloys	3,500	1,800	52%	100%
Use in metallurgical alloys	69,300	20,600	30%	100%
Use in cemented carbide/diamond tools	25,600	9,700	38%	100%
Total upper bound	**659,100**	**74,300**	**11%**	**88%**
Total lower bound	**418,900**	**45,000**	**11%**	**88%**

Tables notes:

- Employment is presented as full-time equivalents (FTEs), which considers part-time employment as a percentage of 1 FTE employee. Figures are rounded to the nearest 100 FTE.
- Potentially exposed refers to employees who work in and/or visit the production site where cobalt substances are present (e.g., staff working in buildings far away from the production process may not be exposed to cobalt in the same way as those workers involved in the production process).
- * number of workers potentially exposed estimated based on the median number of workers potentially exposed per site across the broad uses from eftec (2020), multiplied by the estimated number of sites in that broad use in the EU-27 (see **Table 3.7** for the estimated number of sites in each broad use).
- "Upper bound" includes overlap with other broad uses, which means that summing across multiple uses will lead to double counting.
- "Lower bound" is estimated by using the overlap factor from the respondent data to proportionally reduce the EU-level estimates.

3.7.3 Recyclers

Table 3.11 presents the total number of employees and the number and share of employees potentially exposed to cobalt for companies in the EU-27. The estimated total number of workers employed in the EU-27 related to recycling of materials containing cobalt substances is based on uplifting respondent data according to the number of recycling sites in the EU-27, as there is a lack of other data sources to base the estimate on.

Table 3.11: Numbers of employees (total and exposed to cobalt) in recycling of cobalt metal and/or cobalt substances (recyclers)

	Number of FTE workers employed	Number of FTE workers potentially exposed	% potentially exposed relative to total employment	% of workers exposed in scope (based on respondent data)
Total upper bound	34,900	7,300	21%	100%
Total lower bound	22,200	4,400	20%	100%

Table notes:

- Employment is presented as full-time equivalents (FTEs), which considers part-time employment as a percentage of 1 FTE employee. Figures are rounded to the nearest 100 FTE.
- Potentially exposed refers to employees who work in and/or visit the production site where cobalt substances are present (e.g., staff working in buildings far away from the production process may not be exposed to cobalt in the same way as those workers involved in the production process).
- "Upper bound" includes overlap with other broad uses, which means that summing across multiple uses will lead to double counting.
- "Lower bound" is estimated by using the overlap factor from the respondent data to proportionally reduce the EU-level estimates.
- The share of those potentially exposed relative to employment differ between the upper and lower bound estimates due to rounding.

3.8. Volumes of cobalt metal and cobalt substances

This section summarises the estimated volumes of cobalt metal and cobalt substances manufactured, imported, used, and recycled[48] in the EU-27.

The volumes manufactured and/or imported in the EU-27 are predominantly based on REACH registration volume data for each of the substances in the Cobalt consortia groups (see Section 3.8.1 for further details on adjustments made to this data). Companies are legally obligated to report the volume of the substances they manufacture and/or import (above one tonne) into the EU-27 to ECHA (ECHA, n.d.). The REACH registration volume data is therefore considered the most comprehensive and robust data available and is therefore the preferred source of information on volumes.

The downstream user volumes build on the manufacture and import volumes, alongside respondent data on sales and internal use in the EU. It further relies on respondent and other sources in order to arrive at a breakdown of the volumes for each broad use (see Section 3.8.2 for further details).

As mentioned in Sections 3.6 and 3.7, some sites only manufacture and/or use substances outside the scope. Substances on these sites would not be subject to a BOEL and should be excluded from further assessment. However, due to the paucity of data from the industry questionnaire, the extent to which this is representative for the wider EU-27 market is unclear. The share of the volume (based on respondent data) directly and indirectly in scope is therefore reported separately.

[48] Due to lack of data, it was not possible to derive EU estimates for recycling. Instead, the collated data from the eftec 2023 questionnaire is presented.

3.8.1 Manufacture / Import

Table 3.12 presents estimated annual volumes of cobalt metal and cobalt substances manufactured and imported in the EU-27, as well as the share of that volume that is subsequently used in the EU-27 and the share that is exported. The results are presented at a substance group level, aligned with the consortia set out in **Table 1.3**.

Estimated volumes manufactured in and imported into the EU-27 are based on volume data reported in eftec (2019a), publicly available REACH registration tonnage band data available on the ECHA website as well as the respondent data and respondent feedback. The lower band REACH registration volume data for the substances in each substance group was compared to the volume data reported in eftec (2019a) – "Cobalt value chain" and the respondent data. The highest values amongst these three sources would be the minimum EU volumes.

The eftec (2019a) report did not provide volume data for the IPC and Other substance groups. The volumes in these substance groups were estimated using the average of the upper and lower volume bands reported in REACH registration for the relevant substances and adjusted based on information provided by the Cobalt Institute.

In the next step the derived total volume was split into manufacture and import, and export and use. This was calculated using the corresponding split from respondent data and adjustments made after feedback from stakeholder webinars. The underlying assumption is thus that the manufacture, import, export and use shares from the respondent data is representative for the EU-27.

Some cobalt substances (e.g., inorganic cobalt compounds) are required for the production of other cobalt substances (e.g., organic[2] cobalt compounds). These inorganic cobalt compounds (for example, cobalt dihydroxide) therefore act as intermediates[49] which are not directly used in downstream uses. Therefore, summing the volumes manufactured and imported across the substance groups would lead to double counting.

The Green Consortium substances are all outside the scope defined by the EC contractor, however, the questionnaire data revealed that a significant share (75%) is manufactured or internally used alongside substances in scope. It is therefore believed that the majority of the Green Consortium volumes will be impacted by a BOEL and are thus indirectly in scope for the purpose of the SEIA.

[49] REACH defines an intermediate as *a substance that is manufactured for and consumed in or used for chemical processing in order to be transformed into another substance* (Article 3(15)) (ECHA, 2010).

Table 3.12: Annual volumes manufactured and/or imported in the EU-27

Cobalt consortia group	Total manufactured (M) in the EU-27 (tonnes/year)	Total imported (I) into the EU-27 (tonnes/year)	Total EU-27 volume (M+I) (tonnes/year)	% sold and/or internally used in the EU-27	% sold and/or internally used outside the EU-27	% of volume directly or indirectly in scope (based on respondent data)
Blue Consortium	13,500	14,600	28,100	62%	38%	100%
Red Consortium	171,600	33,700	205,300	97%	3%	100%
Green Consortium	9,400	4,600	14,000	97%	3%	75%
IPC	25,500	6,800	32,300	100%	0%	84%
Other	136,900	58,600	195,500	99%	1%	100%

Table notes:

- Figures are rounded to the nearest 100 tonnes.
- See **Table 1.3** for substances included in each consortium.

Eurostat reports statistics on the production of manufactured goods (Prodcom), including the production of some cobalt substances in the EU. These volumes are reported for different groups of substances, as opposed to being reported on a substance level. The volumes reported by Eurostat for the identified relevant groups of substances is less than 20% of the volume reported in **Table 3.12**. There are a number of reasons for this:

i) **The volume of cobalt substances reported by Eurostat do not include all of the substances reported in Table 3.12**, partially due to the difficulty in mapping the Eurostat group of substances and the substances in this analysis (as detailed in (i) above). Approximately 29 of the 40 substances directly and indirectly in scope of this analysis (i.e., 73% of substances) do not have a corresponding substance group in Eurostat.

ii) **Eurostat production volumes can be less reliable than REACH registration volumes.** Eurostat production statistics are obtained by surveying producer enterprises. Therefore, the statistics rely on questionnaires completed by enterprises, which can lead to problems in the quality of the data including missing data or measurement errors, whereby enterprises, for example, report data according to the wrong product code (Eurostat, 2022). These problems are expected to be less common in reporting substance volumes to ECHA through a registration dossier as companies are less likely to misinterpret the substance code given that accompanying hazard information also must be provided (ECHA, n.d.). Companies also have a legal obligation to report substance volumes to ECHA via REACH, whilst obligations in reporting production statistics to Eurostat are less stringent.

Further complications are related to the Eurostat **substance groups which do not map onto the substances in the scope of this analysis**, and therefore cannot provide accurate volume data for each substance and consortia group. The groups of substances reported in Eurostat are sometimes broader (i.e., include a wider range of substances) than the substance itself. For example, Eurostat reports the volume for "*sulphates of cobalt; of titanium"* which would include the substance "*cobalt sulphate*" but include other substances (i.e., titanium sulphate).

The volumes presented in **Table 3.12**, which is primarily based on REACH Registrations and respondent data, is considered more robust than the Eurostat data, and has therefore been used in this analysis.

3.8.2 Downstream Users

Some cobalt substances are used as intermediates in the production of other cobalt substances and are not used in downstream uses. This translates into downstream user volumes being significantly lower than the manufacture and import volumes. Based on respondent data and data from stakeholder webinars, it was found that only 39% of the volumes sold and/or internally used in the EU-27 is actually used in downstream uses. eftec (2019a) on the other hand, found that 67% of the volumes sold and/or internally used was eventually used in downstream uses. This may be partly due to the differing substances in scope but is also an indication of potential underreporting of downstream use volumes (insufficient responses from downstream users) compared to manufacture and import in the respondent data.

On the other hand, it is also known that some downstream users may manufacture materials or products that are used in other downstream uses. For example, the substances manufactured in the "Manufacture of other chemicals" broad use are used in the "Manufacture of precursor chemicals for batteries" broad use. Adding volumes across all the uses may therefore lead to double counting.

Considering the above observations (comprising both positive and negative bias), it was concluded that the questionnaire data ratio (39% of volumes sold and internally used is applied in downstream uses) would be an acceptable indicator[50] to use to derive the total downstream use volume at the EU-27 level.

The share of the total downstream use volumes allocated to each use is based on respondent data and reflects the share of volume of cobalt substances used in each broad use. The split across the substance consortia also reflects the split found in the respondent data and stakeholder feedback.

Table 3.13 shows the resulting downstream use volumes split by substance group. These should be interpreted as non-overlapping volumes.

[50] Total downstream use volume was derived by taking 39% of the estimated volumes internally used or sold within EU-27.

Table 3.13: Annual volume of cobalt substances used in the EU-27 per broad use, tonnes/year

Broad use	Use volumes (tonnes/year)						% directly or indirectly in scope (based on respondent data)
	Blue Consortium	Red Consortium	Green Consortium	IPC	Other	Total	
Manufacture of other chemicals	0	1,500	1,500	1,000	0	4,000	75%
Manufacture of precursor chemicals for batteries	5	82,200	0	0	53,800	136,000	100%
Manufacture of catalysts	900	3,200	0	0	0	4,100	100%
Manufacture of pigments and dyes	0	1,500	0	2,000	0	3,500	97%
Manufacture of driers / paints	700	0	2,300	0	0	3,000	100%
Use as catalysts - used as catalyst precursor	0	2,300	0	0	0	2,300	100%
Use as catalysts - used as oxidation catalyst/for PTA and IPA	300	1,700	100	0	0	2,100	100%
Use in surface treatment - Formulation of surface treatment	300	100	0	0	0	400	100%
Use in surface treatment - Passivation or anti-corrosion treatment processes	400	0.4	0	0	0	400	100%
Use in surface treatment - Metal or metal alloy plating	10	300	0	0	0	300	103%
Use in biotechnology – Formulation and industrial use of mixtures in biogas production	0	100	0	0	0	100	100%
Use in biotechnology – Professional use in biogas production	0	100	0	0	0	100	100%
Use in biotechnology – Use in fermentation, fertilizers, biotech, scientific research and standard analysis	0	10	0	0	0	10	100%
Use in biotechnology – Formulation and use in animal feed grade materials	0	700	100	0	0	800	100%

Broad use	Use volumes (tonnes/year)						% directly or indirectly in scope (based on respondent data)
	Blue Consortium	Red Consortium	Green Consortium	IPC	Other	Total	
Bespoke uses – Use in humidity indicators cards, plugs and/or bags with printed spots	0	100	0	0	0	100	100%
Bespoke uses – Formulation of water treatment chemicals, oxygen scavengers, corrosion inhibitors	0	100	0	0	0	100	100%
Bespoke uses – Use of water treatment chemicals, oxygen scavengers, corrosion inhibitors	0	100	0	0	0	100	100%
Adhesion (inc. rubber adhesion agent)	0	0	8,700	0	0	8,700	77%
Use in electronics	0	100	0	0	0	100	100%
Use in magnetic alloys	1,300	0	0	0	0	1,300	100%
Use in metallurgical alloys	3,800	0	0	0	0	3,800	100%
Use in cemented carbide/diamond tools	4,800	700	0	0	0	5,500	100%
Total across all uses	**12,515**	**94,810**	**12,700**	**3,000**	**53,800**	**176,810**	**98%**

Table note: Figures are rounded to the nearest 100 tonnes except for volumes <50 tonnes which have been rounded to the nearest 10 tonnes and volumes <10 tonnes which have been rounded to the nearest 5 tonnes.

3.8.3 Recycled

Based on the available data, it has not been possible to estimate the volumes recycled across the EU-27. This aspect may be explored further as part of future research by the CI. Volume data for this broad use, as reported by respondents to the eftec (2023) questionnaire, is presented in **Table 3.14**.

Table 3.14: Annual volumes recycled by questionnaire respondents

Cobalt consortia group	Types of end-of-life materials recovered and recycled	Annual volume of material recycled (tonnes/year)	Volume of cobalt recovered (tonnes/year)
Blue Consortium	Scrap metals (including magnets, cemented carbide scraps and lithium-ion batteries)	21,400	4,150
Red Consortium	Scrap metals (including lithium-ion and NMC batteries, catalysts and black mass)	10,150	1,250
Green Consortium	-	0	0
IPC	-	0	0
Other	-	0	0
Totals	*See above*	31,550	5,400

Table notes:

- Figures are rounded to the nearest 50 tonnes.
- See **Table 1.3** for substances included in each consortium. Substances were grouped to maintain confidentiality. Recycling at the level of the consortium does not mean all substances in that consortium are recycled.

3.9. Summary

Section 3 has presented information on the manufacture of cobalt (including REACH registration and CMR classification), description of the broad uses of cobalt, the functions of cobalt, market info / value added from across the value chain, volumes, and the number of companies, sites, and employees. This information has established the baseline scenario and supports the analysis of the four policy options. Key highlights include:

- The global market for cobalt manufacturing has grown substantially in the last half decade (CAGR 9% from 2015-20) and grew by 22% in 2021 compared to 2020 (Cobalt Institute, 2022). The primary uses of cobalt in the EU-27 are Li-ion batteries (85.3%), industrial metals (6.1%), superalloys (5.1%), and industrial chemicals (3.5%) (Cobalt Institute, 2022). Activity in the cobalt recycling industry doubled through 2010 to 2021.
- Cobalt metal is classified by the EC as a CRM. It is one of the raw materials of highest economic importance in the EU. It has a relatively low (compared to 26 other materials) supply risk despite the EU-27's dependence on the DRC for raw materials and China for refined cobalt.
- An estimated 80 companies, with 145 sites, manufacture and/or import cobalt substances in the EU-

27, employing around 89,600 people. The cobalt substances manufactured and/or imported in the EU-27 are subsequently used by downstream users spanning 22 broad uses and employing around 660,000 people in production sites using cobalt substances. Products containing cobalt substances are recycled by an estimated 45 companies, employing 34,900 people.

- An estimated 475,200 tonnes per year of cobalt substances are manufactured in and imported into the EU-27, of which approximately 96% are sold and/or internally used in the EU-27 (with the remaining 4% being exported). Given that some cobalt substances are required for the production of other cobalt substances, these total volumes include overlapping amounts and do not reflect the volume of cobalt substances subsequently used by downstream users. It has been estimated that approximately 39% of the volume manufactured and imported in the EU-27, which is not exported, is used by downstream users, amounting to approximately 176,810 tonnes per year[51].

[51] Numbers may not add up due to rounding.

4. Cost of inaction

4.1. Introduction

This section covers the costs (to workers, households, and businesses) that would be incurred without an EU-wide BOEL (i.e., inaction). In order to calculate these costs, the first step is to establish the current levels and routes of workplace exposure given the existing BOEL compliance (both at national (legislative) and at site level). The second step is to use dose response functions and unit cost estimates to calculate the current societal costs of these health impacts, i.e., the costs of inaction (no BOEL). These steps are detailed in this Chapter in the following order:

- National BOELs (Section 4.2);
- Workplace exposure routes, levels, existing the Risk Management Measures (RMMs) and resulting compliance with each BOEL assessed in this report (Section 4.3);
- Health end points, dose response functions and excess risk at current levels (Section 4.4); and,
- Costs of inaction covering the costs due to three health endpoints: lung cancer, respiratory irritation and restrictive lung disease (Section 4.5).

4.2. National OELs

Some countries in the EU have already established OEL values. **Table 4.1** presents OELs (in terms of 8-hour Time-Weighted Averages (TWA)) in the EU-27 plus Norway, Switzerland and United Kingdom (where available). Germany is the only country whose OEL is a respirable fraction value, while all other values are based on the inhalable fraction. It should be noted that some countries have guidance OELs which are not legally binding.

Both respirable and inhalable OELs consider the fraction of dust that enters workers' bodies through the nose and mouth. The respirable dust is the fraction that penetrates to the gas exchange region of the lung, while inhalable fraction accounts for dust that is available for deposition in the respiratory tract.

Table 4.1 also shows the Biological Limit Values (BLV) where these are adopted, namely, Finland and Germany (ECHA, 2022a). The most common (mode) OEL across Member States is 20 μg/m^3. Mandatory biological monitoring of cobalt is not common among European countries, even though voluntary practice of biomonitoring through urine testing is used by manufacturers of cobalt metal and/or cobalt compounds to trace concentrations of cobalt in urine (Cohrssen, 2021).

Table 4.1: OELs and BLVs at European country level

Country	OEL (TWA μg/m^3)	BLV
Austria	100 μg/m^3	-
Belgium	20 μg/m^3	-
Croatia	100 μg/m^3	-

Country	OEL (TWA µg/m³)	BLV
Denmark	10 µg/m³	-
Finland	20 µg/m³	7.7 µg/L
Germany*	5 µg/m³, 0.5 µg/m³	Range of 3 µg/L to 300 µg/L
Hungary	100 µg/m³	-
Ireland	20 µg/m³	-
Latvia	500 µg/m³	-
Netherlands	20 µg/m³	-
Poland	20 µg/m³	-
Romania	50 µg/m³	-
Spain	20 µg/m³	-
Sweden	20 µg/m³	-
Norway	20 µg/m³	-
Switzerland	50 µg/m³	-
United Kingdom	100 µg/m³	-

Table notes:

- *Germany OEL is based on a respirable fraction rather than an inhalable fraction.
- *Source,* ECHA (2022a).

4.3. Workplace exposure routes and levels

Binding OELs are maximum levels of exposure to regulated substances that are set by the EU and which cannot be exceeded by the Member States when establishing any national limits on exposure to regulated substances. Sections 4.3.1and 4.3.2 describe the routes of exposure and exposure levels (by broad use) for cobalt metal and cobalt substances, respectively.

4.3.1 Routes of exposure

ECHA's (2022a) Scientific Report describes three routes of worker exposure to cobalt metal and cobalt inorganic compounds during both the manufacture and downstream user (DU) use of the substances. These are inhalation, dermal and (potentially) oral routes of exposure. Prevention of dermal exposure is relevant for cobalt metal and cobalt substances due to skin sensitisation.

The highest inhalable exposure occurs during packaging or handling powders containing cobalt metal or cobalt substances. According to the REACH Registration dossiers, cobalt powders have high dustiness, and the cobalt salts are prepared and used as solids in powder form with medium dustiness. Some of the processes (e.g., in animal feed, manufacture of catalysts, etc.) result in the transformation of the cobalt salts into dry solids (cakes, granules, pellets, etc.) with a lower potential for dust emission. Additionally, inorganic cobalt compounds (except for cobalt carbonate) are also produced and used in liquid form, mainly as aqueous solutions. The use of aqueous solutions can lead to the generation of mists and fumes in high energy activities such as surface treatment (e.g., electroplating) and hot metallurgical (alloy) processes (ECHA, 2022a).

4.3.2 Current exposure levels

EBRC Consulting has gathered exposure data and derived exposure estimates for the broad uses within this SEIA, based on monitoring data from the REACH database covering personal monitoring submitted within 1995-2019 and recently submitted data (2012-2023). All data was quality screened for compliance with EN482. Further descriptions of the data and the approach to deriving the exposure estimates are presented in **Section A 1.2** - EBRC (2023).

It is noted that in contrast to REACH exposure scenarios, exposure estimates are exclusively based on monitoring data in this report. Thus, differences may exist, since REACH exposure scenarios may also include estimates that are based on published or modelled data. This is also likely one of the reasons why the exposure data for *Recycling of materials containing cobalt substances* is so low, as monitoring data was only available for a single worker contributing scenario. It may also be the case be that this is sampled from a company primarily carrying out recovery (e.g., on-site scrap), which would not involve the same exposure as a metal recycler. It is deemed likely that the actual exposure associated with this broad use will be significantly higher. EBRC (2023) has indicated that if a read-across from published data on the hard metal sector is used, the resulting maximum exposure level would be around 15 µg/m³. With an Assigned Protection Factor (APF) of 10, the resulting exposure would be lower than the threshold for the non-cancer health endpoints and the excess risk of cancer would be very low, hence the impact on the total number of cases would be marginal.

The derived exposure data does not reflect the use of Personal Protective Equipment (PPE), and could therefore not, in its raw form, be used to derive representative risk level. In order to adjust the exposure level for the use of RPE, EBRC also considered bespoke APFs according to EN BS 529 for each broad use, based on what is reported in REACH Registration data. These APFs have been used to reflect the current use of RPE; i.e., the broad use exposure estimates are divided by each respective APF.

Table 4.2 shows the exposure data used to derive human health impacts from exposure to cobalt metal and cobalt substances. Due to a lack of monitoring data for the respirable fraction, only the inhalable fraction was derived by EBRC. Broadly in line with the EC contractor's approach, it has been assumed that the relationship between the inhalable and respirable fraction is 4:1.

It can be observed that there is large variation in exposure across the broad uses. This can be explained by the nature of activities involved, the RMMs already in place and, to some extent, representatives of available exposure data.

Table 4.2: **Estimated exposure levels per broad use, without PPE**

Broad use	Count of GWCS	APF	Inhalable fraction (8h TWA in µg/m³)				
			P50	P75	P90	P95	Max
Manufacture of cobalt metal and/or cobalt substances	45	7	14.2	37.9	99.7	158.8	677.9
Recycling of materials containing cobalt substances*	1	10	1.0	1.0	2.5	3.3	4.0
Manufacture of other chemicals**	n/a	7	3.5	9.8	36.5	59.9	147.7
Manufacture of precursor chemicals for batteries	5	5	5.4	26.0	72.2	97.7	262.0
Manufacture of catalysts	11	6	6.2	9.2	12.7	14.4	37.3
Manufacture of pigments and dyes	15	1	1.5	5.6	11.8	18.3	52.1
Manufacture of driers / paints	6	12	11.1	27.4	116.3	203.3	433.7
Use as catalysts - used as a catalyst or catalyst precursor	18	17	1.9	6.6	16.3	21.6	96.9
Use as catalysts - used as oxidation catalyst/for PTA and IPA	9	12	11.1	27.3	116.4	203.1	420.0
Use in surface treatment - Formulation of surface treatment	10	10	11.0	34.4	99.0	150.7	471.0
Use in surface treatment - Passivation or anti-corrosion treatment processes	21	3	3.1	11.4	26.5	37.7	109.1
Use in surface treatment - Metal or metal alloy plating	23	4	8.7	24.7	52.7	71.7	437.9
Use in biotechnology – Formulation and industrial use of mixtures in biogas production	10	8	12.2	58.5	162.8	213.1	652.3
Use in biotechnology – Professional use in biogas production	1	1	0.5	0.5	0.5	0.5	0.5
Use in biotechnology – Use in fermentation, fertilizers, biotech, scientific research and standard analysis	12	10	8.8	14.7	115.7	220.1	289.4
Use in biotechnology – Formulation and use in animal feed grade materials	4	11	18.1	49.1	128.5	218.7	1187.9
Bespoke uses – Use in humidity indicators cards, plugs and/or bags with printed spots	4	1	0.1	0.2	0.3	0.4	0.5
Bespoke uses – Formulation of water treatment chemicals, oxygen scavengers, corrosion inhibitors	4	19	16.8	29.5	223.3	423.8	602.8

Broad use	Count of GWCS	APF	Inhalable fraction (8h TWA in µg/m³)				
			P50	P75	P90	P95	Max
Bespoke uses – Use of water treatment chemicals, oxygen scavengers, corrosion inhibitors	1	1	2.4	3.2	8.7	9.8	11.0
Adhesion (inc. rubber adhesion agent)	11	1	0.2	0.7	2.1	4.2	18.7
Use in electronics	16	6	21.6	40.6	91.0	166.7	380.3
Use in magnetic alloys	16	6	21.6	40.6	91.0	166.7	380.3
Use in metallurgical alloys	12	11	44.1	112.3	244.1	305.7	1354.6
Use in cemented carbide/diamond tools	23	20	70.2	120.2	170.7	207.4	470.4

Tables notes:

- The exposure levels were calculated by EBRC based on monitoring data from the REACH database, P50, P75, P90, P95 and Max are percentiles from the exposure distribution derived by EBRC.
- Assigned protection factors (APFs) are based on the Personal Protective Equipment (PPE) already in place. These are based on the REACH Registration dossiers.
- GWCS stands for General Workers Contributing Scenarios
- All exposure estimates are given in µg Co/m³ and are <u>not adjusted</u> for the use of PPE.
- *Exposure for *Recycling of cobalt substance* is based on only GWCS and is overall expected to be higher than indicated in the table.
- ***Manufacture of other chemicals* is a read-across from *Manufacture of cobalt metal and/or cobalt substances*, excluding GWCSs of cobalt metal exposure scenario.

It should be noted that other report such as RPA (2020) are using exposure data from other sources, with resulting estimates being overall lower. Table 2-13 of RPA's report present estimates for different broad uses with PPE, which on average 1.5 – 9 times higher than what is used in the current analysis (**Table 4.2** adjusted for PPE). The biggest difference is observed for the median exposure levels, which averaged across broad uses[52] are 9 times higher than the levels estimated by EBRC (2023).

No data was found on the share of the workers exposed at specific exposure levels. Therefore, an exposure distribution (i.e., share of the workers exposed at difference exposure levels) had to be assumed. The assumed distribution presented in **Table 4.3**, broadly follows a lognormal distribution and aligns with the approach taken in RPA (2020).

Table 4.3: Assumed exposure distribution

Group identifier	Assumed exposure level	Proportion of workers exposed (%)
Median	Median or 50th percentile	50%
P50-P75	Arithmetic mean of 50th and 75th percentiles	25%
P75-P90	Arithmetic mean of 75th and 90th percentiles	15%

[52] Note that the broad uses in RPA (2020) are not identical to those in the present report.

P90-P95	Arithmetic mean of 90th and 95th percentiles	5%
P95-Max	Geometric mean of 95th and maximum value	5%

Table note: The proportions (%) relates to the workers potentially exposed, not the total number of employees.

4.3.3 RMMs in place

This section sets out the Risk Management Measures (RMMs), including PPE, already used at sites in the EU-27. The presence of an RMM at a site does not necessarily mean that the measure is in place for all activities at that site, or that the measure cannot be implemented more widely. For example, some training may currently be carried out for workers at a site, but *more* training can still be implemented. Information in this section is based on respondent data from the industry questionnaire (eftec, 2023), and hence may not be fully representative of all sites in the EU-27.

Table 4.4 presents the share of sites reported as using each RMMs assessed in the questionnaire. The most commonly used RMMs are the use of gloves (99% of sites), training (97% of sites) and cleaning[53] (98% of sites). Respondents remarked that gloves are commonly used or even mandated while masks are only used for certain processes, particularly where workers may be exposed to certain types of dust/fumes. Companies reported variation in the frequency of training, ranging from "regular" training to annual training and training of new employees.

Two of the least used RMMs are minimising the amount of substance used (23%) and substitution of the substance (20%). For many applications, substitution is not possible due to a lack of available or known alternatives, despite ongoing R&D and application trials. For some broad uses, such as recycling, substitution or minimisation of the amount of substance are not possible due to the nature of the industry. This will affect the overall share of sites where these RMMs are in place as these shares have been estimated based on the total number of sites (as opposed to the number of sites in which these RMMs would be feasible). For a number of other broad uses, minimising the amount of substance is not possible without losing the functionality of the product.

The two least used engineering control RMMs (pressurised or sealed control cabs (23%) and continuous measurement to detect unusual exposures (26%)) are difficult to implement because (i) some companies believe they would need to redesign their process to use control cabs and (ii) the technology that measures continuously is not commonly used as respondents believe it does not provide accurate readings. As shown in **Table 4.4**, many companies have designed their systems to enclose (72%) or ventilate (91% and 89%) cobalt dust rather than monitor for it. Stakeholder feedback on the industry questionnaire (eftec, 2023) further emphasised the importance of these enclosure and ventilation measures. For example, feedback from the animal feed sector highlighted the use of coating material and the delivery of feed in non-powder form as the most significant RMMs implemented in the feed chain to reduce dust emissions.

[53] Cleaning refers to the measures that improve the sanitation of work areas to minimize the risk of exposure and are therefore considered an RMM.

Table 4.4: Share of sites with risk management measures (RMMs) in place

Types of RMMs	RMMs	Share of sites with RMM is in place
Elimination / substitution	Minimised the amount of substance used	23%
	Discontinuation	46%
	Substitution	20%
Engineering controls	Closed systems	56%
	Partial hood enclosures	72%
	Open hoods over equipment or local extraction ventilation	91%
	General ventilation	89%
	Pressurised or sealed control cabs	23%
	Simple enclosed control cabs	37%
	Continuous measurement to detect unusual exposures	26%
	Redesign	73%
Administrative controls	Rotating the workers exposed	42%
	Redesigned of work processes to avoid exposure	73%
	Minimised the number of workers exposed	70%
	Cleaning	98%
	Training	97%
PPE	Gloves	99%
	Goggles	90%
	HEPA Masks	85%
	Respiratory Equipment	81%
	Simple Masks	37%

Table note: The share of sites with RMMs in place have been estimated based on the number of sites across questionnaire respondents.

Respondents to the industry questionnaire provided information on RMMs that were not listed in the industry questionnaire (respondents were given a dropdown with the option to write in "other" RMMs). These included:

- Worker hygiene (e.g., daily change of work clothing, daily mandatory showers);
- Worker health checks (e.g., biological monitoring, medical surveillance, dedicated welfare facilities, etc.); and
- Technical measures (e.g., Use of anti-dust treated cobalt, workstation ventilation, styropore covers on electrowinning tank, sealed bags and locks).

4.3.4 *Level of compliance with each potential BOEL*

This section considers the level of existing compliance with each of the four BOEL policy options assessed in this report across sites manufacturing, using, and/or recycling cobalt metal and/or cobalt substances in the EU-27.

Table 4.5 reports the share of sites in the EU-27 that comply with each BOEL across the broad uses. These shares were estimated using respondent data from eftec's 2023 industry questionnaire, based on the number of sites complying and not complying to each BOEL. The compliance level across sites, and their potential to comply, can differ based on:

i) volumes of cobalt handled;

ii) particle size of cobalt handled;

iii) temperature of processes in which cobalt is handled, and;

iv) the level of automation/encapsulation that is compatible with the processes involved.

As shown in **Table 4.5**, and as would be expected, the share of sites that comply with a BOEL declines as the BOEL value decreases or BOEL values become more stringent. The share of sites that comply with each BOEL steadily decreases between a BOEL of 30 $\mu g/m^3$ and 10 $\mu g/m^3$. There is then a sharp decrease in the share of sites that comply with a 1 $\mu g/m^3$, and this could be largely attributed to the difficulty in achieving this BOEL, as has been suggested by stakeholders.

To comply with a 1 $\mu g/m^3$, sites would likely need to implement more comprehensive (and expensive) engineering control measures such as closed systems, pressurised or sealed control cabs, and simple enclosed control cabs. **Table 4.4** shows that currently these measures are implemented less frequently than other RMMs. Based on information provided by respondents, measures such as enclosed control cabs and closed systems would require conversion or complete reconstruction of a site, which may not be economically feasible for a company to implement across all sites. The technical and economic feasibility of complying with each of the BOELs assessed is further discussed for each Policy Option in Chapters 7 to 10.

Table 4.5 also reports the share of sites complying with each BOEL that are directly or indirectly in scope. Since the data collected through the industry questionnaire was sparse, it is unclear to what extent this is representative for the wider EU-27 market. The share of the sites complying (based on respondent data) directly and indirectly in scope is therefore reported separately. The biggest difference is in the level of compliance with a 1 $\mu g/m^3$ limit. This is expected to be largely driven by the adhesion sector which has the highest proportion of sites outside of the scope of the analysis and the amongst the highest share of sites complying with a BOEL of 1 $\mu g/m^3$.

The share of sites complying with each BOEL in each of the broad uses is reported in **Appendix Table 9**, which should be interpreted with caution as the broad uses with fewer respondents tend to skew to more extreme shares (i.e., close to 100% and 0%). The share of sites complying with each BOEL per broad use have been estimated based on the companies that reported being part of that broad use and the number of sites they reported complying with each BOEL. Therefore, the share of sites complying with each BOEL per broad use may include a company's sites unrelated to that particular broad use. This is because information was not provided on which activities take place at a specific site that would qualify it as a specific broad use. These estimates are therefore likely to overlap.

Compliance with each BOEL amongst the broad uses (**Appendix Table 9**) largely follows overall compliance (**Table 4.5**) with some notable variations. Overall, an estimated 64% of sites comply with a BOEL of 10 µg/m^3 but there is deviation between the broad uses reflecting differing activities undertaken in each broad use, RMMs currently implemented, and the ability to control exposure in these activities. For example, an estimated 50% of sites comply with a BOEL of 10 µg/m^3 in the cemented carbide and diamond tools sector (less than 64% overall compliance reported in **Table 4.5**). Some stakeholders commented that this compliance rate might be high for the sector. An explanation for this might be that the sector is made up of distinct stages with differing levels of exposure. The first stage is the production of hard metal powder, and these powder-producing sites have the most difficulty in complying with the BOELs, which drives down the level of compliance in the sector compared to other broad uses. The second stage is the finalisation (e.g., grinding) of hard metals, which is a widespread branch of the sector with a higher number of sites and lower exposure. Stakeholders state that finalisation sites often have exposure levels in the range of 1 µg/m^3 to 20 µg/m^3 (and therefore a higher compliance rate with these BOELs) because the machines are typically enclosed, and the raw tool is constantly flushed with oil or water during the grinding process. This part of the sector increases the compliance rate within the sector.

The share of sites complying with a BOEL of 1 µg/m^3 varies more widely between the broad uses (see **Appendix Table 9**), with recycling and the manufacture of catalysts having the lowest level of compliance (0% sites comply) whilst the animal feed and adhesion sectors have the highest level of compliance (67% and 62% sites comply respectively). Stakeholder feedback from the adhesion sector stated that the level of compliance with a 1 µg/m^3 limit is significantly higher than what has been reported. As there are companies carrying out activities in multiple broad uses, including the adhesion sector, these are likely to have driven down the estimated compliance rate in the adhesion sector, even if the activities at particular sites are not linked to adhesion.

Conversely, the overlap between broad uses is likely to have driven up the level of compliance in the catalysts precursor sector. In the sector, 75% of sites are estimated to comply with a BOEL of 20 µg/m^3 and 50% of sites are estimated to comply with a BOEL of 10 µg/m^3 (see **Appendix Table 9**). However, stakeholder feedback noted that these are likely to be closer to 50% of sites and 25% sites complying, respectively.

Table 4.5: Share of sites that comply with each BOEL

BOEL	Share of sites that comply	% of sites directly or indirectly in scope that comply (based on questionnaire data)
30 µg/m^3	84%	81%
20 µg/m^3	78%	74%
10 µg/m^3	64%	57%

1 μg/m³	27%	14%

Table notes:

- The share of sites that comply with each BOEL has been estimated using respondent data.
- The share of sites directly or indirectly in scope comply is based on the number of sites complying that use substances within the scope of the analysis.

A previous cost benefit analysis on the restriction of cobalt salts (eftec, 2019a) found lower levels of compliance with a 30 μg/m³ limit value (~74% of sites) and higher levels of compliance with a 1 μg/m³ limit value (~39%) than those reported in **Table 4.5**. The scope of the study differed from the current assessment, in terms of the number of substances being assessed and therefore broad uses included in the assessment. For example, the previous cost benefit analysis (eftec, 2019a) did not include cemented carbide tools sector, which, as discussed above, includes production processes in which it is extremely difficult to reduce exposure to very low levels through engineering controls, and will always require the use of PPE. These sites are prone to higher exposure levels because the temperature of the process (iii) and the level of automation/encapsulation that is compatible with the process (iv).

4.4. Dose response and excess risk

4.4.1 Health endpoints

This analysis includes the three health endpoints assessed by the EC's contractor: lung cancer, restrictive lung disease, and respiratory irritation.

Cancer is a disease in which cells in the body grow out of control (CDC, 2022). **Lung cancers** usually are grouped into two main types called small cell and non-small cell (including adenocarcinoma and squamous cell carcinoma). Someone who has lung cancer may experience the following symptoms: coughing that gets worse or does not go away; chest pain; shortness of breath; wheezing; and, coughing up blood.

Respiratory irritants are substances which can cause inflammation or other adverse reactions in the respiratory system (lungs, nose, mouth, larynx and trachea) after being inhaled. Depending on the type and amount of irritant inhaled, patients can experience symptoms ranging from minor respiratory discomfort to acute airway and lung injury and even death (Patočka and Kuča, 2014). **Respiratory irritation** may result in severe burning and other manifestations of irritation of the eyes, nose, throat, trachea, and major bronchi. Permanent damage of the upper respiratory tract, distal airways, and lung parenchyma most likely occurs if repeated exposure occurs to a high enough exposure concentration (David W. Cugell et al., 1990; Mizutani et al., 2016; Patočka and Kuča, 2014).

Restrictive lung disease results in a decrease in the total volume of air that the lungs are able to hold (Johns Hopkins Medicine, 2023). This is often due to a decrease in the elasticity of the lungs themselves or caused by a problem related to the expansion of the chest wall during inhalation. Symptoms of restrictive lung disease also include coughing, shortness of breath, wheezing and chest pain. Restrictive lung diseases can be divided into two groups depending on the place of action: intrinsic lung diseases (diseases of the lung parenchyma like interstitial lung diseases and pneumonitis) and extrinsic diseases (extrapulmonary diseases involving for example the respiratory muscles) (Caronia et al., 2020).

4.4.2 Dose response functions

The dose-response functions used in this assessment are aligned with those used by the EC contractor, which are based on the RAC opinion and (Nemery et al., 1992). The functions used are set out in **Table 4.6**.

Table 4.6: Dose response functions for endpoints included in the impact assessment

Health endpoint	Excess risk (derived by COM contractor)
Cancer (respirable fraction)	Above 0.5 µg/m³ : 0.00106 x Exposure Concentration (Respirable - µg/m³)
	At and below 0.5 µg/m³ : 0.000105 x Exposure Concentration (Respirable - µg/m³)
Respiratory irritation (inhalable fraction)	Above and equal to 2.12 µg/m³ : 1.06 x Exposure Concentration (Inhalable - µg/m³) - 2.1233
Restrictive lung disease (inhalable fraction)	Above and equal to 5.30 µg/m³ : 0.52 x Exposure Concentration (Inhalable - µg/m³) – 2.7795

Table note: The dose response function for cancer has been derived by RAC, whilst the dose response functions for respiratory irritation and restrictive lung disease has been derived by the EC contractor.

4.4.3 Excess risk

Excess risk has been derived by combining the dose response functions set out in Section 4.4.2 with exposure estimates and the exposure distribution from Section 4.3.2. The exposure levels in **Table 4.2**, adjusted for PPE[54], were used to arrive at the excess risk levels for each of the exposure groups defined in **Table 4.3**. To derive an overall excess risk for each broad use, the weighted average (using the shares set out in **Table 4.3** as weights) across all exposure groups were calculated. **Figure 4.1** illustrates the approach used to estimate excess risk for each broad use.

[54] PPE adjustments were made by dividing the exposure levels by the respective APFs.

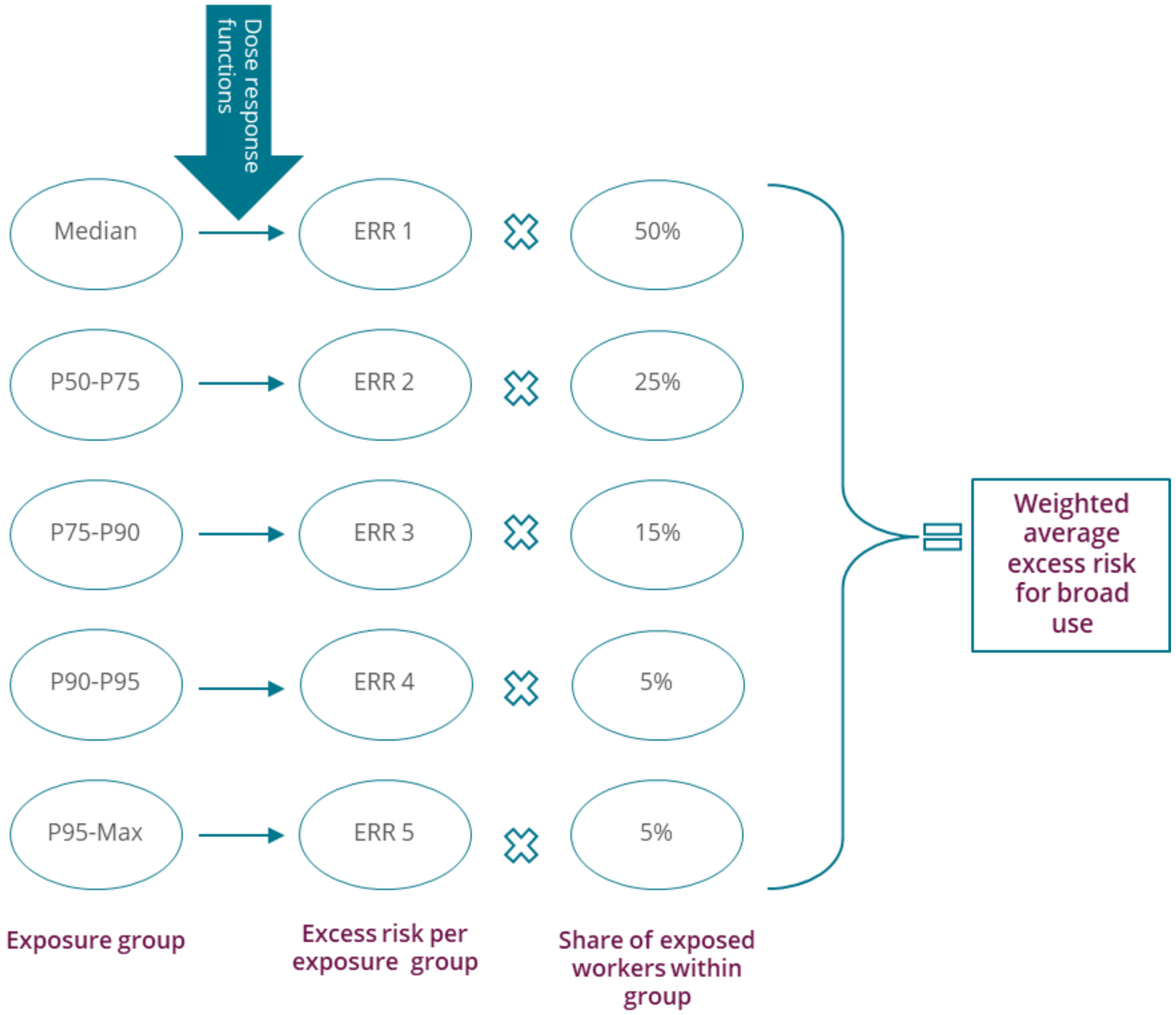

Figure 4.1: **Illustration of excess risk calculation**

The resulting excess risk estimates vary significantly between the broad uses, as can be seen in **Table 4.7**. At the lower end is use in humidity indicators and recycling, which have cancer risk in the order of magnitude of 10^{-6} and zero risk associated with other endpoints. At the other end, higher risks tend to be for respiratory irritation, with the highest (at 9.6% of exposed workers) being the use in metallurgical alloys. Looking at all uses collectively, the excess risks are in the range of 0.1% for lung cancer, 4.1% for respiratory irritation and 1.4% for restrictive lung disease. The large differences in excess risks mirror reflect the fact that it is more challenging to control exposure in some activities and some industries than other. Further details on the methodology used to derive these results can be found in Appendix A 1.4.

Table 4.7: **Baseline weighted average excess risk over 40 years, % of exposed workers by broad use**

Broad use	Cancer	Respiratory irritation	Restrictive lung disease
Manufacture of cobalt metal and/or cobalt substances	0.1%	4.4%	1.7%
Recycling of materials containing cobalt substances	0.0004%	0%	0%
Manufacture of other chemicals	0.03%	0.9%	0.2%
Manufacture of precursor chemicals for batteries	0.1%	4.2%	1.6%

Broad use	Cancer	Respiratory irritation	Restrictive lung disease
Manufacture of catalysts	0.0%	0.1%	0%
Manufacture of pigments and dyes	0.1%	2.2%	0.7%
Manufacture of driers / paints	0.1%	2.3%	0.8%
Use as catalysts - used as a catalyst or catalyst precursor	0.003%	0.1%	0%
Use as catalysts - used as oxidation catalyst/for PTA and IPA	0.1%	2.2%	0.8%
Use in surface treatment - Formulation of surface treatment	0.1%	2.7%	1.0%
Use in surface treatment - Passivation or anti-corrosion treatment processes	0.1%	2.5%	0.8%
Use in surface treatment - Metal or metal alloy plating	0.2%	5.6%	2.2%
Use in biotechnology – Formulation and industrial use of mixtures in biogas production	0.2%	5.8%	2.4%
Use in biotechnology – Professional use in biogas production	0.001%	0%	0%
Use in biotechnology – Use in fermentation, fertilizers, biotech, scientific research and standard analysis	0.1%	2.4%	0.9%
Use in biotechnology – Formulation and use in animal feed grade materials	0.1%	5.1%	2.1%
Bespoke uses – Use in humidity indicators cards, plugs and/or bags with printed spots	0.0004%	0.0%	0.0%
Bespoke uses – Formulation of water treatment chemicals, oxygen scavengers, corrosion inhibitors	0.1%	2.6%	1.0%
Bespoke uses – Use of water treatment chemicals, oxygen scavengers, corrosion inhibitors	0.1%	1.6%	0.3%
Adhesion (inc. rubber adhesion agent)	0.01%	0.5%	0.1%
Use in electronics	0.2%	5.8%	1.9%
Use in magnetic alloys	0.2%	5.8%	1.9%
Use in metallurgical alloys	0.3%	9.6%	3.7%
Use in cemented carbide/diamond tools	0.1%	3.2%	0.6%
Across all uses	**0.1%**	**4.1%**	**1.4%**

Table note: The excess risk estimates only relate to workers exposed, not the entire workforce.

4.5. Cost of inaction

Cost of inaction is defined as the costs incurred if now further action is taken, i.e., continuation of current health impacts if a BOEL is not introduced. The approach taken is deliberately conservative, to ensure that later estimates of benefits are not underestimated. This will lead to an overestimation of the number of cases associated with each endpoint both with and without a BOEL.

As shown in **Figure 4.2**, the starting point for estimating health impacts is the excess risk derived in Section 4.4 above. These are multiplied with the respective number of workers exposed for each broad use and each health endpoint to arrive at the number of cases for each health endpoint (Section 4.5.1). The cost of inaction (or disease burden) (in Section 4.5.3) is then derived by multiplying the number of additional cases with valuation factors (unit value of a case of a worker suffering a given illness), which are set out in Section 4.5.2.

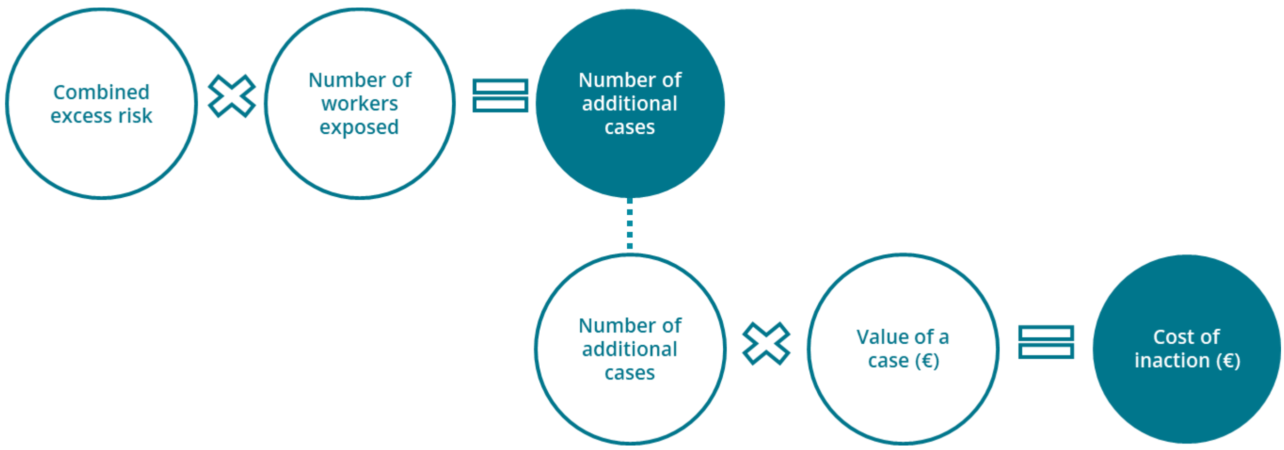

Figure 4.2: Approach to derive cost of inaction from each health endpoints

4.5.1 Number of cases

A conservative approach was applied when estimating the number of cases associated with each endpoint. It has been assumed that there is no staff turnover (i.e., the workers are exposed over 40-years), and the exposure is not reduced over time in the absence of an EU-wide BOEL. Furthermore, it has been assumed that maximum risks occur from year 1 for all endpoints. These are all highly conservative assumptions, which will lead to an overestimation of the number of cases associated with each health endpoint.

The number of workers is likely to increase over time, in particular for uses where there is rapidly increasing demand, such as for the battery sector. It has not been possible to find reliable estimates for the potential increase in the number of workers for each broad use. In the absence of this, we have applied a 25% increase of the number of workers as compared to the baseline. The number of workers exposed used for the estimation of number of cancer cases is thus 68,000 – 113,800.

As can be seen in **Table 4.8**, *Use in metallurgical alloys* is by far the largest contributor to the number of cases, comprising over 50% of the number of cases for each health endpoint. This is due to high exposure combined with a high number of workers exposed (~30% of total workers exposed are associated with this use). Other uses of concern are *Manufacture of cobalt metal and/or cobalt substances*, *Use in cemented carbide/diamond tools* and *Use in surface treatment - Metal or metal alloy plating*. These four uses together account for almost 80% of the total number of cases for each of the endpoints assessed.

Table 4.8: Baseline number of cases per broad use over 40 years

Broad use	Number of workers exposed	Cancer (No. cases)	Respiratory irritation (No. cases)	Restrictive lung disease (No. cases)	Average share of total cases (%)
Manufacture of cobalt metal and/or cobalt substances	10,000	12	435	168	9.6%
Recycling of materials containing cobalt substances	9,000	0.03	0	0	0.01%
Manufacture of other chemicals	3,000	1	27	7	0.5%
Manufacture of precursor chemicals for batteries	3,000	3	126	49	2.8%
Manufacture of catalysts	1,000	0.07	1	0	0.03%
Manufacture of pigments and dyes	3,000	2	67	21	1.4%
Manufacture of driers / paints	1,000	1	23	8	0.5%
Use as catalysts - used as a catalyst or catalyst precursor	1,000	0.03	1	0	0.01%
Use as catalysts - used as oxidation catalyst/for PTA and IPA	300	0.2	7	2	0.1%
Use in surface treatment - Formulation of surface treatment	300	0.2	8	3	0.2%
Use in surface treatment - Passivation or anti-corrosion treatment processes	7,000	5	172	57	3.6%
Use in surface treatment - Metal or metal alloy plating	6,000	9	338	133	7.5%
Use in biotechnology – Formulation and industrial use of mixtures in biogas production	1,000	2	58	24	1.3%
Use in biotechnology – Professional use in biogas production	6,000	0.1	0	0	0.02%
Use in biotechnology – Use in fermentation, fertilizers, biotech, scientific research and standard analysis	1,000	1	24	9	0.5%
Use in biotechnology – Formulation and use in animal feed grade materials	3,000	4	152	63	3.4%
Bespoke uses – Use in humidity indicators cards, plugs and/or bags with printed spots	100	0.0004	0	0	0.0001%

Bespoke uses – Formulation of water treatment chemicals, oxygen scavengers, corrosion inhibitors	2,000	1	53	19	1.1%
Bespoke uses – Use of water treatment chemicals, oxygen scavengers, corrosion inhibitors	100	0.1	2	0.3	0.03%
Adhesion (inc. rubber adhesion agent)	14,000	2	64	19	1.3%
Use in electronics	2,000	3	115	37	2.4%
Use in magnetic alloys	2,000	3	115	37	2.4%
Use in metallurgical alloys	26,000	68	2,499	951	54.3%
Use in cemented carbide/diamond tools	12,000	11	382	67	6.9%
Total – Upper bound	**113,800**	**130**	**4,669**	**1,673**	**100%**
Total – Lower bound	**68,900**	**78**	**2,825**	**1,012**	**100%**

Table notes:

- The estimated numbers of cases have been derived using highly conservative assumptions and are likely overestimated (see Appendix A 1.4).
- The share of total number of cases is an average of the shares across each endpoint.
- The estimates include overlap across broad uses, i.e., they represent an upper bound for the number of cases.
- Numbers of workers exposed are rounded to the nearest 100.

A summary of the number of cases across all broad uses is presented in **Table 4.9**, which includes both the lower and the upper bound reflecting the double counting of workers across the broad uses (see Appendix A 1.1 and Appendix A 1.4 for further explanation of methodology used and the potential for double-counting).

Table 4.9: Total number of cases, annual and over 40 years

Health endpoint	**Annual number of cases (cases/year)**		**Number of cases over 40 years (cases)**	
	Lower bound	Upper bound	Lower bound	Upper bound
Cancer	2.0	3.2	78	130
Respiratory irritation	71	117	2,825	4,669
Restrictive lung disease	25	42	1,012	1,673

Table notes:

- The estimated numbers of cases have been derived using highly conservative assumptions and are likely overestimated (see Appendix A 1.4).
- Values above 10 has been rounded to the nearest 1, and values below 10 are rounded to the first decimal.

4.5.2 Valuation factors

In order to monetise the number of cases associated with each health endpoint, a suitable set of valuation factors from the available literature is chosen, relevant to the health impacts from exposure to chemicals.

Lung cancer

Generic valuation factors for premature death and cancer morbidity were agreed by SEAC in 2017 (ECHA, 2017b), which are shown in **Table 4.10**. These form the basis for the valuation factors used in this assessment.

Table 4.10: Valuation factors adopted by SEAC

Health endpoint	Value (2012 €)	Value (2022 €)
Premature death - Low	3.5 million	4.2 million
Premature death – High	5.0 million	6.0 million
Cancer morbidity	410,000	490,000

Table note:

- 2012 values are from (ECHA, 2020a).
- Values above one million is rounded to the nearest 100,000, and values below one million are rounded to the nearest 10,000.

In the current assessment the relevant endpoint is lung cancer. To derive a composite value for lung cancer the approach in ECHA (2016) "Valuing selected health impacts of chemicals" has been used:

$$\begin{aligned}&WTP\ to\ avoid\ one\ cancer\ case\\&\qquad = (Fatality\ probability\ x\ Value\ of\ cancer\ mortality\\&\qquad + Value\ of\ a\ cancer\ morbidity)\ x\ dicount\ factor^{-latency}\end{aligned}$$

According to ECIS (2020), the fatality probability for lung cancer is 80%, and the latency of onset of cancer vary significantly between 10-50 years (Rushton et al., 2012). For this analysis, a latency period of 20 years has been assumed.

The valuation factors agreed by SEAC are composite factors taking into account a variety of potential impacts associated with cancer morbidity and fatalities. The values are based on an underlying willingness to pay (WTP) study: "Stated-preference study to examine the economic value of benefits of avoiding selected adverse human health outcomes due to exposure to chemicals in the European Union (ECHA, 2014). The survey underlying that study informed the respondent about potential consequences of getting cancer, including impact on normal activities, lack of ability to self-care, lack of ability to take care of others (e.g., children), missed work, pain, anxiety and more. This means that it is challenging to combine these valuation factors with other cost indicators (e.g., value of avoided sick-leave) without double-counting. The only aspect believed not to be covered by the WTP estimates are treatment costs, which for cancer can be substantial. A study from 2018 looking at the cost of cancer in Europe (Hofmarcher et al., 2020) found that of the €199 billion disease burden of cancer in Europe (including direct, indirect and intangible effects) around €32 billion was attributable to the cost of cancer drugs. This implies cancer treatment will comprise at least 16% of the total societal costs associated with cancer, which can be used to upscale the WTP estimates for the inclusion of treatment costs.

Combining the SEAC valuation factors, with lung cancer survival rate, a latency of 20 years and adding treatment costs result in the high and low values of a statistical lung cancer case shown in **Table 4.11**. The "central" value is an average of the high and the low values.

