# Inventory of estimates of ENMs and nano-enabled products value chain

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|---|---|
| **Deliverable Number:** | D4.1 |
| **Work Package Number:** | WP4 |
| **Lead Beneficiary:** | TNO Netherlands Organisation for Applied Scientific Research |
| **Dissemination Level:** | Public (PU) |
| **Delivery Date:** | 01/03/2017 |

| Partner No. | Partner short name | Role in deliverable |
|---|---|---|
| 3 | LEITAT | Drafting specific chapters of this report |
| 18 | EMPA | Drafting specific chapters of this report |
| 20 | ETSS | Review of the deliverable report |
| 21 | TNO | Lead author and editor of this deliverable report |

**This report was prepared under contract from the European Commission**
Contract n° 646002, Horizon 2020


| | |
|---|---|
| Project acronym: | NanoFASE |
| Project full title: | Nanomaterial Fate and Speciation in the Environment |
| Research ID | E-2356-2016 |
| Start of the project: | 1 Sept 2015 |
| Duration: | 4 years |
| Project coordinator: | Dr. Claus Svendsen, CEH, NERC (National Environmental Research Council), Wallingford, UK. |
| Project website | www.NanoFASE.eu |

| | |
|---|---|
| Deliverable title: | D4.1 Inventory of estimates of ENMs and nano-enabled products value chain |
| Deliverable n°: | D4.1 |
| Nature of the deliverable: | Report |
| Dissemination level: | Public (PU) |
| Public Document Title | NanoFASE Inventory of estimates of ENMs and nano-enabled products value chain |


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|---|---|
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|---|---|
| Citation: | Kuenen J., et al. Inventory of estimates of ENMs and nano-enabled products value chain. H2020 NanoFASE Project Deliverable D4.1. March 2017. |

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|---|---|
| Due date of deliverable: | Month n° 18 |
| Submitted to coordinator: | Month n° 18 |

Document history:

| Version | Status | Date | Author(s)/Reviewer(s) |
|---|---|---|---|
| 1.0 | Initial draft | 17/02/2017 | First draft circulated to partners and reviewers for comments |
| FINAL | Final | 01/03/2017 | Final draft circulated to partners and NanoFASE project leaders for submission to EC |

# ABSTRACT

Releases of engineered nanomaterials (ENMs) to the environment may have harmful effects on human health. To get an understanding of the fate of engineered nanomaterials in our environment, modelling tools are used which need information on the release patterns of ENMs as input. This study describes a first country-specific ENM release model for Europe. Releases are quantified for the different stages (production, manufacturing, consumption of ENMs), and also the ENM flows into waste management (e.g. landfilling, recycling, incineration) are improved.

A first step is to estimate production of ENMs, as well their incorporation into products (manufacturing) and consumption of these products. Available estimates of European production of different ENMs often show a wide variation, indicating the large uncertainties about the actual production rates. By comparing different estimates and discussion with experts we have selected the most likely values. For manufacturing and consumption, it is assumed that all ENMs produced in Europe are also manufactured and consumed in Europe (no net import/export from the EU) in the absence of any specific data on this. Also, the ENMs are broken down to various product categories where they are used. Then, the European production, manufacturing and consumption are broken down to country level by using proxy parameters, being production facilities, specific expenditure on products such as sunscreens, but also more generic proxies such as GDP or population. Finally, releases to the environmental compartments and end-of-life pathways are estimated.

Separately in this study, the releases of ENM waste compartments and end-of-life routes were better quantified and broken down to the country level. This led to an improved estimation of release factors and fate of the ENMs resulting from the production and use of them.

In the quantification of releases of ENM to the environment, significant uncertainties exist. This starts with the uncertainty in the amount of ENMs produced, in some cases multiple orders of magnitude. All the steps in the methodology to refine and detail the ENM production, manufacturing, consumption, end-of-life pathways and environmental releases also have their associated uncertainties, therefore the results should be regarded as a first estimate. During the course of the NanoFASE project, these estimates will be further improved and refined.

A next step is to incorporate the updated release factors into the PMC model, which will be further spatially detailed to allow ENM releases to be used as input for ENM fate modellers looking at specific geographical areas.

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# 1. INTRODUCTION AND MAIN OBJECTIVE

## 1.1. Introduction

Releases of engineered nanomaterials (ENMs) into the environment may have harmful impact on the environment and human health (Gottschalk et al. 2013). To assess this impact, knowledge about the actual concentrations of ENMs in the different environmental compartments is needed. However, since measurements of concentrations of ENMs in the ambient environment are difficult due to the low concentrations of ENMs (e.g. Gottschalk et al. 2013b; von der Kammer et al. 2012), environmental concentrations of ENMs are modelled to get a picture of how ENMs move through the environment. An input to such models and a prerequisite for an environmental assessment of the fate of ENMs in the environment is to have a good overview of the releases of ENMs to the different environmental compartments.

Since the concerns of the possible harmful effects of ENMs to the environment are growing with the increased use and release of nanomaterials, several studies have addressed the issue of quantifying these effects (e.g. Gottschalk et al. 2013b, Boxall et al. 2007, Gottschalk et al. 2009, Keller et al. 2013, Sun et al. 2014). Given the limited information on the releases and dispersion of ENMs through the environment and the difficulty in measuring actual man-made nanomaterial concentrations in the ambient environment, most studies use modelling approaches to assess the issue (Sun et al. 2016).

Most of these models attempt to quantify the values and major uncertainties about the annual fluxes and related environmental emissions of ENM into the environment. Due to missing data time and space dependencies (variability) are often ignored and the whole ENM product life cycle release broken down to constant annual release and fate figures. First geographic variation on ENM in the environment has been modelled in Swiss river studies (e.g. Gottschalk et al. 2011). First release time dependencies have been successfully performed in dynamic flow modelling for ENM release and fate in waste incineration processes (Walser & Gottschalk 2014). Dynamic modelling of time influences on generic ENM release and fate for human and environment is in its earliest children's shoes (e.g., Sun et al. 2016; Giese et al. 2017).

Apart from methodological and data requirements there is no doubt that there is a certain release of ENMs in the environment assumed, from which a certain flow into different environmental compartments is calculated.

Improved ENM modelling tools are developed in NanoFASE which predict the releases of ENM to the environment, and methods and tools are being developed to quantify ENM concentrations in water, air and soil. These models explicitly combine time- and space variation input of ENM releases in order to run.

Several studies have aimed to quantify the production amounts of different ENMs for Europe and global (e.g. Piccinno et al. 2012, Holden et al. 2014, Sun et al. 2016). These estimates show large variations, which is illustrative for the uncertainties in these estimates. In this study, the aim is not to repeat these assessments but to select the best estimates available and build up an application- and country specific release model for the selected ENMs.

## 1.2. What's new in this report

In NanoFASE, we present the first spatially resolved European ENM release model. As a start this study builds on earlier estimates of ENM releases for Europe as a whole and provides an update with the latest available information from literature, industry and other expert sources. Furthermore, the NanoFASE release model will keep track of and will include a differentiation of the chemical/physical state of the ENM in question at points of release, which has not been undertaken at this level so far. Another new element in this study is the way how European figures for the production, manufacturing, consumption and waste management are further detailed to the country level. A next step (but this is beyond the scope of D4.1) will be to allocate these to more exact locations as input to the environmental fate modellers. Thus, this ENM release model does not end at the administrative level of country borders but allocates all release points to specific locations.

In addition, this report will address further improvements and quantification of the flows of ENMs into the different end-of-life pathways i.e. recycling, incineration and landfills. Moreover, a better specification of the product categories is provided, a remarkable feature in comparison with other existing models. The nano-applications specific to each product were defined, enabling a better tracking of the ENM fate towards waste treatment. This will also enable, in future work, a better assessment of their fate and behaviour in the waste treatment processes.

In terms of the ENMs covered, this report addresses the nanomaterials titanium dioxide, zinc oxide, silver, carbon black and copper.

## 1.3. Goal of this work

The main objectives of the work described in this deliverable report are:

- To provide a first release model for ENMs and nano-enabled products. This will take the form of country specific production, manufacturing and consumption for each ENM and for its detailed applications.
- To better specify the product categories and better tracking of ENM fate towards waste treatment.

## 2. METHODOLOGY FOR PMC

### 2.1. Methodology for the release model

This ENM release model for Europe is constructed using a top-down approach. We started from the material flow diagrams for different engineered nanomaterials as they are presented in Gottschalk et al. (2015a). An example is shown in Figure 1. As for the model, we focus on the technical compartments (left side of the box). This chapter describes the estimation of the ENM flows from production, manufacturing and consumption (PMC box). Also, the initial releases of ENMs to the various environmental compartments and end-of-life routes are quantified, while Chapter 4 is about improving the release factors and the end-of-life pathways for the ENMs.

The production, manufacturing and consumption (PMC) box is the initial source of ENMs in the environment, as illustrated by Figure 1. Direct release to natural compartments (atmosphere, fresh and sea waters) from PMC may however be limited and the majority of the mass (be it in a different release form) may then be passed on to technical compartments. In Figure 1, technical compartments are waste water, sewage treatment and waste incineration and these represent indirect release sources. Release from recycling and landfill processes is not considered and as far as we currently may assume not relevant. what can be underscored in pure release modelling is that due to missing data no (or almost no) feedback flows such as for example bioaccumulation and real recycling and reuse of ENM and its products are considered.

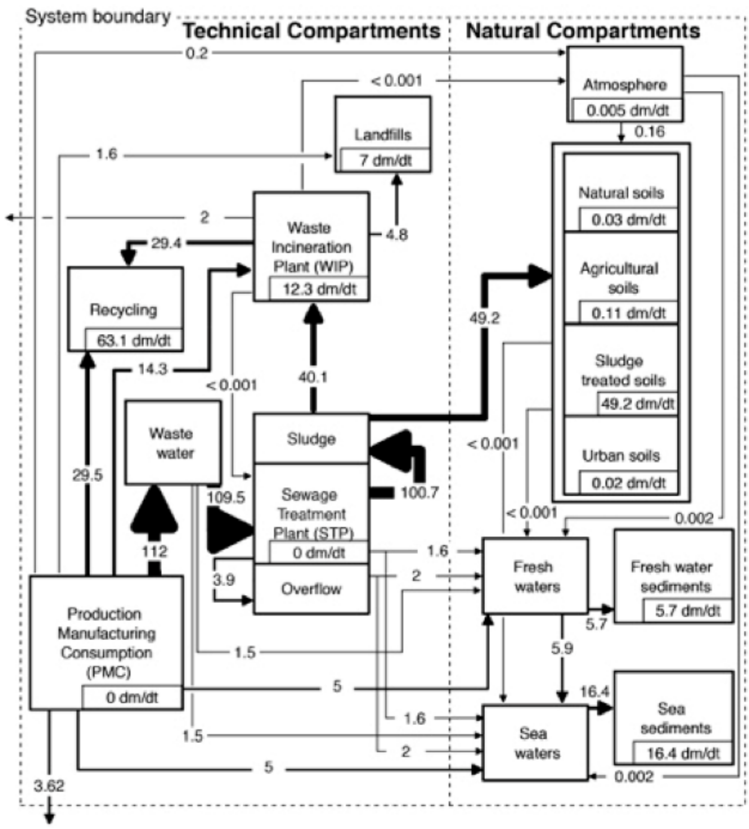



Figure 1: Example of a material flow diagram, for photostable $TiO_2$ (taken from Gottschalk et al. 2015a)

Figure 2 shows the different steps of the methodology. The first step is about quantifying the total production for the selected ENMs for Europe, where Europe is considered as the EU28 plus Norway and Switzerland, thus making up a total of 30 countries. For Europe as a whole, the amount of ENM produced is expected to be of the same order as the amount of ENMs used in ENM-containing product manufacturing/formulation and the amount of ENM present in ENM-containing products consumed in Europe. At this stage, it is assumed that no significant ENM transfer takes place between Europe and other regions and that there is no accumulation of ENMs, as there are no indications for large trade or accumulation. This implies that all ENMs that are produced in Europe are also manufactured into products/applications in Europe, and their consumption also takes place in Europe.

The second step concerns downscaling to the level of individual products and appliances in which the produced ENMs are integrated. In the third step, for each ENM and individual appliance the production, manufacturing and consumption are downscaled to the level of each of the 30 individual countries.

Finally, the last step concerns the estimation of the releases of ENMs to the different environmental compartments (air, soil, waste water, surface water) and the amounts going into end-of-life routes such as incineration, landfilling, recycling or others after the consumption stage.