Table 4.11: Valuation factors for cancer cases

Type of cost	Value per case (PV, 2022 € million), adjusted for 20-year latency		
	Low	Central	High
WTP to avoid lung cancer	3.2	3.8	4.4
Treatment costs	0.6	0.7	0.9
Total cost of a lung cancer case	3.9	4.6	5.3

Table notes:

- The values take into account the lung cancer fatality rate of 80% (ECIS, 2020), and a latency of onset of 20 years.
- A 3% discount rate has been used to derive present values, and values are rounded to the nearest 100,000
- The values are given in 2022 €, and have been uplifted using GDP deflators from (World Bank, 2023)

Restrictive lung disease

There are no readily available valuation factors for "restrictive lung disease" resulting from cobalt exposure, so the chosen approach is based on proxy valuation factors linked to occupational asthma. It is not clear whether occupational asthma would be considered more or less severe than restrictive lung diseases from cobalt exposure, which makes it challenging to determine whether the lower or upper end of available valuation factors would be most appropriate. The chosen values for the "low" and the "high" factors therefore cover a broad range.

The "low" value for restrictive lung disease (using occupational asthma as a proxy) is taken from the SEAC opinion on the Annex XV dossier for diisocyanates (ECHA, 2018b). This value includes three components: the direct costs (therapy/medicine); indirect costs (sick leave days and lost income and productivity) and intangible costs (pain and suffering). It was chosen as the "low" value, as SEAC noted that some of the components of the valuation factor may have been underestimated. In eftec and wca (2015), which is based on the same underlying source, the reduction in earnings associated with occupational asthma was increased, resulting in a significantly higher valuation factor. This has been used in this assessment as the "high" value (see **Table 4.13**).

Table 4.12: Societal costs of occupational asthma

Type of cost	Cost driver	(ECHA, 2018b) **€/case/year (2014 €)**	(eftec, 2019b) **€/case/year (2018 €)**	(ECHA, 2018b) **€/case/year (2022 €)**	(eftec, 2019b) **€/case/year (2022 €)**
Direct	Therapy/medicine costs	1,764	1,865	2,049	2,074
Indirect costs	Disability (sick leave days - costs for the employer)	881	1,539	1,024	1,711
	Reduction in earning and value creation capacity (cost for the employee)	10,144	22,648	11,785	25,185
Intangible costs	Pain & suffering/ Welfare loss	1,800	1,903	2,091	2,116
Total per case		14,589	27,955	16,949	31,087

Table note: The values are given in 2022 €, and have been uplifted using GDP deflators from (World Bank, 2023)

It is considered unlikely that a person experiencing respiratory symptoms for an extended period of time due to occupational exposure to cobalt will continue his job as usual (i.e., without attempting to avoid the exposure through additional PPE or by finding a new job). However, to keep the analysis conservative, a total duration of the illness of 10 years (low) to 30 years (high) has been assumed. The resulting valuation factors used in this analysis is shown in **Table 4.13**.

Table 4.13: Valuation factors for restrictive lung disease

Health endpoint	Value € per case (PV, 2022 €)		
	Low	Central	High
Restrictive lung disease	149,500	403,100	656,800

Table notes:

- The values are given in 2022 €, and have been uplifted using GDP deflators from (World Bank, 2023)
- The valuation factors have been rounded to the nearest €100.

Respiratory irritation

Most of the studies valuing respiratory illnesses are linked to more severe disease states, such as asthma and other chronic diseases, hence applying such values to respiratory irritation will significantly overestimate the impacts. The symptoms may be similar but milder and are therefore likely to lead lower direct (costs of medication), indirect (sick-leave and lost income) and intangible (pain and discomfort) costs than more severe illnesses. In the absence of valuation factors that can be used as a reasonable proxy and lack of information on the relative severity of these illnesses, it has been assumed that respiratory irritation can be valued at 25% of restrictive lung disease, i.e., restrictive lung disease is 4 times worse than respiratory irritation. The resulting values used in this analysis are presented in **Table 4.14**.

Table 4.14: Valuation factors for respiratory irritation

Health endpoint	Value € per case (PV, 2022 €)		
	Low	Central	High
Respiratory irritation	37,400	100,800	164,200

Table notes:

- The values are given in 2022 €.
- The valuation factors have been rounded to the nearest €100.

4.5.3 Monetising health effects of inaction

As illustrated in Figure 4.2, the monetised health impacts were estimated by multiplying the number of cases derived in **Table 4.9** with their respective “central” valuation factors from Section 4.5.2. The resulting cost of inaction (i.e., impacts occurring with no EU-wide BOEL) shown in **Table 4.15** is in the range of €12 - €19 million per year, and around €460– €770 million over 40 years. Further details on the methodology used can be found in Appendix A 1.4, and results when using the low and the high valuation factors are presented in the sensitivity analysis in Section 12.5.2.

Table 4.15: Monetised health impacts with no EU-wide BOEL – Cost of inaction

Health endpoint	Annual human health impacts (PV € million/year)		Human health impacts over 40 years (PV € million)	
	Lower bound	Upper bound	Lower bound	Upper bound
Cancer	3.0	5.0	122	202
Respiratory irritation	3.5	5.9	142	234
Restrictive lung disease	5.1	8.4	203	335
Total	**12**	**19**	**466**	**771**

Table notes:

- The lower and upper bound correspond to the lower and upper bound number of workers exposed.
- The total present values (i.e., sum of discounted future costs) were derived using a 3% discount rate and are given in 2022 €.
- Values below € 10 million are rounded to the nearest €100,000, and values above are rounded to the nearest million.

5. Availability of alternatives

5.1. Introduction

Information on the availability of alternatives is essential when assessing the potential substitution of a substance. The information presented here is primarily based on the responses to the industry questionnaire (eftec, 2023) and subsequent stakeholder engagement.

It is not possible to substitute cobalt from the process of manufacturing cobalt metal and/or cobalt substances. As for recyclers substitution is not logical as cobalt cannot be substituted when recycling cobalt-containing substances. As such, the eftec (2023) respondent data refers to downstream user broad uses. Also, as noted in Section 3.2.3, cobalt is a critical raw material (CRM) and as such, is difficult to substitute (when compared to other non-CRM substances).

As stated in Section 3.4, cobalt substances serve different functions depending on the broad (and specific) use(s). There could be substitutes for some of these functions or uses but not others. In order for an alternative substance (or process) to be viewed as a suitable substitute, it needs to be able to provide similar technical functions (i.e., performance) as the potentially substituted substance, has acceptable substitution costs, be available in sufficient quantity to replace the potentially substituted substance, and not have a worse hazard profile (i.e., increase risks). This section explores the role of R&D in developing alternatives (Section 5.2), technical feasibility of alternatives (Section 5.3); availability of alternatives (Section 5.4), barriers and time required to substitute (Section 5.5), and risks/hazards associated with alternatives (Section 5.6).

A full Assessment of Alternatives (AoA) includes an economic feasibility analysis which is not within the scope of this assessment. Instead, the costs associated with substitution are discussed in sub-section "Substitution" of each Policy Option chapter (i.e., 7.4.1, 8.4.1, 9.4.1 and 10.4.1).

5.2. Research and Development (R&D)

Respondents to eftec's 2023 questionnaire were asked about their efforts to substitute cobalt substances and substitution activities including R&D. **Table 5.1** details different R&D programmes by broad use and cobalt substance, description of the R&D and whether the substitution attempt was successful or not.

Table 5.1: Cobalt substances that have undergone R&D and, substitution description, by broad use (Respondent data)

Broad use	Cobalt substance	Description of R&D	Was the substitution attempt successful?
Adhesion (incl. rubber adhesion)	• Cobalt carboxylates	• Laboratory-scale R&D was completed. • Despite some progress, no substance that can completely replace cobalt has been found.	Partially successful
Manufacture of pigments and dyes	• Cobalt chromite blue green spinel • Cobalt zinc aluminate blue spinel • Cobalt aluminate blue spinel	• Replacement of cobalt in some sectors where the specific shade provided by cobalt is not necessary (e.g., paint, plastic, and cement). • The same level of durability and resistance in the pigment could not be achieved without using cobalt.	Partially successful
Manufacture of pigments and dyes	• Tricobalt tetraoxide • Cobalt lithium dioxide	• Substitution of cobalt with other metallic elements was attempted. • Complete substitution is not possible; however, a partial reduction can be achieved by incorporating nickel. • It was not possible to reduce colour.	Partially successful
Use in biotechnology – Formulation and use in animal feed grade materials	• Cobalt carbonate	• Substitution of cobalt with other additives or feed material sources of cobalamin was attempted.	Unsuccessful
Use in cemented carbide/ diamond tools	• Cobalt metal	• Experimenting with combinations based on iron alloys with standard additions was attempted. • However, some of these alloys still had cobalt as a component (at approx. 15%). • The window of application for the iron alloy mixtures is smaller compared to cobalt-based alloys.	Partially successful
Use in cemented carbide/ diamond tools	• Cobalt metal	• Attempted to use a cobalt and nickel free binder as an alternative to cobalt-containing binder.	Partially successful
Use in cemented carbide/ diamond tools	• Cobalt metal	• The focus was on replacing cobalt with different materials such as iron, nickel, steel, and high entropy alloys.	Unsuccessful
Use in cemented carbide/ diamond tools	• Cobalt metal	• Development of cobalt and nickel free cemented carbides was attempted.	Unsuccessful

Broad use	Cobalt substance	Description of R&D	Was the substitution attempt successful?
Use in cemented carbide/ diamond tools	• Cobalt metal	• Laboratory-scale joint research projects with institutes and universities were attempted.	Unsuccessful
Use in cemented carbide/ diamond tools	• Cobalt metal	• Laboratory-scale R&D and prototypes; research on alternatives was attempted.	Unsuccessful
Use in cemented carbide/ diamond tools	• Cobalt metal	• Field tests based on laboratory-scale tests was attempted.	Partially successful
Use in cemented carbide/ diamond tools	• Cobalt metal	• Experimenting with recipes to replace cobalt powder. Key focus was to find the optimal balance between cutting abilities, diamond retention, laser weldability, and tool wear.	Unsuccessful
Use in cemented carbide/ diamond tools	• Cobalt metal	• Testing new complex alloys as alternative binders. • Works performed both in external and internal projects.	Unsuccessful
Use in cemented carbide/ diamond tools	• Cobalt metal	• Attempts to use a metallurgical alloy to replace cobalt metal in abrasive products.	Partially successful
Use in cemented carbide/ diamond tools	• Cobalt metal	• Attempts to find cobalt-free alternatives for the bonds.	Partially successful
Use in cemented carbide/ diamond tools	• Cobalt metal	• Experimenting with various binders for hard metal products.	Unsuccessful
Use in cemented carbide/ diamond tools	• Cobalt metal	• Attempts to use an alternative material for mechanical strength.	Unsuccessful
Use in cemented carbide/ diamond tools	• Cobalt metal	• Using iron as a binder instead of cobalt was attempted.	Partially successful
Use in metallurgical alloys	• Cobalt metal	• Testing with cobalt-free powder.	Unsuccessful
Use in metallurgical alloys	• Cobalt metal	• Testing with molybdenum alloys.	Partially successful
Use in metallurgical alloys	• Cobalt metal	• New alloy designs were assessed.	Unsuccessful
Use in metallurgical alloys	• Cobalt metal	• Attempts to use different binders for wear resistant materials.	Unsuccessful

Broad use	Cobalt substance	Description of R&D	Was the substitution attempt successful?
Use in surface treatment - Formulation of surface treatment	• Cobalt sulphate	• Substitute cobalt sulphate with different inorganic substances. • This substitution results in a significant reduction in corrosion protection.	Unsuccessful
Use in surface treatment - Metal or metal alloy plating	• Cobalt hydroxide oxide • Cobalt sulphate	• Replacement of cobalt with iron was attempted.	Unsuccessful
Use in surface treatment - Passivation or anti-corrosion treatment processes	• Cobalt dinitrate	• Laboratory-scale R&D was attempted. • Cobalt free alternatives exist however, the high demands of the automotive industry could not be achieved.	Partially successful
Use in surface treatment – Passivation or anti-corrosion treatment processes	• Cobalt sulphate	• Attempts to replace cobalt sulphate with other inorganic substances. • While being possible in principle, this approach results in a significant reduction in corrosion protection.	Partially successful
Use in surface treatment – Passivation or anti-corrosion treatment processes	• Cobalt dinitrate	• Laboratory-scale R&D was attempted. • Some cobalt-free alternatives for passivating zinc nickel (ZnNi) show potential.	Partially successful

As presented in **Table 5.1**, of the 27 R&D efforts described by respondents, none was completely successful in identifying a viable alternative that can substitute cobalt. There is no single substance that can replace cobalt in all its applications; each application requires undertaking dedicated R&D projects to find suitable alternatives. This is occurring in a number of broad use sectors; for example, in the manufacture of precursor chemicals for batteries broad use, cobalt oxide concentration is decreased by increasing nickel and manganese concentration. Similarly, in the adhesion sector, efforts have been made to replace cobalt dihydroxide (used in the manufacture of organic[2] cobalt compounds, such as cobalt carboxylates) with non-carcinogenic organic[2] cobalt salts which are required to manufacture the organic[2] cobalt compounds, such as cobalt carboxylates, that are used in tyres and other rubber articles.

Approximately half of these attempts were noted as "partially successful" indicating that progress was made, but complete substitution was not possible. Cobalt's unique properties make it impossible to replace it in certain applications. An example is the animal feed sector reporting that their feed products need cobalt metal (a component of cobalamin and hence an essential trace element) which cannot be substituted. Another example is cobalt metal being used as a binder material in cemented carbide / diamond tools which has been the subject of several decades of R&D and a like-for-like alternative is still not found. Furthermore, most of the R&D activities that are still being carried out are only at the laboratory-scale stage, which shows that a sufficiently suitable alternative is still far from field tests and upscaling. Technical feasibility of alternatives is further discussed in Section 5.3 below.

5.3. Technical feasibility

This section discusses the technical feasibility of potential alternatives to the use of cobalt metal and/or cobalt substances, again based mostly on the responses to the industry questionnaire (eftec, 2023). **Figure 5.1** shows the percentage of respondents who answered whether they know of any cobalt alternatives on the market that their competitors use. The figure demonstrates that 34% of respondents were aware of such alternatives being used by competitors in the EU-27 market, However, it is not known whether such alternatives provide equivalent or inferior performance and hence whether they are viable for a number of uses identified in this report. 66% of respondents stated that there were no alternatives used in Europe for their respective broad use(s).

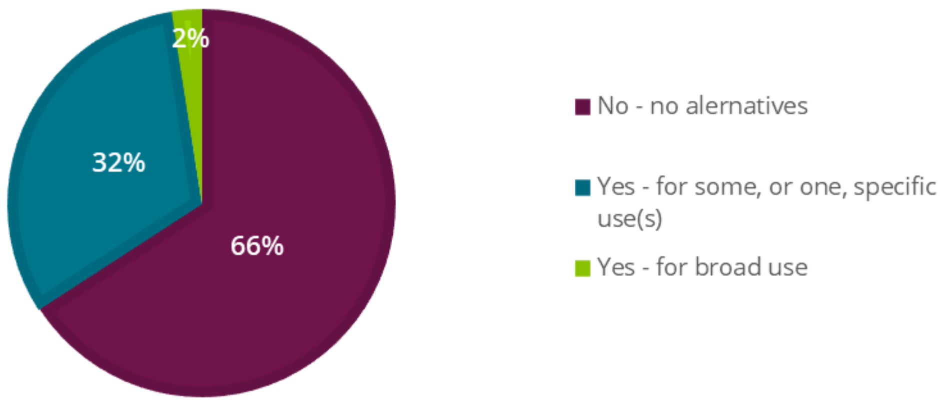

Figure 5.1: Are there any known alternatives on the market that competitors use instead of cobalt? (Respondent data)

Source: (eftec, 2023)

Respondents were asked what are the differences between the use of cobalt metal and/or cobalt substances and potential alternatives that are available on the European market. **Table 5.2** details potential alternatives for specific uses and functionality differences by broad use based on eftec's (2023) questionnaire responses.

As the table shows, respondents in eftec's (2023) questionnaire were clear there are no like-for-like (or "drop-in") alternatives for cobalt metal and cobalt substances that can be used throughout broad uses (or even within one broad use). This is because there are functional differences (e.g., chem-phys characteristics) that cobalt exhibits that other substances cannot. Furthermore, cobalt provides a combination of properties, which make substitution a more challenging endeavour.

In addition, RPA (2022) stated that there were few opportunities to substitute cobalt with other substances in most of its uses (for the short to medium term). Where the opportunity to substitute cobalt exists, there tends to be a shortcoming; for example, reduced quality of the final product (e.g., inferior corrosion resistance), hazard profile of substance (e.g., nickel having a carcinogen hazard classification) or raw material cost (e.g., ruthenium costing approximately 400 times cobalt metal). More details on the primary functions that cobalt exhibits can be found in Section 3.4.

According to eftec's (2023) potential alternatives were identified for the following broad uses:

- Manufacture of catalysts;
- Manufacture of pigments and dyes;
- Use in cemented carbide / diamond tools;
- Use in metallurgical alloys, and
- Use in surface treatment (metal or metal alloy plating).

Respondents in eftec's (2023) questionnaire noted the following substances as potential alternatives: iron, nickel, ruthenium, precious metals, vanadium pentoxide, molybdenum, and sulphate. Additionally, for the manufacture of precursor chemicals for batteries lithium-based (cobalt-free) battery chemistries are assessed.

Table 5.2: Alternatives for specific uses and functionality differences by broad use (Respondent data)

Broad use	Specific use	Alternative	Functionality difference
Manufacture of catalysts	Fischer-Tropsch catalysts	• Iron catalysts	• Catalytic activity is significantly lower than cobalt. • This results in higher quantities of the iron-containing catalyst being required. Additionally, CO_2 emissions from the DSU process[55] are higher.
Manufacture of catalysts	Reduction catalysis	• Ruthenium catalysts • Precious metal catalysts	• Raw material cost • Availability of substances (i.e., ruthenium and other precious metals)
Manufacture of catalysts	Promotor in ammonia synthesis catalysts	• Nickel catalysts	• Hazard profile(s) of substance(s). • Quality of final product.
Manufacture of catalysts	Fischer-Tropsch catalysts	• Vanadium pentoxide (as alternative promotor)	• Hazard profile(s) of substance(s). • Environmental impact of substance.
Manufacture of pigments and dyes	Manufacture of inks	• Nickel compounds	• Hazard profile(s) of substance(s). • Raw material cost. • Quality of final product.
Use in cemented carbide / diamond tool	Manufacture of metal bonds based on cobalt to grind, cut and drill natural stone, concrete, glass, ceramic, etc.	• Iron alloy materials	• Quality of final product - replacing cobalt with iron leads to a reduction of strength.
Use in cemented carbide / diamond tools	Manufacture of cemented carbides (as wear parts) and diamond tools	• Nickel (use as binder) • Iron (use as binder)	• Quality of final product • Hazard profile(s) of the substance(s) (Nickel powder is carcinogen cat. 2.) • The use of nickel instead of cobalt generates more scrap because the production process is more difficult to control as it cannot be checked with non- destructive tests.
Use in metallurgical alloys	Manufacture of cobalt alloy from cobalt metal and other substance	• Other metal alloy without cobalt	• Hazard profile(s) of substance(s). • Raw material cost. • Quality of final product.

[55] The DSU process is a disruptive approach for removing sulphur and metals from heavy oil (Field Upgrading Ltd., 2023).

Broad use	Specific use	Alternative	Functionality difference
Use in metallurgical alloys	Use for heat resistance	• Molybdenum	• Raw material cost.
Use in metallurgical alloys	Binder in wear resistant powders	• Nickel • Iron	• Quality of final product • Hazard profile(s) of the substance(s) (Nickel powder is carcinogen cat. 2.)
Use in surface treatment - Metal or metal alloy plating	Black chromating	• Sulphate	• No difference was found.

Table 5.2 above, presents alternatives for specific uses and functionality differences by broad use based on eftec's (2023) questionnaire responses. The following text is information obtained through desk-based research (where possible, combined with feedback from the industry) which evaluates the technical feasibility of alternatives for the use of cobalt metal and cobalt substances in different broad use applications.

Manufacture of precursor chemicals for batteries

Cobalt is used in lithium-ion (Li-ion) batteries, such as NMC and NCA batteries, to minimise the degradation of the cathode structure. For other cobalt containing-batteries chemistries, such as LCO batteries, cobalt increases the battery life and energy density[35] (Dragonfly Energy, 2022). Cobalt is also used in the manufacturing process of rechargeable Nickel-Cadmium (Ni-Cd) and Nickel-Metal Hydride (Ni-MH) batteries to improve the oxidation of nickel in the battery. In the Ni-MH batteries, cobalt alloys enhance the cells' lifespan by increasing hydride thermodynamic stability and inhibiting corrosion (eftec and wca, 2015). The use of cobalt in these batteries allows them to charge more quickly and hold charge for a longer period.

According to eftec (2021) and RPA (2022) there are no cobalt-free battery chemistries that provide the same performance as LCO batteries in PEDs. However, for battery chemistries that are used in EVs, such as NMC and NCA batteries, there are ongoing efforts to develop alternative battery chemistries which are cobalt-free. An example of this is lithium iron phosphate (LFP) cathodes. Although LFP batteries are a viable cobalt-free alternative according to certain metrics, such as greater durability, safety (i.e., a low thermal runaway), and longer lifespans, they also have a lower energy density. As they are used in EVs, which require a higher energy density to achieve longer driving ranges, this is a notable shortcoming. Also, as LFP batteries primarily contain cheap materials (e.g., iron and phosphate), stakeholders noted that they are not widely recycled, meaning that they are less environmentally friendly than cobalt-containing battery chemistries. Consequently, cobalt-containing battery chemistries such as NMC and NCA batteries remain popular due to their stability, durability and high-power density.

eftec & wca (2015) stated that there are cobalt-free lithium nickel oxide ($LiNiO_2$) and lithium manganese dioxide ($LiMn_2O$) battery chemistries on the market. However, these manganese- or nickel-based alternatives were initially developed when cobalt prices were higher and exhibit reduced performance compared to equivalent cobalt-containing battery chemistries. This notwithstanding, the use of these cobalt-free alternative battery chemistries can provide extended battery life and increased autonomy for mobile systems, and due to their lighter weight, they can be easily integrated into compact and lightweight systems.

Manufacture and use of catalysts

Cobalt has numerous catalytic applications (see Sections 3.3.5, 3.3.6, and 3.4.1). Cobalt plays an important role in the production of Fischer-Tropsch catalysts that facilitate the conversion of natural gas to synthetic hydrocarbon fuels through the Gas-to-Liquid (GTL) reaction (Jeske et al., 2021). The Fischer-Tropsch catalysts used commercially are either cobalt or iron-based. Cobalt-containing and iron-containing catalysts result in different hydrocarbon products, but the hydrocarbon distribution is primarily driven by the choice of operating temperature. At 200-240°C a cobalt-containing catalyst has higher selectivity for heavier hydrocarbons than an iron-containing catalyst (DHI, 2018). Iron is relatively low cost and suitable for a low hydrogen/carbon monoxide ratio in a fixed-bed operation as in coal gasification. Iron catalysts typically contain a number of promoters, including 1-5% potassium and 1-5% copper, as well as silica as binder (DHI, 2018). Cobalt is preferred over iron for this application as it has a longer active life, and the resulting catalysts are mechanically much stronger (RPA, 2022).

Cobalt is also more cost effective than iron as the lifetime of iron-based catalyst is shorter, measured in months rather than cobalt catalysts which generally last for 2-5 years and can be regenerated (DHI, 2018). Moreover, for iron catalysts, larger quantities of the catalyst are needed as the activity of iron catalysts is significantly lower than that of cobalt. Lastly, cobalt can tolerate higher water levels (compared to iron), and reactors can operate at higher conversion levels, thus increasing reactor capacity (DHI, 2018). It is also important to note that the use of cobalt leads to less CO_2 emissions as it is more energy efficient. GTL catalysts cause part of the carbon to be discarded as CO_2; with a cobalt catalyst, the reaction only produces water as a by-product thus has a lower CO_2 footprint than iron catalysts (DHI, 2018).

Other alternatives include:

- Nickel (RPA, 2022) – however, nickel catalysts are less selective than cobalt catalysts which lead to lower quality of the final product. Moreover, nickel exhibits similar health and environmental impacts as cobalt.
- Ruthenium (DHI, 2018; eftec, 2023) – Ruthenium is the most active of the Fischer-Tropsch catalysts. It operates at the lowest reaction temperatures, and it produces the highest molecular weight hydrocarbons. However, it is currently 400 times more expensive than cobalt and there is not enough ruthenium available in Europe to satisfy the tonnages required.
- Other Platinum Group Metals (excluding ruthenium) - however, they are also scarce and significantly more expensive than cobalt.
- Vanadium pentoxide - however, it has a worse hazard profile than cobalt.

Similar to Fischer-Tropsch catalysts, there is no known alternative to cobalt diacetate for the use used as a catalyst or catalyst precursor in the hydroformylation process known as oxo synthesis or oxo process. Research on cobalt-free alternatives found other substances to be non-viable as they lead to products with different, undesired properties (eftec, 2018).

In summary, alternatives exist but they are less active and/or less specific/selective. Substitution will generally reduce production capacities and lead to lower quality products. While this may be compensated by modifications or reconstruction of existing production facilities, this will dramatically increase production costs. Thus, such substitution will impact the profitability and environmental performance of the facilities negatively (DHI, 2018).

Manufacture of pigments and dyes

Cobalt (primarily cobalt oxide and tricobalt tetroxide) is used in the manufacture of pigments and dyes mainly for ceramics and glass, but also in artistic paints, inks, digital printing and plastics (eftec & wca, 2015) (see Sections 3.3.3 and 3.4.9). Cobalt pigments include (but are not limited to) the following colours: blue, yellow and green (of various shades) (Kremer Pigmente, 2023).

According to RPA (2022) some organic and inorganic alternatives already exist (e.g., titanium dioxide, carbon, calcium's, and iron oxide) some showing better performance than cobalt in certain applications. According to eftec (2023) nickel compounds can be used instead of cobalt in ink manufacture, but nickel compounds have a worse hazard profile than cobalt, and the quality of the final product does not match that of cobalt inks.

There are no alternatives to cobalt that meet the requirements for some specialist uses where the exact colour is necessary, a specific technical function is required (e.g., solubility and stability of the cobalt-containing colourant), and where cultural significance is attached to cobalt blue (eftec, 2021). In some instances, speciality durable (i.e., long lasting) pigments are manufactured with cobalt oxide as cobalt's other characteristics such as corrosion and temperature resistance are beneficial (see Sections 3.4.8 and 3.4.10). RPA (2022) also noted that there is currently also no feasible alternative to cobalt for digital printing.

Manufacture of driers and paints

There are alternatives to cobalt dryers such as lead, manganese, iron, zirconium and calcium. However, these are not viable alternatives, as they either have a worse hazard profile or do not provide the same level of performance or cost-effectiveness (RPA 2022; RPA 2020). For instance, lead driers lead to the loss of flexibility and darkening and have a worse hazard profile than cobalt. Manganese and iron driers also lead to loss of flexibility and are not suitable for use in certain types of coatings, such as those that are sensitive to discoloration or that require a fast-drying time.

Use in surface treatment

Cobalt alloy coatings provide several advantages to the coated material, including corrosion and wear resistance, high temperature resistance, magnetic properties, and low friction. Cobalt is considered essential for passivation and anti-corrosion coatings if corrosion protection is required in warm or hot environments. The formation of a passive oxide layer on the surface of cobalt (when exposed to oxygen or other oxidising agents) acts as a protective barrier against further corrosion by preventing the diffusion of corrosive species into the underlying metal (Atkins et al., 2016). The passive oxide layer can also "self-heal" in the presence of oxygen, which further enhances the corrosion resistance of cobalt metal and its alloys (see Section 3.4.3).

In eftec (2018) it is stated that, whilst there may be technologies discussed as potential alternatives, they often show drawbacks in corrosion resistance, electrical conductivity, noise emission, contact corrosion, wear resistance, resistance against chemicals and others. In particular, for articles with final heat treatment (annealing) process there is no applicable cobalt-free technology with similar properties. While some cobalt salts are interchangeable for use in passivation, alternative non-cobalt metals do not have the same level of corrosion resistance and/or are often not economically viable substitutes (eftec and wca, 2015). Moreover, there are currently no alternatives to cobalt in surface treatment applications where there are high end performance requirements for corrosion protection and resistance to high temperatures (e.g., aerospace and defence applications) (wca, 2012; eftec 2018). RPA (2020) noted that there are no alternatives to the use of cobalt in gold plating, especially in medical devices, because of cobalt's biocompatible properties.

eftec (2021) stated that substitution in coatings is feasible for some markets depending on the specific properties and requirements of the coating. For instance, it is noted in the eftec (2023) that sulphate can serve as an alternative to cobalt for black chromating. By increasing the concentration of sulphate in the process bath, the addition of cobalt can be eliminated with no noticeable difference in the final product. However, it is also noted that this substitution method is only applicable to processes where cobalt is solely used for decorative purposes, such as providing a certain colour or appearance. In other applications where cobalt provides a specific functionality, such as corrosion resistance, no viable substitutes have been found yet. On a separate note, eftec and wca (2015) added that using alternative metals would require a complete process change and end-product re-qualification, resulting in significant time and cost burdens that may ultimately affect the price of the end product.

Use in biotechnology - Formulation and use in animal feed grade materials

Cobalt is used in the animal feed sector due to its essential function in vitamin B12 (eftec and wca, 2015) (see Sections 3.3.8 and 3.4.6). Cobalt sulphate, cobalt dichloride, cobalt diacetate, and cobalt carbonate are added to animal feed pre-mixtures as supplementation to diets for ruminants, horses, and rabbits (ECHA, 2022b). Within the feed supply chain cobalt is present in four stages of preparation: chemical preparation, the formulation of premixes, the development of compound feed, and end-use by farmers (RPA, 2022).

There is no alternative to the supplementation of feed with cobalt for ruminants, horses and animal species with hindgut fermentation (rabbits) as cobalt is an essential component for the synthesis of vitamin B12 by these animals. That being said, according to the European Food Safety Authorities (EFSA) only animals with the capacity of synthesising vitamin B12 in the intestinal tract like ruminants, horses and rabbits can utilise cobalt and there is no need for cobalt supplementation of feed for other animals (European Food Safety Authority (EFSA), 2009).

Bespoke uses

Cobalt dichloride is used in humidity indicators because it has the property of changing colour at differing humidity levels (ECHA, 2017a) (see Section 3.3.9). Humidity indicators are widely used in the military, aerospace and electronics/semi-conductor industries to indicate the presence of moisture that could adversely affect the operation of the devices or materials. While there are known cobalt-free alternatives available on the market, cobalt containing humidity indicators are the only ones that meet the specific sensitivity requirements for military and aerospace applications (eftec, 2018).

Adhesion

Cobalt substances are widely used in the tyre industry as bonding agents between rubber and steel cord (including bead wires[20]). Cobalt improves the bonding of rubber to steel in steel-belted radial tyres and steel-reinforced conveyor belts and hoses (Mandal et al., 2005). Cobalt carboxylates provide a highly rubber-soluble form of cobalt that serves as a chemical adhesive, bonding with sulphur in both the vulcanised rubber[21] and the sulphided brass coating of steel (eftec and wca, 2016). eftec (2023) noted that cobalt substances are vital for adequate steel cord adhesion, and crucial for the production of steel cord conveyor belts (see Section 3.3.10). Despite substantial substitution efforts, cobalt-free alternatives have failed to match the performance standards of cobalt-containing materials. Products made using cobalt alternatives were only usable at lower speeds and had a shorter lifespan, making them unsuitable for use in high-speed or high-performance applications (RPA, 2022).

Similar to their use in the tyre sector, cobalt substances are used as adhesion promoters in the construction of conveyor belts and hoses. There is currently no suitable alternative to cobalt for this process (RPA, 2022).

Use in magnetic alloys

Cobalt metal is used in magnetic alloys due to its strong magnetic properties. Cobalt is one of the three naturally occurring magnetic metals (iron and nickel being the other two) and has the highest Curie Point[24] of all metals, i.e., retains its magnetism at a higher temperature (1100°C) than any other metal (eftec and wca, 2015) (see Sections 3.3.12 and 3.4.7). While some alternatives are available such as iron, nickel, and rare-earth metals such as neodymium and samarium, these alternatives lack the same functionality as cobalt-based alloys (eftec, 2021).

Use in cemented carbide / diamond tools

Cobalt is commonly used in the production of diamond/hard metal tools as one of the primary metal hardening substances (RPA, 2020). Cobalt is used as a binder in the production of cemented carbide and tungsten carbide; the carbide material in isolation is brittle but with the addition of cobalt (in powder form) the material's resistance to wear, hardness, and mechanical strength increases – which is required for cutting tools, machine tools, engine components and other industrial applications (see Section 3.3.14).

Feedback received through the industry questionnaire stated that while alternative substances are feasible for diamond tool use, cobalt cannot be replaced in hard metal use. The diamond tool industry has viable alternatives to the use of cobalt as a binder such as iron or bronze which are already in use in Europe. However, the diamond tools that do not use cobalt are of inferior quality. This is because diamond is attracted by iron and its strength is reduced; therefore, iron alloys tend to need higher temperatures to achieve full density. Previously, when diamonds were more expensive, it was important to extend the lifetime of the diamond tool and use cobalt (as a superior binder) to ensure it. However, during consultations, the industry explained that nowadays diamonds are cheaper so buying two cheaper diamond tools is better than buying one more expensive one. As diamonds are far cheaper, it is the cobalt which is making them more expensive and a candidate for substitution. That being said, RPA (2022) noted that increased use of alternative binders is likely to reduce cobalt recycling because the concentration of cobalt in the scrap is lower.

On the other hand, as mentioned above, there are no suitable alternatives to cobalt for hard metal applications. Hard metal use is related to a unique intrinsic property of metallic cobalt related to the chemical dissolution of tungsten and carbon forming a eutectic point in their ternary phase diagram. Cobalt ensures a full wettability of tungsten carbide which makes substitution physio-chemically possible. During 100 years of R&D and industrial experience, cobalt appears as the unique binder metal providing the required chemical and physical properties. The alternatives to cobalt for this use do not often meet the customer's requirements and the process is more complicated.

5.4. Availability

The role of assessing availability in an AoA is to ensure that there is sufficient quantity of the alternative substance(s) that will be used to replace the hazardous substance in question.

Cobalt metal and cobalt substances are extensively used in the EU-27 as detailed in Sections 3.2.1 and 3.8.2. For some specific uses, where inferior performance is acceptable, nickel and iron can be used instead of cobalt. These are present in large volumes in the EU-27, so would be sufficiently available. Cobalt-free lithium-based battery chemistries are also available in sufficient quantities in Europe. However, for the specific use of replacing cobalt in Fischer-Tropsch catalysts, ruthenium is a technically feasible alternative but is not available in Europe in sufficient tonnages.

5.5. Barriers and time required to substitute

The information provided in this section is based on the industry questionnaire (eftec, 2023). Respondents were asked about what barriers were most relevant to preventing substitution. **Table 5.3** details barriers to substitution by broad use category. Two most common barriers were lack of known alternatives and inferior performance of alternatives, reiterating that viable alternatives (that can reproduce the same technical function as cobalt) are not available.

Table 5.3: Barriers to substitution by broad use

Broad use	Type of barrier												
	Lack of R&D funds	Lack of funds required to change production process	Lack of known alternatives	Inferior performance of alternatives	Cost of possible alternatives	Availability of possible alternatives	Human health risks of possible alternatives	Environmental risks of possible alternatives	Customer acceptance to use alternative	Regulatory barrier	Product approval time/ requirements	Other technical	Other barriers
Manufacture of other chemicals	□		■		□	□					□		□
Manufacture of precursor chemicals for batteries				□	□	□			□				
Manufacture of catalysts					□		■	□					
Manufacture of pigments and dyes	□		■	■	■	□			□		□	□	□
Use as catalyst					□		■	□					
Use in surface treatment	□		■	□	■	□	■	□	■		□		
Formulation and use in animal feed			□		□					■		□	□
Use in humidity indicators cards						□							
Formulation of water treatment chemicals				□	□								
Adhesion (incl. rubber adhesion)			■			□			□		□	□	
Use in magnetic alloys												■	
Use in metallurgical alloys	□		■	■	■				■		□	■	□
Use in cemented carbide/ diamond tools	■	■	■	■	■	■			■		■	■	

Table note: □ one stakeholder ■ more than one stakeholder

The barriers listed in **Table 5.3** can be grouped based on whether they are:

- **technical** (lack of known alternatives; inferior performance of alternatives, availability of possible alternatives; other technical);
- **economic** (lack of R&D funds; lack of funds required to production process; cost of possible alternatives);
- **risk** (human health or environmental risks of possible alternatives);
- **customer / regulatory** (customer acceptance to use alternative; regulatory barrier; product approval time / requirements); or,
- **other** barrier.

Technical barriers were the most common barriers to substitution. For example, cobalt is an essential element for ruminants and cobalt deficiency can lead to serious health risks. Respondents noted that there are no known alternatives to cobalt when used as a precursor of cobalamin in animal feed. When used in cemented carbide/diamond tools, there are no other metals that can fulfil cobalt's intrinsic wetting and cohesion properties. Respondents stated that cobalt's performance for this use is outstanding and despite significant efforts, no suitable alternative has been identified. The cobalt-free cemented carbides tested resulted in less favourable combinations of hardness and toughness compared to tungsten carbide-cobalt. Moreover, some alternatives show additional disadvantages such as increased corrosion sensitivity. Similarly, when used in humidity indicators, alternatives do not meet the required performance standards. Cobalt is an essential alloying element and despite ongoing scientific research, no viable alternatives with comparable durability and wear resistance have been identified.

Economic barriers were also highlighted as common barriers to substitution due to the cost of changes to processes, and the higher cost of alternatives. Examples include more expensive processing methods for cemented carbide/diamond tools, metallurgical alloys, and more expensive substances and processes for the manufacture of pigments and dyes. Examples of risk barriers include the substitution of cobalt with nickel and molybdenum for surface treatment which have human health risks, and alternatives to cobalt substances in humidity indicators which can lead to increased release of refrigerant gases into the environment which contributes to climate change.

Some respondents noted that even if an alternative was viewed as technically feasible by the manufacturer, the customer would need to accept it in order for it to be used. For an alternative to be accepted by customers, the new product (containing the alternative substance) needs to perform as well as the existing product. For example, for adhesion, where the customer requirements for tyres are very strict, and if alternatives do not meet the regulatory or safety standards, they will not be used. Similarly, in competitive markets such as electroplating inserts for brazing, customers are reluctant to accept alternative coatings that require adjustments of brazing parameters. Where alternative products must undergo authorisation (such as animal feed and tyre safety testing), finding an alternative requires long-lasting and costly high-risk technology research.

Table 5.4 shows the substitution steps required for complete substitution of cobalt and time required to implement each step based on the industry questionnaire eftec (2023). The steps have been generalised to show the different areas of substitution that would need to be achieved in order for a complete substitution of cobalt to occur.

Table 5.4: Substitution steps and time required to implement each step

Substitution step	Description	Time required
Step 1 – R&D	R&D is the driving force behind the exploration, development, and testing of potential alternatives to replace cobalt in various applications. The process begins with laboratory-scale testing of candidate alternatives, followed by ongoing R&D efforts to understand their suitability for existing products. This involves extensive research to assess whether an alternative can meet the required specifications and performance criteria.	Less than 1 year to up to 5 years
Step 2 – Pilot tests	Pilot tests involve integrating the alternative into product prototypes or small-scale production runs. Pilot tests allow the industry to gather valuable insights to assess the feasibility and viability of the alternative in real-world scenarios.	Less than 1 year to up to 3 years
Step 3 – Tests with customers	This step involves testing the alternative on an industrial scale, simulating real-world conditions and usage patterns. The objective is to thoroughly evaluate the performance, reliability, and compatibility of the alternative in the hands of end-users.	Less than 1 year to up to 3 years
Step 4 – Establishing alternative processes	This step involves adapting and optimising the manufacturing procedures and techniques to accommodate the alternative.	5 years
Step 5 – Marketing	The final step in the substitution process involves strategic marketing efforts to increase customer adoption.	2 years

The minimum and maximum time required to take an alternative to market is 10 and 18 years, respectively – when the shortest and longest times per step are added across the steps. However, some of these steps could occur simultaneously reducing the total time needed (e.g., pilot tests (Step 2) and tests with customers (Step 3)). On the other hand, at any point during this process, an alternative may fail, and the substitution process would have to start again lengthening the process.

5.6. Risks / Hazards

As there are no alternative substances (including drop-in substances that mimic the role of cobalt, and substances that have different functions to cobalt) or alternative processes, it is not possible to fully compare the hazard profile of a potential alternative substance (or substances).

For some broad uses (e.g., use in surface treatment - passivation or anti-corrosion treatment processes) cobalt was used as an alternative to substances (e.g., chromium (III)) which have worse hazard profiles. Other potential alternatives mentioned in this chapter have less favourable hazard profiles than cobalt. For example, vanadium pentoxide and nickel have less favourable hazard profiles than cobalt.

Conversely, iron substances used in the production and use of iron-based catalysts currently have no classification for carcinogenic, mutagenic or reprotoxic (CMR) properties. Thus, from a purely hazard-based perspective, substitution of cobalt catalysts with iron-based catalysts could reduce the overall hazard related to the use of a CMR substance (DHI, 2018). However, as detailed in Section 5.3, iron-containing catalysts are not technically feasible alternatives.

6. Policy options

6.1. Introduction

This chapter describes the existing policy landscape and the four policy options that are analysed in this report. These policy options represent different potential BOEL values, which may be considered for implementation at an EU level. At the time of writing, the BOEL values assessed by the EC were not known, which means that the scope of the analysis may differ from that of the EC contractor.

6.2. Current policy options in place

There are already OELs in place in several EU Member States and other global competitors such as the UK and USA for cobalt metal and inorganic cobalt compounds. The most frequent OEL is 20 µg/m^3 (inhalable fraction) measured as an 8-hour time weighted average (TWA), which is implemented for eight EU Member States (ECHA, 2022a). Within the EU the OEL values range from 0.5 µg/m^3 in Germany (as a respirable fraction rather than inhalable fraction), to 500 µg/m^3 (inhalable fraction) in Latvia. In the UK and USA, the comparable OEL value is 100 µg/m^3 (ECHA, 2022a). Two EU member states have established BLVs for cobalt metal and its compounds, and two have established BGVs (ECHA, 2022a).

6.3. Policy options assessed

The four policy options that have been assessed are shown in **Table 6.1**. These are different from those analysed by the EC contractor as the details of their analysis was unavailable at the data gathering stage for this project.

Table 6.1: Summary of the four policy options

No.	Policy option	Measure description	Reason for inclusion
1	BOEL 30 µg/m^3	This option is an EU wide BOEL value of 30 µg/m^3 inhalable fraction	Advised by CI, as industry would like to show a broader range of potential limits.
2	BOEL 20 µg/m^3	This option is an EU wide BOEL value of 20 µg/m^3 inhalable fraction	Most frequent OEL applied across the Member States.
3	BOEL 10 µg/m^3	This option is an EU wide BOEL value of 10 µg/m^3 inhalable fraction	Intermediate level and minimum observed OEL amongst Member States
4	BOEL 1 µg/m^3	This option is an EU wide BOEL value of 1 µg/m^3 inhalable fraction	OEL proposed in the RAC opinion

6.3.1 Behavioural responses

When faced with a BOEL, companies may choose to react in different ways, often called "behavioural responses". The following responses have been considered in this analysis:

- **Implement risk management measures (RMMs)** required to comply with the BOELs. This may include (i) engineering controls, which involve changes to the design of the process plant and equipment to maximise containment; (ii) administrative controls, which involve changes to management processes such as operational conditions to minimise exposure; and as a last resort (iii) personal protective equipment (PPE) which protects workers.

- **Substitute substance or process.** This includes companies which substitute to alternative substances or implement process changes avoiding the use of substances.
- **Cease production** of impacted product lines. This includes companies which cease affected production lines, those which shift production to new or existing sites outside of the EU and companies closing down all operations.

There are multiple factors that may influence a company's choice of behavioural response to a BOEL. In addition to technical considerations, there are legal provisions that needs to be followed. Article 6.2 of the Chemical Agents Directive (OSHA, 2021; 2017) sets out rules for how chemical exposure to workers shall be reduced. A "hierarchy of controls" is defined, where the following order of controls should be followed:

1) Substitution;
2) Process design and engineering controls that prevent release of substances at source;
3) Collective protective measures at source, such as ventilation and organisational measures:
4) Individual measures, such as personal protective equipment.

The Carcinogens and Mutagens Directive (OSHA, 2021) is even more stringent in its requirements for how to avoid worker exposure to carcinogenic or mutagenic substances. These substances should be replaced as far as technically possible, regardless of economic considerations (art. 4.1). If that is not possible, the company should use closed systems (art. 5.2), and if that is not possible as well, the employer should ensure that exposure is reduced to a level as low as technically possible by means of a combination of measures, including the limitation of the quantities of substances present and the number of workers exposed (art. 3 & 5).

Although the legal guidelines are stringent, there is some room for individual judgement at a company level. OSHA states that on their website: "*[...] in practice, any hierarchy of control measures should not be seen as a strict rule, but as a tool that provides direction in risk management and helps choosing the best and most effective control measures. Employers should document the rationale of their choice of control measures, regularly revise them, and reflect on their efficacy and appropriateness in cooperation with the workers*" (OSHA, 2017). For example, if a company adapts its production processes, the guidance suggests that the company consult with its workers to agree upon the adoption of new and appropriate RMMs. This process also varies by country, as legislative or recommended OELs will influence a company's choice of RMMs.

The number and nature of RMMs required for compliance, and subsequently the portion of the market utilising each behavioural response, will vary across the BOELs. For all BOELs, companies that have not implemented monitoring systems will have to implement them to demonstrate compliance. All companies must ensure that an adequate respiratory fraction monitoring programme is in place. Many member states have also implemented requirements on biological monitoring alongside country specific OELs, and biological monitoring is considered best practice to measure cobalt exposure. In line with advice from the Cobalt Institute, the analysis therefore also assumes that all companies will implement biological monitoring., Cost is an important factor in a company's choice of behavioural responses. If the costs of substitution or RMMs are such that the regulated activity is no longer profitable, firms will shut down the production of the affected lines, close production all together or move production outside the EU. This is particularly likely where firms are unable to pass on costs to customers, for example because of trade exposure. For those firms continuing to operate in the EU, firms will generally choose the least cost permittable behavioural response. Note that as only costs to society have been considered here, it is not the case that the costs presented below accurately represent the private costs faced by businesses.

7. Policy Option 1 (BOEL 30 μg/m^3)

7.1. Introduction

This chapter covers the potential costs and benefits to society of complying with the Policy Option 1, the introduction of an EU-wide 30 μg/m^3 BOEL for cobalt and inorganic cobalt compounds, in line with the scope of substances considered by the EC. All manufacturers, importers, downstream users, and recyclers who handle cobalt metal and cobalt substances that are either directly or indirectly in scope (see Section 1.4.1) within the EU will be required to adhere to the BOEL 30 μg/m^3 based on an 8-hour based on the industry questionnaire time weighted average (TWA) inhalable fraction. The data used in this chapter is (eftec, 2023), which is the most recent data available.

7.2. Behavioural responses

As explained in Section 6.3, all firms choose one of three behavioural responses: implement risk – level in order to facilitate later cost calculations. The table also provides the share of all sites that are non-compliant, and the behavioural responses are only reported for these non-compliant sites. Where less than three responses for a broad use were received, no data is reported.

Table 7.1: Current non-compliance with and behavioural responses to a 30 μg/m^3 BOEL

Broad use	Share not compliant	Implement RMMs	Substitute regulated substances	Cease production in the EU
	% of all sites	% of non-compliant sites		
All	16%	75%	19%	6%
Manufacture of cobalt metal and/or cobalt substances	14%	100%	0%	0%
Manufacture of other chemicals	0%	0%	0%	0%
Manufacture of precursor chemicals for batteries	25%	100%	0%	0%
Manufacture of catalysts	0%	0%	0%	0%
Manufacture of pigments and dyes	18%	100%	0%	0%
Manufacture of driers / paints	No respondent data	No respondent data	No respondent data	No respondent data
Use as catalysts – used as a catalyst or catalyst precursor	0%	0%	0%	0%
Use as catalysts – used as oxidation catalyst/for PTA and IPA	Insufficient respondent data	Insufficient respondent data	Insufficient respondent data	Insufficient respondent data
Use in surface treatment – Formulation of surface treatment	0%	0%	0%	0%

Use in surface treatment – Passivation or anti-corrosion treatment processes	0%	0%	0%	0%
Use in surface treatment – Metal or metal alloy plating	47%	100%	0%	0%
Use in biotechnology – Formulation and industrial use of mixtures in biogas production	No respondent data	No respondent data	No respondent data	No respondent data
Use in biotechnology – Professional use in biogas production	No respondent data	No respondent data	No respondent data	No respondent data
Use in biotechnology – Use in fermentation, fertilizers, biotech, scientific research and standard analysis	No respondent data	No respondent data	No respondent data	No respondent data
Use in biotechnology – Formulation and use in animal feed grade materials	0%	0%	0%	0%
Bespoke uses – Use in humidity indicators cards, plugs and/or bags with printed spots	Insufficient respondent data	Insufficient respondent data	Insufficient respondent data	Insufficient respondent data
Bespoke uses – Formulation of water treatment chemicals, oxygen scavengers, corrosion inhibitors	29%	100%	0%	0%
Bespoke uses – Use of water treatment chemicals, oxygen scavengers, corrosion inhibitors	No respondent data	No respondent data	No respondent data	No respondent data
Adhesion (inc. rubber adhesion agent)	0%	0%	0%	0%
Use in electronics	No respondent data	No respondent data	No respondent data	No respondent data
Use in magnetic alloys	Insufficient respondent data	Insufficient respondent data	Insufficient respondent data	Insufficient respondent data
Use in metallurgical alloys	13%	50%	25%	25%
Use in cemented carbide/diamond tools	32%	77%	23%	0%
Recycling of materials containing cobalt substances	14%	100%	0%	0%

Table note: The sum of percentages across all behavioural responses may not add up to 100% due to rounding to the nearest percentage point.

Compliance levels are high at this BOEL, with only 16% of all sites being non-compliant. Compliance for each site will depend in part on the nature of site activities and any existing OELs on a national level.

Some broad uses have higher non-compliance rates such as the surface treatment (metal or metal alloy plating) and cemented carbide / diamond tools broad uses, which are at least twice as likely to be non-compliant as the average site. In the case of cemented carbide / diamond tools this may be due to the fact that these sites are dependent on production of RTP powder, which increases exposure levels.

Overall further implementation of RMMs is the dominant behavioural response for all broad uses that currently have sites that are non-compliant. 75% of sites that are not compliant with the BOEL would choose this option. It is the dominant choice for all broad uses for which there were at least some non-compliant sites in the sample. The only respondents choosing to cease production are in the metallurgical alloys broad use, while the only respondents choosing to substitute are in the cemented carbide / diamond tools and metallurgical alloy uses. This is expected to be the result of alternative binder materials to cobalt, which although produce inferior tools, are available on the EU market – more information is presented in Section 5.3.

The compliance rates in this report are based on whether respondents stated they would need further action to comply, and are not necessarily comparable to earlier reports, e.g., RPA (2020).

7.3. Implementation of RMMs

This section reports the technical and economic feasibility of complying with Policy Option 1 through the implementation of RMMs, the types of RMMs that would need to be implemented to comply, and the costs associated with implementing these RMMs.

7.3.1 Feasibility of compliance

This section is about the technical and economic feasibility of currently non-compliant sites to comply with a BOEL of 30 μg/m^3. Note that it can be technically feasible but economically infeasible for a company to comply with a BOEL (i.e., technical solutions could be possible to implement, but it may not be financially possible to do so). Measuring the feasibility of compliance reveals the ease or difficulty companies will face in complying with a BOEL.

Table 7.2 shows the percentage of non-compliant sites with this Policy Option deem it technically and economically feasible or infeasible to comply with a BOEL of 30 μg/m^3. It should be noted that interpretation of data is limited due to the low number of respondents. Overall, it is deemed technically feasible to comply with this BOEL across 75% of non-compliant sites and economically feasible across 63% of sites. Many of the respondents to the industry questionnaire stated that they currently comply with this BOEL at some of their sites or within certain areas within their sites. Multiple respondents also stated that they are already working towards reducing exposure below 30 μg/m^3 at the sites that are currently above this level.

Table 7.2: Share of non-complying sites where it is and is not technically and economically feasible to comply with 30 µg/m³ BOEL

Type of feasibility	% non-complying sites	
Technical feasibility	% of sites technically feasible to comply	75%
	% of sites not technically feasible to comply	25%
	% of sites technical feasibility unknown	0%
Economic feasibility	% of sites economically feasible to comply	63%
	% of sites not economically feasible to comply	25%
	% of sites economic feasibility unknown	13%

Table note: Total share of sites has been estimated using the number of sites currently not complying with a 30 µg/m³ BOEL, as reported by questionnaire respondents, and regardless of broad use.

There is deviation between the broad uses in the technical and economic feasibility to comply with a 30 µg/m³ BOEL. The technical and economic feasibility to comply with this BOEL in each of the broad uses is reported in **Appendix Table 10**. The data available per broad use is even more sparse and therefore should be interpreted with caution; however, there are still some patterns that are worth highlighting. Respondents using cobalt substances in metallurgical alloys voiced more uncertainty about the technical and economic feasibility of complying with this BOEL, with 59% of non-compliant sites thinking it both technically and economically feasible, and 41% and 21% thinking it technically and economically infeasible, respectively. Respondents in some broad uses thought it technically feasible but economically infeasible to comply with a BOEL of 30 µg/m³. For example, out of currently non-compliant sites involved in the manufacture of cobalt metal and/or cobalt substances, 100% thought it would be technically feasible to comply with this BOEL, but 25% thought it economically infeasible.

The questionnaire responses can provide some insight into potential reasons why respondents deemed complying with a BOEL of 30 µg/m³ at some sites economically infeasible: the cost of replacing equipment, their lack of knowledge, and technical infeasibility. When it came to technical infeasibility, several respondents flagged the 30 µg/m³ limit is too low, declaring it impossible "to ensure such low exposure".

7.3.2 RMMs needed to comply with this option

This section reports the types of measures that would need to be implemented by the affected sites in the EU-27 in order to comply with a BOEL of 30 µg/m³. As has been reported above, the implementation of these RMMs is dependent on whether a company considers this the most viable course of action for their sites (reported in Section 7.2) and whether the implementation of RMMs is technically and/or economically feasible for the relevant sites (reported in Section 7.3.1).

Article 6.2 of the Chemical Agents Directive (OSHA, 2021; 2017) sets out rules for how chemical exposure to workers shall be reduced according to a "hierarchy of controls". One of the general principles of prevention is "*giving collective protective measures priority over individual protective measures*" (art. 6.2), which suggests that measures other than PPE should be prioritised. The Carcinogens and Mutagens Directive (OSHA, 2021) is even more stringent in its requirements for how to avoid worker exposure to carcinogenic or mutagenic substances. These substances should be replaced as far as technically possible, regardless of economic considerations (art. 4.1). For these reasons, RMMs required for compliance are reported with and without the use of PPE. Reporting measures in these two scenarios also provides useful information for when the use of PPE becomes necessary for compliance (i.e., if collective protection measures are not enough) (OSHA, 2021b).

The RMMs reported in this section have been collated from responses to the industry questionnaire (eftec, 2023). These RMMs therefore include a suite of measures that could be implemented to comply with Policy Option 1 and it might not be necessary to implement all the measures that have been reported to achieve compliance.

RMMs needed to comply, with PPE

Table 7.3 presents the types of measures that would be implemented by manufacturers, downstream users, and recyclers of cobalt metal and/or cobalt substances to comply with Policy Option 1. Similar measures were reported across these different activities and have therefore been reported together. The listed measures will not all be implemented simultaneously, as these represent responses from several different companies. Instead, it is expected that each non-compliant site will have to implement one or more complementary measures to comply with the BOEL.

Respondents also report the estimated number of years required to implement these RMMs and comply with this Policy Option. The range in the number of years reported by manufacturers and downstream users were the same, with a low estimate of ≤1 year and high estimate of 3 years for manufacturers and 4 years for downstream users. The median number of years were also similar, with a median of 2 years for manufacturers and ≤1 year for downstream users. Recyclers reported the same lower bound estimate of ≤1 year to implement the necessary RMMs but reported a much higher upper bound estimate of ≥8 years and had a higher median estimate of 4 years to comply with this Policy Option. The longer implementation time frame for recyclers suggests that complying with the BOEL would be more challenging than for other affected sectors.

Table 7.3: Types of control measures needed to comply with BOEL, with PPE

Types of RMMs	RMMs
Engineering controls	• Improving general ventilation and better ventilation of working areas • Automation of some key areas to avoid manual handling (e.g., automation of weighting; closed filling into the mills; installing a conveyor system between pastillator and conditioning machine; and loading process) • Significant improvement or replacement of extraction systems • Sealed and closed processing facility • Encapsulation of unloading station • Partial containment of key areas • Upgrading part of the infrastructure (e.g., air stack filters) • Containment of dust in selected equipment (e.g., installing a big-bag discharger, installing a new dust vacuum cleaner, dust extractor sintering, etc.)
Administrative controls	• Training and education on limiting exposure • Reducing exposure time by increasing number of employees and rotating operators • Shorten cleaning cycles • Redesigning workplace cleaning • Redesigning workplace ISO
PPE	• Increase the use of respiratory equipment (e.g., powered air purification respirator or airstream helmets)

	• Air showers • Protective clothes (e.g., gloves, disposable suits etc.)

Table note: RMMs are collated from responses to the industry questionnaire and will not all be implemented by the same company.

RMMs needed to comply, without PPE

The RMMs needed to comply with Policy Option 1 without the use of PPE are presented in **Table 7.4** and broadly align with the RMMs listed in **Table 7.3**. Although it is not possible to estimate the proportion of companies and sites that would implement each of these measures to comply with 30 µg/m^3 BOEL, a number of respondents did mention the installation of machinery to minimise the amount of dust within certain areas of a site.

The data revealed that a longer time-period would be needed to implement RMMs without PPE than if PPE can be utilised. Respondents (i.e., manufacturers, downstream users, and recyclers) reported that it would take between ≤1 year and ≥8 years to implement the RMMs needed to comply without PPE, with manufacturers and downstream users reporting a median of 3 years and recyclers reporting a median of 4 years. For manufacturers and downstream users, the implementation of RMMs without PPE increases between one and two years comparatively to the implementation of RMMs with PPE, which reflects the need to implement more time-consuming measures that are more expensive and require a larger investment over a longer period of time, such as engineering controls. For recyclers, the median implementation time is 4 years, which aligns with the time needed to implement RMMs with PPE, which could reflect the need to implement similar measures with and without the use of PPE to comply with a BOEL of 30 µg/m^3.

Table 7.4: Types of control measures needed to comply with BOEL, without PPE

Types of RMMs	RMMs
Engineering controls	• Automation of process (e.g., installing a conveyor system) • Rebuilding and/or upgrading part of the process infrastructure (e.g., process lines) • Significant improvement of extraction systems/replacement (e.g., air stack filters) • Containment of dust in selected equipment (e.g., installation of new dust vacuum cleaner, installing a big-bag discharger) • Encapsulation of unloading station • Introducing heated buildings for raw material handling (this is required as air-flow PPE cannot be used well in sub-zero temperatures)
Administrative controls	• Training and education (e.g., on limiting exposure, hygiene). • Termination of certain products • Introduction of standard operating procedures (SOP) • Increase the number of shifts or reduce their duration through rotation. • Cooling down time before closed systems can be opened for handling. • Monitor the respirable fraction of cobalt annually. • Discontinuation of packaging/size of pre-weighted bags

Table note: RMMs are collated from responses to the industry questionnaire and will not all be implemented by the same company.

7.3.3 Cost of RMMs

The cost of implementing RMMs is analysed with and without PPE. Given that PPE should be the last option RMM (see Section 6.3.1), it is expected that the actual costs of compliance will be closer to the without PPE estimates. It would be expected that the costs of compliance without PPE are higher as other RMM options available to companies may be limited and more expensive.

Table 7.5 shows the unit costs of implementing RMMs for a single site, and total costs under a BOEL of 30 μg/m^3. This is based on respondents' reports of the total costs they face in complying with the BOEL through RMMs. This is different than the approach taken in RPA (2020), which calculate costs using a model to determine which RMMs are required to go from existing exposure levels to below the BOEL. Total costs only include the costs incurred by sites that implement RMMs, where the number of sites is derived from the behavioural responses discussed in Section 7.2. It is assumed that any capital expenditure must be repeated twice over a period of 40 years, reflecting a capital lifetime of twenty years.

Disaggregated costs for SMEs and large companies were estimated, before these were combined into a weighted average unit cost per site (see Appendix A 1.3 for more details). The costs for SMEs and large companies are based on smaller sample sizes and are thus likely to be less reliable than the aggregate figures.

Table 7.5: Weighted average costs of implementing RMMs to comply with a 30 μg/m^3 BOEL

Cost type	Number of sites incurring costs	With PPE		Without PPE	
		Annualised costs (PV €m/year)	*Costs 2022 – 2061 (PV €m)*	*Annualised costs (PV €m /year)*	*Costs 2022 – 2061 (PV €m)*
SMEs unit costs (per site)	1	0.02	0.7	0.02	0.7
Large companies unit costs (per site)		0.11	4.4	0.13	5.1
Unit costs		0.03	1.4	0.04	1.5
Total costs (SMEs)	900	20	630	20	630
Total costs (Large)	200	20	870	30	1,020
Total costs (all)	1,100	40	1,510	40	1,650

Table notes:

- Annualised cost is the present value (i.e., sum of discounted future costs), divided by the number of years in the analytical period (40 years). Values are discounted using a 3% discount rate and given in 2022 €.
- Number of sites incurring costs is rounded to the nearest 10. Annualised total costs are rounded to the nearest €10 million, while annualised unit costs are rounded to the nearest €10,000. Unit costs over the appraisal period are rounded to the nearest €100,000 and total costs over the appraisal period are rounded to €10 million.
- The assumed number of total sites for the purpose of cost calculations is equal to an average of the upper and lower bound site estimates.
- The unit costs are a weighted average of costs for SMEs and large companies.

The weighted average unit cost of implementing RMMs needed to comply with a BOEL of 30 μg/m^3 is €1.4 million per site across the 40 years appraisal period with PPE, and €1.5 million without PPE.

When applied to all sites that incur this cost, the total cost of implementing RMMs for this BOEL is around €1.5 billion – €1.7 billion in present value terms over the period 2023 – 2062, depending on whether PPE is used.

The unit cost of implementing RMMs is around six times higher for large companies than it is for SMEs, at around €110,000 - €130,000 and €20,000 per year respectively, where the lower end represents compliance with PPE.

7.4. Cease of use of cobalt metal and cobalt substances

As discussed in Section 6.3, instead of implementing RMMs companies could cease the use of cobalt metal and cobalt substances. This could be achieved either by substituting cobalt metal and/or cobalt substances with alternatives, closing affected product lines, complete shut-down of the entire site, and/or shifting production to new or existing sites outside the EU. Shutting down production lines, sites and/or shifting production to sites outside the EU does not reduce demand for cobalt-containing products but increases dependence on imports from outside the EU. As discussed in Section 3.2.3, cobalt metal is classified by the EC as a critical raw material and is used in strategic technologies and sectors (see Section 11.2 for more information).

7.4.1 Substitution

Table 7.6 shows the unit and total costs of substituting cobalt metal and/or cobalt substances. Total costs are calculated for the sites that will substitute cobalt metal and/or cobalt substances, which is estimated from respondent data (discussed in Section 7.2). The unit costs of substitution are the same under all of the BOELs analysed in this report, but the number of sites which incur the cost changes depending on behavioural responses to each of the BOELs.

This cost is based upon historic costs reported by respondents that have already attempted substitution, of which no respondent reported that they were able to fully substitute successfully. Substitution is likely to first be carried out for uses and products for which alternatives exist and is deemed feasible (low hanging fruits). These points both indicate that the derived substitution costs are likely an underestimate of actual substitution costs that would be incurred. Companies are not likely to substitute unless feasible alternatives are available, so these cost estimates are not reflective of substitution costs for all broad uses.

Costs incurred by respondents over the last five years are assumed to continue linearly over five years for all sites substituting to alternatives. Due to small sample sizes, disaggregated costs for SMEs and large companies were not calculated.

Table 7.6: Costs of substituting cobalt metal and/or cobalt substances to comply with a 30 µg/m³ BOEL

Cost type	Number of sites incurring cost	Annualised costs (PV € million/year)	Costs 2022 – 2061 (PV € million)
Unit costs	1	0.004	0.2
Total costs (all)	280	1	40

Table notes:

- Annualised cost is the present value (i.e., sum of discounted future costs), divided by the number of years in the analytical period (40 years). Values are discounted using a 3% discount rate and given in 2022 €.
- Number of sites incurring costs is rounded to the nearest 10. Annualised total costs are rounded to the nearest €1 million, while

annualised unit costs are rounded to the nearest €1,000. Unit costs over the appraisal period are rounded to the nearest €100,000 and total costs over the appraisal period are rounded to €10 million.

- The assumed number of total sites for the purpose of cost calculations is equal to an average of the upper and lower bound site estimates.

The unit cost of substitution in a single site is €0.2 million across the full 40 years appraisal period. As shown in Section 7.2, only the use in metallurgical alloys broad use has sites that substitute at this BOEL, and this is one of the broad uses from which historic data was drawn. When applied to all sites that incur this cost, the total cost of substitution was €40 million in present value terms over the period 2022 – 2061.

7.4.2 Lost profit from ceasing production in the EU

The cost of ceasing production (lines) is assumed to be the same regardless of whether production is stopped altogether or relocated to plants outside of the EU. This reflects the fact that this analysis has the EU-27 as its geographical scope and considers only the cost to society in the EU-27, not the private cost faced by businesses.

Table 7.7 shows the unit and total costs of ceasing production in the EU. Total costs are calculated for the sites that are assumed to cease production based on behavioural responses discussed in Section 7.2. The unit cost of ceasing production is the same under all four BOELs analysed in this report, but the number of sites which incur the cost changes depending on companies' behavioural responses to each BOEL.

These costs only consider profits associated with affected product lines, so ceasing production in the EU only counts profit lost at those affected product lines and not any other activities at the same site or company that are not related to the regulated substances. In some cases, particularly for larger companies, sites ceasing production of affected product lines will continue activities that are not affected by the BOEL. However, this will likely not be feasible for most SMEs, where the whole site or company is more likely to close down or relocate. The estimated unit costs of ceasing production are therefore believed to be underestimated as the costs of complete closure or relocation are not counted.

In earlier report (e.g., RPA (2020) and eftec (2019b)) lost profits were calculated over a 20-year period. However, new guidance from ECHA (2021) has since been released by the Committee for Socio-Economic Assessment (SEAC) under REACH. In line with this guidance, profit loss has been estimated for a period of four years (see Appendix A 1.3 for more details).

Disaggregated costs for SMEs and large companies were estimated, before these were combined into a weighted average unit cost per site (see Appendix A 1.3 for more details). The costs for SMEs and large companies are based on smaller sample sizes and are thus likely to be less reliable than the aggregate figures.

Table 7.7: Costs of ceasing production in the EU to comply with a 30 µg/m³ BOEL

Cost type	Number of sites incurring cost	Annualised costs (PV € million/year)	Costs 2022 – 2061 (PV € million)
SMEs unit costs (per site)	1	0.03	1.4
Large companies unit costs (per site)		0.21	8.3

Unit costs		0.07	2.6
Total costs (SMEs)	80	3	100
Total costs (Large)	20	3	140
Total costs (all)	90	10	240

Table notes:

- Annualised cost is the present value (i.e., sum of discounted future costs), divided by the number of years in the analytical period (40 years). Values are discounted using a 3% discount rate and given in 2022 €.
- Number of sites incurring costs is rounded to the nearest 10. Annualised total costs are rounded to the nearest €10 million, while annualised unit costs are rounded to the nearest €10,000. Unit costs over the appraisal period are rounded to the nearest €100,000 and total costs over the appraisal period are rounded to €10 million.
- The assumed number of total sites for the purpose of cost calculations is equal to an average of the upper and lower bound site estimates.

The average cost of ceasing production in the EU at a single site is €2.6 million across the full 40 years appraisal period. When applied to all sites that incur this cost, the total cost of ceased production within the EU for this BOEL is €240 million in present value terms over the period 2022 – 2061, reflecting the relatively low proportion of sites choosing to cease production at this BOEL.

The annual costs of ceasing production are around seven times higher for large companies than for SMEs, at around €30,000 and €210,000 respectively.

7.5. Costs of compliance

This section presents the total costs of compliance with a 30 µg/m^3 BOEL, considering each of the three behavioural responses, as well as the costs of implementing monitoring programmes. Section 7.5.1 presents the unit costs of compliance on a per-site basis, while Section 7.5.2 presents the total costs of compliance across the industry as a whole, by the type of cost and by broad use.

7.5.1 Unit costs

Table 7.8 shows the unit costs for a single site to comply with a BOEL of 30 µg/m^3 for each of the likely behavioural response (i.e., type of costs). In addition, the average cost for a non-compliant site, and the average cost for all sites are presented. The former figure includes sites not complying with a BOEL of 30 µg/m^3 and reflects the likely costs that would actually be incurred by sites in order to achieve compliance. This latter figure includes compliant sites incurring no costs and compliant sites which have to implement monitoring systems. The average unit cost per site allows for comparison across the Policy Options as the number of sites remains constant, which is in contrast to the average unit cost per non-compliant site where the number of sites not complying changes in each Policy Option (i.e., the number of non-compliant sites increases as the BOEL decreases). Disaggregated costs for SMEs and large companies were estimated, before these were combined into a weighted average unit cost per site (see Appendix 1.3 for more details).

Table 7.8: Unit costs per site to comply with a 30 µg/m³ BOEL

Types of costs	With PPE		Without PPE	
	Annualised costs (PV € million / year)	Costs 2022 – 2061 (PV € million)	Annualised costs (PV € million / year)	Costs 2022 – 2061 (PV € million)
Implementing RMMs	0.03	1.40	0.04	1.50
Implementing biological monitoring	0.03	1.00	0.03	1.00
Implementing respiratory fraction monitoring	0.01	0.50	0.01	0.50
Substitution with alternatives	0.004	0.20	0.004	0.20
Ceasing production in the EU	0.07	2.60	0.07	2.60
Average unit cost per non-compliant site	**0.05**	**2.00**	**0.05**	**2.10**
Average unit cost per site	**0.02**	**1.00**	**0.02**	**1.00**

Table notes:

- Annualised cost is the present value (i.e., sum of discounted future costs), divided by the number of years in the analytical period (40 years). Values are discounted using a 3% discount rate and given in 2022 €. Total number of non-compliant sites requiring monitoring is not calculated as all sites require monitoring under any BOEL.
- Annualised costs are rounded to the nearest €10,000, unless costs <€10,000 in which cases they have been rounded to the nearest €1,000. Costs across the appraisal period are rounded to the nearest €100,000.
- Average unit cost is a composite average cost per site, taking into account the shares of non-compliant sites that will implement RMMs, substitute, and cease production in the EU, as well as the share of all EU sites that will implement monitoring programmes.
- The assumed number of total sites for the purpose of cost calculations is equal to an average of the upper and lower bound site estimates.

The average unit cost per non-compliant site is around €50,000, and the difference between compliance with and without PPE is small (it is not observed due to rounding). The driver behind both of these estimates is the cost of RMMs, as the vast majority of non-compliant sites will implement RMMs (rather than substituting or ceasing production). Compliant sites will only incur the cost of implementing monitoring programmes, if this is not already in place, and the costs for a compliant site is therefore lower. Only 16% of sites are not already compliant with this BOEL (see **Table 7.1**), so the average cost for all sites (i.e., covering both compliant and non-compliant sites) is significantly less than that of non-compliant sites at €20,000 annually.

The unit cost of implementing monitoring is €30,000 annually for biological monitoring and €10,000 annually for respiratory fraction monitoring. This is in line with the cost of substitution and implementing RMMs for this BOEL but is significantly lower than the cost of ceasing production, which is estimated at €70,000 annually per site.

7.5.2 Total costs

Table 7.9 shows the overall costs of compliance with a BOEL of 30 µg/m³, broken down by the type of cost. For the total cost, both a lower and upper bound for the number of sites to which the BOEL will apply is used, while for the remainder of the table a central estimate of the number of sites is used.

Table 7.9: Total costs of compliance with a 30 µg/m³ BOEL, by cost type

Types of costs	Number of sites incurring cost	With PPE		Without PPE	
		Annualised costs (PV € million/year)	Costs 2022 – 2061 (PV € million)	Annualised costs (PV € million/year)	Costs 2022 – 2061 (PV € million)
Implementing RMMs	1,100	40	1,510	40	1,650
Implementing biological monitoring	4,990	130	5,150	130	5,150
Implementing respiratory fraction monitoring	3,810	50	1,840	50	1,840
Substitution with alternatives	280	1	40	-	40
Ceasing production in the EU	90	10	240	10	240
Total cost lower bound	-	170	6,670	170	6,770
Total cost upper bound	-	270	10,900	280	11,070

Tables notes:

- Annualised cost is the present value (i.e., sum of discounted future costs), divided by the number of years in the analytical period (40 years). Values are discounted using a 3% discount rate and given in 2022 €.
- Number of sites incurring costs is rounded to the nearest 10. Annualised costs are rounded to the nearest €10 million, unless costs are <€5 million, in which case they have been rounded to the nearest €1 million. Costs across the appraisal period are rounded to the nearest €10 million.
- The total figures are provided for the lower and upper bound. These are calculated using a lower and upper bound estimate of the number of sites using in scope substances across the EU-27. The remaining figures are estimated using an average of the lower and upper bound site estimates for each type of cost.

The total cost of compliance with a BOEL of 30 µg/m³ is estimated at between €6.7 billion – €11.1 billion, both in present value terms over the period 2022 – 2061. The largest component of this cost is implementing monitoring programmes.

If PPE is used, about 15% of the overall cost of compliance (average) is RMM implementation, with around 80% of costs due to monitoring programmes and the remainder due to lost profit and substitution. If PPE is not used, the cost of RMMs increases marginally, to around 20% of costs. Note that the underlying data did not allow for a separation of behavioural responses with and without PPE, though in practice it is very likely that some companies would change their behaviour if forced to implement higher cost engineering or administrative controls.

Although monitoring programmes are less expensive than the cost of reducing exposure, they are a high proportion of the costs at this BOEL. This is because all companies, regardless of compliance, must have monitoring programmes to demonstrate compliance. Monitoring programmes constitute a smaller proportion of the cost of compliance for more stringent BOELs as the number of sites to monitor falls (as more sites substitute or cease production) even though the unit monitoring cost is the same across BOELs.

Table 7.10 shows the total costs of compliance with a BOEL of 30 µg/m^3 broken down by broad use. Figures are only presented in aggregate across cost types and for the broad uses where there was a sufficient number of responses. These costs differ from the costs presented above because broad-use specific unit costs were used where there were sufficient responses, rather than average unit costs presented in **Table 7.8**. Where there were sufficient responses to calculate broad use specific unit costs for only some cost components, it is assumed that the unit cost is equal to the average shown in **Table 7.8**.

Using broad use specific unit costs would lead to total costs being higher than when using average unit costs across all uses, however, these are generally based on a small sample size and are thus less reliable than the aggregate figures presented above. The subsequent analysis, therefore, relies on the numbers set out in **Table 7.9**.

Table 7.10: Total cost of compliance with a 30 µg/m^3 BOEL, for all sites by broad use

Broad use	Site estimate used	With PPE		Without PPE	
		Annualised costs (PV € million/year)	Costs 2022 – 2061 (PV € million)	Annualised costs (PV € million/year)	Costs 2022 – 2061 (PV € million)
Manufacture of cobalt and/or cobalt substances	Upper bound	4.3	170	10.8	430
	Lower bound	2.6	110	17.5	700
Manufacture of other chemicals	Upper bound	1.7	70	1.0	40
	Lower bound	1.0	40	1.7	70
Manufacture of precursor chemicals for batteries	Upper bound	Insufficient respondent data			
	Lower bound				
Manufacture of catalysts	Upper bound	0.3	10	0.2	10
	Lower bound	0.2	10	0.3	10
Manufacture of pigments and dyes	Upper bound	1.3	50	3.3	130
	Lower bound	0.9	30	5.0	200
Manufacture of driers / paints	Upper bound	No respondent data			
	Lower bound				
Use as catalysts – used as a catalyst or catalyst precursor	Upper bound	1.9	70	1.2	50
	Lower bound	1.2	50	1.9	70
Use as catalysts – used as oxidation catalyst/for PTA and IPA	Upper bound	Insufficient respondent data			
	Lower bound				

Broad use	Site estimate used	With PPE		Without PPE	
		Annualised costs (PV € million/year)	Costs 2022 – 2061 (PV € million)	Annualised costs (PV € million/year)	Costs 2022 – 2061 (PV € million)
Use in surface treatment – Formulation of surface treatment	Upper bound	0.2	10	0.2	10
	Lower bound	0.2	10	0.2	10
Use in surface treatment – Passivation or anti-corrosion treatment processes	Upper bound	30.5	1,220	18.7	750
	Lower bound	18.7	750	30.5	1,220
Use in surface treatment – Metal or metal alloy plating	Upper bound	45.6	1,820	28.8	1,150
	Lower bound	27.9	1,120	46.9	1,880
Use in biotechnology – Formulation and industrial use of mixtures in biogas production	Upper bound	No respondent data			
	Lower bound				
Use in biotechnology – Professional use in biogas production	Upper bound	No respondent data			
	Lower bound				
Use in biotechnology – Use in fermentation, fertilizers, biotech, scientific research and standard analysis	Upper bound	No respondent data			
	Lower bound				
Use in biotechnology – Formulation and use in animal feed grade materials	Upper bound	120.1	4,800	73.3	2,930
	Lower bound	73.3	2,930	120.1	4,800
Bespoke uses – Use in humidity indicators cards, plugs and/or bags with printed spots	Upper bound	Insufficient respondent data			
	Lower bound				
Bespoke uses – Formulation of water treatment chemicals, oxygen scavengers, corrosion inhibitors	Upper bound	Insufficient respondent data			
	Lower bound				
Bespoke uses – Use of water treatment	Upper bound	No respondent data			

Broad use	Site estimate used	With PPE		Without PPE	
		Annualised costs (PV € million/year)	Costs 2022 – 2061 (PV € million)	Annualised costs (PV € million/year)	Costs 2022 – 2061 (PV € million)
chemicals, oxygen scavengers, corrosion inhibitors	Lower bound				
Adhesion (inc. rubber adhesion agent)	Upper bound	0.7	30	0.4	20
	Lower bound	0.4	20	0.7	30
Use in electronics	Upper bound	No respondent data			
	Lower bound				
Use in magnetic alloys	Upper bound	Insufficient respondent data			
	Lower bound				
Use in metallurgical alloys	Upper bound	17.6	700	22.5	900
	Lower bound	10.7	430	37.1	1,480
Use in cemented carbide/diamond tools	Upper bound	28.0	1,120	18.8	750
	Lower bound	17.1	680	30.7	1,230
Recycling of materials containing cobalt substances	Upper bound	2.2	90	5.4	220
	Lower bound	1.4	60	8.8	350

Table notes:

- Annualised cost is the present value (i.e., sum of discounted future costs), divided by the number of years in the analytical period (40 years). Values are discounted using a 3% discount rate and given in 2022 €.
- Annualised costs are rounded to the nearest €100,000. Costs over the appraisal period are rounded to the nearest €10 million.
- The total figures are provided for the lower and upper bound. These are calculated using a lower and upper bound estimate of the number of sites using in scope substances across the EU-27. The remaining figures are estimated using an average of the lower and upper bound site estimates for each type of cost.

The highest costs are faced by formulation and use in animal feed grade materials, use in metallurgical alloys, use in cemented/ carbide tools and passivation or anti corrosion treatment. This reflects the higher number of sites in these broad uses than others and given that the number of sites was the main driver of costs. There was insufficient data to calculate broad use specific figures for professional use in biogas but given the high number of sites in this broad use it is likely to incur a relatively high total cost.

Use in metallurgical alloys is the broad use associated with the highest cost per non-compliant site when PPE was used, reflecting the high costs of ceasing production and the high proportion of sites that choose to cease production at this most lenient BOEL. The costs per non-compliant site were found to be three times higher than the average across all broad uses.

Recycling has the highest cost per site, without PPE, due to their high cost of RMMs that was three times the average across all broad uses. Regardless, the smaller number of recycling sites meant that the total cost is still less than 20% that of metallurgical alloys, cemented carbide / diamond tools and other high cost broad uses.

The unit costs of ceasing production vary significantly (up to €40 million annually per site) across the broad uses. As the cost of ceased production is proportionate to per-site revenue and thus site size, the unit cost of ceasing production is generally inversely proportional to the number of sites across the broad use.

The costs of monitoring programs and substitution are fairly consistent across the broad uses and hence are not drivers of differences in total cost between the broad uses, nor of overall costs.

7.6. Social costs

Social impacts (or social costs) as defined by the EC in "Better Regulation Toolbox (European Commission, 2021) can be classified into three broad categories of: 1) employment, 2) working conditions and 3) income distribution, social protection, and inclusion. Due to data limitations, this analysis only quantified impacts on employment (i.e., lost jobs), but qualitative aspects are further addressed in Chapter 11.

Impacts on EU employment are closely linked to potential production halts, permanent reduction in production and relocation of production outside the EU. A similar approach as used to estimate profit losses was therefore deployed in order to calculate social costs from potential EU jobs lost. The number of jobs at risk (i.e., the total number of jobs lost over 40 years) shown in **Table 7.11** was estimated using the average number of employees per site adjusted for the number of sites which will potentially need to shut down in response to the BOEL. The relevant share of jobs at risk is assumed to be proportional to the share of profits at risk.

The jobs lost will not be equally distributed across the analytical period but will be concentrated in the short period following the announcement and introduction of the BOEL. In this analysis, it has been assumed that all the redundancies associated with ceasing of production will occur in the first year after the BOEL is announced. In line with (ECHA, 2008), job losses are considered to be temporary, i.e., the workers find new jobs after a period of time. In line with the SEAC guidance, the social value of lost jobs has been estimated on the basis of an average EU gross salary after employer taxes of around €35,200, assuming that the societal value of a lost job is around 2.7 times the annual pre-displacement salary (ECHA, 2016b). The SEAC guidance approach to valuing unemployment impacts comprises several components such as the value of productivity loss during the period of unemployment and cost of job search, hiring and firing; the impact of being made unemployed on future employment and earnings, and the value of leisure time during the period of unemployment.

Although the jobs lost will be concentrated in the short period following the introduction of the BOEL, **Table 7.11** reports the annualised costs of lost employment (i.e., the total cost of lost employment, which is likely to occur shortly after the introduction of the BOEL, divided by the 40-year analytical period) for comparability with the costs of compliance (reported in Section 7.5).

Table 7.11: Social costs of ceasing production in the EU to comply with a 30 µg/m³ BOEL

	Number of jobs lost over 40 years	Annualised costs (PV € million/year)	Costs 2022 – 2061 (PV € million)
Unit costs (per job lost)	1	0.002	0.1
Total costs (all jobs)	6,500	15	610

Table notes:

- Annualised cost is the present value (i.e., sum of discounted future costs), divided by the number of years in the analytical period (40 years). Values are discounted using a 3% discount rate and given in 2022 €.
- Annualised costs of lost employment are estimated to allow for comparability with costs of compliance, however, it is assumed that all the costs will be incurred in the first year following the announcement of BOELs, rather than annually over the full period of 40 years.
- Number of jobs lost is rounded to the nearest 100. Annualised total costs are rounded to the nearest 10 million, while annualised unit costs are rounded to the nearest 10,000 unless costs <€10,000 in which cases they have been rounded to the nearest €1,000. Unit costs over the appraisal period are rounded to the nearest 100,000, while total costs over the appraisal period are rounded to 10 million.
- Total cost figures and number of jobs lost are based on the average between the lower and upper bound estimates of the number of sites in scope substances across the EU.

The estimated number of EU jobs lost due to ceasing production is 6,500, with the associated cost of each job least of €100,000, or around €2,000 annually. The total annualised cost of jobs lost associated with a BOEL of 30 µg/m³ is €15 million, reaching €610 million over 40 years.

7.7. Benefits

This section sets out the estimated health benefits to workers from a reduction in worker exposure under Policy Option 1. The method used to estimate new exposure levels and the number of cases reduced is described in **A 1.4**, and the results are shown in **Table 7.12**. The risk reduction capacity, defined as the ability of the BOEL to reduce the number of cases, is high already at 30 µg/m³, with 79% - 95% of cases reduced as compared to the baseline. This is partly due to the conservative assumption that companies will not use PPE in order to comply with the BOEL. In Section 12.5, it is further explored how the results may change if this and other assumptions are altered.

Table 7.12: Number of cases reduced under a BOEL of 30 µg/m³

Health endpoint	Number of cases reduced over 40 years		Risk reduction capacity (%)
	Lower bound	Upper bound	
Cancer	62	103	79%
Respiratory irritation	2,345	3,875	83%
Restrictive lung disease	959	1,585	95%

Table notes:

- The lower and upper bounds correspond to the lower and upper bounds for the number of workers exposed.
- The risk reduction capacity is the number of cases reduced by the policy option divided by the number of cases in the baseline.

The monetised health benefits are derived by multiplying the number of cases associated with each health endpoint with their respective valuation factors (see Section 4.5.2) and discounted over a period of 40 years to arrive at the present value (PV). The total present values were divided by 40, to arrive at the annual benefits estimates.

As can be seen in **Table 7.13**, the total benefits over 40 years are expected to be around €400 – €670 million, with corresponding annual benefits of €10 – €17 million.

Table 7.13: Monetised benefits of a BOEL of 30 μg/m³

Health endpoint	Annual benefits (PV € million/year)		Benefits over 40 years (PV € million)	
	Lower bound	Upper bound	Lower bound	Upper bound
Cancer	2	4	97	160
Respiratory irritation	3	5	118	194
Restrictive lung disease	5	8	192	318
Total	**10**	**17**	**406**	**672**

Table notes:

- Annualised benefit is the present value (i.e., sum of discounted future benefits), divided by the number of years in the analytical period (40 years). Values are discounted using a 3% discount rate and given in 2022 €.
- The lower and upper bounds correspond to the lower and upper bounds for the number of workers exposed.

7.8. Summary

Table 7.14 shows the summary breakdown of monetised impacts of a BOEL of 30 μg/m³ with and without PPE. All values are estimated as averages between the lower and upper bound estimates based on the number of sites and workers employed across the EU. The impact categories comprise of benefits (row 1), different costs of compliance (rows 2-6) and social costs (cost of lost jobs in row 7). The bottom two rows present the net benefits calculated as the difference between benefits and costs found for the lower and upper estimates of the number of sites in the EU, respectively. All cost estimates are presented as negative values, and benefits as positive values.

Table 7.14: Summary of monetised costs and benefits of a BOEL of 30 μg/m³

Types of impact	Annual impact (PV € million/year)	
	Compliance without PPE	Compliance with PPE
Benefits	13	< 13
Implementing RMMs	-41	-38
Implementing biological monitoring	-129	-129
Implementing respiratory fraction monitoring	-46	-46
Substitution with alternatives	-1	-1
Ceasing production in the EU	-6	-6
Lost jobs	-15	-15
Net benefits – lower bound	**-171**	**-168**
Net benefits – upper bound	**-279**	**-275**

Table notes:

- Annualised impact is the present value (i.e., sum of discounted future costs or benefits), divided by the number of years in the analytical period (40 years). Values are discounted using a 3% discount rate and given in 2022 €. The exception are the bottom two rows which show the net present value (PV benefits minus PV costs).

- All cost estimates are presented as negative values, and benefits as positive values.
- All annualised impacts are rounded to the nearest €1 million, to ensure comparability between costs and benefits.
- For each cost component, only central estimates (average between the lower and upper bound estimates) of the number of sites in scope substances across the EU are presented

Regardless of the parameters applied (i.e., without or with PPE, as well as lower/upper bound estimates), the present value of costs of implementing a BOEL of 30 µg/m^3 significantly outweighs the present value of monetised benefits. The total annual net loss to society of implementing a BOEL of 30 µg/m^3 is estimated at €171 million – €279 million with PPE, and €168 million – €275 million without PPE. The annualised benefits are around 16 times smaller than overall costs.

As detailed in Section 7.5.2, the main driver of cost of a BOEL of 30 µg/m^3 is monitoring costs. If PPE is used, around three quarters of costs are due to monitoring programmes, with most of the remaining quarter due to RMM implementation and costs associated with ceasing production. Substitution costs account for less than 5% of costs. Although monitoring programmes are relatively inexpensive compared to the costs of reducing exposure, they are a high proportion of the costs at this BOEL because all companies, regardless of compliance, must have monitoring programmes to demonstrate compliance.

8. Policy Option 2 (BOEL 20 µg/m³)

8.1. Introduction

This chapter covers the potential costs and benefits elaborates on of complying with Policy Option 2, which is the introduction of an EU-wide 20 µg/m³ BOEL for cobalt and inorganic cobalt compounds, in line with the scope of substances considered by the EC. All manufacturers, importers, downstream users, and recyclers who handle cobalt metal and cobalt substances that are either directly or indirectly in scope (see Section 1.4.1) within the EU will be required to adhere to the BOEL 20 µg/m³ based on an 8-hour time weighted average (TWA) inhalable fraction. The data used in this section is based on the industry questionnaires (eftec, 2023), which is the most recent data available.

8.2. Behavioural Responses

As explained in Section 6.3, all firms choose one of three behavioural responses: implement risk management measures, substitute regulated substances, or cease production in the EU. **Table 8.1** summarises the respondent data gathered on behavioural responses to comply with Policy Option 2. This data has been broken down at a site level in order to facilitate later cost calculations. The table also provides the share of all sites that are non-compliant, and the behavioural responses are only reported for these non-compliant sites. Where less than three responses for a broad use were received, no data is reported.

Table 8.1: Current non-compliance with and behavioural responses to a 20 µg/m³ BOEL

Broad use	Share not compliant	Implement RMMs	Substitute regulated substances	Cease production
	of all sites	% of non-compliant sites		
All	22%	40%	23%	37%
Manufacture of cobalt and/or cobalt substances	26%	87%	0%	13%
Manufacture of other chemicals	0%	0%	0%	0%
Manufacture of precursor chemicals for batteries	50%	100%	0%	0%
Manufacture of catalysts	17%	100%	0%	0%
Manufacture of pigments and dyes	36%	100%	0%	0%
Manufacture of driers / paints	No respondent data	No respondent data	No respondent data	No respondent data
Use as catalysts - used as a catalyst or catalyst precursor	17%	0%	0%	0%
Use as catalysts - used as oxidation catalyst/for PTA and IPA	Insufficient respondent data	Insufficient respondent data	Insufficient respondent data	Insufficient respondent data

Broad use	Share not compliant	Implement RMMs	Substitute regulated substances	Cease production
	of all sites	% of non-compliant sites		
Use in surface treatment - Formulation of surface treatment	0%	0%	0%	0%
Use in surface treatment - Passivation or anti-corrosion treatment processes	0%	0%	0%	0%
Use in surface treatment - Metal or metal alloy plating	60%	44%	0%	56%
Use in biotechnology – Formulation and industrial use of mixtures in biogas production	No respondent data	No respondent data	No respondent data	No respondent data
Use in biotechnology – Professional use in biogas production	No respondent data	No respondent data	No respondent data	No respondent data
Use in biotechnology – Use in fermentation, fertilizers, biotech, scientific research and standard analysis	No respondent data	No respondent data	No respondent data	No respondent data
Use in biotechnology – Formulation and use in animal feed grade materials	0%	0%	0%	0%
Bespoke uses – Use in humidity indicators cards, plugs and/or bags with printed spots	Insufficient respondent data	Insufficient respondent data	Insufficient respondent data	Insufficient respondent data
Bespoke uses – Formulation of water treatment chemicals, oxygen scavengers, corrosion inhibitors	57%	100%	0%	0%
Bespoke uses – Use of water treatment chemicals, oxygen scavengers, corrosion inhibitors	No respondent data	No respondent data	No respondent data	No respondent data
Adhesion (inc. rubber adhesion agent)	0%	0%	0%	0%
Use in electronics	No respondent data	No respondent data	No respondent data	No respondent data
Use in magnetic alloys	Insufficient respondent data	Insufficient respondent data	Insufficient respondent data	Insufficient respondent data
Use in metallurgical alloys	23%	57%	29%	14%
Use in cemented carbide/diamond tools	40%	38%	25%	38%
Recycling of materials containing cobalt substances	32%	86%	14%	0%

Table note: The sum of percentages across all behavioural responses may not add up to 100% due to rounding to the nearest percentage point.

Compliance levels are high at this BOEL, with only 22% of all sites non-compliant. This is 6 percentage points higher than the non-compliance rate for a BOEL of 30 µg/m^3. Compliance for each site will depend in part on the nature of site activities and any existing OELs on a national level.

Some broad uses have significantly higher non-compliance rates; for example, sites in the manufacture of precursor chemicals for batteries, surface treatment (metal or metal alloy plating) and formulation of water treatment chemicals, oxygen scavengers, corrosion inhibitors broad uses were at least twice as likely to be non-compliant than the average of 22%.

Overall, further implementation of RMMs is still the most popular choice with 40%, a plurality of sites, choosing this option. However, there is a significant increase in the proportion stating they would cease production when compared to 30 µg/m^3. Including all broad uses, 37% of sites would cease production, driven predominantly by sites in the surface treatment (metal or metal alloy plating) and the cemented carbide/ diamond tools broad uses. This is commensurate with the relatively higher non-compliance rates in these broad uses, suggesting greater barriers to minimising cobalt exposure. Manufacture of cobalt metal and/or cobalt substances and use in metallurgical alloys are the only other broad uses with some sites ceasing production, even though in both cases a significant majority would implement RMMs.

The remaining broad uses with non-compliant sites, for which data is available, continue to largely implement further RMMs. As in Policy option 1 (30 µg/m^3), the choice to substitute was only taken in the metallurgical alloys, cemented carbide / diamond tools and recycling broad uses. With respect to cemented carbide / diamond tools, this is expected to be the result of alternative binder materials to cobalt, which although produce inferior tools, are available on the EU market. Similarly, metallurgical alloys have alternatives (which produce inferior alloys) available in the EU – but these are not currently judged to be feasible alternatives - more information is presented in Section 5.3.

The compliance rates in this report are based on whether respondents stated they would need further action to comply, and are not necessarily comparable to earlier reports, e.g., (RPA, 2020).

8.3. Implementation of RMMs

This section reports the technical and economic feasibility of complying with Policy Option 2 through the implementation of RMMs, the types of RMMs that would need to be implemented to comply, and the costs associated with implementing these RMMs.

8.3.1 Feasibility of compliance

This section is about the technical and economic feasibility of currently non-compliant sites to comply with a BOEL of 20 µg/m^3. Note that it can be technically feasible but economically infeasible for a company to comply with a BOEL (i.e., technical solutions could be possible to implement, but it may not be financially possible to do so). Measuring the feasibility of compliance reveals the ease or difficulty companies will face in complying with a BOEL.

Table 8.2 illustrates the percentage of sites currently not compliant with this Policy Option 2 that deem it technically and economically feasible or infeasible to comply with a BOEL of 20 µg/m^3. There are more sites who reported answers than for the 30 µg/m^3 BOEL, as there are a higher number of sites that do not comply with the lower BOEL of 20 µg/m^3. Overall, it is thought to be technically feasible to comply with this BOEL across 44% of sites and economically feasible across 30% of sites. Compliance with this BOEL is 41% less technically feasible and 52% less economically feasible than compliance with a BOEL of 30 μg/m^3 (see Section 7.3.1).

When it came to the technical infeasibility of complying with this BOEL, respondents' answers to the questionnaire indicated that although they were able to comply with the BOEL in some areas, in others it is impossible to ensure such low exposure. They particularly cited the difficulty of achieving compliance with a BOEL of 20 μg/m^3 during maintenance activities, which are often activities with higher exposure and are therefore only carried out for short periods and with the appropriate PPE, and in powder processing. Respondents were also sceptical about the economic feasibility of complying with a BOEL of 20 μg/m^3, even if compliance were technically feasible. A reason for this, as stated by a respondent, is that high price increases associated with decreases in the production of cobalt would make compliance economically infeasible. To comply with this BOEL without the use of PPE would require the complete redesign or re-installation of "all forms of equipment across the production line from start to finish, inclusive of potentially fully enclosing systems" and it would "become uneconomical to manufacture cobalt-containing products".

The respondent data when split by broad use is sparser, thus should be treated with caution. Nevertheless, some useful inferences can be drawn. Respondents involved in the recycling of materials using cobalt substances, using cobalt substances in metallurgical alloys, and in cemented carbide/diamond tools reported that it is technically feasible to comply with a BOEL of 20 μg/m^3 at 75%, 62%, and 53% of non-compliant sites, respectively. The expected economic feasibility of complying with this BOEL in these sectors is lower, at 51%, 51%, and 34%.

Results from a previous cost-benefit analysis on the restriction of cobalt salts found that 80% of sites thought it would be technically feasible to comply with a restriction of 20 μg/m^3, with the use of PPE, or 57% of sites without PPE (eftec, 2019b). These figures are higher than those suggested by the current study, but reasons for this could include differences of scope between the two studies in terms of the number of substances and broad uses assessed.

Table 8.2: Share of non-complying sites where it is and is not technically and economically feasible to comply with 20 μg/m^3 BOEL

Type of feasibility	% non-complying sites	
Technical feasibility	% of sites technically feasible to comply	44%
	% of sites not technically feasible to comply	51%
	% of sites technical feasibility unknown	5%
Economic feasibility	% of sites economically feasible to comply	30%
	% of sites not economically feasible to comply	56%
	% of sites economic feasibility unknown	14%

Table note: Total share of sites has been estimated using the number of sites currently not-complying with a 20 μg/m^3 BOEL, as reported by questionnaire respondents, and regardless of broad use.

8.3.2 RMMs needed to comply with this option

This section reports the types of measures that would need to be implemented by the affected sites in the

EU-27 in order to comply with a BOEL of 20 µg/m^3. As has been reported above, the implementation of these RMMs is dependent on whether a company considers this the most viable course of action for their sites (reported in Section 8.2) and whether the implementation of RMMs is technically and/or economically feasible for the relevant sites (reported in Section 8.3.1).

Article 6.2 of the Chemical Agents Directive (OSHA, 2021; 2017) sets out rules for how chemical exposure to workers shall be reduced according to a "hierarchy of controls". One of the general principles of prevention is "*giving collective protective measures priority over individual protective measures*" (art. 6.2), which suggests that measures other than PPE should be prioritised. The Carcinogens and Mutagens Directive (OSHA, 2021) is even more stringent in its requirements for how to avoid worker exposure to carcinogenic or mutagenic substances. These substances should be replaced as far as technically possible, regardless of economic considerations (art. 4.1). For this reason, RMMs required for compliance are reported with and without the use of PPE. Reporting measures in these two scenarios also provides useful information for when the use of PPE becomes necessary for compliance (i.e., if collective protection measures are not enough) (OSHA, 2021b).

The RMMs reported in this section have been collated from responses to eftec's 2023 questionnaire (eftec, 2023). These RMMs therefore include a suite of measures that could be implemented to comply with Policy Option 2, and it might not be necessary to implement all the measures that have been reported to achieve compliance.

RMMs needed to comply, with PPE

Table 8.3 presents the types of measures that would be implemented by manufacturers, downstream users, and recyclers of cobalt metal and/or cobalt substances to comply with Policy Option 2. Similar measures were reported in Section 7.3.2 on the RMMs needed to comply with Policy Option 1 with the use of PPE. There is some variation between the measures reported. For example, to comply with Policy Option 2 some respondents reported installing a full enclosure of the operating system, whilst compliance with Policy Option 1 required only partial enclosure of certain key areas.

Respondents also reported the estimated number of years required to implement these RMMs and comply with this Policy Option. Manufacturers reported that implementation of RMMs would take between less than one and five years, with an estimated median of around two years. Downstream users and recyclers estimated that implementation to achieve compliance would require between less than one and more than eight years but varied substantially in the median number of years required. The median number of years required by downstream users is two, whilst recyclers have a median implementation time of six years, suggesting that compliance with this Policy Option is more difficult for recyclers.

As would be expected, the median number of years needed to comply with Policy Option 2, with the use of PPE is higher than the years required to comply with Policy Option 1 for most types of activities. For downstream users it requires an additional year to comply with Policy Option 2, whilst for recyclers it requires an additional two years compared to Policy Option 1 (when comparing the median years). The median implementation time for manufacturers remains the same.

Table 8.3: Types of control measures needed to comply with BOEL, with PPE

Type of RMM	RMMs
Engineering controls	• Increased automation to avoid manual handling (e.g., automated filling of drums and automated loading processes) • Installation of remote processes • Containment of dust in selected equipment (e.g., installation of a suction system) • Installing partial hood enclosures • Detect unusual exposure with continuous measurement. • Better ventilation and installation of a suction system • Full enclosure of current operating systems (i.e., installing only closed systems, sealed and closed processing facility, etc.) • Change of sinter trays • Study to review the process and after modification. • Upgrade of air stack filters
Administrative controls	• Training of potentially exposed employees • Reducing exposure time by rotating operators • Discontinuation of packaging/size of pre-weighted bags
PPE	• Increase use of respiratory equipment (e.g., powered air purification respirator or airstream helmets) • Full PPE required when accessing equipment and or handling powders (i.e., the use of masks, gloves, disposable uniforms, etc.)

Table note: RMMs are collated from responses to the industry questionnaire and will not all be implemented by the same company.

RMMs needed to comply, without PPE

The RMMs needed to comply with this Policy Option for the 40% of non-compliant sites that would opt to implement RMMs (as reported in Section 8.2) are presented in **Table 8.4.**The low proportion of non-compliant sites that would implement RMMs to comply with this Policy Option is further reflected in the fact that it is reportedly technically infeasible to comply with this BOEL in approximately half of non-compliant sites and economically infeasible in more than half of these sites (reported in **Table 8.2**). The non-compliant sites in which it is technically and economically feasible to implement RMMs, the types of RMMs that would need to be implemented with PPE include rebuilding and upgrading sites to increase automation and enclosure as a way of reducing worker contact with the relevant substances, as well as improving extractor systems and containing dust.

Manufacturers and downstream users reported that implementing a selection of these RMMs would require between less than one and more than eight years, with a median implementation time of three years and four years respectively. This is the same as the implementation time required for complying with Policy Option 1. Recyclers also reported an implementation period of between less than one and more than eight years but had a median implementation time of around six years, which is two years longer than the implementation time required to comply with Policy Option 1 but is the same implementation time required for complying with Policy Option 2 with PPE.

Table 8.4: Types of control measures needed to comply with BOEL, without PPE

Type of RMM	RMMs
Engineering controls	• Increased automation (e.g., weighing; powder processing; entire raw material feeding process) • Rebuilding and/or upgrading part of the process infrastructure.

	• Installing extraction and improving ventilation (e.g., installing partial hood enclosures, stronger exhaust systems, installing air stack filters, etc.). • Containment of dust in selected equipment (e.g., by installing a big-bag discharger, dust extractor Sintering, etc.) • Introducing heated buildings for raw material handling (this is required as air-flow PPE cannot be used well in sub-zero temperatures) • Detect unusual exposure with continuous measurement. • Enclosure and containment of key areas to avoid open handling (e.g., by sealed and closed processing facility, encapsulation of unloading station, closed filling into the mill, more sealed equipment, etc.) • Second spray dryer • Installing a conveyor system between pastillator and packaging machine • Redesign areas (e.g., Workplace ISO-Pressing, workplace cleaning)
Administrative controls	• Full training programmes and education on limiting exposure. • Termination of certain products • Reducing exposure time by rotating operators • Introduction of standard operating procedures (SOP) • Discontinuation of packaging/size of pre-weighted bags

Table note: RMMs are collated from responses to the industry questionnaire and will not all be implemented by the same company.

8.3.3 Cost of RMMs[56]

The cost of implementing RMMs is analysed with and without PPE. Given that PPE should be the last option RMM (see Section 6.3.1), it is expected that the actual costs of compliance will be closer to the without PPE estimates. It would be expected that the costs of compliance without PPE are higher as other RMM options available to companies may be limited and more expensive.

Disaggregated costs for SMEs and large companies were estimated, before these were combined into a weighted average unit cost per site (see Appendix A 1.3 for more details). The costs for SMEs and large companies are based on smaller sample sizes and are thus likely to be less reliable than aggregate figures.

Table 8.5 shows the unit costs of implementing RMMs for a single site, and total costs under a BOEL of 20 µg/m^3. This is based on respondents reports of the total costs they face in complying with the BOEL through RMMs. This is different than the approach taken in RPA (2020), which calculate costs using a model to determine which RMMs are required to go from existing exposure levels to below the BOEL. Total costs only include the costs incurred by sites that implement RMMs, where the number of sites is derived from the behavioural responses discussed in Section 8.2. It is assumed that any capital expenditure must be repeated twice over a period of 40 years, reflecting a capital lifetime of twenty years.

Disaggregated costs for SMEs and large companies were estimated, before these were combined into a weighted average unit cost per site (see Appendix A 1.3 for more details). The costs for SMEs and large companies are based on smaller sample sizes and are thus likely to be less reliable than the aggregate figures.

[56] There was an error in the calculation of the RMM costs of RMMs for 20 µg/m^3 in the report originally sent to the European Commission contractor. This has now been corrected throughout the report.

Table 8.5: **Weighted average costs of implementing RMMs to comply with a 20 µg/m³ BOEL**

Cost type	Number of sites incurring costs	With PPE		Without PPE	
		Annualised costs (PV € million/year)	Costs 2022 - 2061 (PV € million)	Annualised costs (PV € million/year)	Costs 2022 - 2061 (PV € million)
SMEs unit costs (per site)	1	0.02	0.9	0.02	0.9
Large companies unit costs (per site)		0.14	5.6	0.16	6.3
Unit costs		0.04	1.8	0.05	1.9
Total costs (SMEs)	**630**	**14**	**570**	**14**	**580**
Total costs (Large)	150	20	820	20	940
Total costs (all)	780	30	1,390	40	1,510

Table notes:

- Annualised cost is the present value (i.e., sum of discounted future costs), divided by the number of years in the analytical period (40 years). Values are discounted using a 3% discount rate and given in 2022 €.
- Number of sites incurring costs is rounded to the nearest 10. Annualised total costs are rounded to the nearest 10 million, while annualised unit costs are rounded to the nearest 10,000. Unit costs over the appraisal period are rounded to the nearest 100,000, while total costs over the appraisal period are rounded to 10 million.
- The assumed number of sites for the purpose of cost calculations is equal to an average of the upper and lower bound site estimates.
- The unit costs are a weighted average of costs for SMEs and large companies.

The weighted average unit cost of implementing RMMs needed to comply with a BOEL of 20 µg/m³ is €1.8million across the full 40 years appraisal period with PPE, and €1.9 million without PPE, meaning the unit cost is more than twice as high if PPE is not used. This is close to 30% higher costs than what was estimated for 30 µg/m³.

When applied to all sites that incur this cost, the total cost of implementing RMMs for this BOEL is €1.39 billion – €1,51 billion in present value terms over the period 2022 - 2061 depending on whether PPE is used as an RMM. As BOELs become more stringent, fewer sites implement RMMs, reducing the total cost of implementing RMMs, but the overall numbers of non-compliant sites and the cost of implementing RMMs per site both rise. In this case these effects roughly cancel each other out.

8.4. Cease of use of cobalt metal and cobalt substances

As discussed in Section 6.3, instead of implementing RMMs companies could cease the use of cobalt metal and cobalt substances. This could be achieved either by substituting cobalt metal and/or cobalt substances with alternatives, closing affected product lines, complete shut-down of the entire site, and/or shifting production to new or existing sites outside the EU. Shutting down production lines, sites and/or shifting production to sites outside the EU does not reduce demand for cobalt-containing products but increases dependence on imports from outside the EU. As discussed in Section 3.2.3, cobalt metal is classified by the EC as a critical raw material and is used in strategic technologies and sectors (see Section 11.2 for more information).

8.4.1 Substitution

Table 8.6 shows the unit and total costs of substituting cobalt metal and/or cobalt substances. Total costs are calculated for the sites that will substitute cobalt metal and/or cobalt substances, which is estimated from respondent data (discussed in Section 8.2). The unit costs of substitution are the same under all of the BOELs analysed in this report, but the number of sites which incur the cost changes depending on behavioural responses to each of the BOELs.

This cost is based upon historic costs reported by respondents that have already attempted substitution, of which no respondent reported that they were able to fully substitute successfully. Substitution is likely to first be carried out for uses and products for which alternatives exist and is deemed feasible (low hanging fruits). These points both indicate that the derived substitution costs are likely an underestimate of actual substitution costs that would be incurred. Companies are not likely to substitute unless feasible alternatives are available, so these cost estimates are not reflective of substitution costs for all broad uses.

Costs incurred by respondents over the last five years are assumed to continue linearly over five years for all sites substituting to alternatives. Due to small sample sizes, disaggregated costs for SMEs and large companies were not calculated.

Table 8.6: Costs of substituting cobalt metal and/or cobalt substances to comply with a 20 µg/m³ BOEL

Cost type	Number of sites incurring cost	Annualised costs (PV € million/year)	Costs 2022 - 2061 (PV € million)
Unit costs	1	0.004	0.2
Total costs (all)	460	2	70

Table notes:

- Annualised cost is the present value (i.e., sum of discounted future costs), divided by the number of years in the analytical period (40 years). Values are discounted using a 3% discount rate and given in 2022 €.
- Number of sites incurring costs is rounded to the nearest 10. Annualised total costs are rounded to the nearest 10 million, while annualised unit costs are rounded to the nearest €1,000. Unit costs over the appraisal period are rounded to the nearest €100,000, while total costs over the appraisal period are rounded to €10 million.
- The assumed number of sites for the purpose of cost calculations is equal to an average of the upper and lower bound site estimates.

The average cost of substitution in a single site is €200,000 across the full 40 years appraisal period. As shown in Section 8.2, the use in metallurgical alloys, cemented carbide/ diamond tools and recycling broad uses have sites that would substitute if this BOEL was introduced. Of these, only the recycling broad use was not represented in the historic substitution costs dataset, suggesting that costs for that broad use are likely underestimated. When applied to all sites that incur this cost, the total cost of substitution is €70 million in present value terms over the period 2022 – 2061.

8.4.2 *Lost profit from ceasing production in the EU*

The cost of ceasing production (lines) is assumed to be the same regardless of whether production is stopped altogether or relocated to plants outside of the EU. This reflects the fact that this analysis has the EU-27 as its geographical scope and considers only the cost to society in the EU-27, not the private cost faced by businesses.

In earlier report (e.g., RPA (2020) and eftec (2019b)) lost profits were calculated over a 20-year period. However, new has since been by the Committee for Socio-Economic Assessment (SEAC) under REACH guidance (ECHA, 2021). In line with this guidance, profit loss has been estimated for a period of four years (see Appendix A 1.3 for more details).

Table 8.7 shows the unit and total costs of ceasing production in the EU. Total costs are calculated for the sites that are assumed to cease production based on behavioural responses discussed in Section 8.2. The unit cost of ceasing production is the same under all four BOELs analysed in this report, but the number of sites which incur the cost changes depending on companies' behavioural responses to each BOEL.

These costs only consider profits associated with affected product lines, so ceasing production in the EU only counts profit lost at those affected product lines and not any other activities at the same site or company that are not related to the regulated substances. In some cases, particularly for larger companies, sites ceasing production of affected product lines will continue activities that are not affected by the BOEL. However, this will likely not be feasible for most SMEs, where the whole site or company is more likely to close down or relocate. The estimated unit costs of ceasing production are therefore believed to be underestimated as the costs of complete closure or relocation are not counted.

It was assumed that profit is lost to the EU economy for four years after production ceases, after which it is assumed that profit is replaced by new and expanding companies. Where production is shifted to new or existing sites outside of the EU, only the profit lost within the EU is considered, not the private costs of relocation faced by businesses.

Disaggregated costs for SMEs and large companies were estimated, before these were combined into a weighted average unit cost per site (see Appendix A 1.3 for more details). The costs for SMEs and large companies are based on smaller sample sizes and are thus likely to be less reliable than the aggregate figures.

Table 8.7: Costs of ceasing production in the EU to comply with a 20 µg/m³ BOEL

Cost type	Number of sites incurring cost	Annualised costs (PV € million/year)	Costs 2022 - 2061 (PV € million)
SMEs unit costs (per site)	1	0.03	1.4
Large companies unit costs (per site)		0.21	8.3
Unit costs		0.07	2.6
Total costs (SMEs)	600	20	840
Total costs (Large)	130	30	1,110
Total costs (all)	740	50	1,950

Table notes:

- Annualised cost is the present value (i.e., sum of discounted future costs), divided by the number of years in the analytical period (40 years). Values are discounted using a 3% discount rate and given in 2022 €.
- Number of sites incurring costs is rounded to the nearest 10. Annualised total costs are rounded to the nearest €10 million, while annualised unit costs are rounded to the nearest €10,000. Unit costs over the appraisal period are rounded to the nearest €100,000, while total costs over the appraisal period are rounded to €10 million.
- The assumed number of sites for the purpose of cost calculations is equal to an average of the upper and lower bound site estimates.

The average cost of ceasing production in the EU at a single site is €2.6 million in present value terms across the full 40 years appraisal period. When applied to all sites that incur this cost, the total cost of ceased production within the EU for this BOEL is €2.0 billion in present value terms over the period 2022 - 2061, reflecting the significantly higher (eight times) proportion of sites choosing to cease production at this more stringent BOEL compared to 30 µg/m³.

The annual costs of ceasing production are around seven times higher for large companies than it is for SMEs, at around €30,000 and €210,000 respectively.

8.5. Costs of compliance

This section presents the total costs of compliance with a 20 µg/m³ BOEL, considering each of the three behavioural responses, as well as costs of implementing monitoring programmes. Section 8.5.1 presents the unit costs of compliance on a per-site basis, while Section 8.5.2 presents the total costs of compliance across the industry as a whole by the type of cost and by broad use.

8.5.1 Unit costs

Table 8.8 shows the unit costs for a single site to comply with a BOEL of 20 µg/m³ for each of the likely behavioural response (i.e., type of costs). In addition, the average cost for a non-compliant site, and the average cost for all sites are presented. The former figure includes sites not complying with a BOEL of 20 µg/m³ and reflects the likely costs that would actually be incurred by sites in order to achieve compliance. This latter figure includes compliant sites incurring no costs and compliant sites which have to implement monitoring systems. The average unit cost per site allows for comparison across the Policy Options as the number of sites remains constant, which is in contrast to the average unit cost per non-compliant site where the number of sites not complying changes in each Policy Option (i.e., the number of non-compliant sites increases as the BOEL decreases). Disaggregated costs for SMEs and large companies were estimated, before these were combined into a weighted average unit cost per site (see Appendix 1.3 for more details).