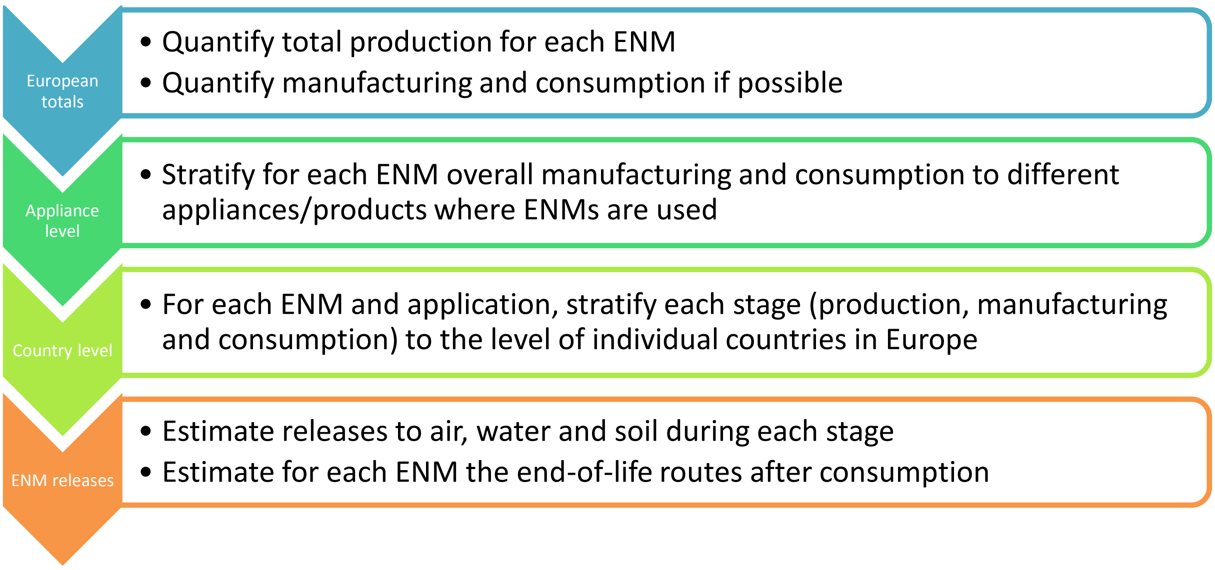



Figure 2: Schematic illustration of the methodology to estimate specific ENM releases from production, manufacturing and consumption at country level

For each of the steps included, the sections below provide more details for the methodology used.

## 2.2. Total ENM volumes produced, manufactured and consumed in Europe

There are several papers published in the last years that present estimates of ENM releases globally, for Europe or for other world regions. Since these papers have rather thoroughly reviewed all the available literature and other information, we will use this information and focus most of our attention on the downscaling and release quantification.

Despite that various studies over the last years have addressed the issue of total ENM production volumes on an annual basis, there is a very wide spread in the numbers reported, as illustrated e.g. by Sun et al. (2016).

### 2.2.1. Overview of available literature

To collect data on ENM production, manufacturing and consumption in Europe multiple literature sources have been searched. This search builds on work performed by ETSS and EMPA in Switzerland in earlier studies, reported in various papers e.g. Sun et al. (2014), Gottschalk et al. (2015a), Sun et al. (2016). In these papers, due to the absence of detailed information on emissions and flows of engineered nanomaterials, the authors use probabilistic modelling of the emissions of engineered nanomaterials to predict these flows going into the environment. Their models build on a collection of available estimates of ENM production in Europe. For the production, expert judgement on the 'degree of belief' for each study is made, and statistical methods are used to extract an estimate for the production. As highlighted in the papers, the currently estimated production amounts of the different ENMs provide a wide range of values, which is illustrated in Table 1 with the different values with 80% degree of belief (DoB) as reported in Sun et al. (2016) for Europe.

Also, other papers have been comparing production estimates for ENMs. Holden et al. (2014) reports suggested nanomaterial production values on the global scale. This paper also includes the values suggested by the European Commission in their staff working document on nanomaterials (EC, 2012). These are based largely on a 2010 SRI market report and on the volumes reported in the REACH submissions.

Table 1: Selected estimates of ENM production (ton per year) in Europe reported in literature

| | $TiO_2$ | ZnO | Ag | $Cu(OH)_2$ and oxides | Carbon black |
|---|---|---|---|---|---|
| **Sun et al. (2016), 80% DoB values** | 246<br>55 - 3,000<br>13,360 - 14,080<br>13,398<br>8,674 - 42,256<br>90,216 | 2,151<br>5.5 – 28,000<br>5,040 – 5,440<br>1,815 | 15<br>0.6 - 55<br>1.2 - 41<br>92<br>58 - 72<br>1<br>3.1 – 22 | | |
| ***Mean:*** | ***38,900*** | ***7,260*** | ***50.1*** | | |
| **Piccinno et al. (2012): *Europe*** | 550 | 55 | 5.5 | | |
| **EC (2012): *global*** | 10,000 | 8,000 | 22 | 200-250 | 9.6 mln |
| **Keller et al. (2013): *global*** | 88,000 | 34,000 | 452 | 200 | |
| **Holden et al. (2014): *global*** | >30,000 | 8,000 | >70 | >>150 | >= 10 mln |
| **Allied Market Research (2016), *European production for 2014*** | 10,487 | 4,768 | 38 | 45 | |
| **Allied Market Research (2016), *European production for 2016*** | 15,304 | 6,901 | 58 | 78 | |
| **Ricardo (2016), *Produced/imported in EU in 2015*** | 92,000 | 200 | 100 | | |
| **PRECHEZA 2016: *global in 2012/2014*** | 45,900 | | | | |
| **Nanowerk (2012), *global production in 2010*** | 50,000 | | | | |
| **TDMA (2010), *global production*** | <= 50,000 | | | | |
| **Weir et al. (2012) based on EPA (2009), *Global production in 2010*** | 5,000 | | | | |
| **Future Markets Inc. (2014), *Global production in 2009*** | | 29,000 | | | |
| ***Projected worldwide production in 2015*** | | 34,000 | | | |
| **Total production capacity of European producers in 2014** | | 10,000 – 20,000 | | | |
| **IARC (2010), 2005 CB plant capacities totalled for EU(28)+** | | | | | 1.4 mln |

***Nano Titanium dioxide***

The EC (2012) noted an issue since the SRI market report showed 10 kton nano-$TiO_2$ being produced globally, however from the filed REACH dossiers a significantly higher number could be extracted. Therefore, the Holden et al. (2014) estimate concluded on a higher production compared to the EC (2012).

Information from other sources suggest the overall $TiO_2$ (bulk, not only nano $TiO_2$) production to be in the order of 5 Mton per year (e.g. http://www.essentialchemicalindustry.org/chemicals/titanium-dioxide.html, http://www.marketresearchstore.com/news/global-titanium-dioxide-market-156, http://www.cristal.com/products-and-services/ultrafine-and-specialty-tio2/Pages/uf-tio2-specific-information.aspx).

The nano-sized $TiO_2$ is estimated to be around 1% or less of the 5 million ton, which would equal a maximum of around 50,000 ton annually (TDMA, 2010). Recognizing that in a growing market this value is likely higher in 2012-2014, the value is in the same order of magnitude of the previously mentioned production amounts. In the production of nanosized $TiO_2$, most major producers are located in Europe (F. Klaessig, pers. Comm.) with one large plant in Japan. This suggests the majority of global nanosized $TiO_2$ production to take place in Europe.

Nanowerk (2012) reports a global production rate of 50,000 ton in 2010, which is likely to increase rapidly to more than 200,000 ton by 2015. On the other hand, a lower estimate is reported in Weir et al. (2012), estimating a global production of 2,000 ton nanoscale $TiO_2$ in 2005, increasing to 5,000 ton in 2010. Weir based these numbers on EPA (2009).

In Ricardo (2016) the total amount produced in Europe and imported in Europe in 2015 is estimated at 92,000 ton, substantially more than other literature source report for Europe and even more than the reported worldwide production.

***Nano Zinc oxide***

Sun et al. (2016) report a total of 7,260 ton nano-ZnO production in Europe, while both EC (2012) and Holden et al. (2014) suggest 8,000 ton globally.

Ricardo (2016) estimate 200 ton for the global nano-ZnO production, which seems very low considering other available information.

Future Markets Inc. (2014) reports the global market for bulk zinc oxide to be around 1.5 million ton, with nano-ZnO accounting for around 31,000 ton. Total production in Europe is mentioned to be 542 ton per year, substantially lower than the Sun et al. (2016) paper suggests.

For bulk zinc oxide, Future Markets Inc. (2014) reports the total consumption in Europe is around 1/3 of the global consumption. Extrapolating this to nanosized ZnO would imply a use of around 10,000 ton per year.

Future Markets Inc. (2014) also lists the companies producing nano-sized ZnO in the world. For primary producers, the production capacity for nano-ZnO is given. Five out of 17 from the globally leading suppliers are European, include 4 German producers (Altana/BYK Chemie, BASF AG, Grillo Zinkoxid GmbH, Symrise GmbH) and 1 from Belgium (Umicore). Additionally, 4 out of 17 secondary suppliers are in Europe (2 in France, 1 in Germany and 1 in Spain). When average production capacity for a secondary producer is estimated at 1700 ton (which is the average for primary producers) the total nano-ZnO production capacity of the European companies is around 20,000 ton (around 10,000 ton for the primary producers only). This does however not necessarily mean that production takes place in Europe.

The fact that 5 out of 17 major producers are in Europe, and additionally some secondary suppliers as well, does not support the earlier statement that only around 2% of the production would take place in Europe (542 ton production in Europe, while 31,000 ton globally), but would suggest a production in Europe of around one third.

***Nano Silver***

For nano-Ag, the production volumes are rather low compared to other nanomaterials, which is shown by both Holden et al. (2014) and Sun et al. (2016)

The EC (2012) estimate of 22 ton/year was found on the low side in Holden et al. (2014) which estimates global production to be above 70 ton per year, recognizing that a large share of the production in Asia (i.e. China) may be unaccounted for. This implies that European production would not exceed 20 ton/year. On the other hand Sun et al. (2016) estimates production in Europe around 50 ton per year, whereas 100 ton is estimated by Ricardo (2016). Piccinno et al. (2012) estimates the production at 5.5 ton/year in Europe, but the production estimates from this study seem to be on the low side for the ENMs considered here, compared to the other estimates.

***Nano Copper***

Copper-based ENMs can be found in different forms (e.g. $CuO$, $Cu_2O$, $CuCO_3$, $Cu^0$) and each of these forms present different potential fields of application. In WP4 it has been proposed to differentiate the production volumes by copper form, since this will allow a more detailed and accurate description when determining the final applications of the nano-enabled products containing copper. Currently, even though different nano-copper forms can be found in real applications, only copper oxides (considering both $CuO$ and $Cu_2O$) and $Cu^0$ are being used in remarkable volumes (in the range of tonnes). Different literature sources as well as market reports have been consulted to determine the total production volumes of copper-based ENM in Europe:

1) nano-CuO production volume in Europe in 2014 was 45 tonnes, according to an industry report published by Allied Market Research (further described in section 2.2.2) (Allied Market Research, 2016);
2) Keller et al. (2013) reported a global production of nano Cu and nano CuO in 2010 of 200 tonnes. This value was also taken from a previous industry report (Future Markets, 2012). If these 200 tonnes are first scaled to 2014 and then scaled down to Europe using the GDP PPP, a value of 44 tonnes is obtained.

From this information, it may be concluded that most of the copper-based ENM production volumes are in nano CuO form. In the present report, it has been assumed that the volume production in Europe of $Cu^0$ is of 1 tonne, resulting in a total amount of 46 tonnes of copper-based nanomaterials. As a result, production volumes of nanoscale copper in Europe ($10^2$ tonnes) is much smaller than for other ENM as $TiO_2$ ($10^5$ tonnes).

***Carbon black***

For carbon black the situation is different from the other ENMs. Due to the large quantities produced and its long history of use, the production amounts are relatively well known. Global production is estimated at 9.6 million ton (EC 2012) and >10 million ton (Holden et al., 2014). A similar production estimate of 10 million ton carbon black is reported in Ceresana (2013).

There have been estimates for the Asian production to account for 60% of the global share (with 40% from China alone). Then, the carbon black production in the US is likely higher than that in Europe, which leads to the conclusion that European production would be around 10-15% of the global share (B. Park, pers. comm., 2017), thus equalling around 1.5 million ton.

IARC (2010) lists carbon black production capacities in 15 EU Member States for 2005, totalling about 1.4 million ton. In the years after 2000, capacity and production in Europe were declining slightly while production in Asia has been increasing. Extrapolating this trend onwards to 2012-2014 would be roughly in line with the 15% global share reported above.

### 2.2.2. Information collected from industry reports

Information regarding the total production volumes in Europe of all the ENM except Carbon Black (CB) is also available from a commercially available market report. In this specific case, the report "Europe Nanomaterials Market: Trends, Share, Opportunities and Forecasts 2014 – 2022", from Allied Market Research (2016) has been used. An example of the kind of information provided is shown in Figure 3. It must be emphasized that information included in the report is not country specific, it just provides values for the whole Europe. Country distribution of the ENMs production volumes is described in the Section 2.6 of this report.

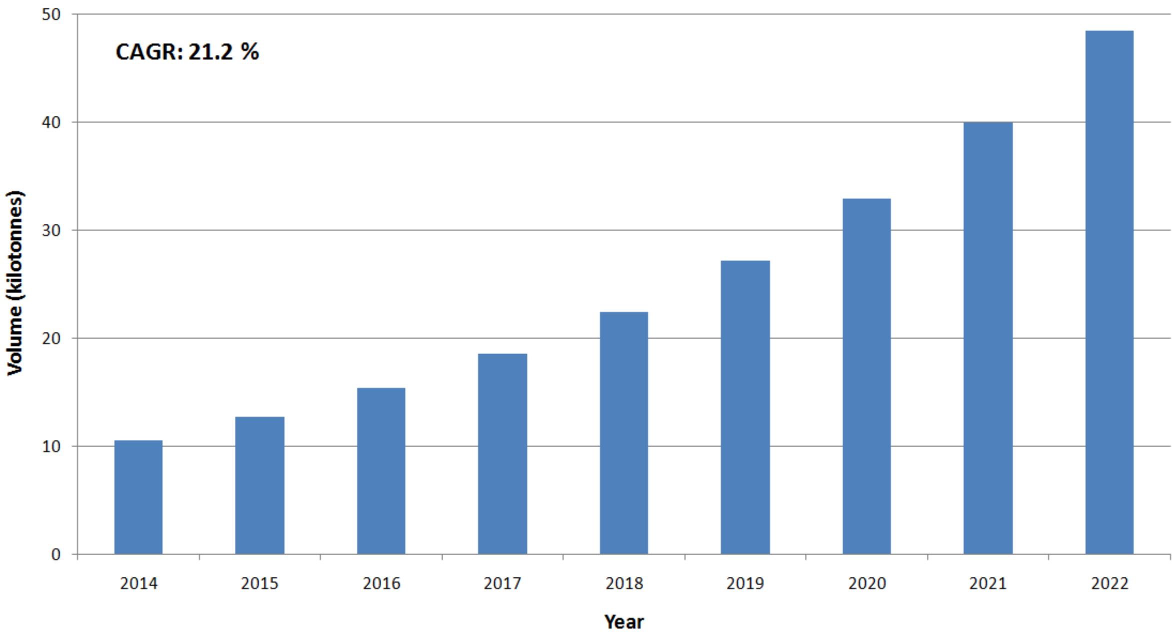



Figure 3: European nanosized $TiO_2$ market for 2014-2022, taken from Allied Market Research (2016).