Table 8.8: Unit costs per site to comply with a 20 µg/m³ BOEL

Types of costs	With PPE		Without PPE	
	Annualised costs per site (PV € million/year)	**Costs 2022 – 2061 per site (PV € million)**	**Annualised Costs per site (PV € million /year)**	**Costs 2022 – 2061 per site (PV € million)**
Implementing RMMs	0.04	1.80	0.05	1.90
Implementing biological monitoring	0.03	1.00	0.03	1.00
Implementing respiratory fraction monitoring	0.01	0.50	0.01	0.50
Substitution with alternatives	0.004	0.20	0.004	0.20
Ceasing production in the EU	0.07	2.60	0.07	2.60
Average unit cost per non-compliant site	**0.06**	**2.40**	**0.06**	**2.50**
Average unit cost per site	0.03	1.10	0.03	1.10

Table notes:

- Annualised cost is the present value (i.e., sum of discounted future costs), divided by the number of years in the analytical period (40 years). Values are discounted using a 3% discount rate and given in 2022 €. Total number of non-compliant sites requiring monitoring is not calculated as all sites require monitoring under any BOEL.
- Number of sites incurring costs is rounded to the nearest 10. Annualised costs are rounded to the nearest €10,000, unless costs are <€5,000 in which case they are rounded to the nearest €1,000. Costs across the appraisal period are rounded to the nearest 100,000.
- Average unit cost is a composite average cost per site, taking into account the shares of non-compliant sites that will implement RMMs, substitute, and cease production in the EU, as well as the share of all sites that will implement monitoring programmes.
- The assumed number of sites for the purpose of cost calculations is equal to an average of the upper and lower bound site estimates.

The average unit cost per non-compliant site is €60,000 per year. This is just slightly higher than a BOEL of 30 µg/m³, as the lower cost of RMMs under 20 µg/m³ was dominated by the effect of the increased proportion of sites ceasing production in the EU. Compliant sites will only incur the cost of implementing monitoring programmes, if this is not already in place, and the costs for a compliant site are therefore comparatively lower. Only 22% of sites are currently non-compliant with this BOEL (see **Table 8.1**) which explains the lower average cost for all sites (regardless of compliance) at €30,000 with PPE and without PPE for each site across the industry.

The unit cost of implementing monitoring is estimated at €30,000 annually for biological monitoring and €10,000 annually for respiratory fraction monitoring. The costs of implementing RMMs and ceasing production substantially exceed the other costs.

8.5.2 Total costs

Table 8.9 shows the overall costs of compliance with a BOEL of 20 µg/m^3, broken down by the type of cost. For the total cost, both a lower and upper bound for the number of sites to which the BOEL will apply is used, while for the remainder of the table a central estimate of the number of sites is used.

Table 8.9: Total costs of compliance with a 20 µg/m^3 BOEL, by cost type

Type of costs	Number of sites incurring cost	With PPE		Without PPE	
		Annualised costs (PV € million/year)	Costs 2022 - 2061 (PV € million)	Annualised costs (PV € million/year)	Costs 2022 - 2061 (PV € million)
Implementing RMMs	780	30	1390	40	1,510
Implementing biological monitoring	4,490	120	4,640	120	4,640
Implementing respiratory fraction monitoring	3,430	40	1,650	40	1,650
Substitution with alternatives	460	2	70	2	70
Ceasing production in the EU	740	50	1,950	50	1,950
Total cost lower bound	-	**180**	**7,340**	**190**	**7,430**
Total cost upper bound	-	**300**	**12,000**	**380**	**12,150**

Table notes:

- Annualised cost is the net present value (i.e., sum of discounted future costs), divided by the number of years in the analytical period (40 years). Values are discounted using a 3% discount rate and given in 2022 €.
- Number of sites incurring costs is rounded to the nearest 10. Costs are rounded to the nearest 10 million, unless costs are less than 10 million in which case, they were rounded to the nearest million.
- The total figures are provided for the lower and upper bound. These are calculated using a lower and upper bound estimate of the number of sites using in scope substances across the EU-27. The remaining figures are estimated using an average of the lower and upper bound site estimates for each type of cost.

The total cost of compliance with a BOEL of 20 µg/m^3 is estimated at between €7.0 billion – €12 billion, in present value terms over the period 2022 - 2061. This is around 10% higher than the costs of 30 µg/m^3. This is driven by the higher non-compliance rate (the number of non-compliant sites is around a third higher than under a BOEL of 30 µg/m^3) on one hand, but the lower cost of implementing RMMs with PPE on the other. For more discussion on this particular result see Section 8.3.3.

The largest component of this overall cost remains monitoring programmes, which have a higher cost due to the high compliance rate and need for all sites to have monitoring programmes in place. This is in line with the figures for 30 µg/m^3. The total cost of monitoring is less, absolutely and proportionally, at this BOEL given the larger number of sites that cease production and hence do not require monitoring as they are no longer operating. Given the higher total costs of RMMs and lost profit under this BOEL, monitoring's share of the overall costs has also slightly declined.

Substitution remains the smallest proportion of costs, reflecting the low unit cost of substituting under our calculations and the small proportion of sites substituting regulated substances.

Note that the underlying data did not allow for a separation of behavioural responses with and without PPE, though in practice it is very likely that some companies would change their behaviour if forced to implement higher cost engineering or administrative controls.

Table 8.10 shows the total costs of compliance with a BOEL of 20 µg/m³ broken down by broad use. Figures are only presented in aggregate across cost types and for the broad uses where there was a sufficient number of responses. These costs differ from the costs presented above because broad-use specific unit costs were used where there were sufficient responses, rather than average unit costs presented in **Table 8.8**. Where there were sufficient responses to calculate broad use specific unit costs for only some cost components, it is assumed that the unit cost is equal to the average shown in **Table 8.8**.

Using broad use specific unit costs would lead to total costs being higher than when using average unit costs across all uses, however, these are generally based on a small sample size and are thus less reliable than the aggregate figures presented above. The subsequent analysis, therefore, relies on the numbers set out in **Table 8.9**.

Table 8.10: Total cost of compliance with a 20 µg/m³ BOEL, for all sites by broad use

Broad use	Sites estimate used	With PPE		Without PPE	
		Annualised costs (PV € million/year)	Costs 2022 - 2061 (PV € million)	Annualised costs (PV € million/year)	Costs 2022 - 2061 (PV € million)
Manufacture of cobalt and/or cobalt substances	Upper bound	5.1	200	9.8	390
	Lower bound	3.2	130	15.8	630
Manufacture of other chemicals	Upper bound	1.7	70	1.0	40
	Lower bound	1.0	40	1.7	70
Manufacture of precursor chemicals for batteries	Upper bound	Insufficient respondent data			
	Lower bound				
Manufacture of catalysts	Upper bound	0.4	20	0.4	20
	Lower bound	0.3	10	0.6	20
Manufacture of pigments and dyes	Upper bound	1.3	50	3.3	130
	Lower bound	0.9	30	5.0	200
Manufacture of driers / paints	Upper bound	No respondent data			
	Lower bound				
Use as catalysts - used as a catalyst or catalyst precursor	Upper bound	2.6	100	2.1	80
	Lower bound	1.6	60	3.4	130
Use as catalysts - used as oxidation catalyst/for PTA and IPA	Upper bound	Insufficient respondent data			
	Lower bound				
	Upper bound	0.2	10	0.2	10

Broad use	Sites estimate used	With PPE		Without PPE	
		Annualised costs (PV € million/year)	Costs 2022 - 2061 (PV € million)	Annualised costs (PV € million/year)	Costs 2022 - 2061 (PV € million)
Use in surface treatment - Formulation of surface treatment	Lower bound	0.2	10	0.2	10
Use in surface treatment - Passivation or anti-corrosion treatment processes	Upper bound	30.5	1,220	18.7	750
	Lower bound	18.7	750	30.5	1,220
Use in surface treatment - Metal or metal alloy plating	Upper bound	165.2	6,610	106.4	4,260
	Lower bound	101.3	4,050	173.6	6,940
Use in biotechnology – Formulation and industrial use of mixtures in biogas production	Upper bound	No respondent data			
	Lower bound				
Use in biotechnology – Professional use in biogas production	Upper bound	No respondent data			
	Lower bound				
Use in biotechnology – Use in fermentation, fertilizers, biotech, scientific research and standard analysis	Upper bound	No respondent data			
	Lower bound				
Use in biotechnology – Formulation and use in animal feed grade materials	Upper bound	120.1	4,800	73.3	2,930
	Lower bound	73.3	2,930	120.1	4,800
Bespoke uses – Use in humidity indicators cards, plugs and/or bags with printed spots	Upper bound	Insufficient respondent data			
	Lower bound				
Bespoke uses – Formulation of water treatment chemicals, oxygen scavengers, corrosion inhibitors	Upper bound	Insufficient respondent data			
	Lower bound				
Bespoke uses – Use of water treatment chemicals, oxygen scavengers, corrosion inhibitors	Upper bound	No respondent data			
	Lower bound				
Adhesion (inc. rubber adhesion agent)	Upper bound	0.7	30	0.4	20
	Lower bound	0.4	20	0.7	30
Use in electronics	Upper bound	No respondent data			
	Lower bound				
Use in magnetic alloys	Upper bound	Insufficient respondent data			
	Lower bound				

Broad use	Sites estimate used	With PPE		Without PPE	
		Annualised costs (PV € million/year)	Costs 2022 - 2061 (PV € million)	Annualised costs (PV € million/year)	Costs 2022 - 2061 (PV € million)
Use in metallurgical alloys	Upper bound	17.5	700	22.5	900
	Lower bound	10.7	430	37.0	1,480
Use in cemented carbide/diamond tools	Upper bound	114.5	4,580	73.8	2,950
	Lower bound	69.9	2,800	120.8	4,830
Recycling of materials containing cobalt substances	Upper bound	2.2	90	5.4	220
	Lower bound	1.4	50	8.7	350

Table notes:

- Annualised cost is the present value (i.e., sum of discounted future costs), divided by the number of years in the analytical period (40 years). Values are discounted using a 3% discount rate and given in 2022 € €.
- Annualised costs are rounded to the nearest €100,000. Costs over the appraisal period are rounded to the nearest €10 million.
- Figures are provided for the lower and upper bound based on the lower and upper bound estimates of the number of sites in scope substances across the EU.

The highest costs are faced by formulation and use in animal feed grade materials, cemented / carbide tools and metal or metal alloy plating. This reflects both the higher number of sites in these broad uses and the higher per site costs of compliance compared to others.

Cemented carbide / diamond tools and metal or metal alloy plating broad uses in particular have high per site costs, driven by very high costs of ceasing production in the EU, due to the large number of sites in this broad use combined with a high share of sites choosing this option. In the cemented carbide / diamond tools sector, 40% of sites are non-compliant of which 38% would cease production. Metal alloy plating has 60% non-compliant site, and 56% of these would cease production. This is compared to the 37% of non-complying sites (22% of total sites are non-compliant) that would cease production across all the broad uses (see **Table 8.1**).

The results from the industry questionnaire suggested that recycling is likely to incur the highest per site cost, when PPE is not used, due to a very high cost of RMMs (double the average across all broad uses), and a high proportion of non-compliant sites choosing to implement RMMs (86% of the 32% of non-compliant sites would implement RMMs). However, the smaller number of recycling sites means that the total cost is still less than 20% of that for metallurgical alloys, cemented carbide / diamond tools and the other high cost broad uses.

The unit costs of ceasing production vary significantly (up to €50 million annually per site) across the broad uses. As the cost of ceased production is proportionate to per-site revenue and thus site size, the unit cost of ceasing production was generally inversely proportional to the number of sites across the broad use.

The notable exceptions to this pattern are cemented carbide / diamond tools and metal or metal alloy plating, which are in the top five broad uses for both number of sites and the unit cost of ceasing production per site. This is the main driving factor for the high costs of compliance within these two broad uses.

The costs of monitoring programs and substitution are fairly consistent across the broad uses and hence are not drivers of differences in total cost between the broad uses, nor of overall costs.

8.6. Social costs

Social impacts (or social costs) as defined by the EC in Better Regulation Toolbox (European Commission, 2021) can be classified into three broad categories of: 1) employment, 2) working conditions and 3) income distribution, social protection, and inclusion. Due to data limitations, this analysis only quantified impacts on employment (i.e., lost jobs), but qualitative aspects are further addressed in Chapter 11.

Impacts on EU employment are closely linked to potential production halts, permanent reduction in production and relocation of production outside the EU. A similar approach as used to estimate profit losses was therefore deployed in order to calculate social costs from potential EU jobs lost. The number of jobs at risk (i.e., the number of jobs lost over 40 years) shown in **Table 8.11** was estimated using the average number of employees per site adjusted for the number of sites which will potentially need to shut down in response to the BOEL. The relevant share of jobs at risk is assumed to be proportional to the share of profits at risk.

The jobs lost will not be equally distributed across the analytical period but will be concentrated in the short period following the announcement and introduction of the BOEL. In this analysis, it has been assumed that all the redundancies associated with ceasing of production will occur in the first year after the BOEL is announced. In line with (ECHA, 2008), job losses are considered to be temporary, i.e., the workers find new jobs after a period of time. In line with the SEAC guidance, the social value of lost jobs has been estimated on the basis of an average EU gross salary after employer taxes of around €35,200, assuming that the societal value of a lost job is around 2.7 times the annual pre-displacement salary (ECHA, 2016b). The SEAC guidance approach to valuing unemployment impacts comprises several components such as the value of productivity loss during the period of unemployment and cost of job search, hiring and firing; the impact of being made unemployed on future employment and earnings, and the value of leisure time during the period of unemployment.

Although the jobs lost will be concentrated in the short period following the introduction of the BOEL, **Table 8.11** reports the annualised costs of lost employment (i.e., the total cost of lost employment, which is likely to occur shortly after the introduction of the BOEL, divided by the 40-year analytical period) for comparability with the costs of compliance (reported in Section 8.5).

Table 8.11: Social costs of ceasing production in the EU to comply with a 20 µg/m³ BOEL

	Number of jobs lost over 40 years	Annualised costs (PV € million/year)	Costs 2022 - 2061 (PV € million)
Unit costs (per job lost)	1	0.002	0.1
Total costs (all jobs)	51,600	120	4,910

Table notes:

- Annualised cost is the present value (i.e., sum of discounted future costs), divided by the number of years in the analytical period (40 years). Values are discounted using a 3% discount rate and given in 2022 €.
- Annualised costs of lost employment are estimated to allow for comparability with costs of compliance, however, it is assumed that all the costs will be incurred in the first year following the announcement of BOELs, rather than annually over the full period

of 40 years.

- Number of jobs lost is rounded to the nearest 100. Annualised total costs are rounded to the nearest 10 million, while annualised unit costs are rounded to the nearest 10,000. Unit costs over the appraisal period are rounded to the nearest 100,000, while total costs over the appraisal period are rounded to 10 million.
- Total cost figures and number of jobs lost are based on the average between the lower and upper bound estimates of the number of sites in scope substances across the EU.

The estimated number of EU jobs lost due to ceasing production is 51,600. The unit cost of each job lost is €100,000, or around €2,000 annually. The total annualised cost of jobs lost associated with a BOEL of 20 μg/m^3 is €120 million, reaching €4.9 billion over 40 years. The total cost of jobs lost over 40 years resulting from implementation of a 20 μg/m^3 BOEL is estimated to be almost eight times higher than the equivalent costs associated with a 30 μg/m^3 BOEL.

8.7. Benefits

This section sets out the estimated health benefits to workers from a reduction in worker exposure under Policy Option 2. The method used to estimate new exposure levels and the number of cases reduced is described in **A 1.4**, and the results are shown in **Table 8.12**. The risk reduction capacity at 20 μg/m^3 is high, with 88% - 97% of cases reduced compared to the baseline: an increase of 2% – 9% from the risk reduction capacity at 30 μg/m^3. As was also the case at a BOEL of 30 μg/m^3, a conservative assumption that companies will not use PPE in order to comply with the BOEL has been applied. Section 12.5 further explores how the results may change if this and other assumptions are altered.

Table 8.12: Number of cases reduced under a BOEL of 20 μg/m^3

Health endpoint	Number of cases reduced over 40 years		Risk reduction capacity (%)
	Lower bound	Upper bound	
Cancer	69	115	88%
Respiratory irritation	2,585	4,273	92%
Restrictive lung disease	984	1,626	97%

Table notes:

- The lower and upper bounds correspond to the lower and upper bounds for the number of workers exposed.
- The reduction capacity is the number of cases reduced by the policy option divided by the number of cases in the baseline.

The monetised health benefits are derived by multiplying the number of cases associated with each health endpoint with their respective valuation factors (see Section 4.5.2) and discounted over a period of 40 years to arrive at the present value (PV). The total present values were divided by 40, to arrive at the annual benefits estimates.

As can be seen in **Table 8.13**, the total benefits over 40 years are expected to be in the range of €430 - €720 million, with corresponding annual benefits of €11 - €18 million.

Table 8.13: Monetised benefits of a BOEL of 20 μg/m^3

Endpoint	Annual benefits (PV € million/year)		Benefits over 40 years (PV € million)	
	Lower bound	Upper bound	Lower bound	Upper bound

Cancer	3	4	108	178
Respiratory irritation	3	5	130	214
Restrictive lung disease	5	8	197	326
Total	**11**	**18**	**434**	**718**

Table notes:

- Annualised benefit is the present value (i.e., sum of discounted future benefits), divided by the number of years in the analytical period (40 years). Values are discounted using a 3% discount rate and given in 2022 €.
- The lower and upper bounds correspond to the lower and upper bounds for the number of workers exposed.

8.8. Summary

Table 8.14 shows the summary breakdown of monetised impacts of a BOEL of 20 µg/m^3 with and without PPE. All values are estimated as averages between the lower and upper bound estimates based on the number of sites and workers employed across the EU. The impact categories comprise of benefits (row 1), different costs of compliance (rows 2-6) and social costs (cost of lost jobs in row 7). The bottom two rows present the net value of benefits calculated as the difference between benefits and costs found for the lower and upper estimates of the number of sites in the EU, respectively. All cost estimates are presented as negative values, and benefits as positive values.

Table 8.14: Summary of monetised costs and benefits of a BOEL of 20 µg/m^3

Types of impact	Annual impact (PV € million/year)	
	Compliance without PPE	**Compliance with PPE**
Benefits	14	< 14
Implementing RMMs	-40	-30
Implementing biological monitoring	-116	-116
Implementing respiratory fraction monitoring	-41	-41
Substitution with alternatives	-2	-2
Ceasing production in the EU	-49	-49
Lost jobs	-123	-123
Net benefits - lower bound	-268	-266
Net benefits - upper bound	-438	-318

Table notes:

- Annualised impact is the present value (i.e., sum of discounted future costs or benefits), divided by the number of years in the analytical period (40 years). Values are discounted using a 3% discount rate and given in 2022 €. The exception are the bottom two rows which show the net present value (PV benefits minus PV costs).
- All cost estimates are presented as negative values, and benefits as positive values.
- All annualised impacts are rounded to the nearest €1 million, to ensure comparability between costs and benefits.
-
- Only central estimates based on the average between the lower and upper bound estimates of the number of sites in scope substances across the EU are presented.

Regardless of the parameters applied (i.e., without or with PPE, as well as lower/upper bound estimates), the present value of costs of implementing a BOEL of 20 µg/m^3 significantly outweighs the present value of monetised benefits. The total annual net loss to society of implementing an BOEL of 20 µg/m^3 is estimated at €258 million – €422 million with PPE, and €313 million – €511 million without PPE. The annualised benefits are 25 and 30 times smaller than the overall costs. Furthermore, the estimated net loss is around 50% larger than with 30 μg/m^3 with PPE, or 80% larger without PPE.

As detailed in Section 8.5.2, this is driven by the higher non-compliance rate and higher proportion of sites choosing the relatively more costly option of ceasing production in the EU, rather than implementing RMMs. With PPE, around 15% of the overall cost is due to ceasing production, with a further third due to lost jobs. In the with PPE scenario less than 10% of the cost is due to RMMs, a fall of around 15 percentage points due to the particularly low RMM costs for this BOEL. Without PPE this proportion is higher, at around 25% of costs, which is slightly higher than the comparable figure for 30 μg/m^3. Monitoring programmes remain the largest cost component, due to the high numbers of compliant sites requiring monitoring programmes. The cost of substitution remains negligible proportionally, due to the smaller number of sites taking this option and the low unit cost of substitution.

9. Policy Option 3 (BOEL 10 μg/m³)

9.1. Introduction

This chapter covers the potential costs and benefits elaborates on of complying with the Policy Option 3 which is the introduction of an EU-wide 10 μg/m³ BOEL for cobalt and inorganic cobalt compounds, in line with the scope of substances considered by the EC. All manufacturers, importers, downstream users, and recyclers who handle cobalt metal and cobalt substances that are either directly or indirectly in scope (see Section 1.4.1) within the EU will be required to adhere to the BOEL 10 μg/m³ based on an 8-hour time weighted average (TWA) inhalable fraction. The data used in this chapter is based on the industry questionnaire (eftec, 2023), which is the most recent data available.

9.2. Behavioural responses

As explained in Section 6.3, all firms choose one of three behavioural responses: implement risk management measures, substitute regulated substances, or cease production in the EU. Table 9.1 summarises the respondent data gathered on behavioural responses to comply with Policy Option 3. This data has been broken down at a site level in order to facilitate later cost calculations. The table also provides the share of all sites that are non-compliant, and the behavioural responses are only reported for these non-compliant sites. Where less than three responses for a broad use were received, no data is reported.

Table 9.1: Current non-compliance with and behavioural responses to a 10 μg/m³ BOEL

Broad use	Share not compliant	Implement RMMs	Substitute regulated substances	Cease production
	of all sites	% of non-compliant sites		
All	36%	36%	15%	48%
Manufacture of cobalt and/or cobalt substances	36%	20%	0%	80%
Manufacture of other chemicals	100%	0%	0%	0%
Manufacture of precursor chemicals for batteries	71%	0%	0%	100%
Manufacture of catalysts	33%	100%	0%	0%
Manufacture of pigments and dyes	64%	29%	0%	71%
Manufacture of driers / paints	No respondent data	No respondent data	No respondent data	No respondent data
Use as catalysts - used as a catalyst or catalyst precursor	33%	100%	0%	0%
Use as catalysts - used as oxidation catalyst/for PTA and IPA	Insufficient respondent data	Insufficient respondent data	Insufficient respondent data	Insufficient respondent data

Broad use	Share not compliant	Implement RMMs	Substitute regulated substances	Cease production
	of all sites	% of non-compliant sites		
Use in surface treatment - Formulation of surface treatment	67%	100%	0%	0%
Use in surface treatment - Passivation or anti-corrosion treatment processes	44%	100%	0%	0%
Use in surface treatment - Metal or metal alloy plating	71%	0%	0%	100%
Use in biotechnology – Formulation and industrial use of mixtures in biogas production	No respondent data	No respondent data	No respondent data	No respondent data
Use in biotechnology – Professional use in biogas production	No respondent data	No respondent data	No respondent data	No respondent data
Use in biotechnology – Use in fermentation, fertilizers, biotech, scientific research and standard analysis	No respondent data	No respondent data	No respondent data	No respondent data
Use in biotechnology – Formulation and use in animal feed grade materials	0%	0%	0%	0%
Bespoke uses – Use in humidity indicators cards, plugs and/or bags with printed spots	Insufficient respondent data	Insufficient respondent data	Insufficient respondent data	Insufficient respondent data
Bespoke uses – Formulation of water treatment chemicals, oxygen scavengers, corrosion inhibitors	71%	0%	0%	100%
Bespoke uses – Use of water treatment chemicals, oxygen scavengers, corrosion inhibitors	No respondent data	No respondent data	No respondent data	No respondent data
Adhesion (inc. rubber adhesion agent)	0%	0%	0%	0%
Use in electronics	No respondent data	No respondent data	No respondent data	No respondent data
Use in magnetic alloys	Insufficient respondent data	Insufficient respondent data	Insufficient respondent data	Insufficient respondent data
Use in metallurgical alloys	48%	43%	14%	43%
Use in cemented carbide/diamond tools	54%	24%	19%	57%
Recycling of materials containing cobalt substances	36%	0%	13%	88%
Other	No respondent data	No respondent data	No respondent data	No respondent data

Table note: The sum of percentages across all behavioural responses may not add up to 100% due to rounding to the nearest percentage point.

Compliance levels are still high at this BOEL, with 36% of all sites non-compliant, but 14 percentage points fewer sites are compliant at this level than at 20 μg/m^3, which is a substantial drop. Compliance for each site will depend in part on the nature of site activities and any existing OELs on a national level.

There are now 7 broad uses in which the majority of sites are non-compliant, compared to three under 20 μg/m^3. There were no compliant sites in one broad use: the manufacture of other chemicals. Of those broad uses for which data was available, only sites in the animal feed grade materials, and adhesion broad uses are 100% compliant.

Continuing the trend identified for 20 μg/m^3, the most common response to a BOEL at this level is to cease production in the EU rather than implement RMMs. Only 36% of non-compliant sites implement RMMs, down from 40%, while 48% cease production. This is driven by a fall in the proportion of sites choosing to substitute. Note that this does not mean that sites that would substitute under 20 μg/m^3 do not substitute under 10 μg/m^3. Instead, this change is driven by the sites which are compliant with 20 μg/m^3 but not with 10 μg/m^3 which then choose to cease production, driving down the proportion of non-compliant sites that substitute. Similarly, to less stringent BOELs, only sites in the metallurgical alloys, cemented carbide / diamond tools and recycling broad uses elect to substitute. Metallurgical alloys and cemented carbide / diamond tools are likely choosing to substitute due to alternatives being available on the EU market, albeit inferior alternatives that cannot replicate the same performance that cobalt-containing products are able to (see Section 5.3 for more information). As has been noted, recycling sites must implement particularly expensive RMMs to comply given the relatively lower level of control possible over substance exposure, so choice to substitute may reflect the particularly high cost of RMMs in that broad use.

The broad uses which are most likely to cease production in the EU are manufacture of cobalt metal and/or cobalt substances, manufacture of precursor chemicals for batteries, manufacture of pigments and dyes, use in surface treatment (metal or metal alloy plating), formulation of water treatment chemicals, oxygen scavengers, corrosion inhibitors, metallurgical alloys, cemented carbide/diamond tools, and recycling of cobalt materials. In five of these cases at least three quarters of non-compliant sites would cease production in the EU. This is a stark change from 20 μg/m^3, where in only 1 broad use would more than 50% of non-compliant sites cease production in the EU at that level.

The compliance rates in this report are based on whether respondents stated they would need further action to comply, and are not necessarily comparable to earlier reports, e.g., (RPA, 2020).

9.3. Implementation of RMMs

This section reports the technical and economic feasibility of complying with Policy Option 3 through the implementation of RMMs, the types of RMMs that would need to be implemented to comply, and the costs associated with implementing these RMMs.

9.3.1 Feasibility of compliance

This section is about the technical and economic feasibility of currently non-compliant sites to comply with a BOEL of 10 μg/m^3.

Table 9.2 illustrates the percentage of sites currently not compliant with this Policy Option who deem it technically and economically feasible or infeasible to comply with a BOEL of 10 µg/m^3. It should be noted that interpretation of data is limited by a low number of respondents, but also note that the number of sites included is higher than at the 30 µg/m^3 and 20 µg/m^3 levels as there are more sites currently not complying with a lower BOEL of 10 µg/m^3.

Overall, it is deemed technically feasible to comply with this BOEL across 35% of sites and economically feasible across 12% of sites. This is much lower than the technical and economic feasibility of complying with BOELs of 20 µg/m^3 and 30 µg/m^3. However, compared to these other BOELs, there is also a large amount of uncertainty: 24% of sites did not know the technical feasibility of complying with a BOEL of 10 µg/m^3, and 35% of sites did not know the economic feasibility of complying with this BOEL. In comparison, the percentage of "don't know" for the technical and economic feasibility of complying with a BOEL of 20 µg/m^3 is much lower, at 5% and 14% respectively. This suggests that a 10 µg/m^3 limit is a threshold at which there is uncertainty around the ability to comply.

Qualitative information from the industry questionnaire indicates that respondents were uncertain about the technical feasibility of complying with a BOEL of 10 µg/m^3 due to lack of testing at this exposure level and because some process steps cannot be isolated, which would make it difficult to achieve the BOEL. Of those who said it would be technically and/or economically infeasible, the reasons cited included compliance requiring a complete redesign or re-installation of equipment across the entire production line and the expense of buying monitoring equipment that can read cobalt substances at this level.

Looking at the respondent answers split by broad use (see **Appendix Table 12**), non-compliant sites using cobalt metal and cobalt substances in the cemented carbide/diamond tools sector appear to expect it to be particularly challenging to comply with a BOEL of 10 µg/m^3, with only 24% of respondents thinking it would be technically feasible and 15% of sites thinking it would be economically feasible to comply with this BOEL. As has been discussed previously, the non-compliant sites in which compliance is likely to be challenging for the sector are the powder production sites. Most respondents involved in recycling of materials containing cobalt substances also do not think it would be feasible to comply with this BOEL or are unsure about whether it would be feasible: only 21% think it technically feasible to comply with a BOEL of 10 µg/m^3, and no respondents think it would be economically feasible. Respondent feedback noted that even this level of technical feasibility is high given the technical difficulty of the measures that would need to be implemented. Companies operating across multiple broad uses, including recycling, are likely to have driven up the technical feasibility of complying with a BOEL of 10 µg/m^3.

Results from a previous cost-benefit analysis on the restriction of cobalt salts found that 71% of respondents thought it would be technically feasible to comply with an exposure limit of 10 µg/m^3 at some sites with the use of PPE, or 46% of sites without PPE (eftec, 2019b). These figures are higher than those suggested by the current study, but reasons for this could include differences of scope between the two studies in terms of the number of substances assessed and broad uses included.

Table 9.2: Share of non-complying sites where it is and is not technically and economically feasible to comply with 10 µg/m³ BOEL

Type of feasibility		% non-complying sites
Technical feasibility	% of sites technically feasible to comply	35%
	% of sites not technically feasible to comply	41%
	% of sites technical feasibility unknown	24%
Economic feasibility	% of sites economically feasible to comply	12%
	% of sites not economically feasible to comply	53%
	% of sites economic feasibility unknown	35%

Table notes: Total share of sites has been estimated using the number of sites currently not-complying with a 10 µg/m³ BOEL, as reported by questionnaire respondents, and regardless of broad use.

9.3.2 RMMs needed to comply with this option

This section reports the types of measures that would need to be implemented by the affected sites in the EU-27 in order to comply with a BOEL of 10 µg/m³. As has been reported above, the implementation of these RMMs is dependent on whether a company considers this the most viable course of action for their sites (reported in section 9.2) and whether the implementation of RMMs is technically and/or economically feasible for the relevant sites (reported in section 9.3.1).

This section reports the RMMs that would be needed to comply with a BOEL of 10 µg/m³ both with and without the use of personal protective equipment (PPE). Article 6.2 of the Chemical Agents Directive (OSHA, 2021; 2017) sets out rules for how chemical exposure to workers shall be reduced according to a "hierarchy of controls". One of the general principles of prevention is "*giving collective protective measures priority over individual protective measures*" (art. 6.2), which suggests that measures other than PPE should be prioritised. The Carcinogens and Mutagens Directive (OSHA, 2021) is even more stringent in its requirements for how to avoid worker exposure to carcinogenic or mutagenic substances. These substances should be replaced as far as technically possible, regardless of economic considerations (art. 4.1). For these reasons, RMMs required for compliance are reported with and without the use of PPE. Reporting measures in these two scenarios also provides useful information for when the use of PPE becomes necessary for compliance (i.e., if collective protection measures are not enough) (OSHA, 2021b).

The RMMs reported in this section have been collated from responses to eftec's 2023 questionnaire. These RMMs therefore include a suite of measures that could be implemented to comply with 10 µg/m³ limit, and it might not be necessary to implement all the measures that have been reported to achieve compliance.

RMMs needed to comply, with PPE

Table 9.3 presents the types of measures that would be implemented by manufacturers, downstream users, and recyclers of cobalt metal and/or cobalt substances to comply with a 10 µg/m³ BOEL. Although it is not possible to estimate the proportion of respondents that would implement certain measures (since the industry questionnaire allowed respondents to provide a free-text response) it is possible to assess patterns in the types of responses provided. For example, many more respondents mentioned that they would need to implement closed systems or enclose certain processes to comply with a 10 µg/m³ BOEL than was reported to comply with a 20 µg/m³ (see section 8.3.2).

Respondents also reported the estimated number of years required to implement these RMMs and therefore comply with this Policy Option. Manufacturers reported that implementation of RMMs would take between less than one and seven years, with an estimated median of around two years. Whilst the median number of years does not increase compared to the implementation time required to comply with a 20 µg/m^3 BOEL, the upper limit in the range of years required does increase by three years. This suggests that there are respondents who see a substantial increase in the time (and effort) required to comply with a BOEL of 10 µg/m^3.

Downstream users and recyclers estimated that implementation to achieve compliance would require between less than one and more than eight years but varied substantially in the median number of years required. The median number of years required by downstream users is two years, which remains the same as the median number of years to comply with a 20 µg/m^3 BOEL. Recyclers have a median implementation time of more than eight years to comply with a BOEL of 10 µg/m^3, which is two years longer than the time required to comply with a 20 µg/m^3 BOEL (with the use of PPE), and therefore highlighting the additional effort required to comply.

Table 9.3: Types of control measures needed to comply with BOEL, with PPE

Types of RMMs	RMMs
Engineering controls	• Installing closed systems and changing machines to fully closed operation (e.g., negative pressure, closed processing facilities to avoid open handling, etc.) • Containment of dust in most equipment • Better ventilation (e.g., installation of process ventilation at more sites, building ventilation, and local extraction ventilation) • Continuous measurement to detect unusual exposure • Upgrade of air stack filters • Enclosures of process equipment (e.g., encapsulation of unloading station to cleanroom levels) • Redesign of equipment (e.g., equipment that handles powder, filling of presses, etc.) • Increased automation to avoid manual handling (e.g. of loading process) • Separate open forming machines • Regular maintenance of machines
Administrative controls	• Reduce exposure time, (e.g., increasing the number of employees, rotating operators, reducing the duration of shifts, and/or increasing the number of shifts) • Training and education of potentially exposed employees • Discontinuation of product line • Safety data on workstations • Annual monitoring of the respirable fraction of cobalt • Shorten cleaning cycles • Updated routines for cleaning and maintenance
PPE	• Increase use of respiratory equipment (e.g. powered air purification respirator, airstream helmets, HEPA masks, etc.) • Disposable uniforms • Introduction of SCBA equipment • Air showers

Table note: RMMs collated from responses to the industry questionnaire.

RMMs needed to comply, without PPE

The RMMs without PPE needed to comply with on BOEL of 10 µg/m^3 without the use of PPE are presented in **Table 9.4**. **Table** 9.2 (in Section 9.3.1) reports that it is technically infeasible for 41% of non-compliant sites to comply with a BOEL of 10 µg/m^3 and it is economically infeasible for 53% sites. It should be noted that the same table also reports a high proportion of sites where the technical and economic feasibility of complying with 10 µg/m^3 BOEL is unknown. Nonetheless, the large proportion of sites that deem it economically infeasible to comply with this policy option is also reflected in the types of measures that would need to be implemented to comply, which include measures such as complete rebuild of plants or investment in automated machinery and the installation of remote processes.

Manufacturers, downstream users, and recyclers reported that implementing a selection of these RMMs would require between less than one and more than eight years, with a median implementation time of three years for manufacturers and downstream users, and more than eight years for recyclers. For manufacturers and downstream users, the median implementation time to comply with a BOEL of 10 µg/m^3 without PPE is a year longer than the implementation time with PPE. For recyclers, the implementation time is the same across both scenarios.

Table 9.4: Types of control measures needed to comply with BOEL, without PPE

Types of RMMs	RMMs
Engineering controls	• Complete rebuild of the plant • Increased automation (e.g. of handling and loading processes; entire raw material feeding process; weighing; powder processing) • Installing remote processes to avoid open handling • Installing closed systems (e.g., encapsulation of unloading station to cleanroom levels, full enclosures of all processing equipment, isolate installations, etc.) • Containment of dust in most equipment • Better ventilation (e.g., installation of process ventilation at more sites, building ventilation, and local extraction ventilation, upgrade air stack filters, etc.) • Continuous measurement to detect unusual exposure • Modify hoppers • Separate processes (e.g., separate open forming machines, build a dedicated and separate area to prepare mixtures, watertight loading and material discharge systems, etc.) • Regular maintenance of machines • Alternative methods for cleaning and maintenance (e.g. create preventive maintenance of air suctions to reduce level of exposure) • Study to review the process and after modification • Relocate critical processes • Heated buildings for material handling - air flow PPE cannot be used in sub-zero temperatures
Administrative controls	• Training and education on limiting exposure • Termination of certain products or product lines • Reducing exposure (e.g., by rotating operators or reducing duration of shifts) • Introduction of standard operating procedures (SOP) • Safety data on workstation • Updated routines for cleaning and maintenance • Cooling down time before closed systems can be opened for handling

Table note: RMMs are collated from responses to the industry questionnaire and will not all be implemented by the same company.

9.3.3 Cost of RMMs

The cost of implementing RMMs is analysed with and without PPE. Given that PPE should be the last option RMM (see Section 6.3.1), it is expected that the actual costs of compliance will be closer to the without PPE estimates. It would be expected that the costs of compliance without PPE are higher as other RMM options available to companies may be limited and more expensive.

Table 9.5 shows the unit costs of implementing RMMs for a single site, and total costs under a BOEL of 10 μg/m^3. This is based on respondents reports of the total costs they face in complying with the BOEL through RMMs. This is different than the approach taken in RPA (2020), which calculate costs using a model to determine RMMs are required to go from existing exposure levels to below the BOEL. Total costs only include the costs incurred by sites that implement RMMs, where the number of sites is derived from the behavioural responses discussed in Section 9.2. It is assumed that any capital expenditure must be repeated twice over a period of 40 years, reflecting a capital lifetime of twenty years.

Disaggregated costs for SMEs and large companies were estimated, before these were combined into a weighted average unit cost per site (see Appendix A 1.3 for more details). The costs for SMEs and large companies are based on smaller sample sizes and are thus likely to be less reliable than the aggregate figures.

Table 9.5: Weighted average costs of implementing RMMs to comply with a 10 μg/m^3 BOEL

Cost type	Number of sites incurring costs	With PPE		Without PPE	
		Annualised costs (PV € million/year)	Costs 2022 - 2061 (PV € million)	Annualised costs (PV € million/year)	Costs 2022 - 2061 (PV € million)
SMEs unit costs (per site)	1	0.03	1.0	0.01	0.3
Large companies unit costs (per site)		0.18	7.0	0.28	11.1
Unit costs		0.05	2.1	0.06	2.3
Total costs (SMEs)	950	20	970	7	290
Total costs (Large)	210	40	1,480	60	2,340
Total costs (all)	1,160	60	2,460	70	2,630

Table note:

- Annualised cost is the present value (i.e., sum of discounted future costs), divided by the number of years in the analytical period (40 years). Values are discounted using a 3% discount rate and given in 2022 €.
- Number of sites incurring costs is rounded to the nearest 10. Annualised total costs are rounded to the nearest €10 million unless costs <€10 million in which cases they have been rounded to the nearest €1 million, while annualised unit costs are rounded to the nearest €10,000. Unit costs over the appraisal period are rounded to the nearest 100,000, while total costs over the appraisal period are rounded to €10 million.
- The assumed number of total sites for the purpose of cost calculations is equal to an average of the upper and lower bound site estimates.
- The unit costs are a weighted average of costs for SMEs and large companies.

The weighted average unit cost of implementing RMMs to comply with a BOEL of 10 μg/m^3 is €2.1 million per site across the full 40 years appraisal period, around 75% higher than the cost of RMMs with PPE under a BOEL of 20 μg/m^3. The unit cost is around 10% higher without PPE, at €2.3 million over the full appraisal period without PPE. The result that costs are lower without PPE for SMEs is likely a result of a small SME sample size, particularly as there was uneven response rates where respondents provided costs with PPE, but not without PPE.

When applied to all sites that incur this cost, the total cost of implementing RMMs for this BOEL is €60 million – €70 million annually depending on whether PPE is used. This is a roughly 200% increase over the cost of RMMs under the 20 μg/m^3 BOEL, mostly driven by the increase in the numbers of sites implementing RMMs due to lower compliance rates.

The unit cost of implementing RMMs is around six times higher for large companies than it is for SMEs with PPE, at around €30,000 and €180,000 per year respectively, but up to 30 times higher without PPE at around €10,000 and €280,000 per year respectively.

9.4. Cease of use of cobalt metal and cobalt substances

As discussed in Section 6.3, instead of implementing RMMs companies could cease the use of cobalt metal and cobalt substances. This could be achieved either by substituting cobalt metal and/or cobalt substances with alternatives, closing affected product lines, complete shut-down of the entire site, and/or shifting production to new or existing sites outside the EU. Shutting down production lines, sites and/or shifting production to sites outside the EU does not reduce demand for cobalt-containing products but increases dependence on imports from outside the EU. As discussed in Section 3.2.3, cobalt metal is classified by the EC as a critical raw material and is used in strategic technologies and sectors (see Section 11.2 for more information).

9.4.1 Substitution

Table 9.6 shows the unit and total costs of substituting cobalt metal and/or cobalt substances. Total costs are calculated for the sites that will substitute cobalt metal and/or cobalt substances, which is estimated from respondent data (discussed in Section 9.2). The unit costs of substitution are the same under all of the BOELs analysed in this report, but the number of sites which incur the cost changes depending on behavioural responses to each of the BOELs.

This cost is based upon historic costs reported by respondents that have already attempted substitution, of which no respondent reported that they were able to fully substitute successfully. Substitution is likely to first be carried out for uses and products for which alternatives exist and is deemed feasible (low hanging fruits). These points both indicate that the derived substitution costs are likely an underestimate of actual substitution costs that would be incurred. Companies are not likely to substitute unless feasible alternatives are available, so these cost estimates are not reflective of substitution costs for all broad uses.

Costs incurred by respondents over the last five years are assumed to continue linearly over five years for all sites substituting to alternatives. Due to small sample sizes, disaggregated costs for SMEs and large companies were not calculated.

Table 9.6: Costs of substituting cobalt metal and/or cobalt substances to comply with under a 10 µg/m³ BOEL

Cost type	Number of sites incurring cost	Annualised costs (PV € million/year)	Costs 2022 - 2061 (PV € million)
Unit costs	1	0.004	0.2
Total costs	480	2	70

Table notes:
- Annualised cost is the present value (i.e., sum of discounted future costs), divided by the number of years in the analytical period (40 years). Values are discounted using a 3% discount rate and given in 2022 €.
- Number of sites incurring costs is rounded to the nearest 10. Annualised total costs are rounded to the nearest €1 million, while annualised unit costs are rounded to the nearest €1,000. Unit costs over the appraisal period are rounded to the nearest €100,000, while total costs over the appraisal period are rounded to €10 million.
- The assumed number of total sites for the purpose of cost calculations is equal to an average of the upper and lower bound site estimates.

As shown in Section 9.2 the use in metallurgical alloys, cemented carbide/ diamond tools and recycling broad uses have sites that substitute at this BOEL. Of these, the recycling broad use was not represented in the historic substitution costs dataset, suggesting that costs for that broad use are likely underestimated. When applied to all sites that incur this cost, the total cost of substitution is €70 million over the 40-year period.

9.4.2 Lost profit from ceasing production in the EU

The cost of ceasing production (lines) is assumed to be the same regardless of whether production is stopped altogether or relocated to plants outside of the EU. This reflects the fact that this analysis has the EU-27 as its geographical scope and considers only the cost to society in the EU-27, not the private cost faced by businesses.

Table 9.7 shows the unit and total costs of ceasing production in the EU. Total costs are calculated for the sites that are assumed to cease production based on behavioural responses discussed in Section 9.2. The unit cost of ceasing production is the same under all four BOELs analysed in this report, but the number of sites which incur the cost changes depending on companies' behavioural responses to each BOEL.

These costs only consider profits associated with affected product lines, so ceasing production in the EU only counts profit lost at those affected product lines and not any other activities at the same site or company that are not related to the regulated substances. In some cases, particularly for larger companies, sites ceasing production of affected product lines will continue activities that are not affected by the BOEL. However, this will likely not be feasible for most SMEs, where the whole site or company is more likely to close down or relocate. The estimated unit costs of ceasing production are therefore believed to be underestimated as the costs of complete closure or relocation are not counted.

In earlier report (e.g., RPA (2020) and eftec (2019b)) lost profits were calculated over a 20-year period. However, new guidance (ECHA, 2021) has since been released by the Committee for Socio-Economic Assessment (SEAC) under REACH. In line with this guidance, profit loss has been estimated for a period of four years (see Appendix A 1.3 for more details).

It was assumed that profit is lost to the EU economy for four years after production ceases, after which it is assumed that profit is replaced by new and expanding companies. Where production is shifted to new or existing sites outside of the EU, only the profit lost within the EU is considered, not the private costs of relocation faced by businesses.

Disaggregated costs for SMEs and large companies were estimated, before these were combined into a weighted average unit cost per site (see Appendix A 1.3 for more details). The costs for SMEs and large companies are based on smaller sample sizes and are thus likely to be less reliable than the aggregate figures.

Table 9.7: Costs of ceasing production in the EU to comply with a 10 μg/m³ BOEL

Cost type	Number of sites incurring cost	Annualised costs (PV € million/year)	Costs 2022 - 2061 (PV € million)
SMEs unit costs (per site)	1	0.03	1.4
Large companies unit costs (per site)		0.21	8.3
Unit costs		0.07	2.6
Total costs (SMEs)	1,270	40	1,760
Total costs (Large)	280	60	2,340
Total costs (all)	1,550	100	4,100

Table notes:

- Annualised cost is the present value (i.e., sum of discounted future costs), divided by the number of years in the analytical period (40 years). Values are discounted using a 3% discount rate and given in 2022 €.
- Number of sites incurring costs is rounded to the nearest 10. Annualised total costs are rounded to the nearest €10 million, while annualised unit costs are rounded to the nearest €10,000. Unit costs over the appraisal period are rounded to the nearest €100,000, while total costs over the appraisal period are rounded to €10 million.
- The assumed number of total sites for the purpose of cost calculations is equal to an average of the upper and lower bound site estimates.

The average cost of ceasing production in the EU at a single site is €2.6 million across the full 40 years appraisal period.

When applied to all sites that incur this cost, the total cost of ceased production within the EU for this BOEL is €100 million annually, reflecting the significantly higher proportion of sites choosing to cease production at this more stringent BOEL when compared to 20 μg/m³.

The annual costs of ceasing production are around six times higher for large companies than it is for SMEs, at around €30,000 and €210,000, respectively.

9.5. Costs of compliance

This section presents the total costs of compliance with a 10 μg/m³ BOEL, considering each of the three behavioural responses, as well as the costs of implementing monitoring programmes. Section 9.5.1 presents the unit costs of compliance on a per-site basis, while Section 9.5.2 presents the total costs of compliance across the industry as a whole, by the type of cost and by broad use.

9.5.1 Unit costs

Table 9.8 shows the unit costs for a single site to comply with a BOEL of 10 µg/m³ for each of the likely behavioural response (i.e., type of costs). In addition, the average cost for a non-compliant site, and the average cost for all sites are presented. The former figure includes sites not complying with a BOEL of 10 µg/m³ and reflects the likely costs that would actually be incurred by sites in order to achieve compliance. This latter figure includes compliant sites incurring no costs and compliant sites which have to implement monitoring systems. The average unit cost per site allows for comparison across the Policy Options as the number of sites remains constant, which is in contrast to the average unit cost per non-compliant site where the number of sites not complying changes in each Policy Option (i.e., the number of non-compliant sites increases as the BOEL decreases). Disaggregated costs for SMEs and large companies were estimated, before these were combined into a weighted average unit cost per site (see Appendix 1.3 for more details).

Table 9.8: Unit costs per site to comply with 10 µg/m³

Types of costs	With PPE		Without PPE	
	Annualised costs per site (PV € million/year)	**Costs 2022 – 2061 per site (PV € million)**	**Annualised costs per site (PV € million /year)**	**Costs 2022 – 2061 per site (PV € million)**
Implementing RMMs	0.05	2.10	0.06	2.30
Implementing biological monitoring	0.03	1.00	0.03	1.00
Implementing respiratory fraction monitoring	0.01	0.50	0.01	0.50
Substitution with alternatives	0.004	0.20	0.004	0.20
Ceasing production in the EU	0.07	2.60	0.07	2.60
Average unit cost per non-compliant site	**0.07**	**2.70**	**0.07**	**2.80**
Average unit cost per site	**0.03**	**1.40**	**0.03**	**1.40**

Table notes:

- Annualised cost is the present value (i.e., sum of discounted future costs), divided by the number of years in the analytical period (40 years). Values are discounted using a 3% discount rate and given in 2022 €. Total number of non-compliant sites requiring monitoring is not calculated as all sites require monitoring under any BOEL.
- Annualised costs are rounded to the nearest €10,000, unless the costs are <€10,000, in which case they are rounded to the nearest €1,000. Costs across the appraisal period are rounded to the nearest €100,000.
- Average unit cost is a composite average cost per site, taking into account the proportion of non-compliant sites that will take one of the three behavioural responses (implementing RMMs, substitution with alternatives, and ceasing production in the EU), and the proportion of all sites that will implement monitoring programmes.
- The assumed number of total sites for the purpose of cost calculations is equal to an average of the upper and lower bound site estimates.

The average unit cost per non-compliant site is €70,000 per year with PPE, and €70,000 annually without PPE (respectively around 20% and 25% lower than the equivalent costs estimated for 20 µg/m³).

Around a third of sites are not compliant with this BOEL, so the average cost for any site (regardless of compliance) is less, at €30,000 for compliance with PPE and €30,000 for compliance without PPE. These figures are about half of the cost for non-compliant sites due to the cost of monitoring, which is incurred by any site that does not already have monitoring programmes in place, regardless of compliance.

The unit cost of implementing monitoring is €30,000 annually for biological monitoring and €10,000 annually for respiratory fraction monitoring with PPE. This is significantly lower than the costs of implementing RMMs and ceasing production, which costs €50,000 – €60,000 and €70,000 annually per site, respectively. Non-RMM costs are all assumed to be the same regardless of the BOEL.

9.5.2 Total costs

Table 9.9 shows the overall costs across the industry of compliance with a BOEL of 10 μg/m^3, broken down by the type of cost. For the total cost, both a lower and upper bound for the number of sites to which the BOEL will apply is used, while for the remainder of the table a central estimate of the number of sites is used.

Table 9.9: Total costs of compliance with a 10 μg/m^3 BOEL, by cost type

Types of costs	Number of sites incurring cost	With PPE		Without PPE	
		Annualised costs (PV € million/ year)	Costs 2022 - 2061 (PV € million)	Annualised costs (PV € million /year)	Costs 2022 - 2061 (PV € million)
Implementing RMMs	1,160	60	2,460	70	2,630
Implementing biological monitoring	3,980	100	4,110	100	4,110
Implementing respiratory fraction monitoring	3,040	40	1,470	40	1,470
Substitution with alternatives	480	2	70	2	70
Ceasing production in the EU	1,550	100	4,100	100	4,100
Total cost lower bound	-	**230**	**9,270**	**230**	**9,390**
Total cost upper bound	-	**380**	**15,150**	**380**	**15,360**

Table notes:

- Annualised cost is the present value (i.e., sum of discounted future costs), divided by the number of years in the analytical period (40 years). Values are discounted using a 3% discount rate and given in 2022 €.
- Number of sites incurring costs is rounded to the nearest 10. Costs are rounded to the nearest €10 million, unless costs are <€10 million, in which case they are rounded to the nearest €1 million.
- The total figures are provided for the lower and upper bound. These are calculated using a lower and upper bound estimate of the number of sites using in scope substances across the EU-27. The remaining figures are estimated using an average of the lower and upper bound site estimates for each type of cost.

The total figures are provided for the lower and upper bound. These are calculated using a lower and upper bound estimate of the number of sites using in scope substances across the EU-27. The remaining figures are estimated using an average of these two estimates.

The total cost of compliance with a BOEL of 10 μg/m^3 across the industry is estimated at between €9.3

billion and €15.2 billion with PPE and €9.4 billion – €15.4 billion without PPE. This is up to 30% higher than the total cost of compliance with 20 µg/m³. This is driven by the higher non-compliance rate (the number of non-compliant sites is around 50% higher than under a BOEL of 20 µg/m³) and the marginally higher proportion of sites choosing the relatively more costly option of ceasing production in the EU, rather than implementing RMMs.

The largest cost remains monitoring programmes, regardless of whether PPE is used, and accounts for up to around 50% of costs, a fall from the less stringent BOELs. The more conservative assumptions made for the cost of RMMs and profit loss (e.g., capital investments only occur every 20 years, and profit loss is only counted for 4 years) are some of the drivers for monitoring costs being a main cost component. Sensitivity analysis in Section 12.5 shows the impacts of more conservative assumptions on monitoring costs alongside other variations of assumptions.

The remainder costs are split between ceasing production in the EU and the cost of RMMs. The difference between with and without PPE costs are very small for this BOEL. Note that it is assumed that behavioural responses are the same regardless of whether PPE is used, though in practice it is very likely that some companies would change their behaviour depending on whether they implement higher cost engineering or administrative controls or use only PPE.

Substitution remains negligible in cost due to its low unit cost and relatively small share of site responding with substitution at this BOEL.

Table 9.10 shows the total costs of compliance with a BOEL of 10 µg/m³ broken down by broad use. Figures are only presented in aggregate across cost types and for the broad uses where there were a sufficient number of responses. These differ from the costs presented above because broad-use specific unit costs were used where there were sufficient responses, rather than average unit costs presented in **Table 9.8**. Where there were sufficient responses to calculate broad use specific unit costs for only some cost components, it is assumed that the unit cost is equal to the average shown in **Table 9.8**.

Using broad use specific unit costs would lead to total costs being higher than when using average unit costs across all uses, however, these are generally based on a small sample size and are thus less reliable than the aggregate figures presented above. The subsequent analysis, therefore, relies on the numbers set out in **Table 9.9**

Table 9.10: Total costs of compliance with a 10 µg/m³ BOEL, for all sites by broad use

Broad use	Sites estimate used	With PPE		Without PPE	
		Annualised costs (PV € million/year)	Costs 2022 - 2061 (PV € million)	Annualised costs (PV € million/year)	Costs 2022 - 2061 (PV € million)
Manufacture of cobalt and/or cobalt substances	Upper bound	13.4	540	9.4	370
	Lower bound	8.3	330	15.1	600
Manufacture of other chemicals	Upper bound	-	-	-	-
	Lower bound	-	-	-	-

Broad use	Sites estimate used	With PPE		Without PPE	
		Annualised costs (PV € million/year)	Costs 2022 - 2061 (PV € million)	Annualised costs (PV € million/year)	Costs 2022 - 2061 (PV € million)
Manufacture of precursor chemicals for batteries	Upper bound	Insufficient respondent data			
	Lower bound				
Manufacture of catalysts	Upper bound	1.1	40	0.2	10
	Lower bound	0.7	30	0.3	10
Manufacture of pigments and dyes	Upper bound	4.4	180	3.5	140
	Lower bound	2.9	120	5.3	210
Manufacture of driers / paints	Upper bound	No respondent data			
	Lower bound				
Use as catalysts - used as a catalyst or catalyst precursor	Upper bound	6.0	240	1.4	50
	Lower bound	3.8	150	2.2	90
Use as catalysts - used as oxidation catalyst/for PTA and IPA	Upper bound	Insufficient respondent data			
	Lower bound				
Use in surface treatment - Formulation of surface treatment	Upper bound	1.8	70	1.7	70
	Lower bound	1.2	50	2.5	100
Use in surface treatment - Passivation or anti-corrosion treatment processes	Upper bound	124.1	4,960	102.3	4,090
	Lower bound	75.9	3,030	167.5	6,700
Use in surface treatment - Metal or metal alloy plating	Upper bound	314.4	12,580	192.8	7,710
	Lower bound	192.8	7,710	314.4	12,580
Use in biotechnology – Formulation and industrial use of mixtures in biogas production	Upper bound	No respondent data			
	Lower bound				
Use in biotechnology – Professional use in biogas production	Upper bound	No respondent data			
	Lower bound				
Use in biotechnology – Use in fermentation, fertilizers, biotech, scientific research and standard analysis	Upper bound	No respondent data			
	Lower bound				
Use in biotechnology – Formulation and use in animal feed grade materials	Upper bound	120.1	4,800	73.3	2,930
	Lower bound	73.3	2,930	120.1	4,800
	Upper bound	Insufficient respondent data			

Broad use	Sites estimate used	With PPE		Without PPE	
		Annualised costs (PV € million/year)	Costs 2022 - 2061 (PV € million)	Annualised costs (PV € million/year)	Costs 2022 - 2061 (PV € million)
Bespoke uses – Use in humidity indicators cards, plugs and/or bags with printed spots	Lower bound				
Bespoke uses – Formulation of water treatment chemicals, oxygen scavengers, corrosion inhibitors	Upper bound	Insufficient respondent data			
	Lower bound				
Bespoke uses – Use of water treatment chemicals, oxygen scavengers, corrosion inhibitors	Upper bound	No respondent data			
	Lower bound				
Adhesion (inc. rubber adhesion agent)	Upper bound	0.7	30	0.4	20
	Lower bound	0.4	20	0.7	30
Use in electronics	Upper bound	No respondent data			
	Lower bound				
Use in magnetic alloys	Upper bound	Insufficient respondent data			
	Lower bound				
Use in metallurgical alloys	Upper bound	76.7	3,070	55.7	2,230
	Lower bound	46.6	1,860	91.6	3,660
Use in cemented carbide/diamond tools	Upper bound	226.4	9,060	142.4	5,700
	Lower bound	138.4	5,540	233.1	9,320
Recycling of materials containing cobalt substances	Upper bound	16.7	670	10.2	410
	Lower bound	10.2	410	16.7	670

Table notes:

- Annualised cost is the present value (i.e., sum of discounted future costs), divided by the number of years in the analytical period (40 years). Values are discounted using a 3% discount rate and given in 2022 €.
- Annualised costs are rounded to the nearest €100,000. Costs over the appraisal period are rounded to the nearest €10 million.
- The total figures are provided for the lower and upper bound. These are calculated using a lower and upper bound estimate of the number of sites using in scope substances across the EU-27. The remaining figures are estimated using an average of the lower and upper bound site estimates for each type of cost.

The highest costs are faced by formulation and use in animal feed grade materials, passivation or anti-corrosion treatment processes, use in metallurgical alloys, use in cemented/carbide tools and metal or metal alloy plating. Passivation or anti-corrosion treatment processes incur significantly higher costs than less stringent BOELs due to the 100% compliance rate within this broad use for 20 µg/m^3 and 30 µg/m^3. Its unit costs per site are in line with the average across all broad uses, but it is the third largest broad use by number of sites, with over 10% of all sites in this broad use.

Aside from passivation, this is a similar pattern to the less stringent BOELs and mostly reflects the higher number of sites in these high-cost broad uses than others. In particular for metal or metal alloy plating and cemented/carbide tools, high costs are also driven by relatively higher costs of ceasing production in the EU due to large site size. These two broad uses are in the top five broad uses for both number of sites and revenue per site.

Similar to less stringent BOELs, recycling had a particularly high per-site compliance cost, due to a high cost of RMMs compared to other broad uses (around twice the average for the case when PPE is not used). This is due to the particular challenges of controlling exposure in this broad use. Overall costs were still relatively lower in this broad use due to the smaller number of recycling sites. Manufacture of cobalt also had a particularly high cost of RMMs, especially without PPE.

Use in metal or metal alloy plating was the broad use associated with the highest cost per non-compliant site when PPE was used, reflecting the high costs of ceasing production and the high proportion of sites that choose to cease production at this BOEL. The costs per non-compliant site were around eight times higher than the average across all broad uses.

The costs of monitoring programs and substitution are fairly consistent across the broad uses and hence are not drivers of differences in total cost between the broad uses, nor of overall costs.

9.6. Social costs

Social impacts (or social costs) as defined by the EC in "Better Regulation" Toolbox (European Commission, 2021) can be classified into three broad categories of: 1) employment, 2) working conditions and 3) income distribution, social protection, and inclusion. Due to data limitations, this analysis only quantified impacts on employment (i.e., lost jobs), but qualitative aspects are further addressed in Chapter 11.

Impacts on EU employment are closely linked to potential production halts, permanent reduction in production and relocation of production outside the EU. A similar approach is used to estimate profit losses was therefore deployed in order to calculate social costs from potential EU jobs lost. The number of jobs at risk (i.e., the number of jobs lost over 40 years) shown in **Table 9.11** was estimated using the average number of employees per site adjusted for the number of sites which will potentially need to shut down in response to this BOEL. The relevant share of jobs at risk is assumed to be proportional to the share of profits at risk.

The jobs lost will not be equally distributed across the analytical period but will be concentrated in the short period following the announcement and introduction of the BOELs. In this analysis, it has been assumed that all the redundancies associated with ceasing of production will occur in the first year after the BOEL is announced. In line with (ECHA, 2008), job losses are considered to be temporary as the workers find new jobs after a period of time. In line with the SEAC guidance, the social value of lost jobs has been estimated on the basis of an average EU gross salary after employer taxes of around €35,200, assuming that the societal value of a lost job is around 2.7 times the annual pre-displacement salary (ECHA, 2016b). The SEAC guidance approach to valuing unemployment impacts comprises several components such as the value of productivity loss during the period of unemployment and cost of job search, hiring and firing; the impact of being made unemployed on future employment and earnings, and the value of leisure time during the period of unemployment.

Although the jobs lost will be concentrated in the short period following the introduction of the BOEL, **Table 9.11** reports the annualised costs of lost employment (i.e., the total cost of lost employment, which is likely to occur shortly after the introduction of the BOEL, divided by the 40-year analytical period) for comparability with the costs of compliance (reported in Section 9.5).

Table 9.11: Social costs of ceasing production in the EU to comply with a 10 µg/m³ BOEL

	Number of jobs lost over 40 years	Annualised costs (PV € million/year)	Costs 2022 - 2061 (PV € million)
Unit costs (per job lost)	1	0.002	0.1
Total costs (all jobs)	108,600	260	10,330

Table notes:

- Annualised cost is the present value (i.e., sum of discounted future costs), divided by the number of years in the analytical period (40 years). Values are discounted using a 3% discount rate and given in 2022 €. Note that annualised costs of lost employment are estimated to allow for comparability with costs of compliance, however, it is assumed that all the costs will be incurred in the first year following the announcement of BOELs, rather than annually over the full period of 40 years.
- Number of jobs lost is rounded to the nearest 100. Annualised total costs are rounded to the nearest €10 million, while annualised unit costs are rounded to the nearest €10,000. Unit costs over the appraisal period are rounded to the nearest €100,000, while total costs over the appraisal period are rounded to €10 million.
- Total cost figures and number of jobs lost are provided for the central estimates based on the average between the lower and upper bound estimates of the number of sites in scope substances across the EU.

The estimated number of EU jobs lost due to ceasing production is 108,600. The unit cost of each job lost is €100,000, or around €2,000 annually. The total annualised cost of jobs lost associated with a BOEL of 10 µg/m³ is €260 million, reaching €10.3 billion over 40 years. The total cost of jobs lost over 40 years resulting from implementation of a 10 µg/m³ BOEL is estimated to be 2 times and almost 17 times higher than the equivalent costs associated with 20 µg/m³ and 30 µg/m³ BOELs, respectively.

9.7. Benefits

This section sets out the estimated health benefits to workers from a reduction in worker exposure under Policy Option 3. The method used to estimate new exposure levels and the number of cases reduced is described in **Appendix A 1.4**, and the results are shown in **Table 9.12**. The risk reduction capacity of a BOEL of 10 µg/m³ is high, with 95% - 99% of cases reduced as compared to the baseline. This is an increase of 2% - 7% from the risk reduction capacity at 20 µg/m³. A conservative assumption that companies will not use PPE in order to comply with the BOEL has been applied. Section 12.5 further explores how the results may change if this and other assumptions are altered.

Table 9.12: Number of cases reduced under a BOEL of 10 µg/m³

Endpoint	Number of cases reduced over 40 years		Risk reduction capacity (%)
	Lower bound	Upper bound	
Cancer	74	123	95%
Respiratory irritation	2,740	4,528	97%

Endpoint	Number of cases reduced over 40 years		Risk reduction capacity (%)
	Lower bound	Upper bound	
Restrictive lung disease	1,001	1,654	99%

Table notes:

- The lower and upper bounds correspond to the lower and upper bounds for the number of workers exposed.
- The reduction capacity is the number of cases reduced by the policy option divided by the number of cases in the baseline.

The monetised health benefits are derived by multiplying the number of cases associated with each health endpoint with their respective valuation factors (see Section 4.5.2) and discounted over a period of 40 years to arrive at the present value (PV). The total present values were divided by 40, to arrive at the annual benefits estimates.

As can be seen in **Table 9.13**, the total benefits over 40 years are expected to be in the range of €450 - €750, with corresponding annual benefits of €11 - €19 million.

Table 9.13: Monetised benefits of a BOEL of 10 μg/m^3

Endpoint	Annual benefits (PV € million/year)		Benefits over 40 years (PV € million)	
	Lower bound	Upper bound	Lower bound	Upper bound
Cancer	2.9	4.8	115	191
Respiratory irritation	3.4	5.7	137	227
Restrictive lung disease	5	8	201	332
Total	**11**	**19**	**453**	**749**

Table notes:

- Annualised benefit is the present value (i.e., sum of discounted future benefits), divided by the number of years in the analytical period (40 years). Values are discounted using a 3% discount rate and given in 2022 €.
- The lower and upper bounds correspond to the lower and upper bounds for the number of workers exposed.

9.8. Summary

Table 9.14 shows the summary breakdown of monetised impacts of a BOEL of 10 μg/m^3 with and without PPE. All values are estimated as averages between the lower and upper bound estimates based on the number of sites and workers employed across the EU. The impact categories comprise of benefits (row 1), different costs of compliance (rows 2-6) and social costs (cost of lost jobs in row 7). The bottom two rows present the net benefits calculated as the difference between benefits and costs found for the lower and upper estimates of the number of sites in the EU, respectively. All cost estimates are presented as negative values, and benefits as positive values.

Table 9.14: Summary of monetised costs and benefits of a BOEL of 10 μg/m^3

Types of impact	Annual impact (PV € million/year)	
	Compliance without PPE	Compliance with PPE
Benefits	15	< 15
Implementing RMMs	-66	-61
Implementing biological monitoring	-103	-103

Types of impact	Annual impact (PV € million/year)	
	Compliance without PPE	Compliance with PPE
Implementing respiratory fraction monitoring	-37	-37
Substitution with alternatives	-2	-2
Ceasing production in the EU	-103	-103
Lost jobs	-258	-258
Net benefits – lower bound	**-419**	**-416**
Net benefits – upper bound	**-686**	**-680**

Table notes:

- Annualised impact is the present value (i.e., sum of discounted future costs or benefits), divided by the number of years in the analytical period (40 years). Values are discounted using a 3% discount rate and given in 2022 €. The exception are the bottom two rows which show the net present value (PV benefits minus PV costs).
- All cost estimates are presented as negative values, and benefits as positive values.
- All annualised impacts are rounded to the nearest €1 million, to ensure comparability between costs and benefits.
- Only central estimates based on the average between the lower and upper bound estimates of the number of sites in scope substances across the EU are presented.

Regardless of the parameters applied (i.e., without or with PPE, as well as lower/upper bound estimates), the present value of costs of implementing a BOEL of 10 µg/m^3 significantly outweighs the annualised present value monetised benefits of approximately €15 million. The total annual net loss is estimated at €419 million – €686 million with PPE, and €416 million – €680 million, without PPE. The annualised benefits are around 36 times smaller than the overall costs. Furthermore, the estimated loss is between 1.3 and 1.6 times larger than 20 µg/m^3. As detailed in Section 9.5.2, this is driven by the higher non-compliance rate and a marginally higher proportion of sites choosing the relatively more costly option of ceasing production in the EU, rather than implementing RMMs.

The cost of monitoring is no longer the largest cost component, as the costs of lost profit and jobs each account for around two thirds of costs without PPE. The cost of RMMs remains lower than the cost of monitoring and accounts for around 10-15% of costs. The differences compared to 20 µg/m^3 are driven by the larger number of companies choosing to close down their sites and consequently lose more profit and increase the number of redundancies. Monitoring is a less important cost component for this BOEL, due to the larger number of sites ceasing production, and the greater magnitude of other costs.

10. Policy Option 4 (BOEL 1 µg/m^3)

10.1. Introduction

This chapter covers the potential costs and benefits elaborates on of complying with Policy Option 4 which is the introduction of an EU-wide 1 µg/m^3 BOEL for cobalt and inorganic cobalt compounds, in line with the scope of substances considered by the EC. All manufacturers, importers, downstream users, and recyclers who handle cobalt metal and cobalt substances that are either directly or indirectly in scope (see Section 1.4.1) within the EU will be required to adhere to the BOEL 1 µg/m^3 based on an 8-hour time weighted average (TWA) inhalable fraction. The data used in this chapter is based on the industry questionnaires (eftec, 2023), which is the most recent data available.

10.2. Behavioural responses

As stated in Section 6.3, all firms choose one of three behavioural responses to a BOEL of 1 µg/m^3: implementation of risk management measures, substitution of regulated substances, or cease production. **Table 10.1** summarises the respondent data gathered on behavioural responses to comply with Policy Option 4. This data has been broken down at a site level in order to facilitate later cost calculations. The table also provides the share of all sites that are non-compliant, and the behavioural responses are only reported for these non-compliant sites. Where less than three responses were received for a broad use, no data is reported.

Table 10.1: Current non-compliance with and behavioural responses to a 1 µg /m^3 BOEL

Broad use	Share not compliant	Implement RMMs	Substitute regulated substances	Cease production
	% of all sites	% of non-compliant sites		
All	73%	17%	34%	47%
Manufacture of cobalt and/or cobalt substances	97%	18%	39%	43%
Manufacture of other chemicals	100%	0%	0%	0%
Manufacture of precursor chemicals for batteries	100%	0%	0%	100%
Manufacture of catalysts	100%	100%	0%	0%
Manufacture of pigments and dyes	91%	11%	0%	89%
Manufacture of driers / paints	No respondent data	No respondent data	No respondent data	No respondent data
Use as catalysts – used as a catalyst or catalyst precursor	100%	100%	0%	0%
Use as catalysts – used as oxidation catalyst/for PTA and IPA	Insufficient respondent data	Insufficient respondent data	Insufficient respondent data	Insufficient respondent data

Broad use	Share not compliant	Implement RMMs	Substitute regulated substances	Cease production
	% of all sites	% of non-compliant sites		
Use in surface treatment - Formulation of surface treatment	67%	100%	0%	0%
Use in surface treatment - Passivation or anti-corrosion treatment processes	44%	100%	0%	0%
Use in surface treatment - Metal or metal alloy plating	87%	0%	0%	100%
Use in biotechnology – Formulation and industrial use of mixtures in biogas production	No respondent data	No respondent data	No respondent data	No respondent data
Use in biotechnology – Professional use in biogas production	No respondent data	No respondent data	No respondent data	No respondent data
Use in biotechnology – Use in fermentation, fertilizers, biotech, scientific research and standard analysis	No respondent data	No respondent data	No respondent data	No respondent data
Use in biotechnology – Formulation and use in animal feed grade materials	33%	100%	0%	0%
Bespoke uses – Use in humidity indicators cards, plugs and/or bags with printed spots	Insufficient respondent data	Insufficient respondent data	Insufficient respondent data	Insufficient respondent data
Bespoke uses – Formulation of water treatment chemicals, oxygen scavengers, corrosion inhibitors	100%	0%	0%	100%
Bespoke uses – Use of water treatment chemicals, oxygen scavengers, corrosion inhibitors	No respondent data	No respondent data	No respondent data	No respondent data
Adhesion (inc. rubber adhesion agent)	42%	0%	100%	0%
Use in electronics	No respondent data	No respondent data	No respondent data	No respondent data
Use in magnetic alloys	Insufficient respondent data	Insufficient respondent data	Insufficient respondent data	Insufficient respondent data
Use in metallurgical alloys	97%	17%	11%	72%
Use in cemented carbide/diamond tools	98%	0%	26%	74%
Recycling of materials containing cobalt substances	100%	0%	18%	82%
Other	No respondent data	No respondent data	No respondent data	No respondent data

Table note: The sum of percentages across all behavioural responses may not add up to 100% due to rounding to the nearest percentage point.

Compliance levels are significantly lower for this option, with 73% of all sites non-compliant, double the share of non-compliant sites at 10 µg/m^3. Compliance for each site will depend in part on the nature of site activities and any existing OELs on a national level.

Ten of the 15 broad uses for which there is data have non-compliance rates above 90%. The exceptions to the very low compliance rates were formulation of surface treatment, adhesion, formulation and use in animal feed grade materials, and passivation or anti-corrosion treatment processes. These broad uses had compliance rates of between one and two thirds.

Overall, like for 10 µg/m^3, ceasing production is the dominant behavioural response to this BOEL. Although the proportion of non-compliant sites choosing to cease production in the EU (47%) is close to the proportion at 10 µg/m^3 (48%), the higher overall non-compliance rate means that the number of sites ceasing production is expected to be double that under 10 µg/m^3. Feedback provided by stakeholders reiterated the likelihood that the majority of companies would increase production outside the EU if regulation becomes overly restrictive, especially given that larger companies have sites outside the EU from which they can import finished articles.

Only 17% of non-compliant sites implement RMMs at this level, reflecting the higher expense of RMMs for such a stringent BOEL. A higher proportion choose to substitute, driven by a higher proportion of respondents choosing to invest in new potential substitutes under this BOEL. Reflecting the fact that investment in R&D constitutes a more significant proportion of sites under this BOEL, the selection of broad uses from which substituting sites originate is broader than for lower BOELs.

In particular, a large proportion of sites in the manufacture of cobalt metal and/or cobalt substances (39%) and adhesion (100%) state that they would pursue efforts to substitute, which would typically manifest in increased R&D rather than immediate substitution with available alternatives. In the adhesion sector, despite substantial substitution efforts, cobalt-free alternatives have failed to match the performance standards of cobalt-containing materials in the adhesion sector (as detailed in Section 5.3). Substitution would therefore involve finding a substitute. In the case of the manufacture of cobalt metal and/or cobalt substances broad use, this is driven by a large outlier company which is in both the adhesion and cobalt manufacture sectors and is very unlikely to be representative of the broad use as a whole. In the case of the adhesion broad use, a large proportion of the sites used only organic cobalt compounds and did not use substances in scope, so their level of compliance is of less relevance to the impact of a BOEL.

As with other BOEL options, sites in the metallurgical alloys, cemented carbide/diamond tools and recycling broad uses continue to substitute albeit in lower proportions than less stringent BOELs. This reflects the choices of sites who comply with less stringent BOELs, but do not comply with 1 µg/m^3, to cease production in the EU.

The compliance rates in this report are based on whether respondents stated they would need further action to comply, and are not necessarily comparable to earlier reports, e.g., (RPA, 2020).

10.3. Implementation of RMMs

This section reports the technical and economic feasibility of complying with Policy Option 4 through the implementation of RMMs, the types of RMMs that would need to be implemented to comply, and the costs associated with implementing these RMMs.

10.3.1 Feasibility of compliance

This section is about the technical and economic feasibility of currently non-compliant sites to comply with a BOEL of 1 µg/m^3.

Table 10.2 illustrates the percentage of sites currently not compliant with this Policy Option who deem it technically and economically feasible to comply with a BOEL of 1 µg/m^3. Overall, it is thought to be technically feasible to comply with this BOEL across only 10% of sites and economically feasible at no sites. The level of uncertainty around economic feasibility is high, with 37% of sites responding that the economic feasibility of complying with a 1 µg/m^3 is unknown. Nonetheless, the majority of sites would find it technically infeasible (79%) and economically infeasible (63%) to comply with this BOEL. This is the lowest predicted level of feasibility to comply out of all the BOELs looked at within this report.

Reasons respondents gave for the technical infeasibility of complying with a BOEL of 1 µg/m^3 include the value being too restrictive to find a continuous measurement system and it being the quantification limit of accredited laboratories. They said it would be technically infeasible to comply with this limit, as state-of-the-art equipment is not available, and complying would require significant changes in production equipment and ventilation. Additionally, that some process steps cannot be isolated adds an additional barrier to achieving the BOEL. For companies who comply with a 10 µg/m^3 BOEL, they say they have already taken extensive measures to comply with this and further improvements to comply with a 1 µg/m^3 BOEL would require infeasibly costly equipment and sophisticated technical measures. One site said they had already done as much as they can do, and that it is not possible to further improve their processes.

Although some broad uses would find it more technically feasible to comply with a BOEL of 1 µg/m^3 than other broad uses, no sites in any of the broad uses would find it economically feasible to comply (see **Appendix Table 13**). Sites using cobalt substances in the manufacture of catalysts or using them as catalyst precursors find it most technically feasible out of all the broad uses to comply with this BOEL – 33% of sites think it would be technically feasible – followed by sites using cobalt substances in metallurgical alloys (20% of sites).

Results from a previous cost-benefit analysis on the restriction of cobalt salts found that 48% of sites thought it would be technically feasible to comply with a restriction of 1 µg/m^3 with the use of PPE, or 25% of sites without PPE (eftec, 2019b). These figures are higher than those suggested by the current study, but reasons for this could include differences of scope between the two studies in terms of the number of substances assessed and broad uses included.

Table 10.2: Share of non-complying sites where it is and is not technically and economically feasible to comply with 1 µg/m³ BOEL

Type of feasibility		% non-complying sites
Technical feasibility	% of sites technically feasible to comply	10%
	% of sites not technically feasible to comply	79%
	% of sites technical feasibility unknown	11%
Economic feasibility	% of sites economically feasible to comply	0%
	% of sites not economically feasible to comply	63%
	% of sites economic feasibility unknown	37%

Table notes: Total share of sites has been estimated using the number of sites currently not-complying with a 1 µg/m³ BOEL, as reported by questionnaire respondents, and regardless of broad use.

10.3.2 RMMs needed to comply

This section reports the types of measures that would need to be implemented by the affected sites in the EU-27 in order to comply with a BOEL of 1 µg/m³. As has been reported above, the implementation of these RMMs is dependent on whether a company considers this the most viable course of action for their sites (reported in Section 10.2) and whether the implementation of RMMs is technically and/or economically feasible for the relevant sites (reported in Section 10.3.1).

Article 6.2 of the Chemical Agents Directive (OSHA, 2021; 2017) sets out rules for how chemical exposure to workers shall be reduced according to a "hierarchy of controls". One of the general principles of prevention is "*giving collective protective measures priority over individual protective measures*" (art. 6.2), which suggests that measures other than PPE should be prioritised. The Carcinogens and Mutagens Directive (OSHA, 2021) is even more stringent in its requirements for how to avoid worker exposure to carcinogenic or mutagenic substances. These substances should be replaced as far as technically possible, regardless of economic considerations (art. 4.1). For these reasons, RMMs required for compliance are reported with and without the use of PPE. Reporting measures in these two scenarios also provides useful information for when the use of PPE becomes necessary for compliance (i.e., if collective protection measures are not enough) (OSHA, 2021).

The RMMs reported in this section have been collated from responses to the industry questionnaire (eftec, 2023). These RMMs therefore include a suite of measures that could be implemented to comply with 1 µg/m³ limit, and it might not be necessary to implement all the measures that have been reported to achieve compliance.

RMMs needed to comply, with PPE

Table 10.3 presents the types of measures that would be implemented by manufacturers, downstream users, and recyclers of cobalt metal and/or cobalt substances to comply with a 1 µg/m³ BOEL. Similar measures were reported in Section 9.3.2 on the RMMs needed to comply with 10 µg/m³ BOEL with the use of PPE. As shown in **Table 10.1**, only 17% of non-compliant sites would implement RMMs to comply with a 1 µg/m³ BOEL, comparatively to the 36% of non-compliant sites that would implement RMMs to comply with a 10 µg/m³ BOEL (shown in **Table 9.1**). This difference is made even more stark by the fact that 73% of sites are non-compliant with a 1 µg/m³ BOEL (**Table 10.1**) whilst 36% of sites are non-compliant with a

10 μg/m^3 BOEL (**Table 9.1**). The steep drop in the share of non-compliant sites that would implement RMMs to comply with a BOEL of 1 μg/m^3 can be explained by the extensive measures that would need to be implemented to comply, such as rebuilding of plants, which was mentioned by multiple respondents. This is also reflected in the fact that 63% of non-compliant sites deem it economically infeasible to comply with a BOEL of 1 μg/m^3, and 0% of non-compliant sites deem it economically feasible (the remainder of non-compliant sites do not know whether compliance with a BOEL of 1 μg/m^3 is economically feasible, as shown in **Table** 10.2).

Many of the same measures have been reported to comply with a 1 μg/m^3 as were reported to comply with a 10 μg/m^3, but this is largely because many more respondents do not believe complying with a BOEL of 1 μg/m^3 is feasible. Feedback provided by the manufacture of precursor chemicals, adhesion, and cemented carbide and diamond tools uses reiterated the difficulty (and, in some cases, infeasibility) of complying with this BOEL. This is reflected in the fact that 100% of non-compliant sites in the adhesion sector would substitute the relevant substances and 100% of non-compliant sites in the manufacture of precursor chemicals for batteries would cease production rather than implement RMMs to comply with 1 μg/m^3 BOEL (**Table 10.1**).

Stakeholders in the manufacture of precursor chemicals for batteries have stated that a 1 μg/m^3 limit is not achievable when handling raw materials, particularly when an installation needs to be opened or if an installation is not well maintained. Significant automation of raw material handling would be required, but challenges to meet a BOEL 1 μg/m^3 remain, including (i) abnormal pressurization in the equipment, (ii) abrasion of equipment, and (iii) regular maintenance of equipment to keep dust levels low is critical but is costly and requires a lot of effort.

Respondents in sectors including the manufacture of cobalt metal and/or cobalt substances, precursor chemicals for batteries, pigments and dyes, recycling, metallurgical alloys, cemented carbide and diamond tools, and surface treatment, have reported that complying with a BOEL 1 μg/m^3 would require a complete rethinking of the business case. Many respondents also stated that the types of measures needed to comply with this BOEL are simply not known or that the feasibility of comply with this BOEL are not known.

Respondents also reported the estimated number of years required to implement these RMMs and therefore comply with this Policy Option. Manufacturers, downstream users, and recyclers reported that implementation of RMMs would take between less than one and more than eight years. The median implementation time for manufacturers and downstream users was estimated to take around two years, whilst the median implementation time for recyclers was estimated to take more than eight years. The time required to comply with a 1 μg/m^3 limit is the same as the time required to comply with a 10 μg/m^3. As discussed above, a number of respondents reported not knowing the types of RMMs that would be needed to comply with a 1 μg/m^3 and therefore did not report the number of years required to implement RMMs. This is likely to have skewed the number of years required to lower estimates.

Table 10.3: Types of control measures needed to comply with BOEL, with PPE

Types of RMMs	RMMs
Engineering	• Increased automation to avoid manual handling (e.g., of loading process, of discharging process, automated filling of ISO forms, etc.) • Rebuilding the plant (e.g., rebuilding parts of the product line, rebuilding processes, etc.)

Types of RMMs	RMMs
controls	• Installation of components to minimise all fugitive emissions • Installing closed systems (e.g., encapsulation of unloading station to cleanroom levels, full enclosures of all processing equipment, isolate installations, etc.) • Better ventilation (e.g., installation of process ventilation at more sites, building ventilation, and local extraction ventilation, upgrade air stack filters, air treatment, etc.) • Containment of dust in most equipment • Study to review the process after modification • Create workplaces for side-line activities • Relocate critical processes
Administrative controls	• Reduce exposure time (e.g., by reducing duration of each shift or rotating operators) • Education and training on limiting exposure, including training on hygiene (e.g., on washing hands, showering after shifts, and PPE cleaning) • Different procedures and/or operating practices • Discontinuation of packaging/size of pre-weighted bags • Annual monitoring of the respirable fraction of cobalt • Shorten cleaning cycles
PPE	• Increase use of respiratory equipment (e.g., powered air purification respirator, autonomous respiratory units, airstream helmets, breathing apparatus, etc.) • Masks (e.g. Anti dust mask EN-149 FFP3, particle masks (HEPA), etc.) • Protective suits and clothes dedicated to work and disposable uniforms • Introduction of SCBA equipment • Air showers

Table note: RMMs are collated from responses to the industry questionnaire and will not all be implemented by the same company.

RMMs needed to comply, without PPE

The RMMs needed to comply with on BOEL of 10 μg/m^3 without PPE are presented in **Table 10.4**. As has been discussed above, the share of respondents that would implement RMMs to comply with a 1 μg/m^3 limit is significantly lower than the share of respondents that would implement RMMs to comply with a 10 μg/m^3 limit. Several respondents reported that they would either need to shutdown relocate critical processes or substitute the relevant substances.

The RMMs reported in **Table 10.4** broadly align with those reported in **Table 10.3**. However, many respondents reported that it is not possible to comply with a 1 μg/m^3 limit without PPE. The need to use PPE to comply with this limit does not remove the need to also implement extensive engineering and administrative controls but suggests that these measures are not enough to ensure such low exposure.

Manufacturers, downstream users, and recyclers reported that implementing a selection of these RMMs would require between less than one and more than eight years, with a median implementation time of three years for manufacturers and downstream users, and more than eight years for recyclers. For manufacturers and downstream users, the median implementation time to comply with a BOEL of 1 μg/m^3 without the use of PPE is a year longer than the implementation time with the use of PPE. For recyclers, the implementation time is the same across both scenarios. As mentioned above, due to the number of respondents reporting that they do not know what types of RMMs would need to be implemented and therefore do not know the number of years required to comply with a 1 μg/m^3 limit, the median number of years for implementation is likely to skew towards the lower estimate based on the respondents that are more easily able to comply.

Table 10.4: Types of control measures needed to comply with BOEL, without PPE

Types of RMMs	RMMs
Engineering controls	• Increased automation to avoid manual handling (e.g., of loading process, of discharging process, automated filling of ISO forms, etc.) • Rebuilding the plant (e.g. rebuilding parts of the product line, rebuilding processes, etc.) • Installation of components to minimise all fugitive emissions • Installing closed systems (e.g., encapsulation of unloading station to cleanroom levels, full enclosures of all processing equipment, isolate installations, etc.) • Better ventilation (e.g., installation of process ventilation at more sites, building ventilation, and local extraction ventilation, upgrade air stack filters, air treatment, etc.) • Containment of dust in most equipment • Modify hoppers • Built a dedicated and separate area (e.g. to prepare and mixture the bonded; sintering the metal bonded wheels, create workplaces for side-line activities, etc.) • Create preventive maintenance of air suctions to reduce level of exposure • Study to review the process and after modification
Administrative controls	• Training and education on limiting exposure • Reducing exposure (e.g., by rotating operators or reducing duration of shifts) • Discontinuation of packaging/size of pre-weighted bags • Introduction of standard operating procedures (SOP) • Monitor the respirable fraction of cobalt annually • Investment into measurement equipment • Shorten cleaning cycles

Table note: RMMs are collated from responses to the industry questionnaire and will not all be implemented by the same company.

10.3.3 Cost of RMMs

The cost of implementing RMMs is analysed with and without PPE. Given that PPE should be the last option RMM (see Section 6.3.1), it is expected that the actual costs of compliance will be closer to the without PPE estimates. It would be expected that the costs of compliance without PPE are higher as other RMM options available to companies may be limited and more expensive.

Table 10.5 shows the unit costs of implementing RMMs for a single site, and total costs under a BOEL of 1 μg/m^3. This is based on respondents reports of the total costs they face in complying with the BOEL through RMMs. This is different than the approach taken in RPA (2020), which calculate costs using a model to determine which RMMs are required to go from existing exposure levels to below the BOEL. Total costs only include the costs incurred by sites that implement RMMs, where the number of sites is derived from the behavioural responses discussed in Section 10.2. It is assumed that any capital expenditure must be repeated twice over a period of 40 years, reflecting a capital lifetime of twenty years.

Disaggregated costs for SMEs and large companies were estimated, before these were combined into a weighted average unit cost per site (see Appendix A 1.3 for more details). The costs for SMEs and large companies are based on smaller sample sizes and are thus likely to be less reliable than the aggregate figures.

Table 10.5: Weighted average cost of implementing RMMs to comply with a 1 µg /m³ BOEL

Cost type	Number of sites incurring costs	With PPE		Without PPE	
		Annualised costs (PV € million/year)	Costs 2022 - 2061 (PV € million)	Annualised costs (PV € million/year)	Costs 2022 - 2061 (PV € million)
SMEs unit costs (per site)	1	0.02	0.8	0.01	0.4
Large companies unit costs (per site)		0.47	18.9	0.51	20.5
Unit costs		0.10	4.1	0.10	4.0
Total costs (SMEs)	920	18	740	9	350
Total costs (Large)	210	100	3,890	110	4,210
Total costs (all)	1,130	120	4,620	110	4,560

Table notes:

- Annualised cost is the present value (i.e., sum of discounted future costs), divided by the number of years in the analytical period (40 years). Values are discounted using a 3% discount rate and given in 2022 €.
- Number of sites incurring costs is rounded to the nearest 10. Annualised total costs are rounded to the nearest €10 million, while annualised unit costs are rounded to the nearest €10,000. Unit costs over the appraisal period are rounded to the nearest €100,000, while total costs over the appraisal period are rounded to €10 million.
- The assumed number of total sites for the purpose of cost calculations is equal to an average of the upper and lower bound site estimates.
- The unit costs are a weighted average of costs for SMEs and large companies

The weighted average unit cost of implementing RMMs is €4 million per site across the full forty years appraisal period, around 100% higher than the cost of RMMs under a BOEL of 10 µg/m³. The unit cost is approximately 3% lower without PPE, a significantly smaller gap compared to that under previous BOELs. This is likely because to comply with a 1 µg/m³ limit, expensive engineering costs would need to be implemented, regardless of whether PPE is used. Many respondents also stated that it is not feasible to achieve a BOEL of 1 µg/m³ without the use of PPE (see section 10.3.2), which means that with and without PPE may not be meaningful to distinction at this low BOEL.

When applied to all sites that incur this cost, the total cost of implementing RMMs for this BOEL is €3.9 billion – €4.6 billion over the 40-year appraisal period, depending on whether PPE is used.

The unit cost of implementing RMMs is around 25 times higher for large companies than it is for SMEs with PPE, at around €20,000 and €470,000 per year, and as much as 50 times higher without PPE at around €10,000 and €510,000 per year, respectively.

10.4. Cease of use of cobalt metal and cobalt substances

As discussed in Section 6.3, instead of implementing RMMs companies could cease the use of cobalt metal and cobalt substances. This could be achieved either by substituting cobalt metal and/or cobalt substances with alternatives, closing affected product lines, complete shut-down of the entire site, and/or shifting production to new and existing sites outside the EU. Shutting down production lines, sites and/or shifting production to sites outside the EU does not reduce demand for cobalt-containing products but increases dependence on imports from outside the EU. As discussed in Section 3.2.3, cobalt metal is classified by the EC as a critical raw material and is used in strategic technologies and sectors (see Section 11.2 for more information).

10.4.1 Substitution

Table 10.6 shows the unit and total costs of substituting cobalt metal and/or cobalt substances. Total costs only include the costs associated with sites that will substitute cobalt metal and/or cobalt substances, which is estimated from respondent (discussed in Section 10.2). The unit costs of substitution are the same under all of the BOELs analysed in this report, but the number of sites which incur the cost changes depending on behavioural responses to each of the BOELs.

This cost is based upon historic costs reported by respondents that have already attempted substitution, of which no respondent reported that they were able to fully substitute successfully. Substitution is likely to first be carried out for uses and products for which alternatives exist and is deemed feasible (low hanging fruits). These points both indicate that the derived substitution cost is likely an underestimate of actual substitution costs that would be incurred. Companies are not likely to substitute unless feasible alternatives are available, so these cost estimates are not reflective of substitution costs for all broad uses.

Costs incurred by respondents over the last five years by respondents are assumed to continue linearly over five years for all sites substituting to alternatives. Due to small sample sizes, disaggregated costs for SMEs and large companies were not calculated.

Table 10.6: Costs of substituting cobalt metal and/or cobalt substances to comply with a 1 µg /m³ BOEL

Cost type	Number of sites incurring cost	Annualised costs (PV € million/year)	Costs 2022 - 2061 (PV € million)
Unit costs	1	0.004	0.2
Total costs (all)	2,220	8	340

Table notes:

- Annualised cost is the present value (i.e., sum of discounted future costs), divided by the number of years in the analytical period (40 years). Values are discounted using a 3% discount rate and given in 2022 €.
- Number of sites incurring costs is rounded to the nearest 10. Annualised total costs are rounded to the nearest €10 million, while annualised unit costs are rounded to the nearest €1,000. Unit costs over the appraisal period are rounded to the nearest €100,000, while total costs over the appraisal period are rounded to €10 million.
- The assumed number of total sites for the purpose of cost calculations is equal to an average of the upper and lower bound site estimates.

The average cost of substitution in a single site is €200,000 across the full 40 years appraisal period.

As shown in Section 10.2, the manufacture of cobalt metal and/or cobalt substances, adhesion, metallurgical alloys, cemented carbide/ diamond tools and recycling broad uses have sites that substitute at this BOEL. Of these the recycling, adhesion, and manufacture of cobalt metal and/or cobalt substances broad uses are not represented in the historic substitution costs dataset, suggesting that costs for that broad use are very likely to be underestimated. When applied to all sites that incur this cost, the total cost of substitution was €340 million.

10.4.2 Lost profit from ceasing production in the EU

The cost of ceasing production (lines) is assumed to be the same regardless of whether production is stopped altogether or relocated to plants outside of the EU. This reflects the fact that this analysis has the EU-27 as its geographical scope and considers only the social cost to the EU-27, not the private cost faced by businesses.

Table 10.7 shows the unit and total costs of ceasing production in the EU. Total costs only include the costs associated with sites that are assumed to cease production based on behavioural responses discussed in Section 10.2. The unit costs of ceasing production are the same under all four BOELs analysed in this report, but the number of sites which incur the cost changes depending on companies' behavioural responses to each BOEL.

These costs only consider revenues associated with affected profit lines, so ceasing production in the EU is assumed to only refer to those affected product lines and not any other activities at the same site or company that are not related to the regulated substances. In some cases, particularly for larger companies, sites ceasing production of affected product lines will continue activities that are not affected by the BOEL. However, this will likely not be feasible for most SMEs, where the whole site or company is more likely to close down or relocate. The estimated unit costs of ceasing production are therefore believed to be underestimated as the costs of complete closure or relocation are not counted.

In earlier report (e.g., RPA (2020) and eftec (2019b)) lost profits were calculated over a 20-year period. However, new guidance (ECHA, 2021) has since been by the Committee for Socio-Economic Assessment (SEAC) under REACH. In line with this guidance, profit loss has been estimated for a period of four years (see Appendix A 1.3 for more details).

Disaggregated costs for SMEs and large companies were estimated, before these were combined into a weighted average unit cost per site (see Appendix A 1.3 for more details). The costs for SMEs and large companies are based on smaller sample sizes and are thus likely to be less reliable than the aggregate figures.

Table 10.7: Costs of ceasing production in the EU to comply with a 1 µg/m³ BOEL

Cost type	Number of sites incurring cost	Annualised costs (PV € million/year)	Costs 2022 - 2061 (PV € million)
SMEs unit costs (per site)	1	0.03	1.4
Large companies unit costs (per site)		0.21	8.3
Unit costs		0.07	2.6
Total costs (SMEs)	2,490	90	3,470
Total costs (Large)	550	110	4,600

Cost type	Number of sites incurring cost	Annualised costs (PV € million/year)	Costs 2022 - 2061 (PV € million)
Total costs (all)	3,050	200	8,070

Table notes:

- Annualised cost is the present value (i.e., sum of discounted future costs), divided by the number of years in the analytical period (40 years). Values are discounted using a 3% discount rate and given in 2022 €.
- Number of sites incurring costs is rounded to the nearest 10. Annualised total costs are rounded to the nearest €10 million, while annualised unit costs are rounded to the nearest €10,000. Unit costs over the appraisal period are rounded to the nearest €100,000, while total costs over the appraisal period are rounded to €10 million.
- The assumed number of total sites for the purpose of cost calculations is equal to an average of the upper and lower bound site estimates.

The average cost of ceasing production in the EU at a single site is €2.6 million across the full 40 years appraisal period. When applied to all sites that incur this cost, the total cost of ceased production within the EU for this BOEL is €8.1 billion in present value terms over the period 2022 - 2061, reflecting the significantly higher (two times) number of sites ceasing production at this more stringent BOEL when compared to 10 µg/m^3.

The annual costs of ceasing production are around seven times higher for large companies than for SMEs, at around €30,000 and €210,000, respectively.

10.5. Costs of compliance

This section presents the total costs of compliance with a 1 µg /m^3 BOEL, considering each of the three behavioural responses, as well as the costs of implementing monitoring programmes. Section 10.5.1 presents the unit costs of compliance on a per-site basis, while Section 10.5.2 presents the total costs of compliance across the industry as a whole, by the type of cost and by broad use.

10.5.1 Unit costs of compliance

Table 10.8 shows the unit costs for a single site to comply with a BOEL of 1 µg/m^3 for each of the likely behavioural response (i.e. type of costs). In addition, the average cost for a non-compliant site, and the average cost for all sites are presented. The former figure includes sites not complying with a BOEL of 1 µg/m^3 and reflects the likely costs that would actually be incurred by sites in order to achieve compliance. This latter figure includes compliant sites incurring no costs and compliant sites which have to implement monitoring systems. The average unit cost per site allows for comparison across the Policy Options as the number of sites remains constant, which is in contrast to the average unit cost per non-compliant site where the number of sites not complying changes in each Policy Option (i.e., the number of non-compliant sites increases as the BOEL decreases). Disaggregated costs for SMEs and large companies were estimated, before these were combined into a weighted average unit cost per site (see Appendix 1.3 for more details).

Table 10.8: Unit costs per site to comply with 1 μg/m³

Types of costs	With PPE		Without PPE	
	Annualised costs (PV € million/year)	Costs 2022 - 2061 (PV € million)	Annualised costs (PV € million /year)	Costs 2022 - 2061 (PV € million)
Implementing RMMs	0.10	4.10	0.10	4.00
Implementing biological monitoring	0.03	1.00	0.03	1.00
Implementing respiratory fraction monitoring	0.01	0.50	0.01	0.50
Substitution with alternatives	0.004	0.20	0.004	0.20
Ceasing production in the EU	0.07	2.60	0.07	2.60
Average unit cost per non-compliant site	**0.06**	**2.40**	**0.06**	**2.40**
Average unit cost per site	**0.05**	**1.80**	**0.05**	**1.80**

Table notes:

- Annualised cost is the present value (i.e., sum of discounted future costs), divided by the number of years in the analytical period (40 years). Values are discounted using a 3% discount rate and given in 2022 €. Total number of non-compliant sites requiring monitoring is not calculated as all sites require monitoring under any BOEL.
- Annualised costs are rounded to the nearest €10,000, unless costs are <€10,000, in which case they are rounded to the nearest €1,000. Costs across the appraisal period are rounded to the nearest €100,000.
- Average unit cost is a composite average cost per site, taking into account the proportion of non-compliant sites that will take one of the three behavioural responses (implementing RMMs, substitution with alternatives, and ceasing production in the EU), and the proportion of all sites that will implement monitoring programmes.
- The assumed number of total sites for the purpose of cost calculations is equal to an average of the upper and lower bound site estimates.

The average unit cost per non-compliant site is €60,000 per year. The average unit cost per non-compliant site is lower than 10 μg/m³ despite the significant increases in cost of RMMs, due to the commensurately lower proportion choosing to implement RMMs, and higher proportions substituting. As previously mentioned, the substitution costs are believed to be significantly underestimated, which means that the costs associated with 1 μg/m³ is believed to also be underestimated.

Around 73% of sites are not already compliant with this BOEL, so the average cost for across all sites is also high, at €50,000 per year, regardless of whether PPE is used. This is also higher than the average unit costs for all sites to comply with a BOEL of 10 μg/m³.

The unit cost of implementing monitoring is €30,000 annually for biological monitoring and €10,000 annually for respiratory fraction monitoring. This is significantly lower than the cost of implementing RMMs, €100,000 annually, or ceasing production in the EU, which costs €70,000 annually per site.

10.5.2 Total costs of compliance

Table 10.9 shows the overall costs of compliance with a BOEL of 1 μg /m³, broken down by the type of cost.

For the total cost, both a lower and upper bound for the number of sites to which the BOEL will apply is used, while for the remainder of the table a central estimate of the number of sites is used.

Table 10.9: Total costs of compliance with a 1 µg /m³ BOEL, by cost type

Types of costs	Number of sites incurring costs	With PPE		Without PPE	
		Annualised costs (PV € million/year)	Costs 2022 - 2061 (PV € million)	Annualised costs (PV € million /year)	Costs 2022 - 2061 (PV € million)
Implementing RMMs	1,130	120	4,620	110	4,560
Implementing biological monitoring	2,470	60	2,550	60	2,550
Implementing respiratory fraction monitoring	1,890	20	910	20	910
Substitution with alternatives	2,220	10	340	10	340
Ceasing production in the EU	3,050	200	8,070	200	8,070
Total cost lower bound	**-**	**310**	**12,520**	**310**	**12,480**
Total cost upper bound	**-**	**510**	**20,470**	**510**	**20,400**

Tables notes:

- Annualised cost is the present value (i.e., sum of discounted future costs), divided by the number of years in the analytical period (40 years). Values are discounted using a 3% discount rate and given in 2022 €.
- Number of sites incurring costs is rounded to the nearest 10. All costs are rounded to the nearest €10 million.
- The total figures are provided for the lower and upper bound. These are calculated using a lower and upper bound estimate of the number of sites using in scope substances across the EU-27. The remaining figures are estimated using an average of the lower and upper bound site estimates for each type of cost.

The total cost of compliance with a BOEL of 1 µg/m³ is estimated at between €12.5 billion – €20.5 billion, if PPE is used, and €12.5 billion – €20.4 billion if PPE is not used, both in present value terms over 2022 - 2061.

Regardless of whether PPE is used, this is around a third higher than the total cost of compliance with 10 µg/m³. The difference between these and the costs of 10 µg/m³ is mainly driven by the significantly higher non-compliance rate (the number of non-compliant sites is around double that under a BOEL of 10 µg/m³) and the significantly higher costs of RMMs under this more stringent BOEL. Although the proportion of sites implementing RMMs has fallen for this BOEL when compared to less stringent options, the absolute number of sites implementing RMMs is similar due to the lower compliance rate.

The largest component of this overall cost changes is lost profit, which is not influenced by whether PPE is used or not. This is reflected in the small gap between RMM costs with and without PPE, and the large number of sites choosing to cease production, the highest cost option. Together the cost of RMMs and lost profit make up around 75% of the costs, with the remainder under the cost of monitoring and substitution. This continues the trends from previous BOELs, with monitoring an increasingly small proportion of the costs due to the smaller number of sites needing to implement monitoring and higher costs of behavioural responses. Substitution remains small due to its low unit cost, even though the share of sites choosing this option substantially increases at this level. It is likely that total costs of substitution are underestimated for this level, see Section 12.6 for more details..

Table 10.10 shows the total costs of compliance with a BOEL of 1 µg/m^3 broken down by broad use. Figures are only presented in aggregate across cost types and for the broad uses where there was a sufficient number of responses. These costs differ from the costs presented above because broad-use specific unit costs were used where there were sufficient responses, rather than average unit costs presented in **Table 10.8**. Where there were sufficient responses to calculate broad use specific unit costs for only some cost components, it is assumed that the unit cost is equal to the average shown in **Table 10.8**.

Using broad use specific unit costs would lead to total costs being higher than when using average unit costs across all uses, however, these are generally based on a small sample size and are thus less reliable than the aggregate figures presented above. The subsequent analysis, therefore, relies on the numbers set out in.

Table 10.10: Total costs of compliance with a 1 µg /m^3 BOEL, for all sites by broad use

Broad use	Sites estimate used	With PPE		Without PPE	
		Annualised costs (PV € million/year)	Costs 2022 - 2061 (PV € million)	Annualised costs (PV € million/year)	Costs 2022 - 2061 (PV € million)
Manufacture of cobalt and/or cobalt substances	Upper bound	19.7	790	75.4	3,020
	Lower bound	12.2	490	121.5	4,860
Manufacture of other chemicals	Upper bound	-	-	-	-
	Lower bound	-	-	-	-
Manufacture of precursor chemicals for batteries	Upper bound	Insufficient respondent data			
	Lower bound				
Manufacture of catalysts	Upper bound	6.2	250	0.3	10
	Lower bound	4.1	170	0.5	20
Manufacture of pigments and dyes	Upper bound	13.1	520	12.8	510
	Lower bound	8.7	350	19.2	770
Manufacture of driers / paints	Upper bound	No respondent data			
	Lower bound				
Use as catalysts - used as a catalyst or catalyst precursor	Upper bound	33.5	1,340	1.7	70
	Lower bound	20.9	840	2.8	110
	Upper bound	Insufficient respondent data			

Broad use	Sites estimate used	With PPE		Without PPE	
		Annualised costs (PV € million/year)	Costs 2022 - 2061 (PV € million)	Annualised costs (PV € million/year)	Costs 2022 - 2061 (PV € million)
Use as catalysts - used as oxidation catalyst/for PTA and IPA	Lower bound				
Use in surface treatment - Formulation of surface treatment	Upper bound	4.2	170	3.0	120
	Lower bound	2.8	110	4.4	180
Use in surface treatment - Passivation or anti-corrosion treatment processes	Upper bound	267.5	10,700	172.5	6,900
	Lower bound	163.5	6,540	282.2	11,290
Use in surface treatment - Metal or metal alloy plating	Upper bound	379.6	15,180	232.8	9,310
	Lower bound	232.8	9,310	379.6	15,180
Use in biotechnology – Formulation and industrial use of mixtures in biogas production	Upper bound	No respondent data			
	Lower bound				
Use in biotechnology – Professional use in biogas production	Upper bound	No respondent data			
	Lower bound				
Use in biotechnology – Use in fermentation, fertilizers, biotech, scientific research and standard analysis	Upper bound	No respondent data			
	Lower bound				
Use in biotechnology – Formulation and use in animal feed grade materials	Upper bound	646.7	25,870	414.4	16,580
	Lower bound	394.5	15,780	679.3	27,170
Bespoke uses – Use in humidity indicators cards, plugs and/or bags with printed spots	Upper bound	Insufficient respondent data			
	Lower bound				
Bespoke uses – Formulation of water treatment chemicals, oxygen scavengers, corrosion inhibitors	Upper bound	Insufficient respondent data			
	Lower bound				
Bespoke uses – Use of water treatment chemicals, oxygen scavengers, corrosion inhibitors	Upper bound	No respondent data			
	Lower bound				

Broad use	Sites estimate used	With PPE		Without PPE	
		Annualised costs (PV € million/year)	Costs 2022 - 2061 (PV € million)	Annualised costs (PV € million/year)	Costs 2022 - 2061 (PV € million)
Adhesion (inc. rubber adhesion agent)	Upper bound	0.5	20	0.3	10
	Lower bound	0.3	10	0.5	20
Use in electronics	Upper bound	No respondent data			
	Lower bound				
Use in magnetic alloys	Upper bound	Insufficient respondent data			
	Lower bound				
Use in metallurgical alloys	Upper bound	230.3	9,210	140.9	5,640
	Lower bound	139.9	5,600	231.9	9,270
Use in cemented carbide/diamond tools	Upper bound	485.2	19,410	296.5	11,860
	Lower bound	296.5	11,860	485.2	19,410
Recycling of materials containing cobalt substances	Upper bound	41.1	1,650	25.3	1,010
	Lower bound	25.3	1,010	41.1	1,650

Table notes:

- Annualised cost is the present value (i.e., sum of discounted future costs), divided by the number of years in the analytical period (40 years). Values are discounted using a 3% discount rate and given in 2022 €.
- Annualised costs are rounded to the nearest €100,000. Costs over the appraisal period are rounded to the nearest €10 million.
- The total figures are provided for the lower and upper bound. These are calculated using a lower and upper bound estimate of the number of sites using in scope substances across the EU-27. The remaining figures are estimated using an average of the lower and upper bound site estimates for each type of cost.

The highest costs are faced by formulation and use in animal feed grade materials, use in metallurgical alloys, use in cemented/ carbide tools, passivation or anti-corrosion treatment processes, and metal or metal alloy plating. This is the same pattern was for the less stringent BOELs and reflects the higher number of sites in these broad uses than others, and in particular for metal or metal alloy plating and cemented/ carbide tools, the particularly high costs of ceasing production in the EU due to large site size.

Similar to less stringent BOELs, recycling, manufacture of pigments, frits and dyes, cemented carbide/ diamond tools and manufacture of cobalt metal and/or cobalt substances have particularly high per-site compliance costs, due to a high cost of RMMs compared to other broad uses. Overall, costs were still largely determined by the number of sites. For example, recycling costs are relatively lower in this broad use due to the smaller number of recycling sites.

The cost of compliance for the adhesion broad use increased sharply to an upper bound of €20 million at this BOEL, due to the existing compliance of all adhesion sites for less stringent BOELs. This is still a very low overall cost compared to other broad uses, due to the small number of sites and the small per site compliance cost. The latter is driven by the fact that all non-compliant sites in the adhesion broad use elected to substitute at this BOEL, and substitution is the lowest type of cost in this model. As the substitution cost estimates are based on historic data from broad uses for which substitutes are more widely available, which did not include adhesion, this is likely a significant underestimate of the *per site* costs of finding an alternative to cobalt metal and cobalt substances in the adhesion broad use. This consideration must be weighed against the fact that a large proportion of sites did not use substances that are directly in scope, reducing the relevance of this sector to overall costs of compliance with a BOEL.

The costs of monitoring programs and substitution are fairly consistent across the broad uses and hence are not drivers of differences in total cost between the broad uses, nor of overall costs.

10.6. Social costs

Social impacts (or social costs) as defined by the EC in Better Regulation Toolbox (European Commission, 2021) can be classified into three broad categories of: 1) employment, 2) working conditions and 3) income distribution, social protection, and inclusion. Due to data limitations, this analysis only quantified impacts on employment (i.e., lost jobs), but qualitative aspects are further addressed in Chapter 11.

Impacts on EU employment are closely linked to potential production halts, permanent reduction in production and relocation of production outside the EU. A similar approach is used to estimate profit losses was therefore deployed in order to calculate social costs from potential EU jobs lost. The number of jobs at risk (i.e., the number of jobs lost over 40 years) shown in **Table 10.11** was estimated using the average number of employees per site adjusted for the number of sites which will potentially need to shut down in response to this BOEL. The relevant share of jobs at risk is assumed to be proportional to the share of profits at risk.

The jobs lost will not be equally distributed across the analytical period but will be concentrated in the short period following the announcement and introduction of the BOEL. In this analysis, it has been assumed that all the redundancies associated with ceasing of production will occur in the first year after the BOEL is announced. In line with (ECHA, 2008), job losses are considered to be temporary i.e., the workers find new jobs after a period of time. In line with the SEAC guidance, the social value of lost jobs has been estimated on the basis of an average EU gross salary after employer taxes of around €35,200, assuming that the societal value of a lost job is around 2.7 times the annual pre-displacement salary (ECHA, 2016b). The SEAC guidance approach to valuing unemployment impacts comprises several components such as the value of productivity loss during the period of unemployment and cost of job search, hiring and firing; the impact of being made unemployed on future employment and earnings, and the value of leisure time during the period of unemployment.

Although the jobs lost will be concentrated in the short period following the introduction of the BOEL, **Table 10.11** reports the annualised costs of lost employment (i.e., the total cost of lost employment, which is likely to occur shortly after the introduction of the BOEL, divided by the 40-year analytical period) for comparability with the costs of compliance (reported in Section 10.6).

Table 10.11: Social costs of ceasing production in the EU to comply with a 1 µg/m³ BOEL

	Number of jobs lost over 40 years	Annualised costs (PV € million/year)	Costs 2022 - 2061 (PV € million)
Unit costs (per job lost)	1	0.002	0.1
Total costs (all jobs)	213,700	510	20,320

Table notes:

- Annualised cost is the present value (i.e., sum of discounted future costs), divided by the number of years in the analytical period (40 years). Values are discounted using a 3% discount rate and given in 2022 €.
- Annualised costs of lost employment are estimated to allow for comparability with costs of compliance, however, it is assumed that all the costs will be incurred in the first year following the announcement of BOELs, rather than annually over the full period.
- Number of jobs lost is rounded to the nearest 100. Annualised total costs are rounded to the nearest €10 million, while annualised unit costs are rounded to the nearest €10,000. Unit costs over the appraisal period are rounded to the nearest €100,000, while total costs over the appraisal period are rounded to €10 million.
- Total cost figures and number of jobs lost are based on the average between the lower and upper bound estimates of the number of sites in scope substances across the EU.

The estimated number of EU jobs lost due to ceasing production is 213,700. The unit cost of each job lost is €100,000, or around €2,000 annually. The total annualised cost of jobs lost associated with a BOEL of 1 µg/m³ is €510 million, reaching €20 billion over 40 years. The total cost of jobs lost over 40 years resulting from implementation of a 1 µg/m³ BOEL is estimated to be 2, 4 and 33 times higher than the equivalent costs associated with 10 µg/m³, 20 µg/m³ and 30 µg/m³ BOELs, respectively.

10.7. Benefits

This section sets out the estimated health benefits to workers from a reduction in worker exposure under Policy Option 4. The method used to estimate new exposure levels and the number of cases reduced is described in Section **A 1.4**, and the results are shown in **Table 10.12**. The risk reduction capacity at 1 µg/m³ is close to 100% reduction of cases as compared to the baseline for all the endpoints. For this BOEL, the conservative assumptions have a minimal effect, which is further explained in Section 12.5.

Table 10.12: Number of cases reduced under a BOEL of 1 µg/m³

Endpoint	Number of cases reduced over 40 years		Risk reduction capacity (%)
	Lower bound	Upper bound	
Cancer	78	129	99.5%
Respiratory irritation	2,825	4,669	100%
Restrictive lung disease	1,012	1,673	100%

Table notes:

- The lower and upper bounds correspond to the lower and upper bounds for the number of workers exposed.
- The reduction capacity is the number of cases reduced by the policy option divided by the number of cases in the baseline.

The monetised health benefits are derived by multiplying the number of cases associated with each health endpoint with their respective valuation factors (see Section 4.5.2) and discounted over a period of 40 years to arrive at the present value (PV). The total present values were divided by 40, to arrive at the annual benefits estimates.

As can be seen in **Table 10.13**, the total benefits over 40 years are expected to be in the range of €460 - €770, with corresponding annual benefits of €12 - €19 million.

Table 10.13: Monetised benefits of a BOEL of 1 µg/m³

Endpoint	Annual benefits (PV € million/year)		Benefits over 40 years (PV € million)	
	Lower bound	Upper bound	Lower bound	Upper bound
Cancer	3	5	121	201
Respiratory irritation	4	6	142	234
Restrictive lung disease	5	8	203	335
Total	**12**	**19**	**466**	**770**

Table notes:

- Annualised benefit is the present value (i.e., sum of discounted future benefits), divided by the number of years in the analytical period (40 years). Values are discounted using a 3% discount rate and given in 2022 € and rounded to the nearest € million.
- The lower and upper bounds correspond to the lower and upper bounds for the number of workers exposed.