According to Allied Market Research (2016), the information contained in the reports is obtained through interviews with industry participants, a thorough research in literature, industry annual reports, government websites and other such documents which may provide relevant information on the topic. Moreover, a set of analysis tools and data models are used where there is significant lack of information and estimates, to translate qualitative and quantitative industry indicators into exact industry estimates. These models also allow analysts to examine the prospects and opportunities prevailing in the market to accurately forecast its course. Thus, a prediction of production volumes from 2014 to 2022 is provided in terms of Compound Annual Growth Rate (CAGR), a business and investing specific term that indicates the mean annual growth rate of an investment over a specified period longer than one year. Although in this model it is not currently used as input, it might be applied to obtain temporal release predictions over a wide period.

The advantage of using market reports information is that data reliability is assured by a recognized organism, in this case Allied Market Research. However, as disadvantages, the price of the reports is usually high, so their acquisition is limited. Moreover, even if the procedure followed to obtain the data is accurate and representative, the values are subjective and dependent on the approach taken by the market research organization to which the report is bought. Market reports usually contain little methodological background. As supporting information to substantiate results is lacking, in addition to the reports being confidential and not published in scientific literature, none of the information is peer reviewed in any way.

In any case, alternative forms of data collection would lead to higher inaccuracy and above all a much higher data compilation time. Due to the short project duration, it is convenient to invest time in other novel features included in the database structure as the country distribution of ENMs.

### 2.2.3. Selection of adopted production values for this study

Based on the available inputs described in the preceding sections, the numbers highlighted in Table 2 will be used as input for the ENM release modelling described in this deliverable report. In the absence of any information on trade and specific data of ENM manufacturing and/or consumption, we assume that all ENMs that are produced in Europe are also used in the manufacturing in Europe and consumed in Europe. A rationale for the numbers selected is provided below.

Table 2 Total production, manufacturing and consumption amounts for Europe adopted in this study

| | **Estimated production amount for Europe* (ton)** |
|---|---:|
| **$TiO_2$** | 30,000 |
| **ZnO** | 8,000 |
| **Ag** | 20 |
| **Copper (CuO and $Cu^0$)** | 46 (45 ton CuO, 1 ton $Cu^0$) |
| **Carbon black** | 1,500,000 |

* In this work, Europe comprises of the EU28 Member States plus Norway and Switzerland

- For $TiO_2$, estimated production amounts vary widely across literature sources. However, the key sources identified in this study, both having reviewed existing estimates (Sun et al. 2016 and Holden et al. 2014) come up with values in the same order of magnitude, despite being for Europe and global. This would be in line with the assumption that Europe is a major player in global $TiO_2$ production (F. Klaessig, personal communication, 2016). Based on this, the value of 30,000 ton reported in Holden et al. (2014) is selected as the primary estimate for this study.

- For ZnO, the reported values in Sun et al. (2016), EC (2012) and Holden et al. (2014) are in the same order of magnitude. Again, this would suggest most production takes place in Europe. Future Markets Inc. (2014) suggests a nano-ZnO production of 31,000 ton globally, with 5 out of 17 major producers being located in Europe. Assuming the same production for each major facility, this would be in line with the estimated production of just below 10,000 ton in Europe. We therefore adopted the 8,000 ton reported in Holden et al. (2014) for this study.
- For Ag, the situation is different as production rates are much lower compared to $TiO_2$ or ZnO. Given the different values reported we feel the 50 ton/year may be overestimating given the apparent large production in China and other parts of Asia. Therefore, we adopt a value of 20 ton for nano-Ag production in Europe which would be within the 22 ton/year globally as given by the EC (2012).
- For copper, the value from Allied Market Research (2016) has been adopted, estimating total nano-CuO production in Europe at 45 ton, and nano-$Cu^0$ production at 1 ton, totalling 46 ton nanosized copper. This is in line with the estimates by Keller et al. (2013) and EC (2012) when these are scaled down to Europe and a trend correction towards 2014 is applied.
- For carbon black, the production in Europe is estimated at 15% of the global production reflecting the various sources available. With a total production around 10 Mton this yields 1.5 Mton carbon black production in nanoform for Europe.

## 2.3. Information about the expected release forms from production, manufacturing and use of ENMs

As mentioned in the introduction, current (nano)material flow models track (nano)materials life cycle paths from one compartment to the other and identify at each stage how much materials (mass) are released into environmental (e.g. freshwater) and technological compartments (e.g. waste water treatment plant). For that purpose, transfer factors are used. The final aim of these models is to estimate predicted environmental concentrations (PEC) in the environment, therefore to assess environmental exposure. Depending on the scope of the published studies, the number of compartments evaluated, the number of life cycle stages considered of a product, the target environmental / technological compartments as well the extent to which some fate processes are evaluated greatly differ. It has been already discussed in literature that MFA are meant to provide a first step in environmental exposure estimation of NMs, but such estimates are in general not based on fundamental multimedia fate and transport analysis (Gottschalk et al., 2010).

One parameter that is not considered in current models, from a qualitative/informative nor from a quantitative perspective, is the released form of ENMs during the different stages of a product. It is well known from literature that different situations can lead to different release forms and amounts, depending on the composition and the intended use of a nano-enabled product (Figure 4). Generally speaking, the consideration of particles transformation on their life cycle way due to dissolution, aggregation, forming of new chemical complexes and other material degradation processes have only to a very limited degree been considered (e.g. in WIP, STP, waters). Such consideration mostly resulted in ENM flows into material elimination or, in other words, into material forms not considered anymore as pristine nanomaterial. It is however for most life cycle steps generally assumed that particles do not transform during synthesis / manufacturing / use / end-of-life and keep the same size/form than pristine ENMs. This is a key point since the relevant ENM exposure forms entering the different compartments will determine further fate and transport of the (nano)materials in the environment. The aim of WP4 is to categorize release forms of ENM, based on the following criteria:

1. Matrix-embedded
2. Pristine (most probable during production)
3. Aggregated
4. Dissolved
5. Transformed (e.g. by sulfidation or oxidation)

Figure 4 illustrates possible release forms (covering from point 1 to 4 above) during the use of nano-enabled products formed during the use phase because of external physical or chemical processes. Dissociated ions released from ENMs might further react to form other species (e.g. AgCl) which will cover point five above.

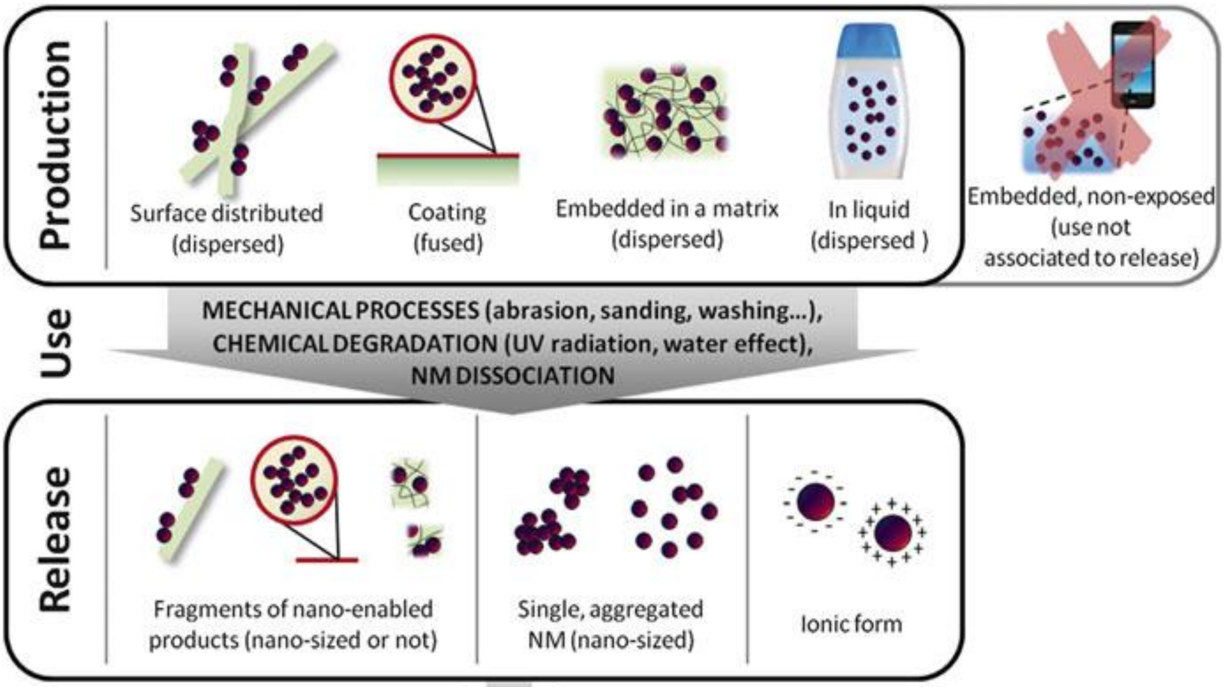



Figure 4: Possible forms of NMs released during the use of these products that can end up into the different environmental compartments. Adapted from Vílchez et al. (2015).

Along the project, release experiments at lab scale, literature revision and better knowledge of the case studies will help in defining release forms for a large variety of nano-enabled products. These release forms will be introduced in the ENM release model presented in this report and if feasible will be introduced in the mass flow modelling that is being performed in WP4. Moreover, this will be a valuable input for the different WPs in NANOFASE (WP4-WP8) evaluating fate of NMs in the different environmental / technological compartments (Figure 5).

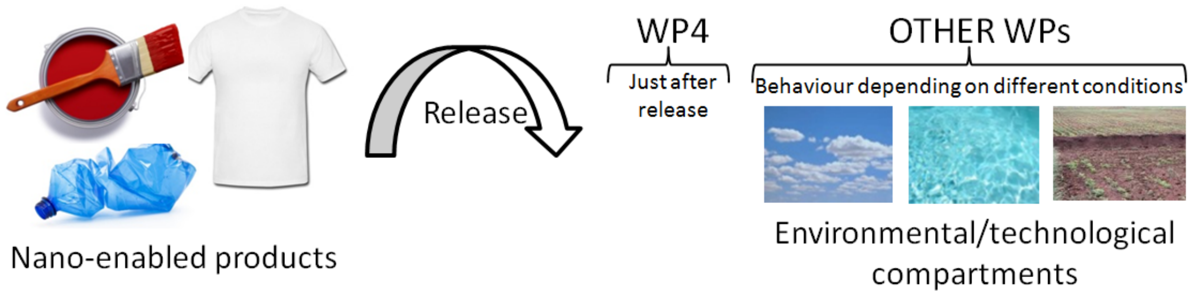



Figure 5: Role of WP4 in the assessment of the ENMs forms of exposure

As an example, the evaluation of two case studies included in NANOFASE and the corresponding relevant exposure forms are indicated below.

| Case 1: Antifouling paints for marine activities (with $Cu_2O$ NPs as antibacterial agent) provided by HEMPEL |
| --- |
| • Synthesis: $Cu_2O$ nanoparticles, dispersed in water, and coated with polyethylene glycol are synthesized by Promethean particles (PP). According to PP, uncontrolled emissions to the environment are negligible in the wet synthesis procedure they use. However, synthesis waste containing ENMs is produced, which is disposed as hazardous waste. This waste will be eliminated through a controlled treatment afterwards, thus not ending up in the waste water treatment plant. The ENMs concentration in the waste depends on the process, but taking PP synthesis method as a reference, it is considered to be ≤0.1wt%. Particles are considered to be pristine ENMs dispersed in water.<br>• Coating process (painting): the hull of the vessel can be painted using different methods in the shipyard: spray, paintbrush and roller, where each of them presents a different release probability. Paintbrush and roller are the most directional methods, meaning that a higher amount of paint ends up on the surface, while sprayed paint could be more easily released to air and propagated. In any case, the product would maintain its original composition so, the $Cu_2O$ NPs released would remain embedded in the liquid matrix.<br>• Use phase: experimental results obtained in Task 4.2 suggest that $Cu^{2+}$ is released to water when panels coated with antifouling paints have been immersed in water at controlled temperature (25 ºC). Therefore, it can be assumed that most probably the $Cu_2O$ NPs are dissolved in the sea water compartment.<br>• End of life: old paint layers are commonly removed by sanding the surface before painting again. During this process, small particles containing ENM could be released to air due to mechanical stress. As in the coating process, the most likely release form of the $Cu_2O$ NPs is embedded in the matrix, but in this case in solid form. |
| **Case 2: Photocatalytic coating for roads (with $TiO_2$ NPs as photoactive agent) provided by FCCO** |
| • Synthesis: $TiO_2$ NPs have been obtained from Cristal Global, presenting a 70:30 mixture by weight of anatase and rutile structures. Both chloride and sulphate processes to produce various grades of materials, including nano variants, are used by Cristal Global. Given the quoted HCl content, this product may be most likely produced by the chloride process. However, there is no information about ENM release/waste during synthesis. In any case, is highly probable that ENMs are being generated in pristine form or aggregated.<br>• Coating process (product application on the road): The photocatalytic coating is applied by means of specific machinery with a coating process similar to spraying. $TiO_2$ ENMs are mixed with resin to form an aqueous dispersion. Consequently, the product can be easily released to the air and spread. Since the spraying process is the one producing the release, the $TiO_2$ NPs are released embedded in the liquid matrix (i.e. TiO2 with adsorbed resin on the surface).<br>• Use phase: nanoparticles loosely attached to the road, extracted by the wheels and/or washed away by rain could end up in the sewerage system and then to the WWTP, from where they could arrive to the soil (as sludge) or to the water. $TiO_2$ NPs loosely attached to the road or washed away by rain might be released as aggregated, or particles embedded in the matrix, since it has been demonstrated that subproducts generated by the photoxidation of the bituminous surface are also released to the water compartment. Regarding the particles generated by wheel abrasion, they are probably released to air as matrix embedded.<br>• End of life: generally speaking, old roads do not experience any end-of-life process, maintenance of roads is usually made by paving new asphalt over the old road surface. Thus, any ENM release is produced. |

## 2.4. Trends in ENM volumes across Europe

The current estimate of ENM releases is not given for a specific year, however when data allows we used the latest year if possible, 2014 preferable. Given that this assumption might be justified for products for which the production and use is not changing very much, the reality is that production and use of several engineered nanomaterials is changing rapidly (e.g. Ricardo 2016).