10.8. Summary

Table 10.14 shows the summary breakdown of monetised impacts of a BOEL of 1 µg/m³ with and without PPE. All values are estimated as averages between the lower and upper bound estimates based on the number of sites and workers employed across the EU. The impact categories comprise of benefits (row 1), different costs of compliance (rows 2-6) and social costs (cost of lost jobs in row 7). The bottom two rows present the net benefits calculated as the difference between benefits and costs found for the lower and upper estimates of the number of sites in the EU, respectively. All cost estimates are presented as negative values, and benefits as positive values.

Table 10.14: Summary of monetised costs and benefits of a BOEL of 1 µg/m³

Types of impact	Annual impact (PV € million/year)	
	Compliance without PPE	Compliance with PPE
Benefits	15	< 15
Implementing RMMs	-114	-116
Implementing biological monitoring	-64	-64
Implementing respiratory fraction monitoring	-23	-23
Substitution with alternatives	-9	-9
Ceasing production in the EU	-202	-202
Lost jobs	-508	-508
Net benefits - lower bound	**-687**	**-687**
Net benefits - upper bound	**-1122**	**-1123**

Table notes:

- Annualised impact is the present value (i.e., sum of discounted future costs or benefits), divided by the number of years in the analytical period (40 years). Values are discounted using a 3% discount rate and given in 2022 €. The exception are the bottom two rows which show the net present value (PV benefits minus PV costs).
- All cost estimates are presented as negative values, and benefits as positive values.

- All annualised impacts are rounded to the nearest €1 million, to ensure comparability between costs and benefits.
- Only central estimates based on the average between the lower and upper bound estimates of the number of sites in scope substances across the EU are presented.

Regardless of the parameters applied (i.e., without or with PPE, as well as lower/upper bound estimates), the present value costs of implementing a BOEL of 1 μg/m^3 significantly outweighs the present value of monetised benefits. The total annual net loss to society of implementing a BOEL of 1 μg/m^3 is estimated at €687 billion – €1.1 billion, with no significant difference in costs with and without PPE. The annualised benefits is around 60 times smaller than the overall costs. The estimated loss is around 1.6 times larger than with 10 μg/m^3.

Around 15% of the overall cost is RMMs, with monitoring and substitution accounting together for around 10% of costs. The remainder of the costs relate to lost profit and jobs.

11. Non-quantified impacts

Quantification and monetisation of all impacts associated with regulatory interventions are rarely, if ever, achievable. It is not always the case that the non-quantified effects are less important or have a smaller effect than the quantified impacts, which means that the conclusions of the analysis may be incorrect or inaccurate if non-quantified impacts are not assessed. To avoid this type of “numbers’ bias”, a qualitative analysis of the non-quantified impacts has been carried out.

This chapter covers the non-quantified economic impacts, wider economic impacts and distributional effects on cobalt metal and cobalt substances induced by a potential BOEL on cobalt and inorganic cobalt substances. These impacts are of a more general or overarching nature and has therefore not been assessed per policy option. However, it can be inferred that these impacts will be more prevalent and more significant with the lower BOELs.

11.1. Non-quantified economic impacts

Table 11.1 presents the non-quantified economic impacts from an EU-level BOEL. Impacts are categorised by the type of economic impact, affected actors are identified and a brief description with selected examples are included where appropriate. Impacts are further categorised with either a (+) or (-) to indicate whether the impact is a benefit or cost to companies using cobalt, their supply chain, consumers, and/or the general public.

Table 11.1: Non-quantified economic impacts.

Type of impact	Impacts	Description of Impacts	Cost (-) or benefit (+)
Costs for regulators / public sector	Enforcement costs	The costs to companies for monitoring have been quantified, but the costs to regulators of enforcement have not been quantified. The introduction of a BOEL could lead to an increase in the number of companies covered by a BOEL, which could increase enforcement costs. Enforcement activities are already being carried out for other substances that currently have BOEL, so it is likely that the cost per additional company will be lower than for previously implemented OELs (economy of scale). The total enforcement costs are expected to be significantly lower than the quantified costs.	**(-)**
	Inspection and monitoring costs of imports	If companies cease production in the EU-27, as opposed to implementing RMMs to comply with a BOEL, this will likely increase imports of products containing or manufactured using cobalt. Increased imports would increase regulatory inspection and monitoring costs. Inspection costs are expected to be significantly lower than the quantified costs.	**(-)**
	Costs of transposing regulatory changes	Member States would incur short-term administrative costs when transposing the relevant regulatory changes into national legislations. These costs are expected to be negligible compared to quantified costs.	**(-)**
	Reduced tax revenue for public authorities	Income from corporate tax would decrease if companies cease production (production lines or complete site shut-down) in the EU-27. This impact would be most prominent with lower BOEL values as a larger proportion of companies will cease production rather than implement RMMs or substitute to comply with the BOEL. For example, 6% of non-compliant sites will cease production with a BOEL of 30 $\mu g/m^3$ (see **Table 7.1**), whilst 47% of non-compliant sites would cease production if a BOEL of 1 $\mu g/m^3$ was introduced (see **Table 10.1**).	**(-)**
Consumer impacts	Increased market prices	An increase in market prices of products would impact consumers. Costs to consumers from a change in market prices could occur where companies pass on the cost of compliance with a BOEL to their customers. They could also occur from changes in the supply chain for example higher transportation costs if import replaces EU-based production.	**(-)**
Indirect impacts to businesses	Reduction in demand, due loss of functionality	If companies choose to substitute to inferior alternatives, this may reduce the demand for the affected products, leading to a reduction in sales and associated profits for companies located in the EU-27. A likely scenario is that some downstream users (including professionals and consumers) will choose to import products manufactured using cobalt substances instead of purchasing products manufactured without cobalt, but with inferior functionality. This will increase the overall producer surplus loss in the	**(-)**

	EU and thereby increase the overall costs to the EU-27. This cost is, however, expected to be small compared to the quantified consumer surplus loss (lost profit) associated with cease of EU production.	
Costs to downstream users further along the value chain (e.g., innovation and R&D costs to find alternative solutions, replacement costs of lower quality products, import costs)	Costs to “direct” downstream users have been quantified, but costs to downstream users further along the value chain have not been quantified. For example, costs for manufacturers of diamond tools have been estimated in this assessment, but the (downstream) users of these tools are not included in this assessment. In the case that there is product scarcity and/or significantly increases in product prices, downstream users further along the supply chain may have to consider using alternative products. In some cases, companies may need to invest in R&D and other substitution activities to find alternatives to cobalt-dependant products. In some cases, this might involve using worse-performing products that need to be replaced more frequently. Professionals and downstream users may bear costs from less effective products if cobalt-co products are replaced by lower quality products. For example, there are no other metals that can fulfil cobalt’s intrinsic wetting and cohesion properties in cemented carbide/diamond tools. The cobalt-free cemented carbides offer less favourable combinations of hardness and toughness compared to tungsten carbide-cobalt. Considering that products are unlikely to become unavailable, it is deemed unlikely that these costs will be prevalent, as companies may import products instead of substituting and will likely choose the least costly options of the two.	**(-)**
Increased profits for importers	Importers of cobalt substances and cobalt-containing products would experience increased sales and associated profits if companies in the EU-27 choose to cease production or substitute to inferior alternatives, in response to a BOEL. This impact may not be insignificant, but the majority of the consumer surplus from increased imports will be gained by companies outside the EU-27 (i.e., the manufacturers of the products being imported). By this logic it is expected that the increase in profits for importers will be low compared to the corresponding loss associated with ceasing EU production.	**(+)**
Relocation or shut down costs for businesses ceasing production	Companies that close sites in the EU will incur costs such as remediation costs, administrative costs of closing a business and selling capital assets. With relocation there will be additional costs associated with rebuilding or expanding sites and employing new workers in a new location. However, the latter will occur outside the EU-27, and will thus be outside the scope of the analysis, unless the company remains an EU-based company in terms of location of income and taxation.	**(-)**

11.2. Wider economic impacts

11.2.1 Critical raw material

As discussed in Section 3.2.3, cobalt is a CRM, meaning it has significant economic importance to the EU-27 and has a high supply risk. The Critical Raw Materials Act sets out four benchmarks for annual consumption of CRMs (European Commission, 2023):

- At least 10% of the EU's annual consumption for extraction;
- At least 40% of the EU's annual consumption for processing;
- At least 15% of the EU's annual consumption for recycling, and
- Not more than 65% of the EU's annual consumption of each strategic raw material at any relevant stage of processing from a single third country.

In 2015, the EU-28[38] extracted about 7% of annual consumption for extraction (eftec and wca, 2015), which is less than the benchmark goal. A survey by the British Geological Survey (2021) identified 79 deposits of cobalt in the EU-27, located in Finland, Norway and Sweden, that are currently being explored. A BOEL would likely impact the process of extraction for operational mining companies as sites may have to adopt new RMMs, which can potentially decrease volume while transitioning, and would consequently increase RMM costs, which would likely trickle down the supply chain. A BOEL may also disincentivise increasing the volume of cobalt manufactured in the EU-27 either at new or current sites if the operational costs are so high as to render EU companies uncompetitive against the non-EU producers.

Further, lost profit from ceasing cobalt production in the EU, as shown in Sections 7.4, 8.4, 9.4, and 10.4, would negate the funds already invested by EU member states into critical raw materials and strategic industries that use cobalt, such as the German government's investments in gigafactories (EURACTIV, 2023).The remainder of this chapter will cover potential impacts caused by a BOEL that would affect the ability to meet the benchmark goals for the EU's annual consumption for processing and recycling, and impacts on the EU's competitiveness and ability to meet its climate and strategic autonomy objectives (RPA, 2022).

Energy supply

Cobalt metal and cobalt substances are commonly used as catalysts in the fuels sector, which is a critical sector for the EU. Catalysts containing cobalt, including precursor materials, are used in oil refining, natural gas (converting natural gas into liquid), and energy recovery from waste, green hydrogen and carbon monoxide (such as turning these sources into synthetic fuel for jets) (RPA, 2022). Although there is a move to transition to renewable energy sources, oil remains an important part of the EU's energy mix making up approximately 35% of energy consumption in 2020 (Eurostat, 2020). Maintaining a stable and cost-competitive supply of oil during the transition to green energy is crucial for the functioning of society such as transport, industry, and household use, affecting consumers and businesses.

The recent energy crisis in Europe (and globally) has put further pressure on the oil market, with the price of oil reaching €122 per barrel in March 2022, which was 21% above the earlier peak in 2012 (Bolton, 2022). Increasing energy prices is a wide-reaching issue, which will disproportionately impact smaller businesses and lower-income households that are less resilient to cost increases. Whilst global geopolitical issues have been the primary cause for the energy crisis, it highlights Europe's dependence on oil and the socioeconomic value in maintaining a stable supply chain and minimising potential disruptions where possible.

Similarly, cobalt plays a crucial role in the manufacture of battery catalysts, which are an essential component within electronic devices, transport, renewable energy, and numerous other applications as discussed in Section 3.3.2. Interruptions to the manufacture of precursor chemicals for batteries, for example, would impact the availability of battery catalysts and, therefore, would have knock-on impacts on these sectors. Electric vehicle batteries and batteries used in renewable energy sources (e.g., wind and solar power) play a crucial role in meeting the EU's climate and material use goals (EERA, 2023), are alternatives to polluting energy sources, and can positively impact the lived experiences of Europeans through improved health and social cohesion (van der Waal, 2020).

Sustainability and circularity

Sustainability and circular economy goals strongly influence the EU economy. A circular economy is an economic model designed to minimise resource input, as well as the production of waste and emission to the environment. Two goals of the European Commission's Circular Economy Action Plan are to normalise sustainable products in the EU and to ensure less waste (European Commission, 2023).

Cobalt is used in various applications due to its superior quality compared to other materials. Products of lower quality and/or durability will increase energy use in downstream production processes, as well as requiring the products to be replaced more often, increasing resource use. For example, cobalt substances are used for surface treatment where there are high-end performance requirements for corrosion protection and resistance to high temperatures (e.g., car bonnets) (wca, 2012). Restricting the availability of cobalt in such products due to a BOEL may thus negatively impact meeting EU's sustainability goals. Additionally, rather than ceasing production or use of cobalt-containing products, companies will likely import these products from other countries, primarily China, where their quality and environmental performance are generally not known.

Increased waste from lesser quality products will either need to be disposed of via landfill, incineration, or be recycled, which comes at a cost. Furthermore, replacing products more frequently due to using fewer durable products will also increase resource consumption and greenhouse gas emissions, which is contrary to the EU's 2050 strategy for climate neutrality (EERA, 2023).

Health

Cobalt is used in a variety of products in the healthcare sector. In the medical devices industry, cobalt is present in stainless-steel used in hypodermic needles, introducer needles, and laparoscopic devices and instruments (RPA, 2022). For example, cobalt chrome alloys (CoCAs) are used for many permanent implants and devices such as aneurysm stents. A restriction on these products would likely impact the availability and quality of crucial medical devices. When significant changes occur in these products, such as material change, they often have to go through regulatory approval which can take an upwards of a year (RPA, 2022). Many companies in the biotechnological and pharmaceutical sector are SMEs (see Section 3.6). Cobalt is used in a variety of products in the healthcare sector. In the medical devices industry, cobalt is present in stainless-steel used in hypodermic needles, introducer needles, and laparoscopic devices and instruments

(RPA, 2022). A restriction on these products would likely impact the availability and quality of crucial medical devices. For example, cobalt chrome alloys (CoCAs) are used for many permanent implants and devices such as aneurysm stents. When significant changes occur in these products, such as material change, they often have to go through regulatory approval which can take an upwards of a year (RPA, 2022). SMEs in the sector may not be able to afford research into alternatives and choose to cease production, further impacting the availability of these products. Availability of these products from large companies would also be impacted as new devices would need to gain regulatory approval.

If there is a shortage of medical products containing cobalt metal and/or the price of these products increases to meet a BOEL, buyers may choose similar non-cobalt containing products from producers either within the EU-27, impacting the competitiveness of these companies, or outside, impacting the competitiveness of the EU-27 market. Additionally, alternative products may be of a lesser quality, meaning end-users would receive lesser quality medical devices, negatively affecting their health, and may have to replace the devices more regularly, increasing the costs for these devices over the end-user's lifetime.

Animal feed

Many companies that produce animal feed (cobalt is used to add vitamin B12 into feed (see Section 3.3.8) are SMEs. Impacts to the animal feed sector could impact the quality of feed given to animals if farmers choose lower quality feed, such as feed that does not contain cobalt or is imported from China where quality may not be regulated. Use of lower quality feed would likely affect an animal's health. If the price of cobalt-containing animal feed increases so that production sites may comply with a BOEL, these prices would likely trickle down to the buyers (i.e., animal farmers), impacting sales for animal feed producers (farmers may choose other products) and/or availability of end products (farmers choosing to cease production if cost of animal feed is too high or no other animal feed is available).

Recycling

Metal recycling is a key industry for the EU's strategic economic strategic goals, as demonstrated by the Critical Raw Materials Act, which sets a benchmark for 15% of EU material consumption to come from recycled materials by 2030 (European Commission, 2023). As discussed in Section 3.2.3, cobalt is a CRM with a high economic importance for the EU. As metal recycling is a recently growing industry (Wood Mackenzie, 2022), a stringent OEL may discourage further investment and development. An interruption to the recycling industry caused by a BOEL would therefore impact the ability of the EU market to meet its recycling goals of a CRM and limit the domestic supply of recycled materials to producers, impeding EU strategic autonomy objectives (RPA, 2022).

At a stringent BOEL (1 $\mu g/m^3$ or below), for the catalysts, tires, and diamond tool/hard metal industries, recycling material may become too complicated (EoL materials are initially converted into powder before leaching), and for the oil production and chemical manufacturing industries, recycling of cobalt would likely cease (RPA, 2022). This would cause companies in these sectors to rely entirely on imported cobalt substances and cobalt-containing products, keeping their economic security at risk of changes in the global value chain for cobalt.

Macroeconomic

ECHA's Guidance on Socio-Economic Analysis recommends a consideration of the macroeconomic impacts caused by a restriction, such as a BOEL, including changes in competition within and outside the EU and changes to international trade (ECHA, 2008).

The introduction of an EU-wide BOEL would likely contribute to a level playing field, Member States today have differing BOELs place as discussed in Section 4.2. A uniform BBOEL would reduce the likelihood of companies choosing to locate in countries with higher or no BOELs than countries with lower (stricter) BOELs. Impacts on competition within the EU are not known for all sectors as this would depend on the ability of sites within a broad use to comply with a BOEL and its general market structure, e.g., number of sites and type of products available. For example, regarding the RTP and diamond carbide tools industries, a respondent to the industry questionnaire wrote:

"A large number of companies are relying on the few companies who produce the RTP powder. So, if 200-odd companies that produce the RTP powder cannot comply with the BOEL, it will impact the entire supply chain. It is possible to import the RTP powder from outside Europe – and if the companies cannot comply with the BOEL, they may decide to move the dusty part of the supply chain outside of Europe – but the Asian market is keen to replace the supply chain and as such, want to sell the final finished hard metal product, as opposed to selling the RTP powder.

In the diamond tool industry, cobalt used to be quite high in the product (up to 25% of total volumes manufactured, and up to 10% of cobalt content in the cemented carbide tools). However, as time has passed the diamond tool industry has competition from Asia and have started to reduce cobalt content with cheaper alternatives as they have had to compete with cheaper outputs. As a result, the European diamond tool industry is dying out / reducing in numbers and the Asian market is growing. The remaining European market is specialising in niche products (e.g., very big tools, as opposed to regular sized tools)."

That is, for these two uses, a BOEL may impact the parts of production that occur in the EU-27 and the type of products produced in the EU. Production impacts on a macro-level are difficult to estimate across all broad uses of cobalt.

It is also not known how a BOEL would affect competition between EU and non-EU actors placing products on the market in the EU. However, the use of cobalt plays important roles across many broad uses in the EU and impacts to the use of cobalt due to a BOEL may impact the competitiveness of these industries on the global market (Cobalt Institute, 2023).

11.3. Distributional effects

The costs and the benefits of a BOEL will not be distributed equally across the different actors involved. The directly affected actors are:

- Workers
- Companies
- Public sector

11.3.1 Distribution of costs

The distribution of costs of a BOEL will, to some extent, depend on the BOEL value. For the higher BOEL values, where there the cease of production is limited, the majority of the costs will be borne by companies manufacturing, using and recycling cobalt substances. As discussed in the previous chapters, the most significant cost will be associated with the implementation of RMMs that companies need to implement (and in some cases substitution), in order to comply with the BOEL. These costs will be even higher for the lower BOELs, but additional costs following cessation of EU production will be an equally important cost driver for companies.

Cost of cessation will also impact workers who will lose their jobs and reduce[57] their earning (at least for a period of time), as well as public authorities who will have to pay unemployment benefits to the workers during their time of unemployment. The relative distribution of loss between the workers and the public authorities will vary between Member State, as unemployment benefits differ. In addition to unemployment wages, there will also be enforcement costs which are fully borne public authorities. However, these are expected to be low in comparison with other costs.

The type of jobs available and the quality of jobs may be impacted by a BOEL. For instance, the implementation of RMMs, such as automation, would disproportionately affect manual workers. Implementation of PPE, such as full body suits or respirators, may make work more physically intense for employees.

It is also expected that the relative burden of the costs will vary between different sectors, due to large differences in current exposure levels and RMMs already in place (see Section 4.3.2 - 4.3.3), which determine the need for further RMMs. In addition, it is expected that the costs will have a larger impact on SMEs, albeit their total costs may be lower. The reason for this is that the costs of implementing RMMs for an SME may be high relative to their revenue, which threatens the financial viability of the company.

11.3.2 Distribution of benefits

The benefits of a BOEL reflect avoided illness amongst workers, which means that workers are expected to receive a significant share of the benefits as they bear the majority of the costs under the baseline. However, there are more actors who will receive benefits from the introduction of a BOEL.

As explained in Section 4.5.2, the SEAC valuation factors are composite WTP estimates that includes a multitude of effects. These may span across different actors, which means that it is challenging to map the distribution of benefits. The avoided treatment costs, which are estimated separately, comprising around 16% of the total of the benefits (avoided costs) can, however, be assumed to be primarily borne by public authorities.

The benefits associated with avoided non-cancer endpoints are easier to "detangle", as the valuation factors used are broken down per type of benefit, as can be seen in **Table 11.2**. The largest contributor to the benefits is associated with avoided productivity loss for the employers and avoided loss in earning for the workers. A take-away from that is that the actual costs that companies are faced with, if a BOEL is introduced, is lower than the costs of e.g., implementing RMMs, as productivity will likely increase alongside reduced sick-leave.

[57] Worker will not lose all their earnings, due to compensation (unemployment benefits) provided by the public authorities.

Table 11.2: **Distribution of benefits for non-cancer endpoints**

Type of benefit	Benefit = Avoided costs of…	Affected actor	Share of total benefits (%)	
			Low value	High value
Direct	Therapy/medicine costs	Worker and public sector	12%	7%
Indirect costs	Disability (sick leave days)	Employer	6%	6%
	Reduction in earning and value creation capacity	Worker and Employer	70%	81%
Intangible costs	Pain & suffering/ Welfare loss	Worker	12%	7%

12. Proportionality Assessment

12.1. Introduction

This chapter collates the results from the previous chapters and takes a broader perspective by comparing impacts across the different policy options. First, the key results are summarised (Section 12.2) before the impacts across the four policy options are compared (Section 12.3) and benefit-cost ratios are derived (Section 12.4). A sensitivity analysis (Section 12.5) to test the robustness of the results derived in the core analysis is carried out, followed by key uncertainties (Section 12.6) that cannot be expressed quantitatively. Lastly, the conclusions on proportionality (Section 12.7) are drawn.

12.2. Summary of impacts

This section summarises impacts derived in Chapters 7 - 10, and looks at differences across the four Policy Options.

Table 12.1 shows the compliance rates across all BOELs, the number of sites that incur each of the cost types to comply with the BOEL and the number of jobs lost as a result of companies closing production in the EU. The rate of compliance decreases from 84% for the least stringent BOEL to 27% for the most stringent BOEL. The number of jobs lost in the EU increases from 6,500 under 30 μg/m³ to over 200,000 jobs under 1 μg/m³.

Table 12.1: Compliance rate, sites incurring costs under each BOEL and jobs lost

BOEL	Compliance rate	Number of sites incurring each cost type					Number of jobs lost
		Implementing RMMs	Ceasing production in the EU	Substitution to alternatives	RFMs	BMPs	
30 μg/m³	84%	1,100	90	280	3,810	4,990	6,500
20 μg/m³	78%	780	740	460	3,430	4,490	51,600
10 μg/m³	64%	1,160	1,550	480	3,040	3,980	108,600
1 μg/m³	27%	1,130	3,050	2,220	1,890	2,470	213,700

Table note:

- Number of sites is rounded to the nearest 10 sites.
- Number of lost jobs is rounded to the nearest 100 jobs.
- The figures use the central estimate of an average of the lower and upper bound number of sites. These are calculated using a lower and upper bound estimate of the number of sites using in scope substances across the EU-27.
- Acronyms used: Binding Occupational Exposure Limit (BOEL), Risk Management Measures (RMMs), Respiratory Fraction Monitoring (RFMs), Biological Monitoring Programmes (BMPs)

Behavioural responses by companies determine the type of cost they will incur from complying with implementation of a BOEL. These responses change with the stringency of the BOEL, depending on each company's ability to comply with each limit and what is considered the best option from a business perspective. **Figure 12.1** illustrates how the responses vary across the three behavioural responses, with the number of associated sites.

The number of sites implementing RMMs stays roughly the same across all BOELs. This is due to two opposing effects: (i) the number of non-compliant sites increase with more stringent BOELs, and (ii) the proportion of sites ceasing EU production or substituting instead, which reduces non-compliant sites remaining in the EU. There is a particularly large numerical jump in the number of sites ceasing production in the EU or substituting to alternatives when the BOEL decreases from 10 µg/m³ to 1 µg/m³. This reflects the difficulty of complying with 1 µg/m³ through implementation of RMMs. The number of job losses increase for more stringent BOELs, up to over 210,000 under 1 µg/m³. This is equivalent to around 40% of the total estimated workers in companies using or producing cobalt. There is a particularly large jump between 30 µg/m³ and 20 µg/m³, reflecting the increase in sites ceasing production in the EU.

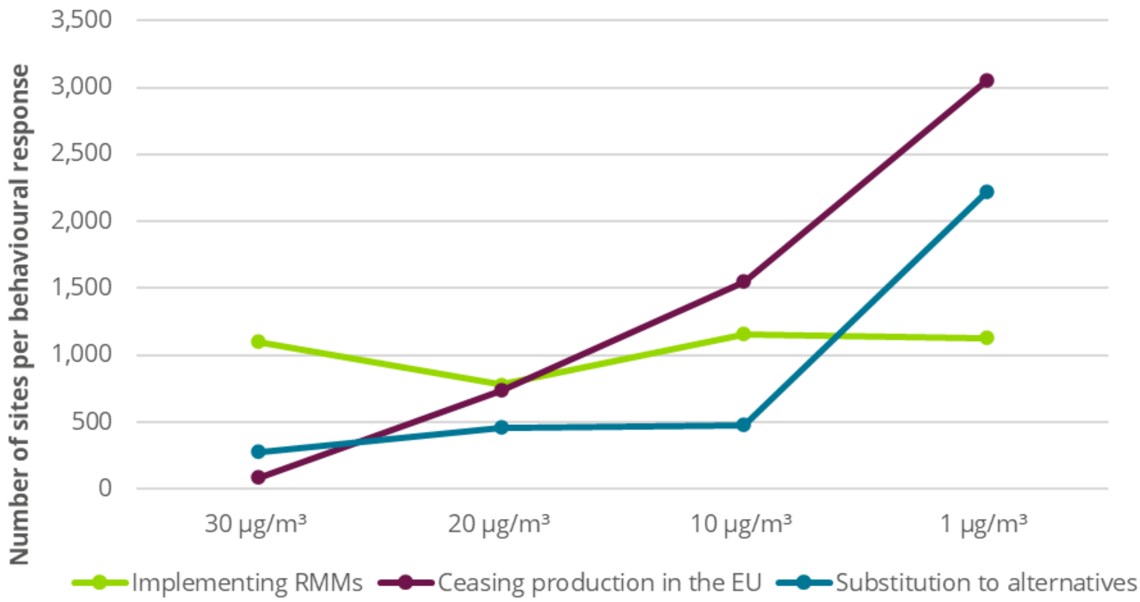

Figure 12.1: Number of sites per behavioural response

As shown in **Table 12.2** the total costs of complying with a BOEL tends to rise as the BOEL becomes more stringent, with a range between €240 million/year and €920 million/year. Monitoring is the largest cost component for the less stringent BOELs (30 µg/m³ and 20 µg/m³), while for more stringent BOELs (10 µg/m³ and 1 µg/m³) the social costs of lost jobs in the EU and costs of ceasing production dominate regardless of whether PPE is used. As discussed in previous chapters, it is believed that the substitution costs are underestimated due to sparse and not fully representative data, which has a higher impact for more stringent BOELs where a higher share of companies choose to substitute. This is apparent when compared to the other cost component estimates.

Table 12.2: Total annual costs of each cost component under each BOEL

BOEL	Implementing RMMs (€ million/year)		Ceasing production in the EU (€ million/year)		Substitution (€ m/y)	RFMs (€ m/y)	BMPs (€ m/y)	Total with PPE (€ m/y)	Total without PPE (€ m/y)
	With PPE	Without PPE	Lost profit	Jobs lost					
30 µg/m³	40	40	10	20	1	50	130	240	240
20 µg/m³	20	100	50	120	2	40	120	350	430
10 µg/m³	60	70	100	260	2	40	100	560	570
1 µg/m³	120	110	200	510	10	20	60	920	920

Table note:

- Annualised cost is the present value (i.e., sum of discounted future costs), divided by the number of years in the analytical period (40 years). Values are discounted using a 3% discount rate and given in 2022 €
- Figures are rounded to the nearest €10 million for figures above €10 million, and to the nearest €1 million for figures below €10 million.
- The figures use the central estimate which is the average of the lower and upper bound number of sites. These are calculated using the lower and upper bound estimates of the number of sites using in scope substances across the EU-27.
- Due to rounding, the individual cost components may not add up to the totals.

Figure 12.2 shows the total annualised costs for each BOEL, with and without the use of PPE. An increase in the steepness of the cost curves can be seen between 30 µg/m³ and 10 µg/m³, which is significantly amplified from 10 µg/m³ and 1 µg/m³. This type of cost curve (i.e., exponential), indicates that costs per additional µg/m³ reduction of the BOEL will be more and more expensive for the EU the more stringent the BOEL is.

The change in steepness of the cost curve mirrors the shift in behavioural responses of companies, due to more limited options, when faced with more stringent BOELs. For example, around 1,500 sites may close EU production with a BOEL of 10 µg/m³, which will increase to over 3,000 sites if a BOEL 1 µg/m³ is introduced. Comparatively, the number of sites ceasing production at 30 µg/m³ is less than 100. This is one of the main drivers behind the steep increase shown in **Figure 12.2**.

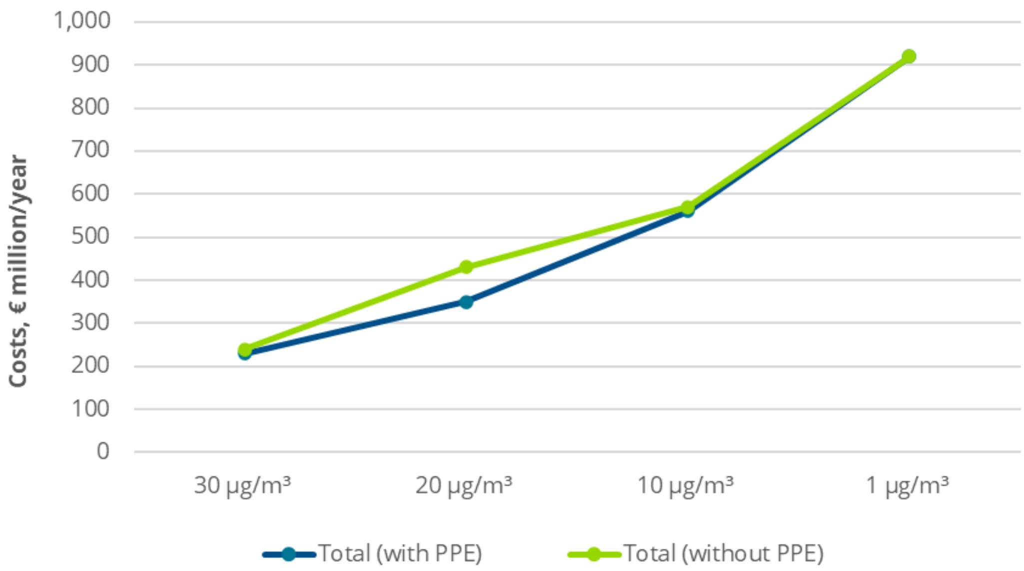

Figure 12.2: Total annualised costs per BOEL, with and without the use of PPE, € million/ year

As noted in Section 7.7, even the less stringent BOELs have high risk reduction capacities. This is shown in **Table 12.3**, which presents the number of cases reduced and the associated risk reduction capacity for each of the BOEL. At a BOEL of 1 µg/m³, 100% risk reduction is achieved for the non-cancer endpoints and 95.5% of cancer cases are avoided.

Table 12.3: Risk reduction capacity across BOELs compared to the current situation

BOEL	Average annual number of cases reduced			Risk reduction capacity (%)		
	Cancer	Respiratory irritation	Restrictive lung disease	Cancer	Respiratory irritation	Restrictive lung disease
30 µg/m³	2.1	78	32	79%	83%	95%
20 µg/m³	2.3	86	33	88%	91%	97%
10 µg/m³	2.5	91	33	95%	97%	99%
1 µg/m³	2.6	94	34	99.5%	100%	100%

Table note:

- The estimated numbers of cases have been derived using highly conservative assumptions and are likely overestimated (see Appendix A 1.4).
- The estimates are derived using an average of the upper and lower bound for the number of workers exposed.

Table 12.3 also shows that marginal risk reduction decreases with more stringent BOELs. For example, going from “no BOEL” to 30 µg/m³ leads to a reduction of 78 cases of respiratory irritation per year. However, lowering the BOEL from 30 µg/m³ to 20 µg/m³ will only lead to a reduction of an additional eight cases per year. Further lowering the BOEL from 20 µg/m³ to 10 µg/m³ gives an additional reduction of five cases, whilst from 10 µg/m³ to 1 µg/m³ only three additional cases are avoided annually.

The decreasing marginal risk reduction capacity is even more apparent in **Figure 12.3**, where it can also be observed that this tendency is more pronounced for the cancer and respiratory irritation endpoints than it is for restrictive lung disease. It should be noted that the conservative assumption that companies will demonstrate compliance with the BOEL without adjusting for PPE amplifies the differences in the marginal risk reduction capacity between the BOELs. This assumption is tested and discussed further in the sensitivity analysis in Section 12.5 and in Appendix A 1.4.

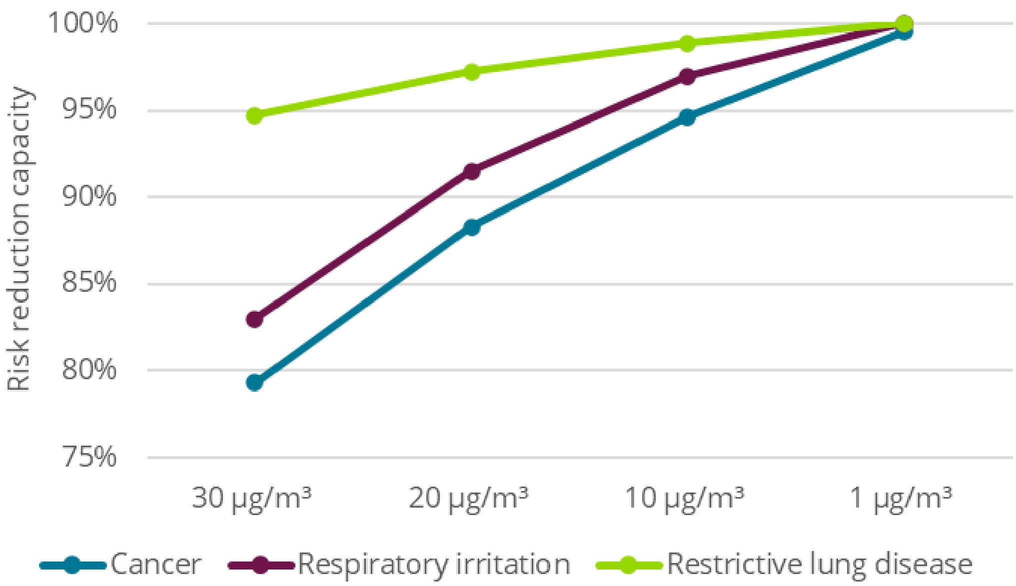

Figure 12.3: Marginal risk reduction capacity for each end point, for the different BOELs

12.3. Net present value

Table 12.4 presents the Net Present Value (NPV) of the four BOELs, for both the upper and lower bound estimates of sites, workers and the compliance costs with and without PPE. All Policy Options have a negative NPV (i.e., costs are higher than benefits) under all analysed scenarios, meaning that the EU would be better off without any of the BOELs included in this analysis. The net loss to society ranges from €1.4 billion to €200 million annually. The BOEL of 30 µg/m³ has the most favourable NPV, with NPV becoming less favourable the more stringent the BOEL.

Table 12.4: Comparison of net present value across BOELs

OEL	Net benefits annualised (€ million/year)			
	Compliance without PPE		Compliance with PPE	
	Upper bound	Lower bound	Upper bound	Lower bound
30 µg/m³	-280	-170	-270	-170
20 µg/m³	-440	-270	-320	-270
10 µg/m³	-690	-420	-680	-420
1 µg/m³	-1,120	-690	-1,120	-690

Table notes:

- The lower and upper bounds correspond to the lower and upper bounds for the number of sites and workers exposed.
- Annualised net benefits are the present value (i.e., sum of discounted future costs), divided by the number of years in the analytical period (40 years). Values are discounted using a 3% discount rate and given in 2022 €
- Figures are rounded to the nearest €10 million.

12.4. Benefit-Cost Ratio (BCR)

When benefits equal the costs (a policy option leads to no net cost or benefit to society), the Benefit-Cost Ratio (BCR) equals 1. Any value below 1 means that costs outweigh the benefits, i.e., the baseline of no BOEL is more beneficial to the EU). A BCR above 1 indicates that the Policy Option will result in net benefits to the EU. As can be seen in **Table 12.5**, all the BCRs are significantly below 1. This means that, given the scope of this analysis and data available, none of the four Policy Options (BOELs) is a better option for the EU society than no BOEL.

Table 12.5 shows low, mid and high estimates for the costs and the benefits associated with each Policy Option, and the resulting BCRs. The "low" cost estimates are those with the lower bound number of sites and compliance with PPE, whilst the "high" cost estimates are those with the upper bound number of sites and compliance without PPE. The benefits are estimated using the "central" valuation factors from Section 4.5.2, and using the lower and upper bound number of workers for the "low" and "high" estimates respectively. All 'Mid' values are averages between the respective 'High' and 'Low' values.

Even if looking at high estimates for benefits and low estimates for cost (High B / Low C), the costs outweigh the benefits by factor of ~11 or more. Other variations and assumptions are explored in the sensitivity analysis below (Section 12.6). It is worth noting that the BCR is strictly declining as the BOEL becomes more stringent (i.e., the more stringent the BOEL is, the less net benefit it has for society) for all variations of costs and benefits included in the core analysis. Overall, the costs are in the range of 11 – 95 times higher than the benefits.

Table 12.5: Benefit-Cost Ratios

BOEL	Total annual costs (PV € million/year)			Total annual benefits (PV € million/year)			Benefit-Cost Ratio (BCR)		
	Low	Mid	High	Low	Mid	High	Low B/ High C	Mid B / Mid C	High B / Low C
30 µg/m³	180	240	300	10	13	17	0.034	0.056	0.093
20 µg/m³	280	370	460	11	14	18	0.024	0.039	0.064
10 µg/m³	430	570	700	11	15	19	0.016	0.026	0.044
1 µg/m³	700	920	1,140	12	15	19	0.010	0.017	0.027

Table notes:

- "Low" cost estimates are with PPE and use the lower bound number of sites, "High" cost estimates are without PPE and use the upper bound number of sites, and "Mid" cost estimates are the average of "Low" and "High".
- "Low" benefit estimates use the lower bound number of workers exposed, "High" benefit estimates use the upper bound number of workers exposed and "Mid" cost estimates are the average of "Low" and "High".
- The costs in this table include both costs of compliance and social costs.
- Annualised cost is the present value (i.e., sum of discounted future costs), divided by the number of years in the analytical period (40 years). Values are discounted using a 3% discount rate and given in 2022 €
- The costs are rounded to the nearest € 10 million and the benefits to the nearest € million.

The BCR itself shows the size of the trade-off between benefits and costs, and whether a Policy Option is preferable to the baseline. The marginal BCR (the steepness of the curves) is important as it also shows the incremental impact of changing the BOEL, which is illustrated in **Figure 12.4.** A flat BCR curve would indicate that the relationship between costs and benefits remains the same, whilst a decreasing (increasing) curve means that society is worse (better) off for each µg/m³ reduction of the BOEL. The steepness of the curve indicates how sensitive the BCR is to changes to BOEL. **Figure 12.4** shows a clear decrease in the BCR from 30 µg/m³ to 1 µg/m³, where the most significant decrease is observed for the scenario comparing the high benefits estimate with the low estimate for the costs (High B / Low C).

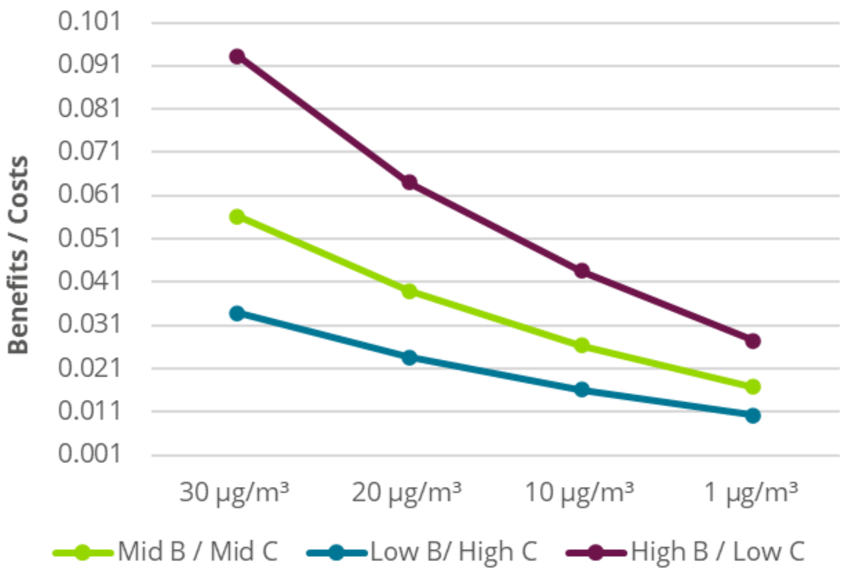

Figure 12.4: Benefit-Cost Ratio for each BOEL

12.5. Sensitivity Analysis

This section sets out a sensitivity analysis, which tests the sensitivity of results to variations in key assumptions to see how they impact the results. This helps to identify the assumptions which are the biggest drivers of the impacts and tests the robustness of the results.

This sensitivity analysis does not test all variables and assumptions that are uncertain either because they were small relative to overall costs or because uncertainty could not be quantified. In particular the sensitivity analysis does not test any variations in the underlying respondent data, which are assumed to be representative. See Section 12.6 for more details on uncertainties not addressed by the sensitivity analysis.

12.5.1 Costs sensitivity

Five variables are included in the sensitivity analysis of the costs, the first two of which are already presented in the core analysis across Chapters 7 to 10. These are:

- **The number of sites.** A lower and upper bound estimates of the number of sites have been calculated based on the respondent data. The upper bound estimates allow for overlap between the broad uses (i.e., a site can be counted for more than one broad use), whilst for the lower bound the double-counting has been removed using survey data (see A 1.1 for more details). The central assumption takes an average between the two.

- **Whether PPE is used to comply with the BOEL.** Costs derived assuming all companies use PPE to comply with the BOEL and costs assuming no companies use PPE have been reported for all costs throughout the analysis, as it is not known to what extent companies will have to use PPE to comply. The "central" assumption listed in **Table 12.1** is therefore the average of estimated costs with PPE and without PPE.
- **RMMs capital lifetime.** The central assumption used is that the capex costs of implementing RMMs will be incurred every 20 years, reflecting a 20-year capital lifetime. This is in line with RPA's estimate of the modal lifespan of typical risk management measures (RPA, 2020). As an upper and lower sensitivity, a capital lifetime of 10 and 30 years are tested, respectively.
- **Period for which profit loss is valued.** The central assumption used is that when a site ceases production, that profit is lost for four years before it is replaced by new companies or the expansion of existing companies. As a lower and upper sensitivity, a profit loss period of two and 20 years are tested.
- **Reduced monitoring costs.** The central assumption used is that all sites implement both biological and respiratory fraction monitoring programmes. Due to the large share of the total costs that is attributable to monitoring, an extreme scenario has been tested where it is assumed that biological monitoring is not implemented by any companies and that respiratory fraction monitoring costs are 50% lower than what was reported by affected actors (eftec, 2023).

It is also recognised that the total costs would be sensitive to using broad use specific costs unit costs. Costs associated with each broad use that had sufficient responses are presented in Chapters 7 to 10. As previously mentioned, these are not considered to be reliable estimates, and are thus not used in any further analysis. It was not considered feasible to create reasonable sensitivity assumptions for each of the broad use costs, hence these are not included in the sensitivity analysis. However, it should be noted that in all cases. when using the broad use specific cost and behavioural data the overall costs exceed the central estimates. This suggest that failure to use broad use specific costs in the central estimates is unlikely to inflate the estimated costs.

Table 12.6 shows the total costs across the four BOELs for each of the tested variables. The variables are tested independently, with all other assumptions in line with the central assumptions described above.

Table 12.6: Impact of each tested variable on total costs across the four BOELs

Parameter	Central assumption	Assumption tested	30 µg/m³ (PV € million / year)	20 µg/m³ (PV € million / year)	10 µg/m³ (PV € million / year)	1 µg /m³ (PV € million / year)
All central assumptions	NA	NA	240	360	570	920
Number of sites	Average of upper and lower	Lower	180	280	430	700
		Upper	290	450	700	1,140

Parameter	Central assumption	Assumption tested	30 µg/m³ (PV € million / year)	20 µg/m³ (PV € million / year)	10 µg/m³ (PV € million / year)	1 µg /m³ (PV € million / year)
Use of PPE	Average of with and without PPE	With PPE	240	360	570	920
		Without PPE	240	360	570	920
RMMs capital lifetime	20 years	30 years	240	360	560	910
		10 years	250	380	590	980
Profit loss period	4 years	2 years	240	360	520	820
		20 years	260	280	870	1,520
Reduced monitoring	BMP and RFM required	BMP not required and RFM costs halved	80	250	450	850

Table notes:

- The costs in this table include both costs of compliance and social costs.
- Annualised cost is the present value (i.e., sum of discounted future costs), divided by the number of years in the analytical period (40 years). Values are discounted using a 3% discount rate and given in 2022 €
- Figures are rounded to the nearest €10 million.

Changing the number of sites to lower or upper bound causes the same proportional difference across all BOELs, as the upper bound sites estimate is around 60% higher than the lower bound sites estimate.

Using PPE as an RMM marginally reduces costs for the 20 µg/m³ BOEL, by around 10%. The 1 µg/m³, 10 µg/m³ and 30 µg/m³ BOELs are largely unaffected, because the estimated costs of implementing RMMs with and without PPE are similar.

Changing the capital lifetime of RMMs has a very small impact on the costs for 30 µg/m³, but for more stringent BOELs the increase in total costs is 5%-10%. Increasing capital lifetime to 30 years makes little difference because the avoided costs from longer capital lifetime occur in future years and are discounted.

The BOELs that are most sensitive to profit loss are those where ceasing production in the EU represents a greater proportion of total costs. Very few companies cease production in the EU under a BOEL of 30 µg/m³, so the values are largely unaffected, while for 1 µg/m³ the upper bound where profit lost is counted over 20 years is around 85% higher than the lower bound of two years.

Assuming no biomonitoring in addition to reducing the cost of air monitoring by 50%, significantly decreases the costs of all BOELs. This is considered an extreme scenario, so it is anticipated that the effects of these assumptions would be large. Particularly large impact is observed for the less stringent BOELs, as the high compliance rates means that monitoring will be the only costs incurred by many companies. Total costs of compliance with a BOEL of 30 µg/m³ falls by two thirds, while the cost of 1 µg/m³ falls by less than 10%.

Table 12.7 shows the costs when combining all lower or upper bound assumptions across all of the sensitivities described above, and thus representing extreme scenarios (i.e., not considered realistic, but outer boundaries estimates).

The **minimum cost** is based on the following assumptions:

- Lower bound number of sites;
- Using PPE as an RMM;
- Capital lifetime of 30 years;
- Lost profit in the EU occurs over two years;
- No companies carry out biological monitoring; and
- The air monitoring costs are half of what was reported by affected actors in eftec (2023).

The **maximum cost** is based on the following assumptions:

- Upper bound number of sites;
- No use of PPE;
- Capital lifetime of 10 years;
- Lost profit in the EU is occurs over 20 years; and
- Monitoring costs are aligned with the central assumptions (i.e., both RFM and BMP)

Table 12.7: Minimum and maximum total costs for all BOELs

BOEL	Minimum costs (PV € million/year)	Central costs (PV € million/year)	Maximum costs (PV € million/year)
30 µg/m³	60	240	340
20 µg/m³	150	360	780
10 µg/m³	300	570	1,130
1 µg/m³	560	920	1,960

Table note:

- Minimum costs is the lowest estimate derived in the sensitivity analysis, and maximum cost is the highest.
- Annualised cost is the present value (i.e., sum of discounted future costs), divided by the number of years in the analytical period (40 years). Values are discounted using a 3% discount rate and given in 2022 €
- Figures are rounded to the nearest €10 million.

Incorporating all sensitivities results in larger ranges with the maximum cost between 45% and 110% higher than the central estimate, and the minimum cost between 40% and 75% lower than the central estimate. The minimum cost estimated for the least stringent BOEL is €60 million per year, while the maximum estimated cost for the most stringent BOEL is close to €2 billion per year.

12.5.2 Benefits sensitivity

As mentioned Chapters 4, 7-10 and further explained in Appendix A 1.4, highly conservative assumptions, which may result in significant overestimation of benefits, have been applied to the assessment of number of cases associated each health endpoint. The valuation factors are also uncertain and heavily impact the results. Another influencing factor is the number of workers exposed. As this has already been covered in the core analysis ("upper" and "lower" bound), it is not the focus in the sensitivity analysis where an average of the two has been used. Three key assumptions were identified and tested in the sensitivity analysis:

- **Reduction in number of workers exposed due to cease of use**: Alongside the changes in the exposure level and distribution, the number of workers exposed would likely be reduced when a BOEL is implemented, in particular for more stringent BOELs. This may be from companies choosing to substitute or relocate[58] their operations outside the EU. As a sensitivity, behavioural responses from the questionnaire data[59] have been used to adjust (reduce) the number of workers for each BOEL.
- **Use of PPE to demonstrate compliance with a BOEL**: PPE is already being used without a BOEL, so it is unlikely that all companies will demonstrate compliance with a BOEL without the use of PPE. As a sensitivity it is assumed that compliance is demonstrated using the same level of PPE as under the baseline. In practise, this means that the Assigned Protection Factors (APFs) are applied (exposure divided by APF) before adjusting exposure levels below the BOEL.
- **Valuation factors for the health endpoints**: Both high and low valuation factors are tested as a sensitivity to the core analysis, which applies an average of the two.

A sensitivity analysis combining the assumptions has also been carried out.

Table 12.8 shows how the risk reduction capacity (i.e., share of total number of cases reduced compared to the baseline) changes when altering the above assumptions. The valuation factors have not been included in this table, as these will not impact the risk reduction capacity.

Key observations are that adjusting the number of workers, to account for cease of use, has a very small impact on the results compared to whether compliance is assumed to be demonstrated with or without PPE. The underlying mechanism for these results is explained in the methodology appendix A 1.4. The most drastic differences can be seen for the higher BOELs, whilst the risk reduction remains close to 100% across all the sensitivity scenarios for 1 μg/m³.

It is likely that the actual risk reduction capacities and associated benefits will lie somewhere between the central estimates and the estimates where cease of use of cobalt and use of PPE have both been adjusted. It is therefore advised that this is taken into account when considering what would be the most appropriate BOEL.

[58] The number of workers exposed outside the EU would increase if a company relocates. However, since the geographical scope of this analysis is the EU, this is not taken into account in the benefits assessment.

[59] Sensitivity workers exposed = Worker exposed with no BOEL x (100% - % of sites ceasing the use of cobalt)

Table 12.8: Risk reduction capacity - sensitivity to key assumptions

BOEL	Risk reduction capacity (%)			
	Central estimate	With cease of use	With PPE for compliance	With cease of use & PPE
30 µg/m³	86%	86%	22%	26%
20 µg/m³	92%	93%	32%	41%
10 µg/m³	97%	98%	54%	65%
1 µg/m³	99.8%	99.9%	99.4%	99.7%

Table note: Central estimates apply the assumptions from the core analysis, i.e., from Chapters 7-0. It also uses an average of lower and upper bound number of workers.

Table 12.9 shows the sensitivity of the benefit estimates to the tested assumptions described above, as well as three combinations of these assumptions. The table shows that the estimated benefits are lowest when low valuation factors are used, number of workers exposed is adjusted for cease of use and it is assumed that PPE is used to demonstrate compliance. Combining these assumptions yields annual benefits of €2 million per year for 30 µg/m³ and €8 million per year for a BOEL of 1 µg/m³. The only assumption that will significantly increase the benefits is to apply a high valuation factor, which is partly due to the core assumptions already being highly conservative (i.e., favouring higher benefits). A high valuation factor results in annual benefits of €20 million per year for 30 µg/m³ and €30 million per year for a BOEL of 1 µg/m³.

Another interesting observation is that adjusting the number of workers exposed will have minimal impact on the total benefits. Assuming PPE is used to demonstrate compliance will significantly reduce the benefits for the less stringent BOELs, whilst only have a marginal effect on 1 µg/m³.

Table 12.9: Annual benefits - sensitivity to key assumptions

BOEL	Annual benefits years (PV € million/year)							
	Central estimate	High valuation factor	Low valuation factor	With cease of use	With PPE	With cease of use & PPE	High valuation, Cease of use & PPE	Low valuation, Cease of use & PPE
30 µg/m³	**13**	20	6	14	4	4	6	2
20 µg/m³	**14**	22	7	15	5	7	10	3
10 µg/m³	**15**	23	7	15	9	10	16	5
1 µg/m³	**15**	23	8	15	15	15	23	8

Table notes:

- Central estimates apply the assumptions from the core analysis used in Chapters 7-10. It also uses an average of lower and upper bound number of workers.
- The total present values (i.e., sum of discounted future costs) were derived using a 3% discount rate, are given in 2022 €, and are rounded to the nearest € million.

12.5.3 *Benefit-Cost Ratio sensitivity*

Several key assumptions and variables were tested for their impacts on the costs and benefits respectively. However, from the perspective of assessing the robustness of BCRs it was deemed sufficient to only look at the "extreme" scenarios. **Table 12.10** sets out the maximum and minimum costs and benefits based on the sensitivity analysis carried out in the previous two sections. These were used to derive maximum and minimum estimates for the BCR, by dividing minimum benefits by maximum costs and vice versa.

The result should be interpreted as the best-case and the worst-case scenario BCRs. In the best-case scenario the costs are 3 times higher than the benefits for a BOEL of 30 µg/m³, while in the worst-case scenario the costs are over 250 times higher the benefits for a BOEL of 1 µg/m³. For both the minimum and maximum scenario, the ranking of the options is largely the same as in the core analysis.

Table 12.10: Benefit- Cost Ratio - Maximum and minimum sensitivities

BOEL	Annual total costs (PV € million/year)		Annual total benefits (PV € million/year)		Benefit-Cost Ratio	
	Min	Max	Min	Max	Min B / Max C	Max B / Min C
30 µg/m³	60	340	2	20	0.0057	0.341
20 µg/m³	150	780	3	22	0.0040	0.145
10 µg/m³	300	1,130	5	23	0.0043	0.076
1 µg/m³	560	1,960	8	23	0.0039	0.042

Table note: The total present values (i.e., sum of discounted future costs) were derived using a 3% discount rate and are given in 2022 €, rounded to the nearest € million.

A notable difference between the extreme scenarios and the central estimates is the steepness of the curves. As can be seen in **Figure 12.5** the maximum BCR (left diagram) is highly sensitive to changes in the BOEL, with a steep decline from 30 µg/m³ to 1 µg/m³. The minimum BCR (right diagram), on the other hand, decreases slightly between 30 µg/m³ and 20 µg/m³, but is approximately constant between 20 µg/m³ and 1 µg/m³.

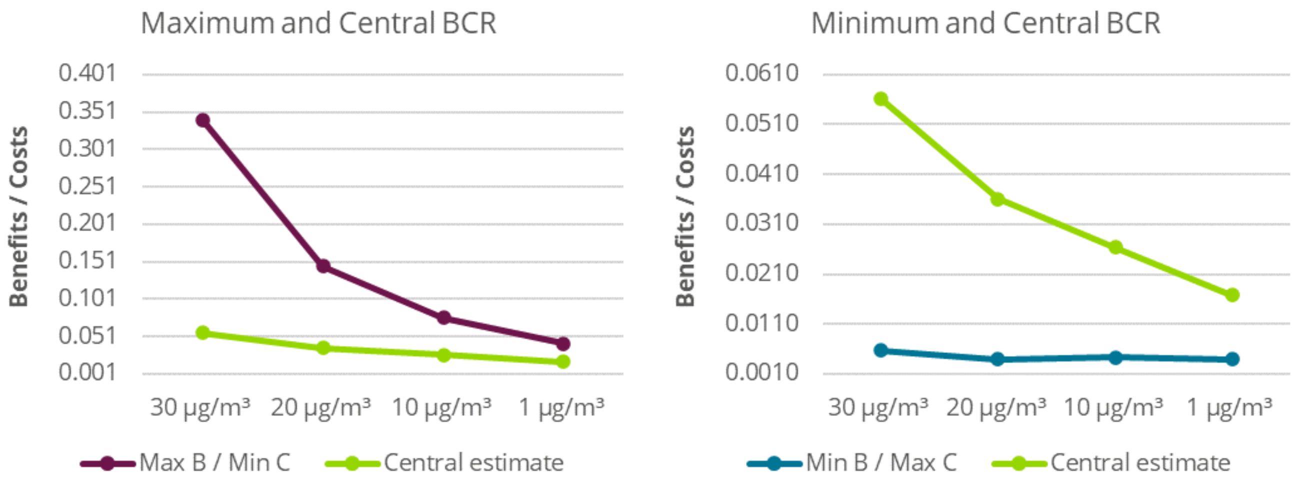

Figure 12.5: **BCR sensitivity**

Figure note: The two diagrams use different scales.