A rapid increase in production may occur for new and innovative ENMs that have been produced on pilot scale only but for which product evaluation testing has shown very promising results and orders for larger quantities are placed. Also, novel applications may be found for certain existing ENMs, after which production of the materials may show a sharp increase again (e.g. quantum dots application in TV displays). Industrial scale application of a certain ENM may until a certain moment have been restricted by law that prohibits the use of the ENM for a specific type of class of product. When further testing shows the product to be safe such legal restrictions may be abrogated after which production and application may boom. Generally, many ENMs are still relatively new and many of their qualities are still to be discovered. In addition, new ENMs such as hybrid particles are being developed each year.

The ENMs selected in NanoFASE are characterised by a significant current industrial production and application, as well as being considered promising in the sense that new applications are likely to be found in the future. The materials are mostly past their development stage and their merits are generally recognised, although they may still await legal approval for certain applications. Most of the selected materials have witnessed a sharp increase in production in recent years and there is enough reason to expect the production of the selected ENMs to continue to increase in the foreseeable future.

Searching in literature for quantitative information very different estimates for the future development of production can be found. For instance, Nanowerk 2012 estimated that compared to 2010 the production of nano-$TiO_2$ would have increased four-fold in 2015, which was however never realised. More examples of past overestimations of future production trends are available. We consider such estimates to be somewhat speculative and highly uncertain. Possibly more conservative consistent trend information is available from specialised commercial market research companies but this type of information is handled confidentially and only available for a fee.

In Allied Market Research (2016) a forecast for the European production of four of the ENMs selected in NanoFASE is given. The projections are stated to be based on “primary research, government publications, company releases and AMR analysis”. Figure 6 shows the estimated ENM production for the period 2014 to 2022, per ENM. In general, Compound Annual Growth Rates (CAGRs) between 20 and 30% are estimated, depending on the ENM. For the ENM market as a whole, Allied Market Research (2016) estimates an almost five-fold increase between 2014 and 2022 for Europe.

Another ENM that is selected in NanoFASE is carbon black (CB, not shown in Figure 6). CB is unlike the other four ENMs in the sense that it is produced in bulk chemical quantities and has been around for many decades. Almost all CB produced can be considered nano-CB. Production in Europe has been relatively stable in the past decade. Since CB is mainly used in the manufacture of rubber products such as tyres and the average CB content in rubber has not changed dramatically during the past decade, regional production roughly follows regional demand for rubber products. A small part of the CB is considered “speciality blacks” and the production of this type of CB may show a significant future increase in production (see e.g.http://carbonblacksales.com/carbon_black_industry_news_market_reports/).

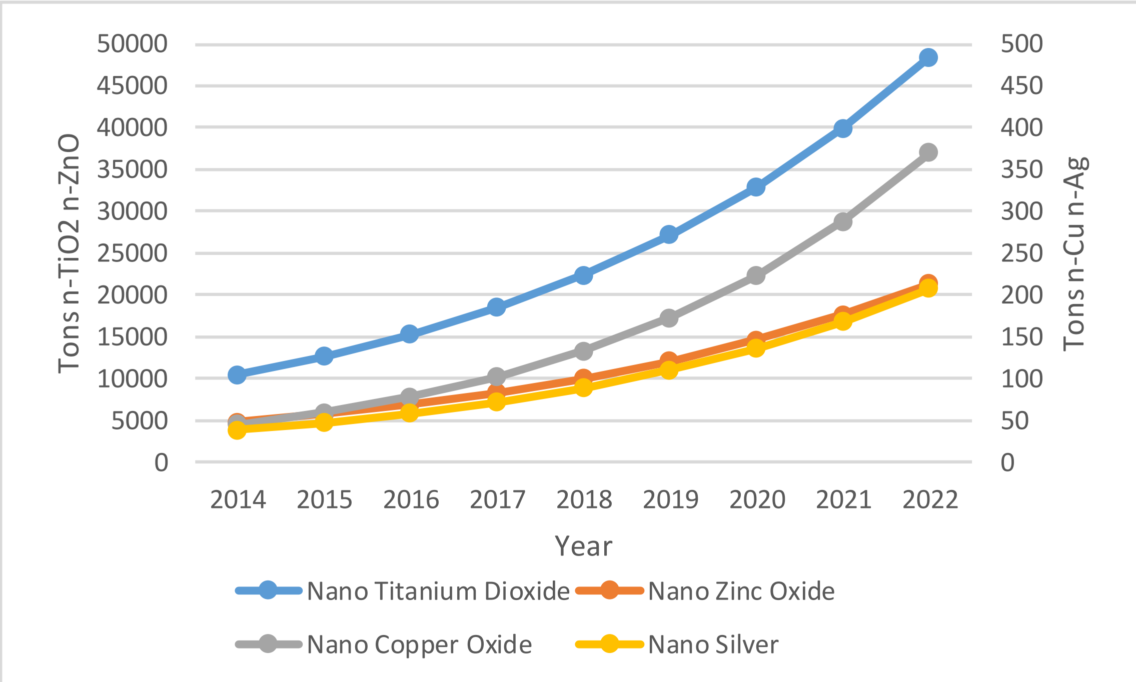



Figure 6: Projected production of nano-$TiO_2$, nano-ZnO (left y-axis), nano-Cu and nano-Ag (right y-axis) according to Allied Market Research (2016)

### 2.5. Methodology for downscaling to ENM product level

As a next step, the estimated European totals for manufacturing and consumption as summarized in Table 2 are further detailed by the product they are used in. For example, since $TiO_2$ is widely used in sunscreens, in our estimate 45% of the total nano-$TiO_2$ is allocated in this specific product. Therefore, it is assumed that 45% of the manufactured amount of $TiO_2$goes into sunscreens, and also that 45% of the consumption of $TiO_2$takes place as part of sunscreen.

To provide the factors for breaking down the overall manufacturing and consumption for each ENM into different products, several literature sources have been used. The most prominent source used is the Danish study (Gottschalk et al., 2015b) where detailed split factors are available for nanosized $TiO_2$, ZnO, silver and carbon black, which have been adopted for this study by basing our shares for each ENM on their modal values. For copper/copper oxides and for carbon black, the product distribution is described below.

- Since carbon black is an established bulk chemical that has been used for decades, information of usage distribution is readily available from literature. In addition, nearly all CB is nano-CB, which further simplifies the allocation of the ENM CB to the various product categories. IARC (2010) quotes the distribution of CB over the range of products in which it is used, reflecting the situation in Europe in 2005 (Table 3).

Table 3: Product allocation for carbon black, for Europe

| Product category | Share (%) |
|---|---|
| Rubber tyres | 70.0 |
| Rubber products | 20.0 |
| Paints and varnishes | 3.0 |
| Antifouling paints | 0.1 |
| Inks | 3.0 |
| Plastic components (various articles) | 3.0 |
| Filters | 0.2 |
| Others | 0.7 |

- The produced volumes of both CuO and $Cu^0$ have been distributed into different products. Nanoscale CuO distribution has been obtained from Caballero-Guzman and Nowack (2017). On the other hand, for $Cu^0$ a new distribution has been performed by looking at different sources of information, since such distribution has not previously been reported in literature. In order to determine the distribution share (%) for each nano product containing $Cu^0$, different online databases containing inventories of nano-enabled products, classified by type of ENM, product category, or even by potential impact were first consulted (The Nanodatabase, 2017; Project on Emerging Nanotechnologies, 2017; Nanotechnology Products Database, 2017; Nanowerk Product Catalog, 2017). Once the products containing nano-copper were identified, they were analysed based on literature and personal judgment in order to determine which of them could contain $Cu^0$. It should be pointed out that in most cases assumptions had to be made because the nano-copper forms were not indicated. As a result, a product distribution for $Cu^0$ was obtained, which is shown in Table 4, together with the nano-CuO distribution.

| ENM | Product category | Share (%) |
|---|---|---|
| **Copper oxide** | Catalysts | 35% |
| | Electronics & Optics | 31% |
| | Coatings, paints and pigments | 24% |
| | Energy and Environment | 4% |
| | Medical | 3% |
| | Cosmetics | 3% |
| **Metallic copper** | Cosmetics | 29% |
| | Food and beverages | 29% |
| | Engine additive | 14% |
| | Filters | 10% |
| | Construction Paints | 5% |
| | Electronic Paints | 5% |
| | Welding nozzle | 5% |
| | Electronics | 5% |

Table 4: Product allocation of nano-CuO and nano-$Cu^0$

Apart from this analysis, additional information was obtained from experts (F. Klaessig, B. Park) which brought up additional applications of nano-copper not considered in Table 4. For instance, major sources of nanosized copper applications would be pesticides and military smoke screens, which are not included in the product allocation presented in Table 4. This information has not been used in the current version of this study to ensure consistency with the product distribution used by all partners in this work package.

However, the distribution presented here should be regarded as a first breakdown which is subject to further discussion and refinement during the next stage of the NanoFASE project.

Figure 7 shows the most important products for each of the 5 ENMs considered.

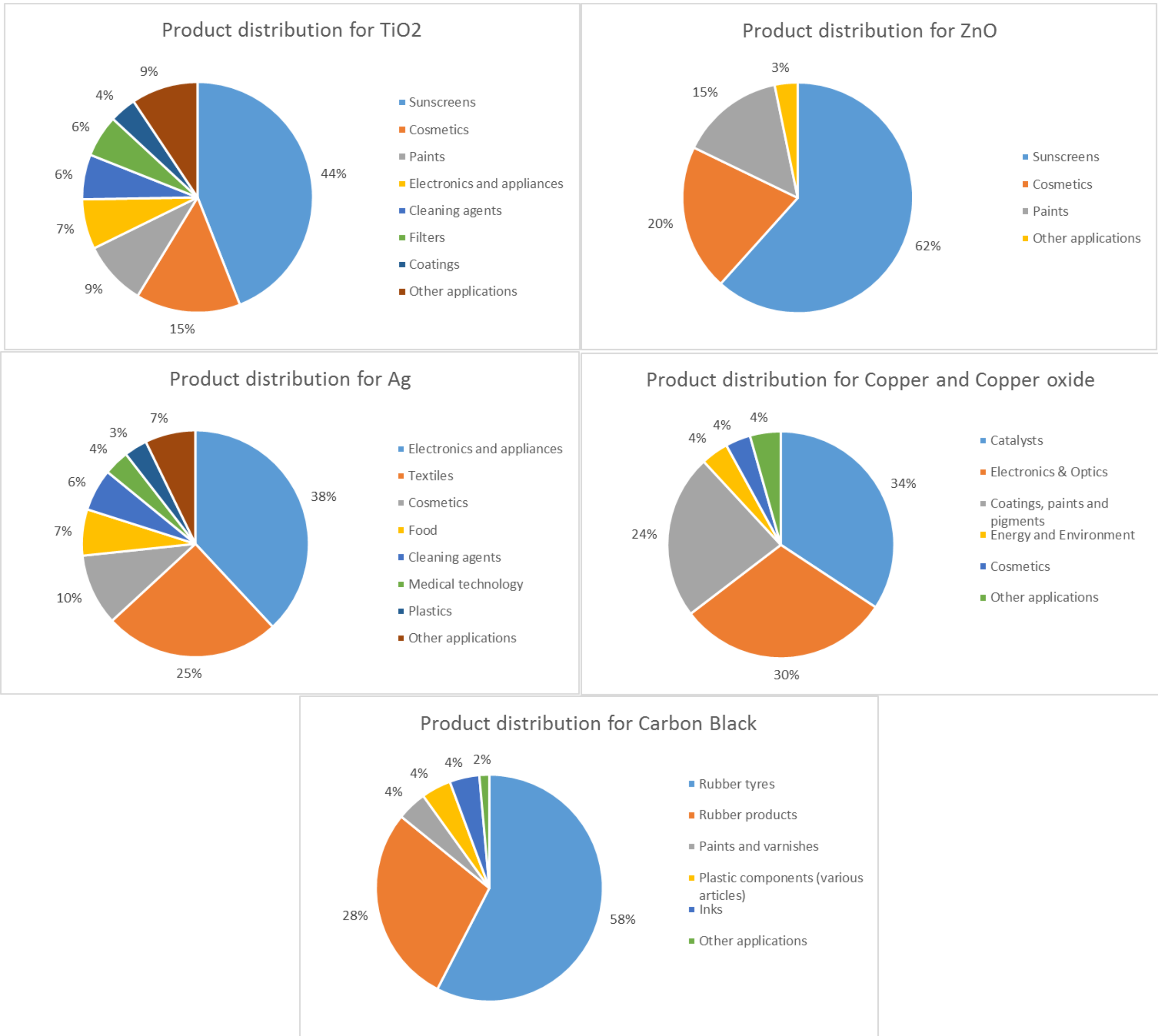



Figure 7: Distribution of ENM manufacturing/consumption over the main products/applications

## 2.6. Methodology for downscaling to country level

After the manufacturing and consumption of ENMs have been downscaled to the level of individual product fields such as tires, textiles, cosmetics, food etc., the next step is to allocate to country level.

For ENM production, the distribution to country level is made by combining information on production locations. Engineered nanomaterials are specific substances which are only made in specific locations, typically not in each country. The information on where this production takes place however, is not easily available. Therefore, we rely on information provided in-kind, information available online and expert judgements.

- For $TiO_2$, the current distribution of production capacity over the different countries has been based on market information (F. Klaessig, personal communication, 2016) stating the name of the company that produces all nano- $TiO_2$for use in cosmetics in Europe and subsequent allocation to countries based on the locations of production sites in Europe of that company. Furthermore, one specific country was named in which all nano- $TiO_2$for non-cosmetics use is thought to be produced.
- For ZnO, information on the main producers was extracted from Future Markets Inc. (2014), where the major producers (both primary and secondary) of nano-ZnO in the world were listed, including their capacities. Given that exact production per facility is not known, the European ZnO production was allocated to these producers proportionally to their production capacity. This capacity was known for most production facilities but had to be estimated in certain cases. By adding up the producers per country, the country distribution was obtained.
- For nano-silver, no information was available and also the production amounts are low compared to the other ENMs. Based on expert knowledge (F. Klaessig and B. Park, personal communication) it is assumed that 50% is produced in Germany, 25% in Belgium and 25% in Poland.
- For copper, there is very little available literature on the allocation of production volumes to individual European countries. In the absence of this information, data from the European mineral statistics from the British Geological Survey (2016) has been used as proxy (reference year was 2014) which is based on production of smelter and refined copper in Europe (not only nanosized but bulk production). In Appendix 1 the corresponding country distributions for smelter and refined copper are shown. The same country distribution percentages are applied to the total production volume of nano-Copper oxide (45 tonnes) and nano-$Cu^0$ (1 tonne), resulting in the distributions observed in Appendix 1.
- For carbon black, the distribution of production capacity is based on an updated list of production locations in Europe and their capacities, taken from IARC (2010).

For ENM product manufacturing, we have collected production data for different products from the Eurostat PRODCOM database (Eurostat, 2017), which contains production data per country in Europe at a detailed level of products. PRODCOM contains mass-based and value-based production data. Since the value-based (monetary data) are the most complete, these data were used to construct the proxy data from. The products considered in PRODCOM were aggregated to the application shares/categories as we used in this study, thus the proxies used for manufacturing based on PRODCOM are calculated by adding up the monetary value for each of the PRODCOM products.

For consumption of ENM containing products (during the use phase), individual proxies were collected based on the product which was used. Default proxies used are population or GDP (collected from Eurostat for the year 2014), however for specific products information on the use of those products has been collected. Here we have started from the most important contributors, e.g. for sunscreens (a key product in which nanosized $TiO_2$and ZnO are a component) a specific proxy has been developed for the use of sunscreens by country.

Table 5 provides an overview of the proxy parameters used for manufacturing and consumption, per ENM and for each of the products in which the ENM is contained.

Table 5: Overview of proxy parameters used to distribute manufacturing and consumption to the level of individual countries in Europe

| ENM | Product where ENM is embedded in | Contribution (%) | Proxies: Manufacturing | Proxies: Consumption |
|---|---|---|---|---|
| $TiO_2$ | Sunscreens | 44.02% | PRODCOM_Sunscreens | Proxy sunscreen use[1] |
| | Cosmetics | 14.67% | PRODCOM_Cosmetics | Proxy cosmetics use[1] |
| | Paints | 9.03% | ESIG paint production | ESIG paint consumption[2] |
| | Electronics and appliances | 7.00% | GDP | GDP |
| | Cleaning agents | 6.29% | PRODCOM_Cleaning agents | Population |
| | Filters | 5.88% | PRODCOM_Filters | GDP |
| | Coatings | 3.75% | PRODCOM_Coatings | ESIG paint consumption[2] |
| | Plastics | 3.65% | PRODCOM_Plastics | Plastic consumption[3] |
| | Glass and ceramics | 1.72% | PRODCOM_Glass and ceramics | Population |
| | Sporting goods | 1.52% | PRODCOM_Sporting goods | GDP |
| | Waste water treatment | 0.71% | PRODCOM_Waste water treatment | Population |
| | Food | 0.41% | PRODCOM_Food | Population |
| | Batteries | 0.41% | PRODCOM_Batteries | GDP |
| | Textiles | 0.30% | Textiles_Manufacturing | Population |
| | Spray | 0.20% | GDP | Population |
| | Light bulbs | 0.20% | GDP | Population |
| | Metals | 0.10% | PRODCOM_Metals | GDP |
| | Cement | 0.10% | Cement production | GDP |
| ZnO | Sunscreens | 61.63% | PRODCOM_Sunscreens | Proxy sunscreen use[1] |
| | Cosmetics | 20.54% | PRODCOM_Cosmetics | Proxy cosmetics use[1] |
| | Paints | 14.60% | ESIG paint production | ESIG paint consumption[2] |
| | Plastics | 2.04% | PRODCOM_Plastics | Plastic consumption[3] |
| | Glass | 0.71% | PRODCOM_Glass | Population |
| | Electronics and appliances | 0.20% | GDP | GDP |
| | Filters | 0.10% | PRODCOM_Filters | GDP |
| | Cleaning agents | 0.10% | PRODCOM_Cleaning agents | Population |
| | Paper | 0.01% | GDP | Population |
| | Metals | 0.01% | PRODCOM_Metals | Population |
| | Wood | 0.01% | GDP | Population |
| | Food | 0.01% | PRODCOM_Food | Population |
| | Textiles | 0.01% | Textiles_Manufacturing | Population |
| Ag | Electronics and appliances | 38.06% | GDP | GDP |
| | Textiles | 25.07% | Textiles_Manufacturing | Population |
| | Cosmetics | 10.19% | PRODCOM_Cosmetics | Proxy cosmetics use[1] |
| | Food | 6.59% | PRODCOM_Food | Population |
| | Cleaning agents | 5.99% | PRODCOM_Cleaning agents | Population |
| | Medical technology | 3.60% | PRODCOM_Medical technology | GDP |
| | Plastics | 3.30% | PRODCOM_Plastics | Plastic consumption[3] |

| | | | | |
|---|---|---|---|---|
| | Paints | 3.00% | ESIG paint production | ESIG paint consumption[2] |
| | Metals | 2.40% | PRODCOM_Metals | Population |
| | Soil remediation | 0.60% | GDP | GDP |
| | Glass and ceramics | 0.60% | PRODCOM_Glass and ceramics | Population |
| | Filters | 0.30% | PRODCOM_Filters | GDP |
| | Diapers | 0.20% | GDP | Population |
| | Paper | 0.10% | GDP | Population |
| Cu / CuO | Catalysts | 34.27% | GDP | GDP |
| | Electronics & Optics | 30.35% | PRODCOM_Electronics and appliances | GDP |
| | Coatings, paints and pigments | 23.50% | PRODCOM_Paints and Coatings | ESIG paint consumption[2] |
| | Energy and Environment | 3.92% | GDP | GDP |
| | Cosmetics | 3.57% | Proxy sunscreen and cosmetics production | Proxy cosmetics use[1] |
| | Medical | 2.94% | PRODCOM_Medical technology | GDP |
| | Food and beverages | 0.63% | PRODCOM_Food | Population |
| | Engine additive | 0.30% | GDP | GDP |
| | Filters | 0.22% | PRODCOM_Filters | GDP |
| | Paints | 0.20% | PRODCOM_Paints | ESIG paint consumption[2] |
| | Welding nozzle | 0.10% | GDP | GDP |
| | Electronics | 0.01% | PRODCOM_Electronics and appliances | GDP |
| CB | Rubber tyres | 70.00% | PRODCOM_Rubber tires | Tyre_consumption[4] |
| | Rubber products | 20.00% | PRODCOM_Rubber products | GDP |
| | Paints and varnishes | 3.00% | PRODCOM_Paints and Coatings | ESIG paint consumption[2] |
| | Plastic components (various articles) | 3.00% | PRODCOM_Plastics | Plastic consumption[3] |
| | Inks | 3.00% | PRODCOM_Ink | GDP |
| | Others | 0.70% | GDP | Population |
| | Filters | 0.20% | PRODCOM_Filters | GDP |
| | Antifouling paints | 0.10% | PRODCOM_Paints | GDP |

[1] Calculated based on Global Insight (2007), proxy is the per capita consumption by country (in US dollars) on cosmetics multiplied with the share of sunscreens / other cosmetics at country level.

[2] Based on production and consumption data for solvent containing products from the European Solvents Industry Group (ESIG, 2015)

[3] Plastic consumption per country from Plastics Europe (2014)

[4] Tyre consumption assumed proportional to vehicle kilometres driven per main vehicle category combined with particulates emission factor

## 2.7. Quantification of releases of ENMs from production, manufacturing and consumption

For the releases of ENMs into the environment, specific release factors have been assigned to each ENM and each application as listed in Table 5. These factors do not only include the releases to environmental compartments such as water, air and soil, but also include the end-of-life routes. All in all, the factors provide an annual mass-based breakdown for ENMs covering their life release.

During production of ENMs, most of the ENMs will go into the manufacturing stage, but a small quantity of the ENMs will end up in the environment. For manufacturing the same applies, most ENMs are taken up in the manufactured products and a small fraction is released to the environment. The manufactured products are then consumed. During this use stage, a higher share of the ENMs is released into the different environmental compartments. The part which is not released is then considered as an input to the different end-of-life routes, including incineration, landfilling, recycling and other waste management treatments.

For each of the ENMs considered and for each product, the releases have been quantified. This has been expressed in percentages, showing the fractions of the environmental releases into the different environmental compartments. Most of these percentages have been based on the Gottschalk et al. (2015b) study, this applies especially for the product use stage. This study did include release factors for production and manufacturing for 10 specific ENMs, including each of the 5 ENMs included in this study. Only for copper, the information available from Gottschalk et al. (2015b) was not given. Since, they focused on copper carbonate based wood treatment to estimate release for all applications, this study did not include all the applications considered in this report. Missing release factors have been estimated through expert judgement.

It should be noted that work is ongoing in the NanoFASE project to improve the release factors at the level of individual ENMs and products for which these ENMs are a component, as well as make these factors country specific with respect to the end-of-life pathways. This is work in progress described in Chapter 3, and the current version of the release model described in this chapter relies on the existing estimates presented in Gottschalk et al. (2015b). Although for copper and copper oxides further work is needed to harmonize the product distribution and release factors, a first calculation of releases of ENMs to the different environmental compartments is presented in this report. used for this study are provided in Appendix 2.

# 3. METHODS FOR WASTE PATHWAYS: RECYCLING, LANDFILLS AND INCINERATION

## 3.1. System definition and general methodology

The flows of $TiO_2$, Ag, ZnO, Cu and carbon black ENM from the production, manufacturing and use of nano-products to solid waste treatment were assessed at the national scale for each European country (EU28, Norway and Switzerland).

The total ENM production of Ag, $TiO_2$ and ZnO was divided into product categories (PC), according to the results from Sun et al. (2014) (Tables 3, 5 and 7), those of carbon black from Gottschalk et al. (2015) (Table 8). Two forms of Cu were considered (Table 10): copper oxide (CuO) and metallic copper. CuO PC were taken from Caballero-Guzman and Nowack (2017, in preparation), those of metallic Cu were previously defined in this work (see Chapter 2).

However, some of these PC are vague. For example, "Coatings" can be applied on construction materials or on vehicles, whose wastes are not treated in the same way. Consequently, the product applications (PA, such as "Construction" or "Automotive") of each PC were specified. In this way, the waste categories (WC) in which the ENM occur could be known, enabling a more accurate data collection and a better tracking of the ENM fate towards solid waste treatment (Figure 8).

Five compartments were considered regarding solid waste treatment: Landfill for construction and demolition waste (CDW), landfill for reactive waste (RW), incineration, recycling and export. The partitioning of the flows towards the CDW landfill and the reactive landfill was based on the nature of the waste: all CDW landfilled was considered going to CDW-specific landfills, while all other waste landfilled was considered to enter reactive landfills. Recycling was understood in the broader sense, meaning that the masses entering this compartment are the masses sent to sorting or recycling plants; they are the amounts collected separately from the mixed (residual) waste. The flows of ENMs exiting these sorting and recycling plants are out of the scope of this report and will be studied in future work.