12.6. Uncertainties in underlying data

This section describes the uncertainties of the analysis that stem from the underlying data used. It is generally not possible or meaningful (e.g., reasonable assumptions cannot be made) to test such uncertainties in a sensitivity analysis, which is why these are addressed separately. Key uncertainties identified include, but are not limited to:

- **Small sample size.** The number of companies responded with usable answers to the survey was 59, a sample which is unlikely to provide accurate and representative estimates for average costs and exposures in an industry encompassing as many as 9,000 companies across 27 Member States. For some questions not all respondents provided data, so the sample size for those is smaller.
- **Lack of representativeness at the broad use level**. For the central estimates, all respondents were weighted equally when calculating average costs per site, which were multiplied by the total number of sites to arrive at total costs. There is evidence covered above that costs vary significantly across broad uses, but the questionnaire data was too small and not sufficiently representative to reliably estimate costs by broad use. As discussed in Section 12.5, the general tendency observed when using the broad use specific cost and behavioural data is that the overall costs typically exceed the central estimates. Hence, the central estimates are unlikely to be inflated as a result of the decision not to calculate broad use specific costs and weightings.
- **Small SME sample size.** At an EU level it was estimated that the share of SMEs is around 93%, whilst only 34% of the survey respondents were SMEs. Separate costs were calculated for SMEs and large companies, and the total costs were adjusted for the higher SME rate at the EU level. However, the smaller sample sizes for SMEs indicate a higher level of uncertainty in these estimates, which will also have a knock-on effect on the total costs.
- **Substitution costs are likely underestimated** for two reasons. Firstly, substitution costs used in this report are only based on historic data from companies that have already attempted substitution. These companies are likely to face lower costs of substitution than companies who would only

substitute in response to a BOEL. This issue is likely to be more significant the more stringent the BOEL is. Secondly, all substitution costs relate to substitution attempts that companies indicated were only partially successful. There were no instances of fully successful substitution which, if possible, would likely be more expensive.

- **Behavioural responses to the BOELs do not change between the with/without PPE scenarios.** It is not clear from the behavioural responses to BOELs provided by companies whether they will use PPE when complying with the BOEL, or whether their compliance levels differ depending on whether exposure is measured inside or outside PPE. It is assumed for the purpose of cost calculations that the companies choose the same behavioural options in either case, but this is unlikely. It is expected that a company's behavioural response to a BOEL will often depend on whether the company is able to justify the use of PPE.
- **Exposure distribution:** Assumptions and simplifications had to be made to adopt the monitoring data to each broad use, in addition to the assumed distribution of workers exposed. It is not known to what extent the resulting exposure levels and distribution of workers exposed is representative for the workers of each broad use. The impacts this may have on the overall results are unknown (i.e., it is not possible to determine any bias).
- **The industry questionnaire data is not linked to the exposure monitoring data used**, which leads to significant uncertainties with regards to the actual exposure reductions achieved when implementing a BOEL.
- **Some health endpoints are not considered**: There are still some endpoints, e.g., occupational asthma, skin sensitisation and reprotoxic effects, for which no dose-response were derived by RAC or the EC contractor. Even if the threshold is higher for these endpoints, they may still increase the overall benefits of a BOEL.

12.7. Proportionality assessment

A proportionality assessment takes into account all the evidence gathered and results produced, as well as uncertainties. This means that it takes a broader perspective than just comparing a singular cost and a singular benefit value.

In the core analysis it was shown that costs outweigh benefits of all BOELs and that in all cases a more stringent BOEL is less beneficial to society than a less stringent one. The ranking of the BOELs is largely the same when assumptions are varied, and the sensitivity analysis shows that even in the 'best-case' scenario the costs will outweigh the benefits for all BOELs by at a factor of three.

Uncertainties are still prevalent in the analysis and associated results. If additional health endpoints were possible to include, this could have increased the overall benefits. However, considering the large differences between the costs and the benefits, it is deemed unlikely that the overall conclusions would change based on any of the identified uncertainties.

Furthermore, there are potentially significant costs to the wider society that have not been possible to quantify (Chapter 11). This includes supply risks of cobalt as a critical raw material, energy production and storage may be adversely affected, and wide-reaching knock-on effects may occur if a large number of companies relocate outside the EU. These are important considerations, in particular for the more stringent BOELs. At the BOEL of 10 μg/m^3 around 1,500 sites are expected to cease EU productions of affected product lines, and this number doubles when if a BOEL of 1 μg/m^3 is introduced. These and other non-quantified impacts, will strengthen the conclusions further.

Overall, none of the policy options assessed is considered proportionate. However, if a BOEL is to be implemented, a less stringent BOEL will be more beneficial to the EU society as a whole.

13. Conclusions and recommendation

The following conclusions can be drawn based on the analysis carried out in this report:

- The costs of implementing an EU-wide BOEL outweigh the benefits for all the values assessed between 1 µg/m^3 and 30 µg/m^3. This means that the baseline (no BOEL) is more beneficial to society than implementing any of the BOELs assessed (between 1 µg/m^3 and 30 µg/m^3)
- Of the Policy Options assessed, 30 µg/m^3 has the highest BCR and is thus the most favourable option.
- Non-quantified impacts are expected to be high for BOELs below 20 µg/m^3, due to companies and sites ceasing production in the EU. At 10 µg/m^3 it is estimated that around 1,500 sites will close EU production, and this number will double at 1 µg/m^3.
- The benefits will increase if further health endpoints were included. However, this is unlikely to change the overall conclusions, as other health endpoints, such as reprotoxic effects, have higher threshold than the ones included.
- The conclusions are robust and internally consistent and do not change with varying assumptions, as demonstrated in the sensitivity analysis.

Based on the assessment carried out, the following recommendations are proposed:

- When setting the EU-wide BOEL, the net impacts on the EU society needs to be carefully considered.
- It is recommended that an EU-wide BOEL is not more stringent than 20 µg/m^3, in order to avoid extensive migration of EU industries.
- A more comprehensive data gathering across affected industry actors could be beneficial, in particular related to feasibility and cost of compliance, and impacts on SMEs.
- Further health endpoints could be considered (e.g., skin irritation and male fertility) in order to get a more complete picture of the potential benefits of a BOEL, which would provide a better evidence base for the choosing the most appropriate BOEL.

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Appendix 1 Methodology

A 1.1 Accounting for double counting

The responses to the industry questionnaire revealed that some companies carry out activities related to more than one broad use, sometimes also at the same site. This indicates that there are overlap between the broad uses defined, in the sense that some companies and sites will fall under multiple broad uses. If the number of companies, sites and workers are summed across broad uses, this will therefore lead to double counting. Using the industry questionnaire responses, it was possible to count companies, sites and workers without overlap, albeit only as a total across all uses (i.e., not at a broad use level). "Overlap factors" were derived by dividing the total number of companies, sites and workers across all uses with the corresponding totals without double counting, presented in **Appendix Table 1**.

Although these factors can fully account for double counting across the respondents, they are not likely to be fully representative for EU-27. In particular, it is believed that there were insufficient SMEs represented amongst the respondents, which means that the overlap between the broad uses is likely to be smaller at the EU level than amongst the respondent. For transparency, two estimates are therefore reported: (i) "Upper bound", which includes overlap with other broad uses, which means that summing across multiple uses will lead to double counting, and (ii) "Lower bound", which was estimated by using the overlap factor derived from the respondent data to proportionally reduce the EU-level estimates.

Appendix Table 1 : Overlap factors derived from industry questionnaire data

Metric	Upper bound (with overlap)	Lower bound (without overlap)	Ratio
	Summed across broad uses	*Summed across questionnaire respondents*	*Indication of double counting*
No. companies	96	54	1.78
No. sites	195	111	1.76
No. workers	128,189	81,470	1.57
No. workers exposed	22,758	13,769	1.65

Table note: Data is from eftec's industry questionnaire respondents (eftec, 2023)

A 1.2 Exposure data

This section is based on data collected by EBRC (2023). All submitted data have been screened for their quality, i.e., for their compliance with EN482. For this purpose, a questionnaire was developed that asked for the required qualifying and contextual information for each measurement. All reported data represent personal exposure data of the inhalable of respirable fraction according to EN481. **Appendix Table 2** shows the number of values received and the number of values that passed the quality check for the existing REACH database and for the recently submitted data.

Appendix Table 2 : Personal exposure data of the inhalable or respirable fraction according to EN481

Fraction of dust (EN481)	Existing REACH database (1995 - 2019)	Recently submitted (2012 - 2023)	Combined database (1995-2023)
Submitted	4,839	1,902	6,741
Passed quality check	3,084	1,386	4,470
... thereof personal monitoring results	2,398	1,188	3,586
... thereof results for inhalable fraction	2,366	987	3,353
... thereof results for respirable fraction	82	391	473

Almost all data have been obtained on a full-shift representative basis (i.e., sampling duration of at least 120 minutes). It is important to note that reported exposure levels have not been recalculated to time weighted averages. Actual full-shift exposure levels are therefore likely to be overestimated with the reported data since the exposure duration may be assumed to be less than full-shift - particularly in downstream user operations. However, information on all conducted tasks and task duration per shift was not consistently available for each reported exposure value, so that (8 hour) time weighted averages could not be calculated.

It is also important to note that the wearing of respiratory protective equipment (PPE) is not reflected in the reported exposure levels. Such PPE is, however, common practice for short-term tasks and for cleaning and maintenance tasks and is often required for pre-cautionary reasons by, e.g., national legislation or company policy.

Since both, exposure duration and wearing of PPE, is not reflected in the data as reported in this document, differences between the REACH exposure assessment as reported in the REACH ES exist (because such information is often available at the contributing scenario level). For some downstream uses, these differences can be significant, because the actual exposure duration could be much less than full-shift and a worker may still be required to wear PPE, further reducing the personal full-shift exposure level. Additional differences exist because DNELs and exposure levels are substance-specific (e.g., given as cobalt sulphate but as cobalt in the CSR for cobalt sulphate).

However, since the contextual information (including exposure duration and PPE worn) is very important for a correct interpretation of the monitoring data, the relevant SEGs per broad use category (BUC) and REACH ES are shown in **Appendix Table 3**. It is noted that some of the SEGs are based on modelled or published data and are therefore not further addressed in this report.

Appendix Table 3 : BUCs and related REACH ES and SEGs

Broad Use Category (BUC)	Exposure Scenario (ES) Title	SEG list
Adhesion (inc. rubber adhesion agent)	Formulation or re-packing - Formulation of masterbatches	041, 042, MEASE, 043, 024
	Use at industrial site - Production and industrial use as rubber adhesion agent	041, 042, 043, 044, 024
	Use at industrial site - Production and use as rubber adhesion agent	041, 042, 043, 044, 024
	Use at industrial site - Production and use as rubber adhesion agent	MEASE
Bespoke uses – Formulation of water treatment chemicals, oxygen scavengers, corrosion inhibitors	Formulation - Formulation of oxygen scavengers for polyolefins	039, 024
	Formulation for water treatment chemicals, oxygen scavengers, corrosion inhibitors	021, 024
	New SEG - no ES yet	113
	Handling of humidity indicator cards and/or bags with printed spots in professional settings	033
	Use in humidity indicator cards, plugs and/or bags with printed spots	034, 035, 033
	New SEG - no ES yet	113
	Production and industrial use of plastics and/or PET using cobalt diacetate as a colorant	040, 002, 136*, 024
	Use at industrial site - Production and industrial use of plastics and/or PET using tricobalt tetraoxide as a colorant	021, MEASE, 018, 136*, 024
	Use at industrial site - Production and industrial use of plastics, UPR, PET and FRP as a catalyst	MEASE, 018, 136*, 134*, 024
	Use at industrial site - Production and industrial use of plastics, UPR, PET and FRP as a catalyst, oxygen scavenger and/or pigment	039, MEASE, 018, 136*, 134*, 024
	Use at industrial site - Use of oxygen scavengers for polyolefins	MEASE
	Use by professional worker - Use of plastics, UPR, PET and/or FRP in professional settings	MEASE, 135*
	Use of water treatment chemicals, oxygen scavengers, corrosion inhibitors	030
Manufacture of catalysts	Manufacture - Manufacture of cobalt hydroxide within catalyst or catalyst precursors	048, 051
	Manufacture - Manufacture of cobalt oxide within catalyst or catalyst precursors (including regeneration)	050, 049, 048, 046, 051
	Manufacture - Manufacture of cobalt sulphide within catalyst or catalyst precursors (including regeneration)	037

Broad Use Category (BUC)	Exposure Scenario (ES) Title	SEG list
	Manufacture - Manufacture of cobalt within catalyst or catalyst precursors (including regeneration)	037, 051
	Manufacture - Manufacture of tricobalt tetroxide within catalyst or catalyst precursors (including regeneration)	049, 048, 051
	Manufacture of cobalt carbonate within catalyst or catalyst precursors	048, 051
	Manufacture of cobalt nitrate within catalyst or catalyst precursors	047, 051
	New SEG - no ES yet	101
Manufacture of cobalt and/or cobalt substances	Manufacture - Manufacture of cobalt	001, 002, 003, 004, 005, 006, 007, 008, 009, 024
	Manufacture - Manufacture of cobalt borate neodecanoate	038, 002, MEASE, 021, 024
	Manufacture - Manufacture of cobalt dihydroxide	016, 017, 018, 019, 020, MEASE, 021, 022, 024
	Manufacture - Manufacture of cobalt hydroxide oxide	016, 017, 018, 019, 020, MEASE, 021, 022, 024
	Manufacture - Manufacture of cobalt oxalate	MEASE, 024
	Manufacture - Manufacture of cobalt oxide	016, 017, 018, 019, 020, MEASE, 021, 022, 024
	Manufacture - Manufacture of cobalt sulphide	016, 017, 018, 019, 020, MEASE, 021, 022, 024
	Manufacture - Manufacture of cobalt(II) 4-oxopent-2-en-2-olate	038, 002, 039, MEASE, 024
	Manufacture - Manufacture of cobalt, borate 2-ethylhexanoate complexes	038, 002, MEASE, 021, 024
	Manufacture - Manufacture of cobalt, borate propionate complexes	038, 002, MEASE, 021, 024
	Manufacture - Manufacture of lithium cobalt dioxide	016, 017, 018, 019, 020, MEASE, 021, 022, 024
	Manufacture - Manufacture of neodecanoic acid, cobalt salt	038, 002, MEASE, 024
	Manufacture - Manufacture of resin acids and rosin acids, cobalt salts	MEASE, 038, 002, 039, 021, 024
	Manufacture - Manufacture of the substance	038, 002, 039, MEASE, 021, 024
	Manufacture - Manufacture of the substance	043
	Manufacture - Manufacture of tricobalt tetraoxide	016, 017, 018, 019, 020, MEASE, 021, 022, 024
	Manufacture of cobalt carbonate	016, 017, 018, 019, 020, 021, 022, 024

Broad Use Category (BUC)	Exposure Scenario (ES) Title	SEG list
	Manufacture of cobalt diacetate	038, 002, 039, 040, 024
	Manufacture of cobalt dichloride	016, 017, 018, 019, 020, 021, 022, 024
	Manufacture of cobalt dinitrate	016, 017, 018, 019, 020, 021, 022, 024
	Manufacture of cobalt sulphate	016, 017, 018, 019, 020, 021, 022, 024
	New SEG - no ES yet	071, 072, 103, 104, 105, 110, 111, 112, 113, 114
	Re-packaging of cobalt(II) 4-oxopent-2-en-2-olate	039, 024
Manufacture of driers / paints	Formulation - Formulation of coatings, paints and inks using cobalt dihydroxide as drier or pigment	021, 018, MEASE, 024
	Formulation - Formulation of coatings, paints and inks using tricobalt tetraoxide as drier or pigment	021, 018, MEASE, 024
	Formulation - Formulation of paints, inks and/or coatings	039, 018, MEASE, 024
	Formulation of coatings, paints and inks using cobalt borate neodecanoate as drier or pigment	039, 018, MEASE, 024
	Formulation or re-packing - Formulation of coatings, paints and inks using cobalt oxide as drier or pigment	021, 018, MEASE, 024
	New SEG - no ES yet	111, 113, 114
	Service life (professional worker) - Handling/Manipulation of dried paints or coatings in professional settings	136*, MEASE
	Use at industrial site - Use of coatings, paints and inks using cobalt dihydroxide as drier or pigment	MEASE, 134*
	Use at industrial site - Use of coatings, paints and inks using cobalt oxide as drier or pigment	MEASE, 134*
	Use at industrial site - Use of coatings, paints and inks using cobalt, borate propionate complexes as drier	MEASE, 134*
	Use at industrial site - Use of coatings, paints and inks using the substance as drier	MEASE, 134*
	Use at industrial site - Use of coatings, paints and inks using the substance as drier or pigment	MEASE, 134*
	Use at industrial site - Use of coatings, paints and inks using tricobalt tetraoxide as drier or pigment	MEASE, 134*
	Use by professional worker - Use of coatings, paints and inks	MEASE, 135*
Manufacture of other chemicals	Manufacture of chemicals and in other wet-chemical processes as intermediate	021, 002, 024
	Manufacture of chemicals and in other wet-chemical processes as intermediate	040

Broad Use Category (BUC)	Exposure Scenario (ES) Title	SEG list
	Manufacture of chemicals in wet-chemical processes (intermediate use)	038, 002, 024
	Manufacture of cobalt carboxylates and resinates (intermediate use)	038, 030, 002
	Manufacture of cobalt carboxylates and resinates (intermediate use)	024
	New SEG - no ES yet	071, 072, 103, 104, 105, 110, 111, 112, 113, 114
	Use at industrial site - Manufacture of chemicals and in other wet-chemical processes as intermediate	021, MEASE, 024
	Use at industrial site - Manufacture of chemicals and in other wet-chemical processes as intermediate	039
	Use at industrial site - Manufacture of chemicals as intermediate	MEASE, 024
	Use at industrial site - Manufacture of chemicals in wet-chemical processes (intermediate use)	021, MEASE, 024
	Use at industrial site - Manufacture of chemicals in wet-chemical processes as intermediate	043, 002
	Use at industrial site - Manufacture of cobalt carboxylates and resinates (intermediate use)	038, 002, 024
	Use at industrial site - Use of cobalt in the manufacture of cobalt carboxylates and resinates (intermediate use)	038, 002, 039, MEASE, 021, 024
	Use at industrial site - Use of cobalt in the manufacture of inorganic cobalt substances (intermediate use)	016, 017, 018, 019, 020, MEASE, 021, 022, 024
	Use at industrial sites - Manufacture of chemicals in wet-chemical processes (intermediate use)	021, MEASE, 024
	Use of cobalt sulphate in the manufacture of other chemicals (intermediate use)	021, 019, 024
Manufacture of pigments and dyes	Manufacture of dyes for the textile, leather, wood and paper industry (intermediate use)	018, 002
	Manufacture of inorganic pigments, ceramic ware, glass (intermediate use)	036, 017, 018, 019, 030, 008, 024
	Manufacture of inorganic pigments, glass and ceramic ware (intermediate use)	036, 017, 018, 019, 030, 008, 024
	New SEG - no ES yet	111, 113, 114
	Production of dyes for the textile, leather, wood and paper industry (intermediate use)	018, 002
	Production of textile dyes (intermediate use)	018, 002

Broad Use Category (BUC)	Exposure Scenario (ES) Title	SEG list
	Use at industrial site - Industrial use of cobalt in the manufacture of inorganic pigments, ceramic ware, glass	016, 017, 018, 019, MEASE, 024
	Use at industrial site - Manufacture of inorganic pigments and ceramic ware (intermediate use)	016, 017, 018, 019, MEASE, 024
	Use at industrial site - Manufacture of inorganic pigments, ceramic ware, glass	016, 017, 018, 019, MEASE, 024
	Use at industrial site - Manufacture of inorganic pigments, ceramic ware, glass (intermediate use)	016, 017, 018, 019, MEASE, 024
	Use at industrial site - Manufacture of inorganic pigment, glass and ceramic ware (intermediate use)	039, 017, 018, 019, MEASE, 024
	Use at industrial site - Use as catalyst in the leather industry	MEASE
	Use by professional worker - Use of fatliquor for leather tanning	MEASE
Manufacture of precursor chemicals for batteries	Battery production (intermediate use)	016, 018, 005, 152
	New SEG - no ES yet	054, 100
	Use at industrial site - Battery production	016, 018, 005, 152
	Use at industrial site - Battery production	Qualitative
	Use at industrial site - Battery production (intermediate use)	016, 018, 005, 152
	Use at industrial site - Production of cobalt-containing batteries	016, 018, 005, 152
No fitting BUC	Handling of plastics and/or PET in industrial settings	136*
	Handling of plastics and/or PET in professional settings	136*
	Service life (professional worker) - Handling of flat glass in professional settings	MEASE, 008
	Service life (professional worker) - Handling of plastic articles (including e.g., PET) in professional settings	136*
	Service life (professional worker) - Handling of plastics and/or PET in professional settings	136*
	Service life (professional worker) - Handling of treated leather articles in professional settings	MEASE
	Service life (professional worker) - Handling of tyres in professional settings	152
	Service life (worker at industrial site) - Handling of flat glass in industrial settings	MEASE, 008
	Service life (worker at industrial site) - Handling of plastic articles (including e.g., PET) in industrial settings	136*
	Service life (worker at industrial site) - Handling of plastics and/or PET in industrial settings	136*

Broad Use Category (BUC)	Exposure Scenario (ES) Title	SEG list
	Service life (worker at industrial site) - Handling of treated leather articles in industrial settings	MEASE
	Service life (worker at industrial site) - Handling of tyres in industrial settings	152
Recycling of materials containing cobalt substances	Manufacture - Recycling of hardmetal-containing scrap materials	098, 097, 148*, 093, 095, 094
	New SEG - no ES yet	096
Use as catalysts - used as a catalyst or catalyst precursor	Formulation or re-packing - Formulation of catalyst or catalyst precursors	037
	Industrial use of RM as intermediate for the production of another substance in catalyst or catalyst precursor manufacture	046, 047, 048, 049, 050, 051
	Industrial use of tricobalt tetraoxide containing catalysts	046, MEASE, ART 1.5, 051
	Use at industrial site - Industrial use in catalysts	037, 051
	Use at industrial site - Industrial use of cobalt oxide containing catalysts	046, MEASE, ART 1.5, 051
	Use at industrial site - Industrial use of RM as intermediate for the production of another substance in catalyst or catalyst precursor manufacture	046, 047, 048, 049, 050, 051
	Use at industrial site - Industrial use of the substance for the production of other catalysts containing cobalt compounds	037
	Use at industrial site - Use in the catalyst industry	037
	Use at industrial sites - Industrial use in catalysts and catalyst precursors	037
	Use at industrial sites - Industrial use in catalysts and catalyst precursors (intermediate use)	037
	Use at industrial sites - Industrial use of cobalt sulphide containing catalysts	046, MEASE, ART 1.5, 051, 037
	Use at industrial sites - Use of cobalt as an intermediate in the manufacture of catalysts	037, 051
Use as catalysts - used as oxidation catalyst/for PTA and IPA	New SEG - no ES yet	115
	Use as catalyst	045
Use in biotechnology – Formulation and industrial use of mixtures in biogas production	Formulation of mixtures for use in biogas production	032, 002, 031, 024
	Formulation of mixtures for use in biogas production	022
	New SEG - no ES yet	113
	Use in biogas production	032, 031
	Formulation - Formulation of fertilizers	021, MEASE, 024

Broad Use Category (BUC)	Exposure Scenario (ES) Title	SEG list
Use in biotechnology – Formulation and use in animal feed grade materials	Formulation - Formulation of fertilizers	039
	Formulation of feed grade materials	021, 024
	Formulation of fertilizers and/or feed grade materials	040, 024
	New SEG - no ES yet	113
	Use at industrial site - Formulation or re-packing - Formulation of fertilizers	021, MEASE, 024
	Use by professional worker - Professional use of fertilizers	MEASE
Use in biotechnology – Professional use in biogas production	Professional use in biogas production	032
	Professional use of formulations in biogas production	032
Use in biotechnology – Use in fermentation, fertilizers, biotech, scientific research and standard analysis	Industrial use of cobalt acetylacetonate for analytical purposes	039, 031, MEASE, 024
	New SEG - no ES yet	107, 108, 109
	Professional use of cobalt acetylacetonate as laboratory agent	039, 031
	Use in fermentation processes, in biotech and scientific research and standard analysis	032, 031
Use in cemented carbide/diamond tools	New SEG - no ES yet	052, 053, 055, 056, 057, 058, 059, 060, 061, 062, 063, 066, 067, 068, 069, 075, 078, 079, 083, 091
	Service life (professional worker) - Service life of cobalt-containing tools in professional settings	MEASE, 013
	Service life (professional worker) - Service life of hardmetal articles in professional settings	066
	Service life (worker at industrial site) - Service life of hardmetal articles in industrial settings	066
	Use at industrial site - Industrial use of cobalt in the production of diamond tools	007, MEASE, 019, 005, 008, 024
	Use at industrial site - Production of hardmetal powder	080, 077, 074, 073, 076
	Use at industrial site - Production of hardmetal powder for surface technology	080, 149*, 073, 150*, 151*, 076
	Use at industrial site - Production of sintered hardmetal articles	092, 086, 088, 089, 090, 084, 082, 147*, 085, 087, 081
Use in electronics	New SEG - no ES yet	052, 053, 054, 100
	Service life (professional worker) - Service life of cobalt-containing batteries in professional settings	152

Broad Use Category (BUC)	Exposure Scenario (ES) Title	SEG list
	Service life (professional worker) - Service life of cobalt-containing batteries in professional settings	Qualitative
	Service life (professional worker) - Service life of cobalt-containing portable batteries in professional settings	152
	Service life (worker at industrial site) - Service life of cobalt-containing batteries in industrial settings	152
	Service life (worker at industrial site) - Service life of cobalt-containing batteries in industrial settings	Qualitative
	Service life (worker at industrial site) - Service life of cobalt-containing industrial batteries in industrial settings	152
	Service life of cobalt-containing batteries in industrial settings	152
	Service life of cobalt-containing batteries in professional settings	152
	Service life of cobalt-containing industrial batteries in industrial settings	152
	Service life of cobalt-containing portable batteries in professional settings	152
Use in magnetic alloys	New SEG - no ES yet	071, 072
	Service life (professional worker) - Service life of cobalt-containing varistors and magnets in professional settings	MEASE, 008
	Service life (worker at industrial site) - Service life of cobalt-containing varistors and magnets in industrial settings	MEASE, 008
	Use at industrial site - Industrial use of cobalt in the production of varistors and magnets (calcination/sintering processes)	016, 017, 018, 014, 019, MEASE, 008, 024
	Use at industrial site - Production of varistors and magnets (calcination/sintering processes)	016, 017, 018, 014, 019, MEASE, 008, 024
	Use at industrial sites - Production of varistors and magnets (calcination/sintering processes)	016, 017, 018, 014, 019, MEASE, 008, 024
Use in metallurgical alloys	Formulation of cobalt for the use in brazing techniques	007, MEASE, 024
	Industrial use of cobalt-containing mixtures in brazing techniques	MEASE
	New SEG - no ES yet	052, 053, 064, 065, 070, 071, 072
	Service life (professional worker) - Service life of dental alloys containing cobalt in professional settings	139*
	Service life (professional worker) - Welding in professional settings	MEASE

Broad Use Category (BUC)	Exposure Scenario (ES) Title	SEG list
	Service life (worker at industrial site) - Service life of cobalt containing alloys, steels and tools in industrial settings	012, 013, MEASE
	Service life (worker at industrial site) - Welding in industrial settings	MEASE, 010
	Use at industrial site - Production and industrial use of cobalt containing alloys, steels and tools	008, 010, 005, 011, MEASE, 133*, 024
	Use at industrial sites - Industrial use of cobalt metal in additive manufacturing (3D-printing)	143*, 144*, 145*, 146*
	Use of cobalt-containing alloys for sandblasting in industrial settings	007, MEASE, 024
Use in surface treatment - Formulation of surface treatment	Formulation - Formulation of metal surface treatment pre-formulations	021, 018, MEASE, 024
	Formulation of metal surface treatment pre-formulations	025, 030, 102, 028
	Formulation of metal surface treatment pre-formulations	027
	New SEG - no ES yet	026
Use in surface treatment - Metal or metal alloy plating	Industrial use of cobalt(II) 4-oxopent-2-en-2-olate in the surface treatment of glass	152
	Plating processes in surface treatment	021, 030, 029, 015, 028
	Plating processes in surface treatment	027
	Use at industrial site - Industrial use of cobalt in plating processes in surface treatment	008, 018, 024
	Use at industrial site - Industrial use of cobalt in thermal spraying in surface treatment	008, 007, MEASE, 005, 024
	Use at industrial site - Plating processes in surface treatment	021, MEASE, 018, 008, 024
Use in surface treatment - Passivation or anti-corrosion treatment processes	Industrial handling of surface treated articles (passivated/plated)	015
	New SEG - no ES yet	099, 106
	Passivation processes in surface treatment at large industrial sites with continuous processes	030, 015
	Passivation processes in surface treatment in large scale operations	008, MEASE
	Passivation processes in surface treatment	025, 030, 015, 028
	Passivation processes in surface treatment	027
	Professional handling of surface treated articles (passivated/plated)	015
	Service life (professional worker) - Professional handling of surface treated articles (passivated/plated)	008

Broad Use Category (BUC)	Exposure Scenario (ES) Title	SEG list
	Service life (professional worker) - Professional handling of surface treated articles (passivated/plated/sprayed)	008
	Service life (worker at industrial site) - Industrial handling of surface treated articles (passivated/plated)	008
	Service life (worker at industrial site) - Industrial handling of surface treated articles (passivated/plated/sprayed)	008
	Use at industrial site - Industrial use of cobalt in passivation processes in surface treatment	008, 018, MEASE, 024
	Use at industrial site - Passivation processes in surface treatment	021, MEASE, 008, 024
	Use at industrial site - Passivation processes in surface treatment at large industrial sites with continuous processes	MEASE, 008

A list of the definitions of SEGs and their codes can be found below in **Appendix Table 4.**

Appendix Table 4 : List of SEGs and their codes

Code	SEG Title
001	CM-Manufacture of cobalt-Raw material handling
002	CM-Manufacture of cobalt-Leaching unit
003	CM-Manufacture of cobalt-Solvent extraction unit
004	CM-Manufacture of cobalt-Tankhouse (electrowinning)
005	CM-Manufacture of cobalt-Shearhouse (cutting)
006	CM-Manufacture of cobalt-Powder production and milling
007	CM-Manufacture of cobalt-Screening and packaging
008	CM-Manufacture of cobalt-Packaging of metal chips
009	NEW: CM-Manufacture of cobalt-Supervision/control room
010	CM-Production and industrial use of cobalt containing alloys, steels and tools-Melting and Casting
011	CM-Production and industrial use of cobalt containing alloys, steels and tools-Handling of powders
012	CM-Service life of cobalt containing alloys, steels and tools in industrial settings-Use and mechanical treatment of hard coated metals and/or alloys-Mechanical treatment of hard coated metals and/or alloys – low kinetic energy
013	CM-Service life of cobalt containing alloys, steels and tools in industrial settings-Use and mechanical treatment of hard coated metals and/or alloys-Use and mechanical treatment of hard coated metals and/or alloys – high kinetic energy
014	CM-Industrial use of cobalt in the production of varistors and magnets (calcination/sintering processes)-Preparation of pre-sintered materials
015	CM-Surface treatment-Finishing of surface treated objects

Code	SEG Title
016	CI-Manufacture of the substance-Raw material handling
017	CI-Manufacture of the substance-Preparation of raw material
018	CI-Manufacture of the substance-Wet process
019	CI-Manufacture of the substance-Hot process
020	CI-Manufacture of the substance-Further processing
021	CI-Manufacture of the substance-Packaging of substances with moderate dustiness potential
022	CI-Manufacture of the substance-Packaging of substances with high dustiness potential
023	CI-Manufacture of the substance-Supervision
024	CI-Manufacture of the substance-Cleaning & Maintenance
025	CI-Formulation-Surface Treatment-Raw material handling (solids)
026	CI-Formulation-Surface Treatment-Filling of solutions containing <25 %
027	CI-Formulation-Surface Treatment-Raw material handling of low dusty solids
028	CI-Plating processes in surface treatment-Cleaning & Maintenance
029	CI-Plating processes in surface treatment-Plating
030	CI-Plating processes in surface treatment-Raw material handling (solutions)
031	CI-Use in fermentation processes, in scientific research, standard analysis and biogas production-Handling at laboratory scale
032	CI-Use in fermentation processes, in scientific research, standard analysis and biogas production-Raw material handling
033	CI-Use in humidity indicator cards, plugs and/or bags with printed spots-Handling of humidity indicator cards or spotted bags
034	CI-Use in humidity indicator cards, plugs and/or bags with printed spots-Handling of liquid raw material
035	CI-Use in humidity indicator cards, plugs and/or bags with printed spots-Further processing
036	CI-Manufacture of inorganic pigments, ceramic ware, glass -Raw material handling
037	CI-Manufacture in the catalyst industry-All workplaces
038	CC-Manufacture of the substance-Raw material handling
039	CC-Manufacture of the substance-Packaging of powders
040	CC-Manufacture of the substance-Packaging of low and/or medium dusty materials
041	CC-Production and industrial use of rubber adhesion agent using cobalt carboxylates-Raw material handling
042	CC-Production and industrial use of rubber adhesion agent using cobalt carboxylates-Kneading (mixing)
043	CC-Production and industrial use of rubber adhesion agent using cobalt carboxylates-Shaping
044	CC-Production and industrial use of rubber adhesion agent using cobalt carboxylates-Finishing and shipping
045	CC-Use of cobalt diacetate as catalyst-Use of catalyst
046	CI-Catalysts-Delivery, transfer, storage

Code	SEG Title
047	CI-Catalysts-Addition of reagents, dissolution, sampling
048	CI-Catalysts-Addition of reagents, impregnation, transfer to dryer, drying
049	CI-Catalysts-Transfer to calciner, calcination
050	CI-Catalysts-Screening to adjust particle size distribution
051	CI-Catalysts-Cleaning and maintenance
052	CM-3DPrinting-Closed process
053	CM-3DPrinting-Handling and sieving
054	CM-Battery production-Battery assembly
055	CM-Cobalt containing alloys, steels and tools (incl. diamond tools)-Further processing
056	CM-Cobalt containing alloys, steels and tools (incl. diamond tools)-Hot (metallurgical) processes
057	CM-Cobalt containing alloys, steels and tools (incl. diamond tools)-Job rotation
058	CM-Cobalt containing alloys, steels and tools (incl. diamond tools)-Mixing and granulation
059	CM-Cobalt containing alloys, steels and tools (incl. diamond tools)-Pressing
060	CM-Cobalt containing alloys, steels and tools (incl. diamond tools)-Raw material handling
061	CM-Cobalt containing alloys, steels and tools (incl. diamond tools)-Welding
062	CM-Cobalt containing alloys, steels and tools (incl. diamond tools)-Wet process
063	CM-Formulation of cobalt containing hardmetal powder for diamond tools-Formulation process
064	CM-Formulation of cobalt for the use in brazing equipment-Formulation process
065	CM-Formulation of cobalt for the use in brazing equipment-Handling of formulation
066	CM-Handling and use of hardmetal articles (at industrial or professional sites)
067	CM-Industrial use of cobalt in the production of diamond tools-Packaging
068	CM-Industrial use of cobalt in the production of diamond tools-Raw material handling
069	CM-Industrial use of cobalt in the production of diamond tools-Wet process
070	CM-Industrial use of cobalt-containing mixtures in brazing techniques-Raw material handling
071	CM-Manufacture of cobalt-Cleaning & Maintenance
072	CM-Manufacture of cobalt-Job rotation
073	CM-Production of hardmetal powder-Drying
074	CM-Production of hardmetal powder-Emptying the mill
075	CM-Production of hardmetal powder-Laboratory handling
076	CM-Production of hardmetal powder-Maintenance
077	CM-Production of hardmetal powder-Milling
078	CM-Production of hardmetal powder-Quality check
079	CM-Production of hardmetal powder-Supervision
080	CM-Production of hardmetal powder-Weighing Powder & Filling the Mill

Code	SEG Title
081	CM-Production of sintered hardmetal articles-Cleaning and maintenance
082	CM-Production of sintered hardmetal articles-Edge rounding
083	CM-Production of sintered hardmetal articles-Granulation
084	CM-Production of sintered hardmetal articles-Grinding and/or turning
085	CM-Production of sintered hardmetal articles-Job rotation
086	CM-Production of sintered hardmetal articles-Mixing
087	CM-Production of sintered hardmetal articles-Packaging
088	CM-Production of sintered hardmetal articles-Press charging/Pressing
089	CM-Production of sintered hardmetal articles-Shaping
090	CM-Production of sintered hardmetal articles-Sintering
091	CM-Production of sintered hardmetal articles-Spray tower
092	CM-Production of sintered hardmetal articles-Transfer to mixer
093	CM-Recycling of hardmetal-containing scrap materials-Chemical recycling
094	CM-Recycling of hardmetal-containing scrap materials-Cleaning & Maintenance
095	CM-Recycling of hardmetal-containing scrap materials-Job rotation
096	CM-Recycling of hardmetal-containing scrap materials-Laboratory handling
097	CM-Recycling of hardmetal-containing scrap materials-Processing operation
098	CM-Recycling of hardmetal-containing scrap materials-Scrap handling
099	CM-Thermal-spraying-closed
100	CI-Battery production-Battery assembly
101	CI-Catalysts-Job rotation
102	CI-Formulation-Surface Treatment-Filling of solutions containing <25 %
103	CI-Manufacture of the substance-Crushing
104	CI-Manufacture of the substance-Job rotation
105	CI-Manufacture of the substance-Laboratory handling
106	CI-Surface Treatment-Passivation
107	CI-Use in fermentation processes, in biotech and scientific research and standard analysis-Handling at laboratory scale
108	CI-Use in fermentation processes, in biotech and scientific research and standard analysis-Handling of liquid stock solution
109	CI-Use in fermentation processes, in biotech and scientific research and standard analysis-Raw material handling
110	CC-Manufacture of the substance-Cleaning & Maintenance
111	CC-Manufacture of the substance-Closed packaging of powders
112	CC-Manufacture of the substance-Job rotation

Code	SEG Title
113	CC-Manufacture of the substance-Packaging of substances with low and/or moderate dustiness potential
114	CC-Manufacture of the substance-Reaction and filtration
115	CC-Use as catalyst-Cleaning & Maintenance
133	CM-Production and industrial use of cobalt containing alloys, steels and tools-Thermal spraying – NOT fully automated
134	CC-Use of coatings, paints and inks using the substance as drier or pigment-Industrial spraying of coatings and inks
135	CC-Use of coatings, paints and inks-Professional spraying of coatings and inks
136	CC-Handling/Manipulation of dried paints or coatings in professional settings-Sanding
137	CM-Service life (worker at industrial site) - Welding in industrial settings
138	CM-Service life (worker at industrial site) - Welding in professional settings
139	CM-Service life of dental alloys containing cobalt in professional settings-All workplaces
140	CM-Pub6-Recycling of hardmetal-containing scrap materials
141	CM-Pub7-Production of hardmetal powder
142	CM-Pub8-Production of sintered hardmetal articles
143	Ni-Pub10-Handling of dusty materials
144	Ni-Pub11-3D-printing in closed process
145	Ni-Pub12-Maintenance work
146	Ni-Pub13-Cleaning & Maintenance
147	CM-Production of sintered hardmetal articles-Coating
148	CM-Recycling of hardmetal-containing scrap materials-Transfer to recycling unit
149	CM-Production of hardmetal powder for surface technology-Agglomeration
150	CM-Production of hardmetal powder for surface technology-Sintering
151	CM-Production of hardmetal powder for surface technology-Packaging
152	NEW: Qualitative assessment-All-ES-Various-Articles

A 1.2.1 Derived exposure levels

The summary statistics derived from the combined exposure database are given in the table below for each SEG. The reasonable worst-case (RWC) estimate in the REACH exposure scenarios will be based on the upper confidence limit of the maximum likelihood estimate for the 75th percentile. For SEGs for which such estimate could not be derived (because of too few data available), twice the maximum value was used as RWC. Maximum likelihood and their confidence intervals are used as RWC estimates for the following reasoning:

ECHA R.14 guidance on occupational exposure assessment requests that the exposure assessor should use "[...] in general the 90th percentile value, representing the reasonable worst case exposure level of a distribution within a generally suitable dataset (i.e., a dataset corresponding to the conditions described in a contributing scenario).” In addition, it is mentioned in the same guidance that “Inhalation exposure data tend to be log-normally distributed.” and that “for regulatory decision-making, enough data are required to establish the key values from the distribution. The confidence in the estimated exposure value, for regulatory purposes, generally increases with sample size, as long as the data truly represent the full variability across industry.” Based on these statements, EBRC applies statistical methods to derive estimates of RWC considering the exposure distribution, sample size and confidence in the estimates. The selected statistics (i.e., the upper 90 percent confidence limit of the 75th percentile, thereby approximates the sample 90th percentile for (lognormal distributed) dataset of moderate extent (around 10 values) and moderate geometric standard deviation (GSD around 2.5). The approach has been presented during various previous occasions to ECHA (e.g., (Vetta, 2020) and has been successfully applied in previous registrations of the inorganic chemicals sector (e.g., nickel and cobalt substances, precious metals). Whereas the details of the approach (e.g., which confidence level and percentile to be selected) were not specified, the general principle (i.e., using confidence intervals of distribution-based statistics) has been accepted (ECHA, 2022) in the context of the metals and inorganic sectorial approach (MISA and Eurometaux, 2020)

Summary statistics and the derived exposure levels are shown in **Appendix Table 5**.

Appendix Table 5 : Summary statistics per SEG for the inhalable and respirable fraction

SEG	n	AM	SD	GM	GSD	Median	P75	P90	P95	Max	P75UCL90	Years	n	AM	SD	GM	GSD	Median	P75	P90	P95	Max	P75UCL90	Years
001	74	1.0	0.4	9.4	5.6	1.0	26.0	102.8	179.3	730.0	39.8	2005-2021	6	98.5	141.5	47.8	3.6	40.0	87.5	240.0	310.0	380.0	229.4	2019-2022
002	133	0.5	0.0	3.4	2.6	0.5	6.0	9.8	24.0	51.0	7.1	2006-2018	no data available											
003	27	0.8	0.3	1.7	2.4	1.0	2.0	4.8	6.7	40.0	3.9	2006-2018	2	1.7	1.6	1.2	3.3	1.7	2.2	2.6	2.7	2.8	16.2	2019-2019
004	41	57.8	48.8	19.0	2.2	39.0	32.0	52.0	65.0	126.0	39.0	2007-2009												
005	32	0.7	0.6	2.0	4.3	0.5	7.2	17.3	20.4	30.0	7.5	2005-2022	4	0.1	0.1	0.1	2.0	0.0	0.1	0.1	0.1	0.2	0.5	2018-2022
006	184	0.0	0.0	29.0	4.2	0.0	75.3	180.0	388.0	870.0	88.7	2007-2021	6	27.6	33.3	8.6	7.1	13.9	48.0	68.0	74.0	80.0	96.1	2019-2022
007	232	0.2	NA	77.8	4.7	0.2	248.8	530.0	694.7	5200.0	257.1	2007-2022	10	305.1	208.1	248.2	2.0	230.0	402.5	618.0	654.0	690.0	524.3	2019-2022
008	11	0.4	0.5	1.9	3.3	0.3	5.5	8.0	8.5	9.0	6.9	2005-2021	2	0.6	0.6	0.4	3.1	0.6	0.8	0.9	1.0	1.0	5.4	2018-2021
009	61	16.2	14.9	7.2	2.1	13.0	11.2	17.0	24.0	33.0	13.6	2010-2022												
010	7	490.5	461.8	1.1	1.3	424.0	1.0	1.4	1.8	2.1	1.5	2007-2008	no data available											
011	20	372.8	340.5	147.6	5.7	450.0	479.3	1079.3	1210.0	1419.0	815.1	2009-2022	3	0.1	0.0	0.1	1.4	0.1	0.1	0.1	0.1	0.1	0.2	2021-2022
012	26	9.2	6.7	5.6	5.5	7.6	10.0	20.0	20.0	20.0	28.0	1998-2021	28	0.6	0.7	0.3	3.4	0.3	0.7	1.3	2.1	2.7	0.9	2017-2022
013	30	26.6	26.3	2.2	13.2	19.0	20.0	31.0	117.0	290.0	23.8	1995-2022	20	0.1	0.1	0.1	2.0	0.1	0.1	0.3	0.3	0.5	0.2	2017-2021
014	11	3.6	3.4	34.0	2.8	2.4	66.4	96.0	109.6	123.2	102.3	2001-2019*	no data available											
015	6	357.8	414.9	1.7	1.6	198.5	2.1	2.8	3.2	3.5	3.1	2007-2013												

SEG	n	AM	SD	GM	GSD	Median	P75	P90	P95	Max	P75UCL90	Years	n	AM	SD	GM	GSD	Median	P75	P90	P95	Max	P75UCL90	Years
016	100	136.7	204.0	12.0	6.7	62.5	45.0	149.6	282.5	680.0	56.5	2007-2022	11	0.6	0.6	0.2	5.7	0.4	1.0	1.4	1.5	1.7	1.5	2018-2022
017	171	80.8	118.0	7.4	3.4	38.0	13.5	32.0	52.5	730.0	19.1	2007-2022	1	70.0	NA	70.0	NA	70.0	70.0	70.0	70.0	70.0	NA	2022-2022
018	159	4.3	3.5	5.3	3.9	3.3	11.0	36.0	70.1	146.0	15.5	2007-2022	19	1.5	1.3	1.0	2.6	1.2	1.6	3.8	3.9	4.3	2.6	2019-2019
019	64	6.7	13.7	47.6	5.6	1.7	137.3	307.0	634.0	910.0	207.1	2007-2022	7	7.6	6.2	3.5	8.1	7.0	10.7	15.0	16.5	18.0	41.6	2019-2020
020	83	0.1	NA	31.2	5.2	0.1	79.0	214.8	277.1	670.0	121.7	2007-2022	2	25.0	14.1	22.9	1.8	25.0	30.0	33.0	34.0	35.0	84.7	2019-2019
021	162	120.0	NA	18.9	4.7	120.0	58.0	162.4	231.8	797.0	63.9	2007-2022	no data available											
022	99	50.5	140.2	84.8	6.2	13.0	342.9	976.0	1210.2	2823.4	372.1	2009-2022	8	162.4	205.3	91.4	3.1	92.5	170.0	353.0	496.5	640.0	336.8	2019-2019
023	50	109.7	216.5	4.3	2.8	33.0	10.0	15.2	18.1	30.0	10.4	2012-2022	no data available											
024	229	4.2	4.5	12.3	5.8	2.0	40.0	100.2	187.7	1482.0	47.8	2010-2022	5	4.5	6.2	0.8	12.9	0.6	8.2	11.5	12.5	13.6	20.8	2020-2022
025	4	1.7	2.0	3.0	2.4	1.1	4.3	8.3	9.7	11.0	NA	2013-2019	3	0.2	0.1	0.2	1.2	0.2	0.3	0.3	0.3	0.3	0.3	2017-2019
026	1	29.4	43.0	1.0	NA	12.0	1.0	1.0	1.0	1.0	NA	2013	no data available											
027	1	12.1	7.3	0.1	NA	11.7	0.1	0.1	0.1	0.1	NA	2013												
028	9	309.1	499.2	3.9	2.7	64.0	6.1	13.6	16.8	20.0	11.5	2004-2019	2	2.5	0.7	2.4	1.3	2.5	2.8	2.9	3.0	3.0	4.6	2019
029	60	60.0	118.7	2.9	2.8	17.0	5.6	12.2	14.2	40.0	7.3	2004-2017	4	0.4	0.0	0.4	1.0	0.4	0.4	0.4	0.4	0.4	NA	2015
030	10	19.2	62.0	2.6	2.2	7.0	3.2	8.7	9.8	11.0	6.2	2013-2017	no data available											
031	6	56.0	115.9	0.5	1.0	12.5	0.5	0.5	0.5	0.5	NA	2017-2017												

SEG	n	AM	SD	GM	GSD	Median	P75	P90	P95	Max	P75UCL90	Years	n	AM	SD	GM	GSD	Median	P75	P90	P95	Max	P75UCL90	Years
032	6	6.8	6.4	0.5	1.0	4.5	0.5	0.5	0.5	0.5	NA	2017												
033	6	5.9	6.2	0.0	1.1	3.9	0.0	0.0	0.0	0.0	0.0	2017												
034	2	5.3	7.6	1.0	1.5	2.8	1.1	1.2	1.2	1.3	NA	2013-2017												
035	10	13.9	25.6	0.3	2.5	5.0	0.4	0.8	1.2	1.6	0.8	2013-2017												
036	13	1.0	NA	3.7	3.1	1.0	9.0	11.4	15.2	20.0	12.3	2013-2017												
037	141	2.4	2.0	2.0	4.8	2.4	7.0	16.2	21.7	110.0	7.1	2005-2019	28	3.8	13.2	0.5	6.2	0.4	1.4	4.8	9.0	70.0	2.6	2015-2022
038	32	31.0	NA	18.3	5.8	31.0	80.1	120.9	298.6	330.0	94.9	2004-2022	no data available											
039	16	74.4	159.0	18.0	4.9	17.1	28.3	232.5	442.8	541.0	90.2	2003-2022												
040	27	89.5	81.2	54.9	3.6	68.0	125.0	178.0	234.0	360.0	181.2	2012-2019	1	60.0	NA	60.0	NA	60.0	60.0	60.0	60.0	60.0	NA	2019
041	33	0.1	0.0	0.1	11.1	0.1	1.0	2.0	5.0	6.1	1.1	2016-2018	1	0.0	NA	0.0	NA	0.0	0.0	0.0	0.0	0.0	NA	2016-2016
042	36	1.6	1.0	0.1	7.1	1.9	0.2	2.3	4.2	4.2	0.5	2016-2018	23	0.0	0.1	0.0	3.7	0.0	0.0	0.1	0.1	0.2	0.1	2016-2018
043	38	0.6	1.3	0.0	4.5	0.1	0.0	0.1	0.4	0.4	0.1	2018-2018	26	0.0	0.0	0.0	2.3	0.0	0.0	0.0	0.0	0.0	0.0	2018-2018
044	4	59.2	89.6	0.0	1.1	25.5	0.1	0.1	0.1	0.1	0.1	2018-2018	no data available											
045	6	0.9	1.6	0.5	5.4	0.1	1.9	2.7	2.9	3.1	4.0	2010												
046	27	7.6	22.4	1.2	2.2	0.9	1.8	2.9	4.5	10.4	2.5	2008-2015	10	3.1	2.3	2.1	2.9	3.3	4.6	6.0	6.2	6.4	6.7	2021-2022
047	6	0.1	0.1	1.1	3.0	0.0	1.9	4.5	5.7	6.8	4.0	2005-2008												

SEG	n	AM	SD	GM	GSD	Median	P75	P90	P95	Max	P75UCL90	Years	n	AM	SD	GM	GSD	Median	P75	P90	P95	Max	P75UCL90	Years
048	4	31.1	65.8	6.6	2.2	6.0	10.4	10.4	10.4	10.4	20.0	2008-2009	8	5.2	6.2	2.4	4.5	3.0	6.9	12.5	15.4	18.3	13.4	2021-2022
049	2	8.0	4.0	1.9	2.6	9.7	3.1	3.5	3.7	3.8	15.3	2013-2014	3	32.4	33.9	7.8	21.1	29.2	48.5	60.1	63.9	67.8	839.4	2021-2022
050	8	1.9	2.5	9.3	2.4	0.6	17.0	20.9	21.3	21.7	25.7	2006-2009	no data available											
051	no data available												1	2.6	NA	2.6	NA	2.6	2.6	2.6	2.6	2.6	NA	2021-2022
052	1	0.7	0.2	0.2	NA	0.7	0.2	0.2	0.2	0.2	NA	2001-2019*												
053	8	6.7	8.2	0.5	2.9	0.6	0.9	1.6	1.7	1.8	1.5	2001-2019*	no data available											
054	9	0.6	NA	0.7	1.8	0.6	1.0	1.0	1.1	1.2	1.3	2001-2019*												
055	10	324.0	542.2	8.7	4.3	20.0	20.3	36.2	41.6	47.0	47.8	2001-2019*	15	5.0	15.8	0.8	5.1	0.9	1.7	2.7	20.7	62.0	4.2	2017-2022
056	5	5.9	12.4	39.4	2.9	2.5	110.0	110.0	110.0	110.0	279.7	2001-2019*	5	11.7	6.2	10.0	2.0	10.0	15.0	18.0	19.0	20.0	19.7	2021-2022
057	3	10.5	20.3	42.5	84.3	1.1	559.0	624.4	646.2	668.0	NA	2001-2019*	4	1.3	2.2	0.4	6.6	0.4	1.6	3.4	4.0	4.6	5.1	2020-2021
058	4	40.8	48.1	251.5	5.3	20.0	713.5	939.4	1014.7	1090.0	2486.0	2001-2019*	3	49.0	78.8	9.7	11.7	6.0	73.0	113.2	126.6	140.0	425.1	2019-2021
059	9	0.4	NA	137.7	2.6	0.4	210.0	254.8	302.4	350.0	400.3	2001-2019*	4	4.0	2.7	3.1	2.4	4.3	6.2	6.2	6.3	6.3	10.5	2021-2021
060	4	236.0	330.9	96.5	2.0	236.0	128.5	205.0	230.5	256.0	252.5	2001-2019*	7	7.1	11.5	3.6	3.0	3.3	4.3	16.0	24.5	33.0	13.0	2018-2021
061	9	1.5	1.2	0.1	1.8	1.0	0.2	0.3	0.4	0.5	0.3	2001-2019*	no data available											
062	2	1.2	0.4	37.8	1.7	1.0	47.8	52.1	53.6	55.0	120.2	2001-2019*	2	10.5	12.0	6.2	4.9	10.5	14.8	17.3	18.2	19.0	198.8	2019-2021
063	2	720.0	NA	1.7	1.8	720.0	2.2	2.4	2.5	2.6	6.2	2001-2019*	no data available											

SEG	n	AM	SD	GM	GSD	Median	P75	P90	P95	Max	P75UCL90	Years	n	AM	SD	GM	GSD	Median	P75	P90	P95	Max	P75UCL90	Years
064	no data available												1	1.0	NA	1.0	NA	1.0	1.0	1.0	1.0	1.0	NA	2021-2021
065													1	1.0	NA	1.0	NA	1.0	1.0	1.0	1.0	1.0	NA	2021-2021
066	1	1.0	0.0	340.0	NA	1.0	340.0	340.0	340.0	340.0	NA	2001-2019*	2	15.0	21.2	1.2	92.1	15.0	22.5	27.0	28.5	30.0	23709.0	2016-2021
070	3	2.2	1.2	0.2	1.9	2.0	0.3	0.3	0.3	0.3	0.5	2001-2019*	no data available											
071	19	1.0	0.0	3.9	4.4	1.0	6.7	33.0	89.8	197.9	16.6	2001-2019*	1	0.5	NA	0.5	NA	0.5	0.5	0.5	0.5	0.5	NA	2022-2022
072	87	0.5	0.0	12.6	4.2	0.5	27.5	90.4	148.4	360.0	41.3	2012-2022	22	10.4	11.7	5.8	3.2	5.7	12.4	26.4	30.2	46.9	17.6	2016-2022
073	9	176.2	93.6	55.7	1.9	195.0	90.0	94.0	102.0	110.0	111.5	2019-2021	10	7.7	6.0	5.5	2.5	5.5	10.3	17.1	17.6	18.0	15.3	2018-2021
074	no data available												1	4.3	NA	4.3	NA	4.3	4.3	4.3	4.3	4.3	NA	2018-2018
075	8	10.0	5.6	4.7	2.4	10.0	8.2	14.0	16.5	18.9	12.8	2001-2019*	no data available											
076	54	118.0	93.6	14.6	2.8	84.0	27.1	54.0	90.6	147.2	35.2	2019-2022	13	6.9	14.0	2.5	4.2	3.0	5.0	7.8	26.0	52.9	11.4	2018-2022
077	5	0.2	0.1	10.8	1.8	0.1	19.0	19.6	19.8	20.0	22.6	2019-2022	5	5.0	7.3	2.7	2.9	2.0	2.0	11.7	14.9	18.1	10.9	2018-2021
078	no data available												2	0.5	0.1	0.5	1.3	0.5	0.6	0.6	0.6	0.6	NA	2018-2018
079	5	23.8	60.2	14.7	2.4	6.0	21.2	35.2	39.8	44.5	45.5	2001-2019*	no data available											
080	41	40.5	20.5	41.3	2.8	40.5	83.0	190.0	190.0	193.0	104.1	2019-2022	23	11.0	8.0	0.0	NA	8.0	16.8	21.0	24.6	30.0	NA	2018-2021
081	16	1.8	1.0	2.1	2.9	1.8	4.4	8.4	9.2	11.0	6.3	2019-2022	12	0.2	0.2	0.2	2.0	0.2	0.3	0.4	0.5	0.6	0.4	2019-2021
083	2	1.9	0.9	0.6	1.4	1.9	0.7	0.8	0.8	0.8	1.3	2001-2019*	2	0.2	0.0	0.2	1.0	0.2	0.2	0.2	0.2	0.2	NA	2021-2021
084	12	340.0	NA	2.1	5.7	340.0	15.1	17.7	19.4	21.0	13.4	2018-2022	10	0.6	0.6	0.4	2.4	0.3	0.8	1.5	1.7	2.0	1.1	2017-2022

SEG	n	AM	SD	GM	GSD	Median	P75	P90	P95	Max	P75UCL90	Years	n	AM	SD	GM	GSD	Median	P75	P90	P95	Max	P75UCL90	Years
085	1	0.2	0.1	0.6	NA	0.2	0.6	0.6	0.6	0.6	NA	2022-2022	no data available											
086	3	50.0	38.7	33.6	22.5	62.4	485.0	764.0	857.0	950.0	4012.7	2016-2021	2	49.4	68.8	8.3	32.9	49.4	73.7	88.3	93.1	98.0	16950.9	2016-2021
088	82	18.1	47.0	2.8	3.0	2.7	4.1	12.0	19.9	100.0	7.0	2013-2022	31	1.9	4.7	0.5	3.9	0.5	0.7	2.8	9.8	22.9	1.8	2016-2021
089	24	35.4	61.4	2.1	5.7	9.5	4.0	38.5	40.0	83.0	11.0	2014-2022	9	0.7	1.1	0.2	4.1	0.2	0.3	2.3	2.8	3.2	1.4	2016-2021
090	9	5.7	8.1	7.5	12.8	3.0	86.0	110.0	110.0	110.0	131.9	2014-2022	4	20.3	22.3	12.7	3.1	12.5	24.5	41.6	47.3	53.0	61.2	2016-2022
091	1	0.3	0.3	0.4	NA	0.1	0.4	0.4	0.4	0.4	NA	2001-2019*	1	0.2	NA	0.2	NA	0.2	0.2	0.2	0.2	0.2	NA	2021-2021
092	2	3.3	3.2	30.7	47.5	1.0	353.0	423.2	446.6	470.0	NA	2016-2021	6	10.6	19.5	3.1	5.0	2.0	6.7	29.0	39.5	50.0	22.6	2016-2021
093	6	77.6	134.3	1.3	1.8	28.0	1.0	2.5	3.3	4.0	NA	2020-2022	no data available											
094	6	44.8	113.2	1.1	1.3	7.5	1.0	1.5	1.8	2.0	NA	2020-2022												
095	1	207.1	407.1	720.0	NA	91.5	720.0	720.0	720.0	720.0	NA	2022-2022	1	75.0	NA	75.0	NA	75.0	75.0	75.0	75.0	75.0	NA	2022-2022
096	3	78.4	117.6	1.0	1.0	40.8	1.0	1.0	1.0	1.0	NA	2001-2019*	no data available											
097	9	5.2	7.4	1.9	1.8	1.0	3.0	4.0	4.0	4.0	NA	2020-2022												
098	9	3.3	7.5	1.0	1.0	1.0	1.0	1.0	1.0	1.0	NA	2020-2022												
099	7	44.5	179.2	0.2	2.7	13.0	0.5	0.7	0.7	0.7	0.6	2001-2019*												
100	29	19.4	15.4	0.8	8.4	15.4	2.0	8.2	48.5	101.2	5.9	2001-2019*	20	0.2	0.6	0.0	5.6	0.0	0.0	0.2	1.6	2.5	0.1	2018-2022
101	no data available												4	5.3	9.0	0.9	13.1	1.1	5.9	13.6	16.2	18.8	30.6	2021-2021

SEG	n	AM	SD	GM	GSD	Median	P75	P90	P95	Max	P75UCL90	Years	n	AM	SD	GM	GSD	Median	P75	P90	P95	Max	P75UCL90	Years
103	1	66.0	61.8	120.0	NA	40.0	120.0	120.0	120.0	120.0	NA	2001-2019*	1	1.5	NA	1.5	NA	1.5	1.5	1.5	1.5	1.5	NA	2020-2020
104	123	6.2	5.6	27.9	6.0	5.0	105.5	282.4	469.0	1600.0	118.2	2012-2022	1	1.2	NA	1.2	NA	1.2	1.2	1.2	1.2	1.2	NA	2021
105	11	3.4	3.3	3.3	2.1	1.8	4.2	7.7	10.6	13.5	7.4	2001-2019*	no data available											
110	1	10.0	NA	10.0	NA	10.0	10.0	10.0	10.0	10.0	NA	2020												
111	no data available	3	0.2	0.0	0.2	1.1	0.2	0.2	0.2	0.2	0.2	NA												
112	3	71.3	102.8	29.9	5.0	14.0	102.0	154.8	172.4	190.0	354.6	2014-2022	no data available											
113	1	6.6	6.1	31.0	NA	4.4	31.0	31.0	31.0	31.0	NA	2001-2019*												
114	4	24.4	29.4	1.0	4.3	15.0	2.3	2.4	2.4	2.4	14.2	2001-2019*	1	0.0	NA	0.0	NA	0.0	0.0	0.0	0.0	0.0	NA	2022-2022
115	17	12.3	6.8	5.7	8.1	10.0	32.0	62.3	124.4	270.0	46.1	2001-2019*	no data available											

A 1.3 Calculation of cost of compliance

Costs of compliance were calculated based on the 59 responses to the industry questionnaire (eftec, 2023) The following four types of costs are considered:

- Costs of risk management measures (RMMs);
- Costs of substitution;
- Cost of ceasing production, and
- Costs of monitoring programmes.

The first stage of the analysis was to calculate the unit costs per site for each type as described below. Where possible, unit costs were calculated for individual broad uses as well as an average unit cost per site that takes into account the proportion of sites incurring each of the cost types above.

The second stage of the analysis was to calculate the proportion of sites that would incur each of these four costs. This was calculated based on the survey responses for each of the four analysed BOELs. This is stage is covered in the last section below.

All calculations were made on the basis of the existing market, and it is assumed that there is no market growth over the appraisal period. When presenting costs of compliance, all figures are shown in present value terms, using a 3% discount rate over the appraisal period (European Commission, 2021).

A 1.3.1 Risk management measures

For each of the BOELs, respondents were asked for the cost of compliance through implementation of risk management measures. Respondents were also asked to differentiate costs with and without PPE as part of compliance with each BOEL. Companies were asked to compare projected expenditure with their current expenditure levels, so all costs in this report are additional.

The unit cost of implementing risk management measures was calculated as the mode of the compliance costs per non-compliant site in the EU-27 as reported by respondents. This was in line with previous eftec reports and the RPA (eftec, 2020, 2019b; RPA, 2020). Respondents were asked for both the capex and opex costs of implementing RMMs. It was assumed that capex costs are incurred once every 20 years (meaning twice over the course of the 40-year appraisal period) and opex costs are incurred annually (40 times over the appraisal period). This was taken from the RPA's findings on capital lifetimes in relevant sectors (RPA, 2020).

Separate capex and opex costs were calculated costs for SMEs (less than 250 employees) and large companies (250 employees or more), based on the modal costs provided by each of these groups. The capex and opex costs used to calculate the final unit cost were an average of the SME and large company capex and opex costs, weighted by the estimated proportion of SMEs and large companies in the industry as a whole.

Respondents were included in this average regardless of whether they stated they would implement RMMs to comply with the BOEL. Only the respondents who did not provide any cost data were excluded. This means that cost estimates associated with sites that are outside of the EU-27 are also included to increase the overall sample size. It was assumed that where a respondent reported a compliance cost, this figure includes the cost of compliance at all of the non-compliant sites that company had reported.

This process was repeated for each BOEL, and for the cases in which PPE is or is not used to be used for compliance.

Average unit cost of implementing RMMs is also calculated for broad uses that have at least three separate substitution attempts reported in eftec's 2023 survey. These costs contribute only to broad use level total costs and are not used when estimating headline results. These were calculated in the same way as the aggregate costs except that due to lack of data, there was no separation between SME and large companies.

A 1.3.2 Substitution

Respondents were asked if they had previously attempted to substitute cobalt substances they use with any other substances and/or processes instead of being asked to project substitution costs in the future. Respondents were able to report multiple attempts (one for each substance for which substitution was attempted), and were asked, for each substance, the total spend on substitution in the last five years.

Spend on substitution was requested as a range and for the central estimate an arithmetic mean of the bottom and top of that range was used. For sensitivity analysis, both the bottom and top of the range were used to produce min and max spends.

No respondent reported that their substitution attempt had been completely successful, but several respondents said their attempts had been at least partially successful. The average cost of substitution per site was calculated as the average amount spent over the previous five years on attempted substitutions that were at least partially successful, weighted by the number of sites owned by companies who had attempted such substitution. Cost estimates associated with sites that are outside of the EU-27 are also included to increase the overall sample size. This resulted in an average cost of substituting a single substance at a single site. Due to limited respondent data from SMEs, no meaningful difference between in per site substitution costs was found between large companies and SMEs. The same unit costs, based on all available data, were therefore used across all sites.

As the costs reported by respondents represented the cost of a substitution attempt for a single substance, this figure was multiplied by the average number of substances used per site across all respondents, resulting in an average cost of substituting all substances at a typical site.

As respondents were not asked to indicate whether the amount that had been spent was capex or opex when annualising the unit cost of substitution, the total cost is assumed distributed equally over the previous five years (one fifth of the cost is assumed to be spent each year). This annual cost was assumed to incur for companies substituting over the first five years of the appraisal period.

Average substitution cost was calculated at a broad use level for the broad uses with at least three separate substitution attempts reported in eftec's 2023 questionnaire. These costs contribute only to broad use level total costs and are not used when estimating headline results, as these are considered less robust than the unit costs derived using all available data.

A 1.3.3 Cease production

Respondents were asked for the revenue associated with products that used an in-scope substance.

The median of the reported revenues is used to calculate the annual profit lost per site (if production ceases in the EU). This approach is preferred to avoid skewing the results due to a small number of particularly large companies in the questionnaire sample. The median annual revenue was divided by the average number of sites among respondents that provided sales data to calculate an average revenue per site that would be lost if the site ceased to operate. The same process was repeated for SMEs and large companies. The final median revenue used to calculate profit loss was an average of the two, weighted by the estimated proportion of SMEs and large companies in the industry as a whole.

This was multiplied by an assumed 10% profit margin to calculate average annual profit loss per site, in line with the approach taken in a previous study (RPA, 2020).

As the objective of this assessment is to estimate the cost to society in the EU of ceased production, it is irrelevant whether companies cease production altogether or shift production to a new or existing site outside of the EU. Although the option chosen will impact the private costs faced by the affected company, any additional costs of shifting production or commensurate increases in profit elsewhere would occur outside of the EU and is thus out of scope of this analysis. The costs associated with closing production lines (e.g., remediation and administrative costs) within the EU were not considered.

If a company, production plant or a production line has to shut down (e.g., due to a regulation) the associated assets will no longer generate value. The main assumption behind this methodology is that "*in the short run there is a fixed availability of tangible and intangible assets and in the long run incumbent or rival firms can augment assets by making investments*" (ECHA, 2021). The guidance provides a default time period over which profits lost should be estimated, which is dependent on whether suitable alternatives are generally available in general (SAGA) or not (no-SAGA). For SAGA cases, 2 years of profits is used to approximate producer surplus losses, whilst a 4-year period is recommended for no-SAGA cases. The short period of profit loss is due to redistribution of assets. After this period it is assumed that other companies expand or are established to capture equivalent lost profit. For example, assets may be redeployed by companies manufacturing alternative products and parts of the profits lost may therefore be redistributed. Where production is shifted to new or existing sites outside of the EU, only the profit lost within the EU is considered, not the private costs of relocation faced by businesses.

As explained in Chapter 5, there are no suitable alternatives for the products covered in this assessment, which means that this is a no-SAGA case. Lost profit from ceasing production in the EU was therefore assumed to continue for 4 years, with 2 years tested as a sensitivity. This is line with the latest recommended approach to estimating producer surplus loss from SEAC (ECHA, 2021).

Any avoided costs, such as reduced PPE spend due to ceased production, are already accounted for, as profit is equal to revenue less costs. It would therefore not be appropriate to subtract such "saving" as they have already been subtracted by using profit as the measure for producer surplus loss, instead of sales (revenue). This may contribute to some differences found between the findings of this report and that of (RPA, 2020).

In addition to lost profit, ceasing production involves social costs of due to jobs lost resulting from cease of production.

Average profit loss is calculated at a broad uses level only for the broad uses having at least three companies reporting revenue in eftec's 2023 questionnaire. These costs contribute only to broad use level total costs, and are not used when estimating headline results. These were calculated in the same way as the aggregate costs except that due to lack of data, there was no separation between SME and large companies.

A similar approach as used to estimate profit losses was therefore deployed in order to calculate social costs from potential EU jobs lost. The number of jobs at risk shown in **Table 12.1** shows the compliance rates across all BOELs, and the number of sites that must incur each of the cost types to comply with the BOEL. **Table 12.1** was estimated using the average number of employees per site adjusted for the number of sites which will potentially need to shut down in response to the BOEL. The relevant share of jobs at risk is assumed to be proportional to the share of profits at risk.

The jobs lost will not be equally distributed across the analytical period but will be concentrated in the short period following the announcement and introduction of the BOELs. In this analysis, it has been assumed that all the redundancies associated with ceasing of production will occur in the first year after BOELs announcement. In line with the "Guidance on Socio-Economic Analysis-Restrictions Guidance for the implementation of REACH" (ECHA, 2008), job losses are considered to be temporary as human resources are assumed to be redistributed, i.e., the workers find new jobs after a period of time. In line with the SEAC guidance, the social value of lost jobs has been estimated on the basis of an average EU gross salary after employer taxes of around €35,200, assuming that the societal value of a lost job is around 2.7 times the annual pre-displacement salary (ECHA, 2016b). The SEAC guidance approach to valuing unemployment impacts comprises several components such as the value of productivity loss during the period of unemployment and cost of job search, hiring and firing; the impact of being made unemployed on future employment and earnings; and the value of leisure time during the period of unemployment.

A 1.3.4 Monitoring programmes

Respondents were asked for the cost of implementing two types of monitoring programmes; respiratory fraction monitoring and biological monitoring programmes. For each of these programmes, respondents were asked for: (i) the actual cost of implementing monitoring programmes at sites that already had them, and (ii) the projected cost of implementing monitoring programmes at sites that do not yet have them. It was assumed that the respondents' estimates represented the past or future costs of monitoring programmes at all sites that already had/ did not have monitoring programmes implemented.

When calculating an overall average of the cost per site of implementing each monitoring programme type, actual and projected costs were given equal weight to produce a single average cost per site for each monitoring programme type.

Respondents were asked for both the capex and opex costs of monitoring programmes. Capex costs were assumed to be incurred every 20 years, while the opex costs were incurred annually over the 40-year appraisal period.

A 1.3.5 Aggregating across behavioural responses

The analysis so far described resulted in unit costs for a single site to take each of the four different actions so far described (implementing RMMs, substituting new substances or processes, ceasing production, or implementing monitoring programmes).

To calculate aggregate costs of complying with a BOEL, the unit costs per site of each cost type is multiplied by the total number of sites which incur each cost type under the different BOELs.

For each of the three costs related to behavioural responses to a BOEL that are mutually exclusive (implementing RMMs, cease production, substitution), the number of sites incurring each cost for BOEL is calculated by:

$$\begin{aligned} &No. of\ sites\ incurring\ cost\ of\ a\ response \\ &\quad = Total\ no. of\ sites \times share\ of\ all\ sites\ that\ are\ non\ compliant \\ &\quad \times share\ of\ non\ compliant\ sites\ choosing\ the\ response \end{aligned}$$

The proportion of sites that are not compliant was calculated as the total non-compliant sites reported by all companies, divided by the total number of sites for which compliance data was available. The proportion of sites choosing each response was calculated as the total non-compliant sites reported by all companies that stated they would choose that response, divided by the total number of non-compliant sites for which behavioural response data was available.

For monitoring programmes, the approach is different as all sites continuing to operate using cobalt metal and/or cobalt substances would have to monitor compliance using both respiratory fraction monitoring and biological monitoring programmes, regardless of how they choose to comply. Sites that are currently compliant and take no behavioural response to the BOEL, but do not have monitoring programmes, would also incur monitoring costs. As such, the number of sites incurring cost for monitoring is as follows:

$$\begin{aligned} &No. of\ sites\ incurring\ cost\ of\ monitoring \\ &\quad = Total\ no. of\ sites \times share\ of\ all\ sites\ without\ monitoring \\ &\quad \times share\ of\ all\ sites\ continuing\ to\ operate\ and\ use\ in\ scope\ substances \end{aligned}$$

For monitoring programmes, it is assumed that the probability that a site already has monitoring programmes in place was independent from the probability of continuing to operate and use in scope substances.

The total cost of compliance for each BOEL is the sum-product of the unit cost of each cost type, and the total number of sites incurring each cost type.

A 1.4 Benefits calculations

Benefits of a BOEL comprise the exposure and adverse health impacts avoided by implementing that BOEL that is below the exposure levels of the baseline (no BOEL). In other words, the benefits are triggered by a reduction in the number of cases associated with each health endpoint induced by the BOEL. The same approach was used to estimate health impacts and the same valuation factors are used both for the baseline (Chapter 4) and for the Policy Options.

The most critical part of estimating the benefits is, therefore, to estimate the new exposure levels after the implementation of the BOEL. Predicting these is difficult as the actual exposure reduction will depend on companies' behavioural responses, down to the level of the type of RMMs implemented. For example, one company may implement closed system throughout all their sites which may lead to exposure reductions below the BOEL (depending on the value), while another may comply with a BOEL by increasing ventilation, which will reduce exposure in the ventilated areas to a lower level but not as low as if closed systems were introduced.

Considering all possible permutations of behavioural responses and the wide variety of RMMs that can be implemented, it is next to impossible to accurately predict what the resulting exposure levels will be. In addition, the exposure data used in this analysis is from external sources which is not linked to eftec's 2023 industry questionnaire and hence not linked to the behavioural responses collated.

Given these large uncertainties, it was considered more proportionate to take a simplistic approach to estimating post-implementation exposure levels: (i) companies reduce air concentration levels below the BOEL, i.e., the levels are not adjusted for any form of PPE, (ii) all exposure levels previously above the BOEL is reduced to (just below) the BOEL, (iii) baseline PPE is still used in line with REACH Registrations, and (iv) the number of workers *potentially* exposed (albeit to lower levels under more stringent BOEL) remains the same under all BOELs. This approach was chosen to ensure that the overall approach taken is conservative, i.e., favouring higher net benefits.

Assumption (i) in combination with (iii) are the most significant and are likely to overestimate benefits. Many companies already use PPE and hence the 'actual' current exposure to the worker is already closer to the BOEL than what measured air concentrations indicate. The average APF under the baseline (representing PPE based on REACH Registrations) is around eight, meaning that an air concentration of 160 $\mu g/m^3$ adjusted for PPE would, on average, be 20 $\mu g/m^3$, which is already below the highest BOEL assessed. It is deemed unlikely that companies will stop using PPE in line with the REACH Registrations, which means that if a company reduce air concentrations below 20 $\mu g/m^3$ the 'actual' exposure to the worker will, on average, be below 3 $\mu g/m^3$ if baseline PPE is still being used. Considering this, all companies may not reduce air concentration below the BOEL, but rather ensure that 'actual' exposure (i.e., PPE adjusted) to the worker is below the BOEL. Assumption (i) in combination with (iii) will therefore likely overestimate the exposure reductions following implementation of a BOEL, which thereby leads to overestimated benefits.

Assumption (ii) is likely to underestimate benefits, at least for the higher BOELs. For example, some RMMs may reduce exposure across the whole site, not just in the high-exposure areas, and the resulting exposure may in some cases be significant benefits for some BOELs. Furthermore, some companies may substitute or cease production, which will remove all exposure to the associated workers.

Assumption (iii) is likely to underestimate benefits, as some companies will cease the use of cobalt (e.g., through substitution or relocation) and their workers will no longer be exposed. Additionally, some RMMs (e.g., automating processes) may also reduce the number of workers exposed.

As can be seen in Section 12.5, the first assumption is by far the largest driver behind the exposure reduction and risk reduction, meaning that it is more likely that the exposure reductions are overestimated rather than underestimated.

The number of cases associated with each health endpoint after the implementation of a BOEL was calculated in the same way as for the baseline (no BOEL), described in Chapter 4. Benefits of the BOEL is then represented by the difference, i.e., reduction in the number of cases between the baseline and the policy scenario (with a BOEL). The reduction in cases was monetised using the same valuation factors presented in Chapter 4, to arrive at the benefits of each BOEL.

Appendix 2 Stakeholder Engagement

A 2.1 Introduction

This section outlines respondent data from a company level Microsoft Excel-based questionnaire that was live between October 2022 and January 2023, and includes information on:

- Number of companies and sites;
- Employment, including percentage potentially exposed and broken down by male and female;
- Volumes manufactured/used and recycled;
- Existing compliance with the BOELs; and
- Feasibility of compliance with the BOELs.

Data is presented for sites that are located in the EU-27 and is organised by broad use. To maintain confidentiality, only data from broad uses where 3 or more responses were received is presented. For broad uses where less than 3 companies responded to the questionnaire, "Insufficient respondent data" is used to describe results as they cannot be presented as they are not aggregated or anonymised. For broad uses where no companies responded to the questionnaire, "No respondent data" is used.

A 2.2 Respondent data results

A 2.2.1 Companies and sites

Appendix Table 6 provides an overview of the total number of companies that responded to the questionnaire and the share of companies that are SMEs.

Appendix Table 6 : Number of companies and sites and percent of which are SMEs

Broad use	Total number of companies	Total number of sites in the EU-27	Share of companies that are SMEs
Manufacture of cobalt and/or cobalt substances	15	27	13%
Recycling of materials containing cobalt substances	7	9	14%
Manufacture of other chemicals	5	8	60%
Manufacture of precursor chemicals for batteries	Insufficient respondent data	Insufficient respondent data	Insufficient respondent data
Manufacture of catalysts	3	3	0%
Manufacture of pigments and dyes	6	11	17%
Manufacture of driers / paints	No respondent data	No respondent data	No respondent data
Use as catalysts - used as a catalyst or catalyst precursor	3	3	0%

Broad use	Total number of companies	Total number of sites in the EU-27	Share of companies that are SMEs
Use as catalysts - used as oxidation catalyst/for PTA and IPA	No respondent data	No respondent data	No respondent data
Use in surface treatment - Formulation of surface treatment	4	6	75%
Use in surface treatment - Passivation or anti-corrosion treatment processes	5	9	60%
Use in surface treatment - Metal or metal alloy plating	5	14	60%
Use in biotechnology – Formulation and industrial use of mixtures in biogas production	No respondent data	No respondent data	No respondent data
Use in biotechnology – Professional use in biogas production	No respondent data	No respondent data	No respondent data
Use in biotechnology – Use in fermentation, fertilizers, biotech, scientific research and standard analysis	No respondent data	No respondent data	No respondent data
Use in biotechnology – Formulation and use in animal feed grade materials	4	4	100%
Bespoke uses – Use in humidity indicators cards, plugs and/or bags with printed spots	Insufficient respondent data	Insufficient respondent data	Insufficient respondent data
Bespoke uses – Formulation of water treatment chemicals, oxygen scavengers, corrosion inhibitors	Insufficient respondent data	Insufficient respondent data	Insufficient respondent data
Bespoke uses – Use of water treatment chemicals, oxygen scavengers, corrosion inhibitors	No respondent data	No respondent data	No respondent data
Adhesion (inc. rubber adhesion agent)	5	22	0%
Use in electronics	No respondent data	No respondent data	No respondent data
Use in magnetic alloys	Insufficient respondent data	Insufficient respondent data	Insufficient respondent data
Use in metallurgical alloys	12	28	33%
Use in cemented carbide/diamond tools	17	36	47%

Table notes:

- The number of sites only relates to sites relevant to the use of cobalt metal and/or cobalt substances or supporting business. The results indicated that companies typically have more than 1 site in the EU-27 relevant to the use of cobalt metal and/or cobalt substances.
- For companies that perform more than one broad use, all sites were assumed to perform all broad uses indicated by the company. Therefore, the number of sites should not be summed across broad uses to avoid over estimation.

A 2.2.2 Employment

Respondents were asked the number of employees, both male and female, at their sites and the share of employees potentially exposed to cobalt substances. **Appendix Table 7** presents employment data at companies in the EU-27 and the percentage potentially exposed to cobalt substances.

Appendix Table 7 : Numbers of employees (total and potentially exposed to cobalt)

Broad use	Number of FTE workers employed		Number of FTE workers potentially exposed		% potentially exposed relative to total employment
	Male	*Female*	*Male*	*Female*	
Manufacture of cobalt and/or cobalt substances	23,620	4,380	2,240	260	9%
Recycling of materials containing cobalt substances	4,030	800	900	110	21%
Manufacture of other chemicals	390	120	200	10	42%
Manufacture of precursor chemicals for batteries	Insufficient respondent data	Insufficient respondent data	Insufficient respondent data	Insufficient respondent data	Insufficient respondent data
Manufacture of catalysts	800	130	140	20	17%
Manufacture of pigments and dyes	2,350	670	720	110	28%
Manufacture of driers / paints	No respondent data	No respondent data	No respondent data	No respondent data	No respondent data
Use as catalysts - used as a catalyst or catalyst precursor	800	130	140	20	17%
Use as catalysts - used as oxidation catalyst/for PTA and IPA	No respondent data	No respondent data	No respondent data	No respondent data	No respondent data
Use in surface treatment - Formulation of surface treatment	1,210	330	140	10	9%
Use in surface treatment - Passivation or anti-corrosion treatment processes	9,110	3,730	300	50	3%
Use in surface treatment - Metal or metal alloy plating	3,700	890	1,340	190	33%
Use in biotechnology – Formulation and industrial use of mixtures in biogas production	No respondent data	No respondent data	No respondent data	No respondent data	No respondent data

Broad use	Number of FTE workers employed		Number of FTE workers potentially exposed		% potentially exposed relative to total employment
	Male	*Female*	*Male*	*Female*	
Use in biotechnology – Professional use in biogas production	No respondent data	No respondent data	No respondent data	No respondent data	No respondent data
Use in biotechnology – Use in fermentation, fertilizers, biotech, scientific research and standard analysis	No respondent data	No respondent data	No respondent data	No respondent data	No respondent data
Use in biotechnology – Formulation and use in animal feed grade materials	160	90	70	0	28%
Bespoke uses – Use in humidity indicators cards, plugs and/or bags with printed spots	Insufficient respondent data	Insufficient respondent data	Insufficient respondent data	Insufficient respondent data	Insufficient respondent data
Bespoke uses – Formulation of water treatment chemicals, oxygen scavengers, corrosion inhibitors	Insufficient respondent data	Insufficient respondent data	Insufficient respondent data	Insufficient respondent data	Insufficient respondent data
Bespoke uses – Use of water treatment chemicals, oxygen scavengers, corrosion inhibitors	No respondent data	No respondent data	No respondent data	No respondent data	No respondent data
Adhesion (inc. rubber adhesion agent)	36,010	4,740	6,730	520	18%
Use in electronics	No respondent data	No respondent data	No respondent data	No respondent data	No respondent data
Use in magnetic alloys	Insufficient respondent data	Insufficient respondent data	Insufficient respondent data	Insufficient respondent data	Insufficient respondent data
Use in metallurgical alloys	7,430	2,240	2,290	580	30%
Use in cemented carbide/diamond tools	8,400	2,440	3,430	670	38%

Tables notes:

- Potentially exposed refers to employees who work in and/or visit the production site where cobalt substances are present (e.g., staff working in buildings far away from the production process may not be exposed to cobalt in the same way as those workers involved in the production process).
- Figures are rounded to the nearest 10 FTE.

A 2.2.3 Volumes

Appendix Table 8 presents respondent annual volume data. Respondent data was collected on the annual volumes of cobalt substances manufactured / used during the last 3 years and projected volumes for substances that will be manufactured / used over the next 5 years. The results are presented by consortium.

Appendix Table 8 : Volumes manufactured / used, tonnes per year

Broad use	Blue Consortium	Red Consortium	Green Consortium	IPC	Other
Manufacture of cobalt and/or cobalt substances	6,600	55,200	6,600	750	9,350
Recycling of materials containing cobalt substances	21,400	10,150	0	0	0
Manufacture of other chemicals	0	30	30	20	0
Manufacture of precursor chemicals for batteries	Insufficient respondent data	Insufficient respondent data	Insufficient respondent data	Insufficient respondent data	Insufficient respondent data
Manufacture of catalysts	180	610	0	0	0
Manufacture of pigments and dyes	0	540	0	690	0
Manufacture of driers / paints	No respondent data	No respondent data	No respondent data	No respondent data	No respondent data
Use as catalysts - used as a catalyst or catalyst precursor	0	170	0	0	0
Use as catalysts - used as oxidation catalyst/for PTA and IPA	No respondent data	No respondent data	No respondent data	No respondent data	No respondent data
Use in surface treatment - Formulation of surface treatment	40	20	0	0	0
Use in surface treatment - Passivation or anti-corrosion treatment processes	110	0	0	0	0
Use in surface treatment - Metal or metal alloy plating	0	<10	0	0	0
Use in biotechnology – Formulation and industrial use of mixtures in biogas production	No respondent data	No respondent data	No respondent data	No respondent data	No respondent data
Use in biotechnology – Professional use in biogas production	No respondent data	No respondent data	No respondent data	No respondent data	No respondent data
Use in biotechnology – Use in fermentation, fertilizers, biotech, scientific research and standard analysis	No respondent data	No respondent data	No respondent data	No respondent data	No respondent data

Broad use	Blue Consortium	Red Consortium	Green Consortium	IPC	Other
Use in biotechnology – Formulation and use in animal feed grade materials	0	20	0	0	0
Bespoke uses – Use in humidity indicators cards, plugs and/or bags with printed spots	Insufficient respondent data	Insufficient respondent data	Insufficient respondent data	Insufficient respondent data	Insufficient respondent data
Bespoke uses – Formulation of water treatment chemicals, oxygen scavengers, corrosion inhibitors	Insufficient respondent data	Insufficient respondent data	Insufficient respondent data	Insufficient respondent data	Insufficient respondent data
Bespoke uses – Use of water treatment chemicals, oxygen scavengers, corrosion inhibitors	No respondent data	No respondent data	No respondent data	No respondent data	No respondent data
Adhesion (inc. rubber adhesion agent)	0	0	2,810	0	0
Use in electronics	No respondent data	No respondent data	No respondent data	No respondent data	No respondent data
Use in magnetic alloys	Insufficient respondent data	Insufficient respondent data	Insufficient respondent data	Insufficient respondent data	Insufficient respondent data
Use in metallurgical alloys	1,550	0	0	0	0
Use in cemented carbide/diamond tools	2,080	300	0	0	0

Tables note: Figures are rounded to the nearest 10 tonnes.

A 2.2.4 *Existing compliance*

Appendix Table 9 presents the share of sites that comply with each of the BOEL values in each of the broad uses, based on the number of sites complying reported by respondents to the industry questionnaire. A traffic light system has been used to colour code the level of compliance to each BOEL. As would be expected, **Appendix Table 9** shows higher levels of compliance with a BOEL of 30 μg/m^3, which steadily decreases between 30 μg/m^3 and 10 μg/m^3, and sharply decreases at a BOEL of 1 μg/m^3.

Appendix Table 9 : Share of sites that comply with each BOEL

Broad use	% sites that comply with each BOEL				% of sites directly in scope (based on questionnaire data)
	30 μg/m^3	20 μg/m^3	10 μg/m^3	1 μg/m^3	
Manufacture of cobalt and/or cobalt substances	87%	73%	62%	3%	89%

Broad use	% sites that comply with each BOEL				% of sites directly in scope (based on questionnaire data)
	30 µg/m³	20 µg/m³	10 µg/m³	1 µg/m³	
Manufacture of other chemicals	Insufficient respondent data	Insufficient respondent data	Insufficient respondent data	Insufficient respondent data	88%
Manufacture of precursor chemicals for batteries	Insufficient respondent data	Insufficient respondent data	Insufficient respondent data	Insufficient respondent data	100%
Manufacture of catalysts	100%	100%	50%	0%	100%
Manufacture of pigments and dyes	82%	64%	36%	9%	91%
Manufacture of driers / paints	No respondent data	No respondent data	No respondent data	No respondent data	No respondent data
Use as catalysts - used as a catalyst or catalyst precursor	100%	75%	50%	0%	100%
Use as catalysts - used as oxidation catalyst/for PTA and IPA	No respondent data	No respondent data	No respondent data	No respondent data	No respondent data
Use in surface treatment - Formulation of surface treatment	100%	100%	33%	33%	100%
Use in surface treatment - Passivation or anti-corrosion treatment processes	100%	100%	56%	56%	100%
Use in surface treatment - Metal or metal alloy plating	53%	40%	29%	13%	100%
Use in biotechnology – Formulation and industrial use of mixtures in biogas production	No respondent data	No respondent data	No respondent data	No respondent data	No respondent data
Use in biotechnology – Professional use in biogas production	No respondent data	No respondent data	No respondent data	No respondent data	No respondent data

Broad use	% sites that comply with each BOEL				% of sites directly in scope (based on questionnaire data)
	30 µg/m³	20 µg/m³	10 µg/m³	1 µg/m³	
Use in biotechnology – Use in fermentation, fertilizers, biotech, scientific research and standard analysis	No respondent data	No respondent data	No respondent data	No respondent data	No respondent data
Use in biotechnology – Formulation and use in animal feed grade materials	100%	100%	100%	67%	100%
Bespoke uses – Use in humidity indicators cards, plugs and/or bags with printed spots	Insufficient respondent data	Insufficient respondent data	Insufficient respondent data	Insufficient respondent data	100%
Bespoke uses – Formulation of water treatment chemicals, oxygen scavengers, corrosion inhibitors	Insufficient respondent data	Insufficient respondent data	Insufficient respondent data	Insufficient respondent data	100%
Bespoke uses – Use of water treatment chemicals, oxygen scavengers, corrosion inhibitors	No respondent data	No respondent data	No respondent data	No respondent data	No respondent data
Adhesion (inc. rubber adhesion agent)	100%	100%	100%	62%	27%
Use in electronics	No respondent data	No respondent data	No respondent data	No respondent data	100%
Use in magnetic alloys	Insufficient respondent data	Insufficient respondent data	Insufficient respondent data	Insufficient respondent data	100%
Use in metallurgical alloys	85%	76%	53%	3%	100%
Use in cemented carbide/diamond tools	71%	63%	50%	2%	100%
Recycling of materials containing cobalt substances	84%	68%	64%	0%	100%
Total (without overlap)	**84%**	**78%**	**64%**	**27%**	**89%**

Table notes:

- The broad uses highlighted in grey report information from fewer than three respondents to the industry questionnaire and therefore may not be representative of the broad use as a whole.
- The total share of sites that comply with each BOEL has been estimated using respondent data across the broad uses and is

therefore weighted according to the number of sites. The total cannot be estimated by averaging the shares in each broad use.

- The share of sites complying have been colour coded based on: ≥ 70% sites complying is green; 30% to 69% sites complying is yellow; < 30% sites complying is red.

A 2.2.5 Feasibility of compliance

Feasibility of complying with 30 µg/m³ BOEL

Appendix Table 10 presents the share of respondents' sites that do not comply with a BOEL of 30 µg/m³ by their potential technical and/or economic feasibility for compliance. This provides a more detailed breakdown than is provided in the policy option sections. As mentioned previously, the results provided per broad use should be interpreted with caution as each broad use is based on fewer responses.

Appendix Table 10 : Share of non-complying sites where it is and is not technically and economically feasible to comply with 30 µg/m³ BOEL

Broad uses	Technical feasibility			Economic feasibility		
	% of sites technically feasible to comply	% of sites not technically feasible to comply	% of sites technical feasibility unknown	% of sites economically feasible to comply	% of sites not economically feasible to comply	% of sites economic feasibility unknown
Manufacture of cobalt and/or cobalt substances	100%	0%	0%	75%	25%	0%
Manufacture of other chemicals	No respondent data with non-complying sites	No respondent data with non-complying sites	No respondent data with non-complying sites	No respondent data with non-complying sites	No respondent data with non-complying sites	No respondent data with non-complying sites
Manufacture of precursor chemicals for batteries	Insufficient respondent data	Insufficient respondent data	Insufficient respondent data	Insufficient respondent data	Insufficient respondent data	Insufficient respondent data
Manufacture of catalysts	No respondent data with non-complying sites	No respondent data with non-complying sites	No respondent data with non-complying sites	No respondent data with non-complying sites	No respondent data with non-complying sites	No respondent data with non-complying sites
Manufacture of pigments and dyes	Insufficient respondent data	Insufficient respondent data	Insufficient respondent data	Insufficient respondent data	Insufficient respondent data	Insufficient respondent data
Manufacture of driers / paints	No respondent data	No respondent data	No respondent data	No respondent data	No respondent data	No respondent data

Broad uses	Technical feasibility			Economic feasibility		
	% of sites technically feasible to comply	% of sites not technically feasible to comply	% of sites technical feasibility unknown	% of sites economically feasible to comply	% of sites not economically feasible to comply	% of sites economic feasibility unknown
Use as catalysts - used as a catalyst or catalyst precursor	No respondent data with non-complying sites	No respondent data with non-complying sites	No respondent data with non-complying sites	No respondent data with non-complying sites	No respondent data with non-complying sites	No respondent data with non-complying sites
Use as catalysts - used as oxidation catalyst/for PTA and IPA	No respondent data	No respondent data	No respondent data	No respondent data	No respondent data	No respondent data
Use in surface treatment - Formulation of surface treatment	No respondent data with non-complying sites	No respondent data with non-complying sites	No respondent data with non-complying sites	No respondent data with non-complying sites	No respondent data with non-complying sites	No respondent data with non-complying sites
Use in surface treatment - Passivation or anti-corrosion treatment processes	No respondent data with non-complying sites	No respondent data with non-complying sites	No respondent data with non-complying sites	No respondent data with non-complying sites	No respondent data with non-complying sites	No respondent data with non-complying sites
Use in surface treatment - Metal or metal alloy plating	Insufficient respondent data	Insufficient respondent data	Insufficient respondent data	Insufficient respondent data	Insufficient respondent data	Insufficient respondent data
Use in biotechnology – Formulation and industrial use of mixtures in biogas production	No respondent data	No respondent data	No respondent data	No respondent data	No respondent data	No respondent data
Use in biotechnology – Professional use in biogas production	No respondent data	No respondent data	No respondent data	No respondent data	No respondent data	No respondent data
Use in biotechnology – Use in fermentation, fertilizers, biotech, scientific research	No respondent data	No respondent data	No respondent data	No respondent data	No respondent data	No respondent data

Broad uses	Technical feasibility			Economic feasibility		
	% of sites technically feasible to comply	**% of sites not technically feasible to comply**	**% of sites technical feasibility unknown**	**% of sites economically feasible to comply**	**% of sites not economically feasible to comply**	**% of sites economic feasibility unknown**
and standard analysis						
Use in biotechnology – Formulation and use in animal feed grade materials	No respondent data with non-complying sites	No respondent data with non-complying sites	No respondent data with non-complying sites	No respondent data with non-complying sites	No respondent data with non-complying sites	No respondent data with non-complying sites
Bespoke uses – Use in humidity indicators cards, plugs and/or bags with printed spots	No respondent data with non-complying sites	No respondent data with non-complying sites	No respondent data with non-complying sites	No respondent data with non-complying sites	No respondent data with non-complying sites	No respondent data with non-complying sites
Bespoke uses – Formulation of water treatment chemicals, oxygen scavengers, corrosion inhibitors	Insufficient respondent data	Insufficient respondent data	Insufficient respondent data	Insufficient respondent data	Insufficient respondent data	Insufficient respondent data
Bespoke uses – Use of water treatment chemicals, oxygen scavengers, corrosion inhibitors	No respondent data	No respondent data	No respondent data	No respondent data	No respondent data	No respondent data
Adhesion (inc. rubber adhesion agent)	No respondent data with non-complying sites	No respondent data with non-complying sites	No respondent data with non-complying sites	No respondent data with non-complying sites	No respondent data with non-complying sites	No respondent data with non-complying sites
Use in electronics	No respondent data	No respondent data	No respondent data	No respondent data	No respondent data	No respondent data
Use in magnetic alloys	No respondent data with non-complying sites	No respondent data with non-complying sites	No respondent data with non-complying sites	No respondent data with non-complying sites	No respondent data with non-complying sites	No respondent data with non-complying sites

Broad uses	Technical feasibility			Economic feasibility		
	% of sites technically feasible to comply	% of sites not technically feasible to comply	% of sites technical feasibility unknown	% of sites economically feasible to comply	% of sites not economically feasible to comply	% of sites economic feasibility unknown
Use in metallurgical alloys	59%	41%	0%	59%	21%	21%
Use in cemented carbide/diamond tools	92%	8%	0%	83%	0%	17%
Recycling of materials containing cobalt substances	Insufficient respondent data	Insufficient respondent data	Insufficient respondent data	Insufficient respondent data	Insufficient respondent data	Insufficient respondent data
Total (no overlap)	**75%**	**25%**	**0%**	**63%**	**25%**	**13%**

Table notes:

- Share of sites is based on the number of sites currently not-complying with a 30 µg/m^3 BOEL in the EU-27.
- Total share of sites has been estimated using the number of non-complying sites reported by questionnaire respondents regardless of broad use and therefore cannot be estimated by averaging the shares in each of the broad uses.

Feasibility of complying with 20 µg/m^3 BOEL

Appendix Table 11 presents the share of respondents' sites that do not comply with a BOEL of 20 µg/m^3 by their potential technical and/or economic feasibility for compliance. This provides a more detailed breakdown than is provided in the policy option sections.

Appendix Table 11 : Share of non-complying sites where it is and is not technically and economically feasible to comply with 20 µg/m^3 BOEL

Broad uses	Technical feasibility			Economic feasibility		
	% of sites technically feasible to comply	% of sites not technically feasible to comply	% of sites technical feasibility unknown	% of sites economically feasible to comply	% of sites not economically feasible to comply	% of sites economic feasibility unknown
Manufacture of cobalt and/or cobalt substances	87%	13%	0%	73%	27%	0%
Manufacture of other chemicals	No respondent data with non-complying sites	No respondent data with non-complying sites	No respondent data with non-complying sites	No respondent data with non-complying sites	No respondent data with non-complying sites	No respondent data with non-complying sites

Broad uses	Technical feasibility			Economic feasibility		
	% of sites technically feasible to comply	% of sites not technically feasible to comply	% of sites technical feasibility unknown	% of sites economically feasible to comply	% of sites not economically feasible to comply	% of sites economic feasibility unknown
Manufacture of precursor chemicals for batteries	Insufficient respondent data	Insufficient respondent data	Insufficient respondent data	Insufficient respondent data	Insufficient respondent data	Insufficient respondent data
Manufacture of catalysts	Insufficient respondent data	Insufficient respondent data	Insufficient respondent data	Insufficient respondent data	Insufficient respondent data	Insufficient respondent data
Manufacture of pigments and dyes	Insufficient respondent data	Insufficient respondent data	Insufficient respondent data	Insufficient respondent data	Insufficient respondent data	Insufficient respondent data
Manufacture of driers / paints	No respondent data	No respondent data	No respondent data	No respondent data	No respondent data	No respondent data
Use as catalysts - used as a catalyst or catalyst precursor	Insufficient respondent data	Insufficient respondent data	Insufficient respondent data	Insufficient respondent data	Insufficient respondent data	Insufficient respondent data
Use as catalysts - used as oxidation catalyst/for PTA and IPA	No respondent data	No respondent data	No respondent data	No respondent data	No respondent data	No respondent data
Use in surface treatment - Formulation of surface treatment	No respondent data with non-complying sites	No respondent data with non-complying sites	No respondent data with non-complying sites	No respondent data with non-complying sites	No respondent data with non-complying sites	No respondent data with non-complying sites
Use in surface treatment - Passivation or anti-corrosion treatment processes	No respondent data with non-complying sites	No respondent data with non-complying sites	No respondent data with non-complying sites	No respondent data with non-complying sites	No respondent data with non-complying sites	No respondent data with non-complying sites
Use in surface treatment - Metal or metal alloy plating	Insufficient respondent data	Insufficient respondent data	Insufficient respondent data	Insufficient respondent data	Insufficient respondent data	Insufficient respondent data
Use in biotechnology – Formulation and industrial use of mixtures in biogas production	No respondent data	No respondent data	No respondent data	No respondent data	No respondent data	No respondent data

Broad uses	Technical feasibility			Economic feasibility		
	% of sites technically feasible to comply	**% of sites not technically feasible to comply**	**% of sites technical feasibility unknown**	**% of sites economically feasible to comply**	**% of sites not economically feasible to comply**	**% of sites economic feasibility unknown**
Use in biotechnology – Professional use in biogas production	No respondent data	No respondent data	No respondent data	No respondent data	No respondent data	No respondent data
Use in biotechnology – Use in fermentation, fertilizers, biotech, scientific research and standard analysis	No respondent data	No respondent data	No respondent data	No respondent data	No respondent data	No respondent data
Use in biotechnology – Formulation and use in animal feed grade materials	No respondent data with non-complying sites	No respondent data with non-complying sites	No respondent data with non-complying sites	No respondent data with non-complying sites	No respondent data with non-complying sites	No respondent data with non-complying sites
Bespoke uses – Use in humidity indicators cards, plugs and/or bags with printed spots	No respondent data with non-complying sites	No respondent data with non-complying sites	No respondent data with non-complying sites	No respondent data with non-complying sites	No respondent data with non-complying sites	No respondent data with non-complying sites
Bespoke uses – Formulation of water treatment chemicals, oxygen scavengers, corrosion inhibitors	Insufficient respondent data	Insufficient respondent data	Insufficient respondent data	Insufficient respondent data	Insufficient respondent data	Insufficient respondent data
Bespoke uses – Use of water treatment chemicals, oxygen scavengers, corrosion inhibitors	No respondent data	No respondent data	No respondent data	No respondent data	No respondent data	No respondent data
Adhesion (inc. rubber adhesion agent)	No respondent data with non-complying sites	No respondent data with non-complying sites	No respondent data with non-complying sites	No respondent data with non-complying sites	No respondent data with non-complying sites	No respondent data with non-complying sites

Broad uses	Technical feasibility			Economic feasibility		
	% of sites technically feasible to comply	**% of sites not technically feasible to comply**	**% of sites technical feasibility unknown**	**% of sites economically feasible to comply**	**% of sites not economically feasible to comply**	**% of sites economic feasibility unknown**
Use in electronics	No respondent data	No respondent data	No respondent data	No respondent data	No respondent data	No respondent data
Use in magnetic alloys	Insufficient respondent data	Insufficient respondent data	Insufficient respondent data	Insufficient respondent data	Insufficient respondent data	Insufficient respondent data
Use in metallurgical alloys	62%	38%	0%	51%	36%	13%
Use in cemented carbide/diamond tools	53%	47%	0%	34%	53%	13%
Recycling of materials containing cobalt substances	75%	13%	13%	51%	36%	13%
Total	**44%**	**51%**	**5%**	**30%**	**56%**	**14%**

Table notes:

- Share of sites is based on the total number of sites currently not-complying with a 20 µg/m^3 BOEL in the EU-27.
- Total share of sites has been estimated using the number of non-complying sites reported by questionnaire respondents regardless of broad use and therefore cannot be estimated by averaging the shares in each of the broad uses.

Feasibility of complying with 10 µg/m^3 BOEL

Appendix Table 12 presents the share of respondents' sites that do not comply with a BOEL of 10 µg/m3 by their potential technical and/or economic feasibility for compliance. This provides a more detailed breakdown than is provided in the policy option sections.

Appendix Table 12 : Share of non-complying sites where it is and is not technically and economically feasible to comply with 10 µg/m^3 BOEL

Broad uses	Technical feasibility			Economic feasibility		
	% of sites technically feasible to comply	**% of sites not technically feasible to comply**	**% of sites technical feasibility unknown**	**% of sites economically feasible to comply**	**% of sites not economically feasible to comply**	**% of sites economic feasibility unknown**
Manufacture of cobalt and/or cobalt substances	30%	20%	50%	0%	20%	80%

Broad uses	Technical feasibility			Economic feasibility		
	% of sites technically feasible to comply	% of sites not technically feasible to comply	% of sites technical feasibility unknown	% of sites economically feasible to comply	% of sites not economically feasible to comply	% of sites economic feasibility unknown
Manufacture of other chemicals	Insufficient respondent data	Insufficient respondent data	Insufficient respondent data	Insufficient respondent data	Insufficient respondent data	Insufficient respondent data
Manufacture of precursor chemicals for batteries	Insufficient respondent data	Insufficient respondent data	Insufficient respondent data	Insufficient respondent data	Insufficient respondent data	Insufficient respondent data
Manufacture of catalysts	Insufficient respondent data	Insufficient respondent data	Insufficient respondent data	Insufficient respondent data	Insufficient respondent data	Insufficient respondent data
Manufacture of pigments and dyes	29%	0%	71%	0%	14%	86%
Manufacture of driers / paints	No respondent data	No respondent data	No respondent data	No respondent data	No respondent data	No respondent data
Use as catalysts - used as a catalyst or catalyst precursor	Insufficient respondent data	Insufficient respondent data	Insufficient respondent data	Insufficient respondent data	Insufficient respondent data	Insufficient respondent data
Use as catalysts - used as oxidation catalyst/for PTA and IPA	No respondent data	No respondent data	No respondent data	No respondent data	No respondent data	No respondent data
Use in surface treatment - Formulation of surface treatment	Insufficient respondent data	Insufficient respondent data	Insufficient respondent data	Insufficient respondent data	Insufficient respondent data	Insufficient respondent data
Use in surface treatment - Passivation or anti-corrosion treatment processes	Insufficient respondent data	Insufficient respondent data	Insufficient respondent data	Insufficient respondent data	Insufficient respondent data	Insufficient respondent data
Use in surface treatment - Metal or metal alloy plating	Insufficient respondent data	Insufficient respondent data	Insufficient respondent data	Insufficient respondent data	Insufficient respondent data	Insufficient respondent data
Use in biotechnology – Formulation and industrial use of mixtures in biogas production	No respondent data	No respondent data	No respondent data	No respondent data	No respondent data	No respondent data

Broad uses	Technical feasibility			Economic feasibility		
	% of sites technically feasible to comply	% of sites not technically feasible to comply	% of sites technical feasibility unknown	% of sites economically feasible to comply	% of sites not economically feasible to comply	% of sites economic feasibility unknown
Use in biotechnology – Professional use in biogas production	No respondent data	No respondent data	No respondent data	No respondent data	No respondent data	No respondent data
Use in biotechnology – Use in fermentation, fertilizers, biotech, scientific research and standard analysis	No respondent data	No respondent data	No respondent data	No respondent data	No respondent data	No respondent data
Use in biotechnology – Formulation and use in animal feed grade materials	No respondent data with non-complying sites	No respondent data with non-complying sites	No respondent data with non-complying sites	No respondent data with non-complying sites	No respondent data with non-complying sites	No respondent data with non-complying sites
Bespoke uses – Use in humidity indicators cards, plugs and/or bags with printed spots	No respondent data with non-complying sites	No respondent data with non-complying sites	No respondent data with non-complying sites	No respondent data with non-complying sites	No respondent data with non-complying sites	No respondent data with non-complying sites
Bespoke uses – Formulation of water treatment chemicals, oxygen scavengers, corrosion inhibitors	Insufficient respondent data	Insufficient respondent data	Insufficient respondent data	Insufficient respondent data	Insufficient respondent data	Insufficient respondent data
Bespoke uses – Use of water treatment chemicals, oxygen scavengers, corrosion inhibitors	No respondent data	No respondent data	No respondent data	No respondent data	No respondent data	No respondent data
Adhesion (inc. rubber adhesion agent)	No respondent data with non-complying sites	No respondent data with non-complying sites	No respondent data with non-complying sites	No respondent data with non-complying sites	No respondent data with non-complying sites	No respondent data with non-complying sites

Broad uses	Technical feasibility			Economic feasibility		
	% of sites technically feasible to comply	**% of sites not technically feasible to comply**	**% of sites technical feasibility unknown**	**% of sites economically feasible to comply**	**% of sites not economically feasible to comply**	**% of sites economic feasibility unknown**
Use in electronics	No respondent data	No respondent data	No respondent data	No respondent data	No respondent data	No respondent data
Use in magnetic alloys	Insufficient respondent data	Insufficient respondent data	Insufficient respondent data	Insufficient respondent data	Insufficient respondent data	Insufficient respondent data
Use in metallurgical alloys	46%	20%	34%	20%	39%	40%
Use in cemented carbide/diamond tools	24%	45%	30%	15%	50%	35%
Recycling of materials containing cobalt substances	21%	11%	68%	0%	32%	68%
Total (no overlap)	**35%**	**41%**	**24%**	**12%**	**53%**	**35%**

Table notes:

- Share of sites is based on the total number of sites currently not-complying with a 10 µg/m³ BOEL in the EU-27.
- Total share of sites has been estimated using the number of non-complying sites reported by questionnaire respondents regardless of broad use and therefore cannot be estimated by averaging the shares in each of the broad uses.

Feasibility of complying with 1 µg/m³ BOEL

Appendix Table 13 presents the share of respondents' sites that do not comply with a BOEL of 1 µg/m³ by their potential technical and/or economic feasibility for compliance. This provides a more detailed breakdown than is provided in the policy option sections.

Appendix Table 13 : Share of non-complying sites where it is and is not technically and economically feasible to comply with 1 µg/m³ BOEL

Broad uses	Technical feasibility			Economic feasibility		
	% of sites technically feasible to comply	**% of sites not technically feasible to comply**	**% of sites technical feasibility unknown**	**% of sites economically feasible to comply**	**% of sites not economically feasible to comply**	**% of sites economic feasibility unknown**
Manufacture of cobalt and/or cobalt substances	4%	93%	4%	0%	39%	61%

Broad uses	Technical feasibility			Economic feasibility		
	% of sites technically feasible to comply	**% of sites not technically feasible to comply**	**% of sites technical feasibility unknown**	**% of sites economically feasible to comply**	**% of sites not economically feasible to comply**	**% of sites economic feasibility unknown**
Manufacture of other chemicals	Insufficient respondent data	Insufficient respondent data	Insufficient respondent data	Insufficient respondent data	Insufficient respondent data	Insufficient respondent data
Manufacture of precursor chemicals for batteries	Insufficient respondent data	Insufficient respondent data	Insufficient respondent data	Insufficient respondent data	Insufficient respondent data	Insufficient respondent data
Manufacture of catalysts	33%	33%	33%	0%	33%	67%
Manufacture of pigments and dyes	0%	100%	0%	0%	90%	10%
Manufacture of driers / paints	No respondent data	No respondent data	No respondent data	No respondent data	No respondent data	No respondent data
Use as catalysts - used as a catalyst or catalyst precursor	33%	33%	33%	0%	33%	67%
Use as catalysts - used as oxidation catalyst/for PTA and IPA	No respondent data	No respondent data	No respondent data	No respondent data	No respondent data	No respondent data
Use in surface treatment - Formulation of surface treatment	Insufficient respondent data	Insufficient respondent data	Insufficient respondent data	Insufficient respondent data	Insufficient respondent data	Insufficient respondent data
Use in surface treatment - Passivation or anti-corrosion treatment processes	Insufficient respondent data	Insufficient respondent data	Insufficient respondent data	Insufficient respondent data	Insufficient respondent data	Insufficient respondent data
Use in surface treatment - Metal or metal alloy plating	0%	100%	0%	0%	92%	8%
Use in biotechnology – Formulation and industrial use of mixtures in biogas production	No respondent data	No respondent data	No respondent data	No respondent data	No respondent data	No respondent data

Broad uses	Technical feasibility			Economic feasibility		
	% of sites technically feasible to comply	% of sites not technically feasible to comply	% of sites technical feasibility unknown	% of sites economically feasible to comply	% of sites not economically feasible to comply	% of sites economic feasibility unknown
Use in biotechnology – Professional use in biogas production	No respondent data	No respondent data	No respondent data	No respondent data	No respondent data	No respondent data
Use in biotechnology – Use in fermentation, fertilizers, biotech, scientific research and standard analysis	No respondent data	No respondent data	No respondent data	No respondent data	No respondent data	No respondent data
Use in biotechnology – Formulation and use in animal feed grade materials	Insufficient respondent data	Insufficient respondent data	Insufficient respondent data	Insufficient respondent data	Insufficient respondent data	Insufficient respondent data
Bespoke uses – Use in humidity indicators cards, plugs and/or bags with printed spots	No respondent data with non-complying sites	No respondent data with non-complying sites	No respondent data with non-complying sites	No respondent data with non-complying sites	No respondent data with non-complying sites	No respondent data with non-complying sites
Bespoke uses – Formulation of water treatment chemicals, oxygen scavengers, corrosion inhibitors	Insufficient respondent data	Insufficient respondent data	Insufficient respondent data	Insufficient respondent data	Insufficient respondent data	Insufficient respondent data
Bespoke uses – Use of water treatment chemicals, oxygen scavengers, corrosion inhibitors	No respondent data	No respondent data	No respondent data	No respondent data	No respondent data	No respondent data
Adhesion (inc. rubber adhesion agent)	Insufficient respondent data	Insufficient respondent data	Insufficient respondent data	Insufficient respondent data	Insufficient respondent data	Insufficient respondent data
Use in electronics	No respondent data	No respondent data	No respondent data	No respondent data	No respondent data	No respondent data

Broad uses	Technical feasibility			Economic feasibility		
	% of sites technically feasible to comply	**% of sites not technically feasible to comply**	**% of sites technical feasibility unknown**	**% of sites economically feasible to comply**	**% of sites not economically feasible to comply**	**% of sites economic feasibility unknown**
Use in magnetic alloys	Insufficient respondent data	Insufficient respondent data	Insufficient respondent data	Insufficient respondent data	Insufficient respondent data	Insufficient respondent data
Use in metallurgical alloys	20%	77%	3%	0%	93%	7%
Use in cemented carbide/diamond tools	8%	79%	13%	0%	87%	13%
Recycling of materials containing cobalt substances	0%	96%	4%	0%	91%	9%
Total (no overlap)	**10%**	**79%**	**11%**	**0%**	**63%**	**37%**

Table notes:

- Share of sites is based on the total number of sites currently not-complying with a 1 µg/m^3 BOEL in the EU-27.
- Total share of sites has been estimated using the number of non-complying sites reported by questionnaire respondents regardless of broad use and therefore cannot be estimated by averaging the shares in each of the broad uses.

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