As described earlier, the amounts of ENM produced, manufactured and consumed differ within one country, because imports and exports occur between each stage. To keep a mass balance through the system, two fictive compartments were added in the conceptual model, to manage the imports and exports of the ENM: M0 (between Production and Manufacturing) and M2 (between Manufacturing and Consumption). Additionally, releases of 0.5% were assumed from the production and manufacturing stages towards both waste water and air.

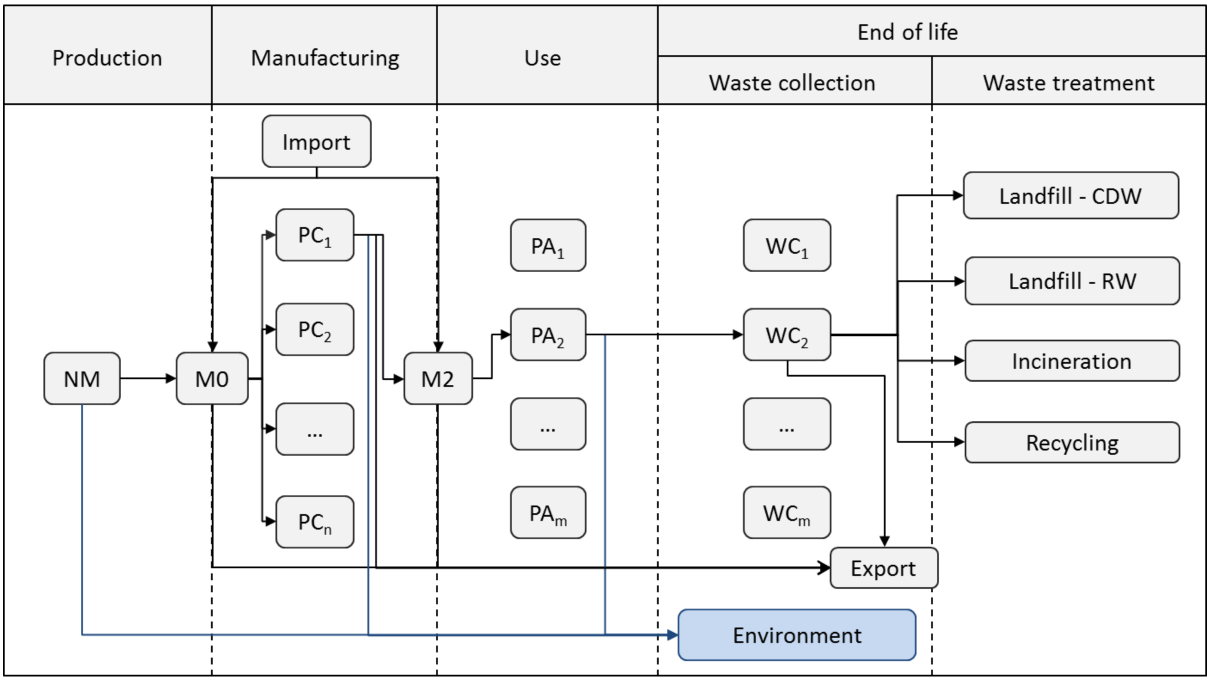



Figure 8: Definition of the system. PC: Product category; PA: Product application; WC: Waste category. CDW: Construction and demolition waste; RW: Reactive waste.

## 3.2. Data collection and quality assessment

### 3.2.1. Characterisation of the product applications

To identify the PA relevant for each PC (see Section 4.2), various sources were searched online: (1) consumer product inventories: the Woodrow Wilson nanotechnology consumer product inventory (http://www.nanotechproject.org/cpi/), the Danish Nano Database (nanodb.dk), the BUND database (http://archiv.bund.net/nc/themen_und_projekte/nanotechnologie/nanoproduktdatenbank); (2) commercial platforms: alibaba.com, amazon.com, ec21.com; and (3) Google. This method was applied to have a clearer idea of what each product category includes and to base our modelling on the best data we could find. However, we acknowledge that it cannot be considered exhaustive. Each source was given a weighting factor, or degree of belief (DoB), based on a decision tree (Appendix 3). A weighted distribution of PAs could be obtained for each PC by summing the number of products obtained from each source in each application, multiplying this sum by the DoB and dividing it by the total weighted number of applications (Equation 1, Figure 9):

$$f_{PA_J} = \frac{\sum_{k=1}^{p}(\#PA_{k,J} \times DoB_k)}{\sum_{k=1}^{p}\sum_{j=1}^{m}(\#PA_{k,j} \times DoB_k)} \qquad (1)$$

Where $f_{PA_J}$ is the fraction of $PA_J$ (a given product application) in a given PC, $\#PA_{k,J}$ is the number of products for $PA_J$ in the reference $k$ and $DoB_k$ is the degree of belief of reference $k$.

| | $PA_1$ | $PA_2$ | ... | $PA_m$ |
|---|---|---|---|---|
| Reference 1 | **$\#PA_{1,1}$** | **$\#PA_{1,2}$** | ... | **$\#PA_{1,m}$** |
| Reference 2 | **$\#PA_{2,1}$** | **$\#PA_{2,2}$** | ... | **$\#PA_{2,m}$** |
| ... | | | | |
| Reference p | **$\#PA_{p,1}$** | **$\#PA_{p,2}$** | ... | **$\#PA_{p,m}$** |

$\#PA_{k,j}$ = number of products in application j and reference k

| **W_Tot_PA₁** | **W_Tot_PA₂** | ... | **W_Tot_PAₘ** | **W_Total** |
|---|---|---|---|---|
| $= \sum_{k=1}^{p}(\#PA_{k,1} \times DoB_k)$ | $= \sum_{k=1}^{p}(\#PA_{k,2} \times DoB_k)$ | ... | $= \sum_{k=1}^{p}(\#PA_{k,m} \times DoB_k)$ | $= \sum_{k=1}^{p}\sum_{j=1}^{m}(\#PA_{k,j} \times DoB_k)_{k,j}$ |

$W\_Tot\_PA_j$ = weighted total number of products in application j
$DoB_k$ = degree of belief (weighting factor) of reference k

| **Fraction of PA** | $\frac{W\_Tot\_PA_1}{W\_Total}$ | $\frac{W\_Tot\_PA_2}{W\_Total}$ | ... | $\frac{W\_Tot\_PA_m}{W\_Total}$ |
|---|---|---|---|---|

Figure 9: Calculation of PA distributions in each PC

### 3.2.2. Waste collection and waste treatment

The data regarding solid waste collection and treatment were obtained from reports and personal communications from government organisations and ministries or, when these were not available, from the Eurostat database (http://ec.europa.eu/eurostat/web/environment/waste/database). The references used are detailed in Appendix 4.

Both industrial and household wastes were included in the assessment. The exact fraction of industrial waste from manufacture was assessed for textiles and plastics. For the other solid products, this waste was assumed to be equal to 1%. No solid waste was considered for the liquid products such as paints and cleaning agents. All industrial waste was assumed to be sent to sorting or recycling plants. Illegal waste treatment was not considered in this work, so the construction and demolition waste and the end-of-life vehicles were considered to be all sent to sorting and recycling plants.

The quality of the data used for waste collection and treatment was assessed based on a pedigree matrix adapted from Weidema and Wesnæs (1996) (Table 6). Three data quality indicators were used: Geographical relevance (G), Temporal relevance (T), and Reliability (R). A score was given to each reference used for each indicator, on a scale ranging from 1 to 3 (1: best quality, 3: worst quality).

The geographical relevance indicator was used because for some of the countries and waste categories, data could not be found. In such a case, we had to use data from another country, with the most similar waste management system. This assessment was based on the waste streams of total municipal waste (Eurostat data, Appendix 5), neglecting the fractions composted. Local data were mostly used for the composition of the mixed municipal waste. The temporal relevance indicator was used to manage the different years of reference associated with the data. The reliability indicator enabled an assessment of the expected accuracy of the reference. Eurostat was given a score of 2 because the definitions behind the data were not always fully clear.

Table 6: Pedigree matrix used for the quality assessment of the references used for waste collection and treatment

| **Indicator score** | **1** | **2** | **3** |
|---|---|---|---|
| **Geographical relevance** | Data for the country considered | Local data for the country considered | Data for a different country with similar waste management system |
| **Temporal relevance** | Year 2014 or later | Older than year 2014 and more recent than, or of year 2010 | Older than year 2010 |
| **Reliability** | Report from governmental organisation or waste management company;<br>Personal communication from governmental organisation or waste management company;<br>Peer-reviewed scientific literature | Eurostat database | Expert estimation |

An overall data quality rating was then calculated for each datum, equivalent to its uncertainty level (EC et al., 2010; Turner et al., 2015; Equation 2).

$$\mathrm{DQR} = \frac{\mathrm{G+T+R+}\ \mathrm{W_i}\times 4}{\mathrm{i}+4} \qquad \text{(Eq. 2)}$$

$\mathrm{W_i}$ is the weakest score obtained among $\mathrm{i}$ number of data quality indicators. Finally, a coefficient of variation (CV) was attributed to each DQR, which represents the uncertainty of the datum (Table 7, Hedbrant and Sörme (2001); Lanet et al. (2015)).

Table 7: Allocation of the coefficients of variation

| **Data quality rating (DQR)** | **Coefficient of variation** |
|---|---|
| 0 < DQR ≤ 1 | 4.5% |
| 1 < DQR ≤ 2 | 13.75% |
| 2 < DQR ≤ 3 | 41.5% |

### 3.3. Material flow assessment

The data collected and their associated uncertainties were implemented in one R code for one directional as well as constant probabilistic material flow analysis (PMFA). The method used for calculating the transfer coefficients (TCs) was adapted from Caballero-Guzman et al. (2015). First, in excel, the TC of a PC to a waste treatment type was calculated as the sum of the TCs determined for each PA to this waste treatment type, weighted by the share of the PA in the PC (Figure 10). Then, in R, these intermediate TCs were weighted with the share of the PCs before being summed, to result in the total TC of an ENM to the waste treatment processes.

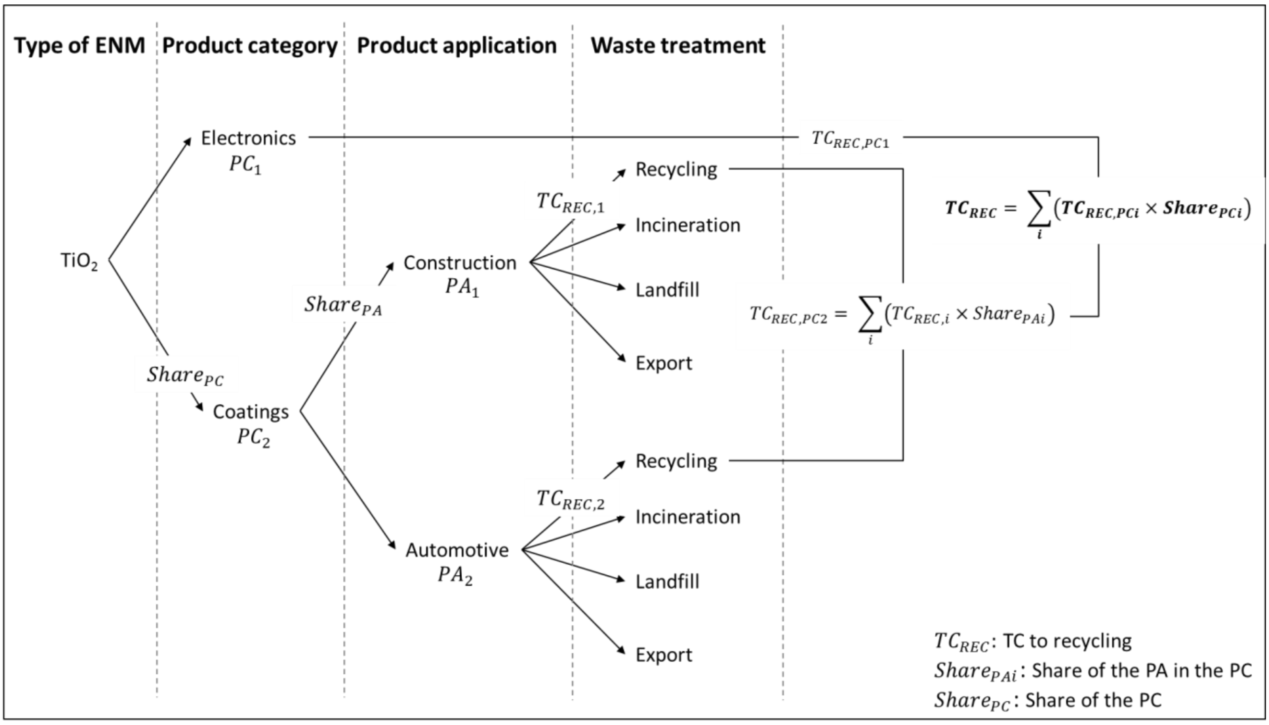



Figure 10: Calculation of the transfer coefficients

The uncertainty behind each TC were combined in the same way and used to generate probability distributions: the coefficient of variation associated to each TC determined the width of its triangular distribution (Figure 11).

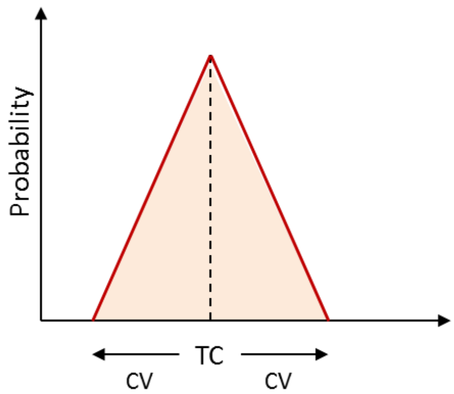



Figure 11: Probability distribution and uncertainty of the TCs

# 4. RESULTS

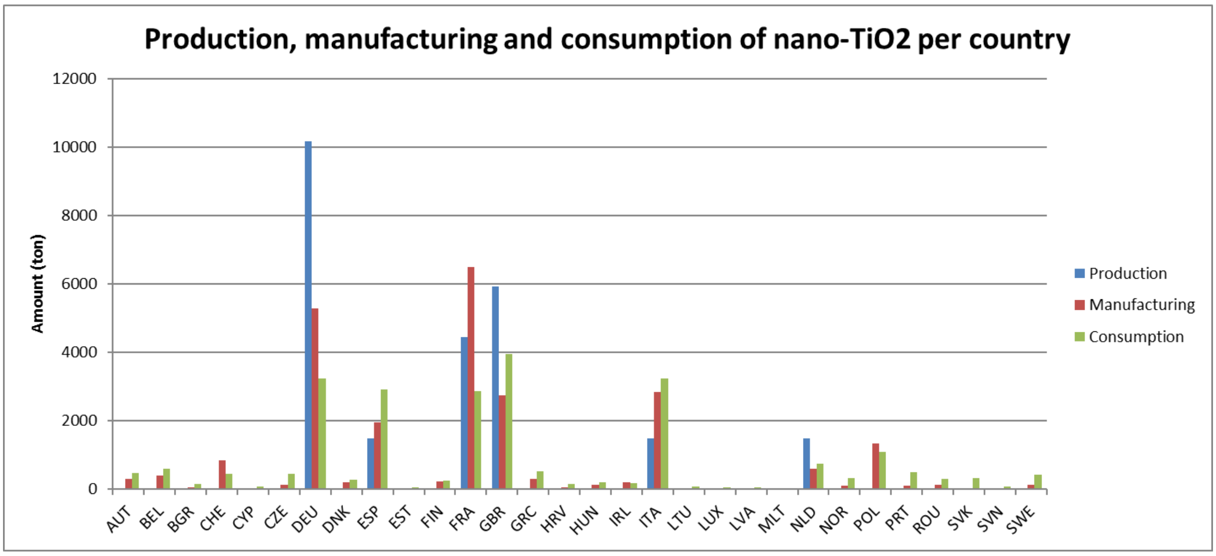
## 4.1. Production, manufacturing and consumption of engineered nanomaterials

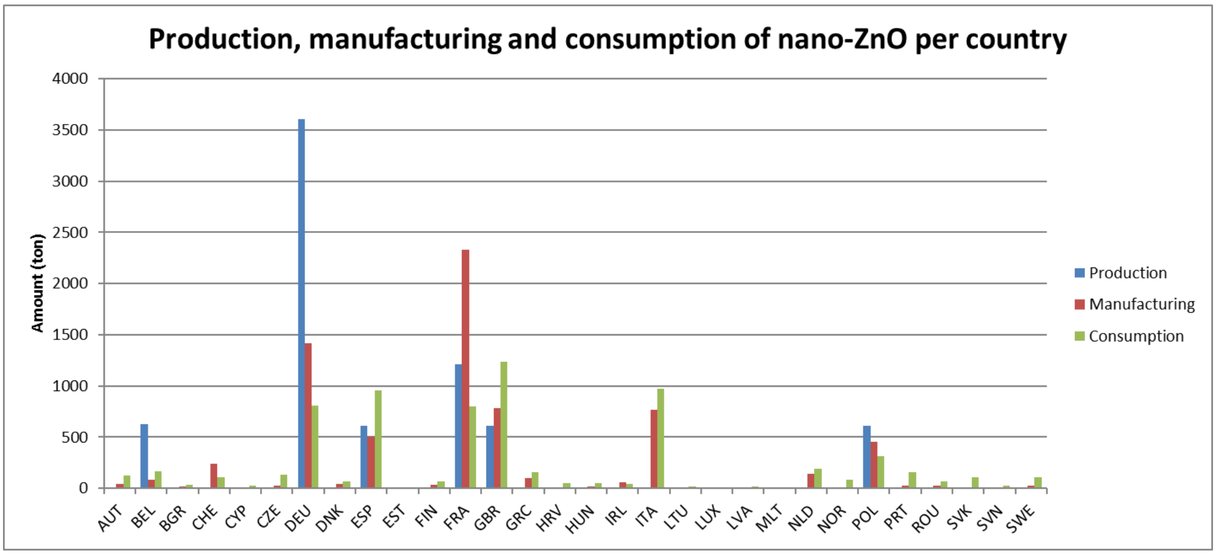
This section presents the main results for the production, manufacturing and consumption of the 5 selected engineered nanomaterials in this study at the level of individual countries.

It should be noted that all results presented are preliminary results, as the production, manufacturing and consumption amounts, the distribution to products as well as to countries, and the release factors are subject to further refinement during the next phase of the NanoFASE project.

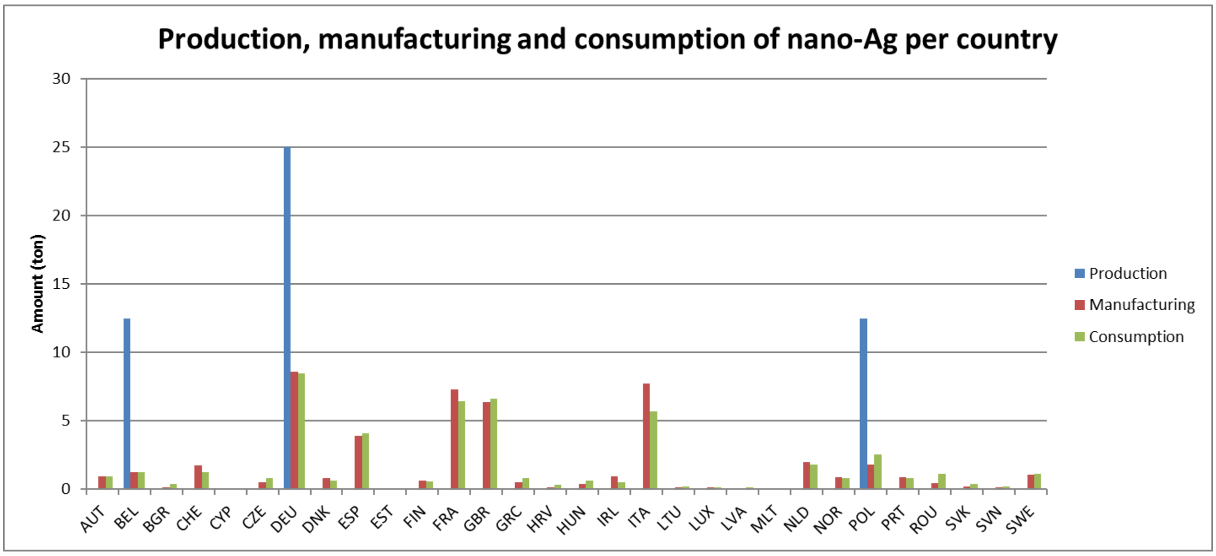
### 4.1.1. Production, manufacturing and consumption

This section presents the production, manufacturing and consumption amounts on a per country basis for the engineered nanomaterials. These are shown in Figure 12. The figures highlight that the distribution of production, manufacturing and consumption over the various countries in Europe is quite different. Especially production of ENMs typically takes place in only a few countries, while the manufacturing is more widespread across countries. For consumption, all countries contribute as the ENMs are widespread in everyday products used by European citizens.

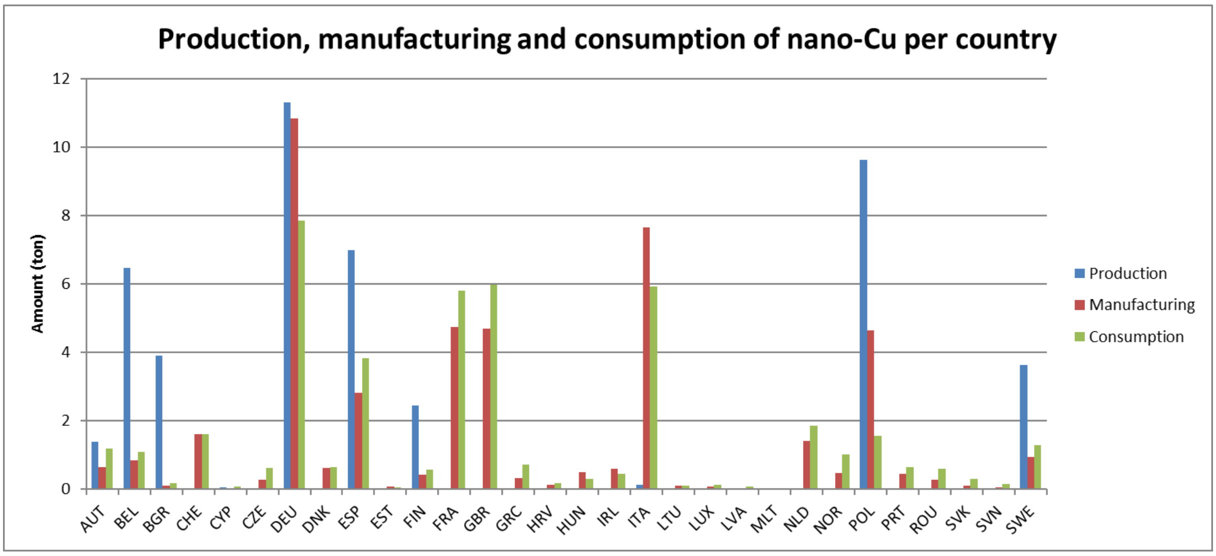




Production, manufacturing and consumption of nano-ZnO per country
Amount (ton)
Production
Manufacturing
Consumption
AUT BEL BGR CHE CYP CZE DEU DNK ESP EST FIN FRA GBR GRC HRV HUN IRL ITA LTU LUX LVA MLT NLD NOR POL PRT ROU SVK SVN SWE

Production, manufacturing and consumption of nano-Ag per country
Amount (ton)
Production
Manufacturing
Consumption
AUT BEL BGR CHE CYP CZE DEU DNK ESP EST FIN FRA GBR GRC HRV HUN IRL ITA LTU LUX LVA MLT NLD NOR POL PRT ROU SVK SVN SWE

Production, manufacturing and consumption of nano-Cu per country
Amount (ton)
Production
Manufacturing
Consumption
AUT BEL BGR CHE CYP CZE DEU DNK ESP EST FIN FRA GBR GRC HRV HUN IRL ITA LTU LUX LVA MLT NLD NOR POL PRT ROU SVK SVN SWE

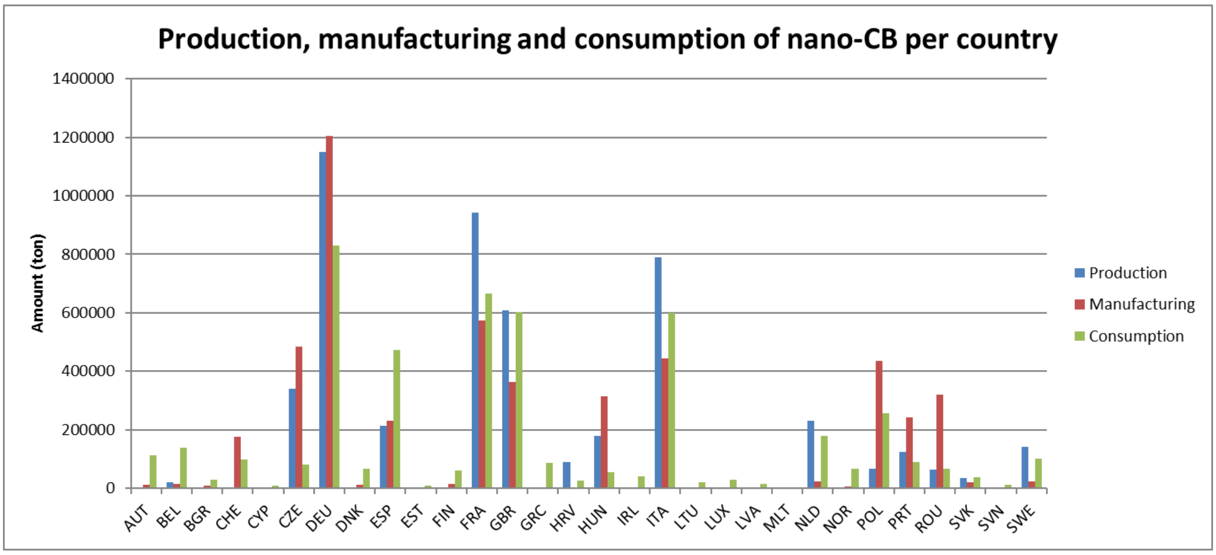
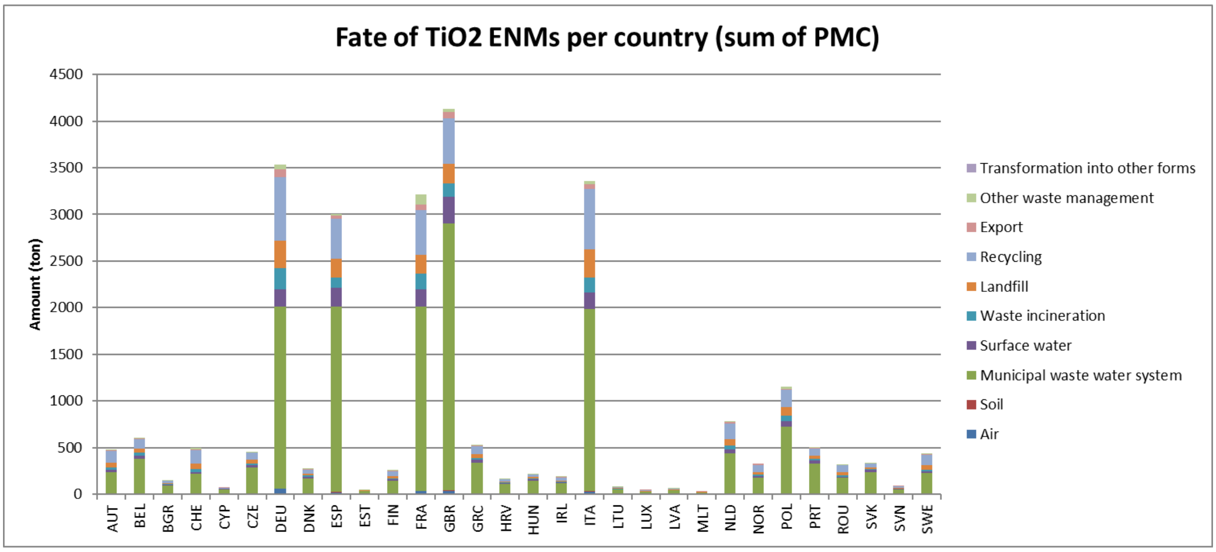


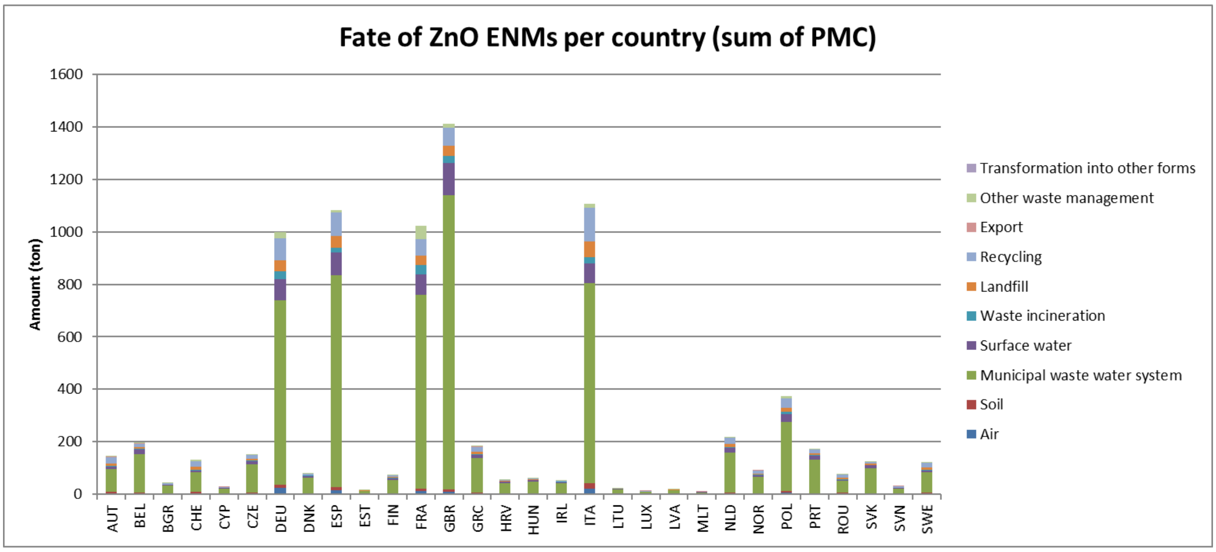

Figure 12: Production, manufacturing and consumption of the 5 ENMs covered by this study for each individual European country

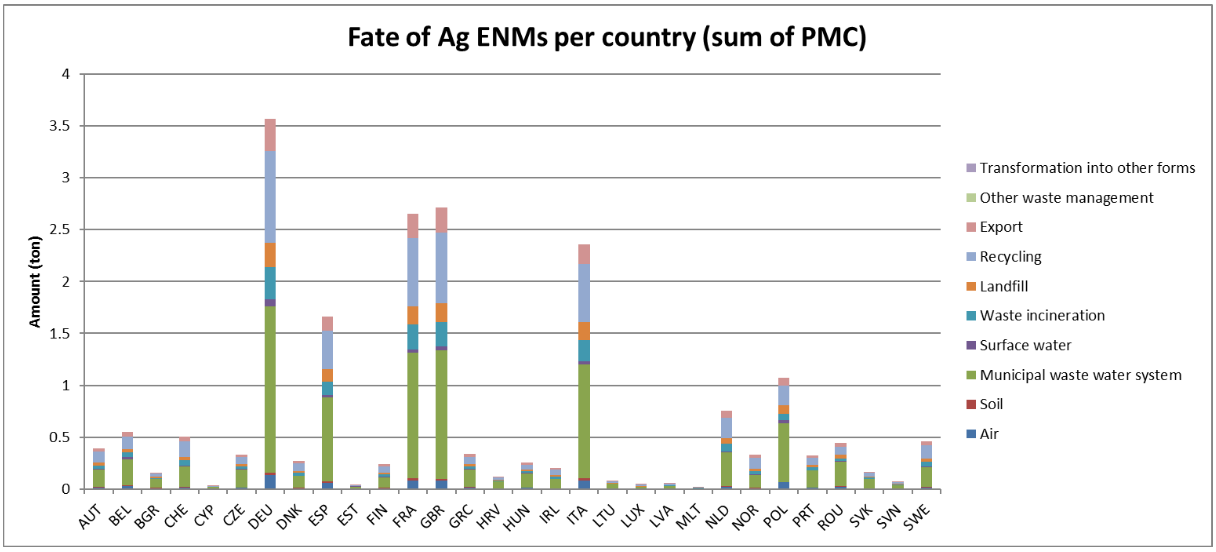
### 4.1.2. Environmental releases

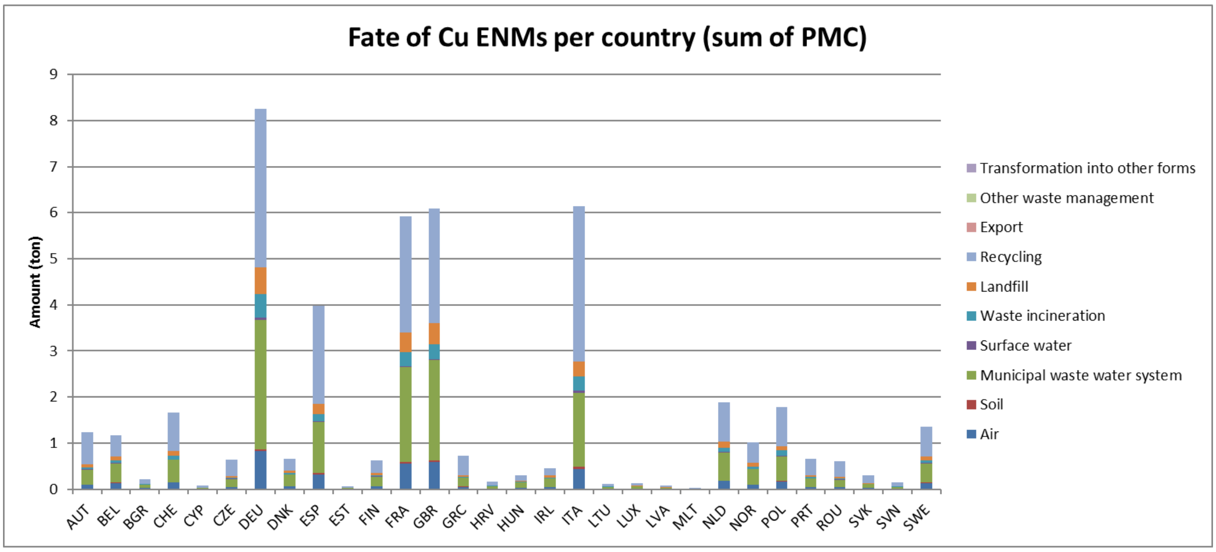
Figure 13 presents the fate of ENMs per country for the sum of production, manufacturing and consumption of each of the 5 ENM, including both product use based releases to the environment and also the end-of-life routes are included. In this way, the fate of all the originally produced PMC is included. It is shown that for $TiO_2$and ZnO, a large share of ENMs is eventually released to water, which is related to the fact that a high share of these ENMs is used in cosmetics and sunscreens. For the other ENMs the situation is quite different due to the other applications, which have different release patterns. Especially for carbon black, the release pattern is very different as most of the CB ends up in recycling and waste incineration.

It should be noted that the release factors used are not yet harmonised with the release factors presented in Section 4.2.2, but mostly based on older versions of these factors presented in Gottschalk et al. (2015). A next step is harmonizing between these factors, and the uptake of the latest information in the ENM release model.


Fate of TiO2 ENMs per country (sum of PMC)
Amount (ton)
0
500
1000
1500
2000
2500
3000
3500
4000
4500
AUT BEL BGR CHE CYP CZE DEU DNK ESP EST FIN FRA GBR GRC HRV HUN IRL ITA LTU LUX LVA MLT NLD NOR POL PRT ROU SVK SVN SWE
Transformation into other forms
Other waste management
Export
Recycling
Landfill
Waste incineration
Surface water
Municipal waste water system
Soil
Air


Fate of ZnO ENMs per country (sum of PMC)
Amount (ton)
0
200
400
600
800
1000
1200
1400
1600
AUT BEL BGR CHE CYP CZE DEU DNK ESP EST FIN FRA GBR GRC HRV HUN IRL ITA LTU LUX LVA MLT NLD NOR POL PRT ROU SVK SVN SWE
Transformation into other forms
Other waste management
Export
Recycling
Landfill
Waste incineration
Surface water
Municipal waste water system
Soil
Air


Fate of Ag ENMs per country (sum of PMC)
Amount (ton)
0
0.5
1
1.5
2
2.5
3
3.5
4
AUT BEL BGR CHE CYP CZE DEU DNK ESP EST FIN FRA GBR GRC HRV HUN IRL ITA LTU LUX LVA MLT NLD NOR POL PRT ROU SVK SVN SWE
Transformation into other forms
Other waste management
Export
Recycling
Landfill
Waste incineration
Surface water
Municipal waste water system
Soil
Air



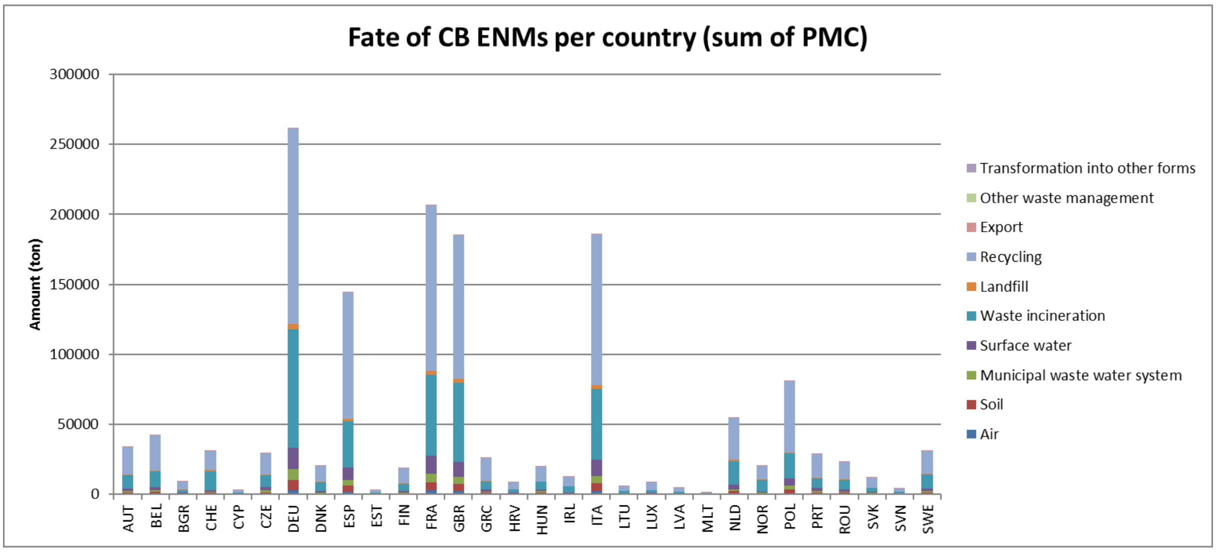




Figure 13: Releases of ENMs to different environmental compartments and to end-of-life routes, for individual European countries (combined releases for production, manufacturing and consumption)

## 4.2. Recycling, landfills and incineration of engineered nanomaterial products

### 4.2.1. Allocation to product applications and waste categories

#### 4.2.1.1. Carbon black

Gottschalk et al. (2015) allocate most of the carbon black ENM in tires and other rubber products (Table 8). Although the category "Tires" is very well defined, no reliable information could be found to allocate "Other rubber products" to specific product applications. The multiple rubber applications appear to be small products such as belts, air springs or shoe soles. These products were considered to be collected in mixed municipal waste. In the same way, "Plastics" and "Fillers" could not be better defined, so they were attributed to total plastic waste and mixed waste, respectively.

Table 8: Allocation of carbon black ENM to applications and waste categories. EoL: End of Life; ELV: End-of-Life Vehicle; CDW: Construction and Demolition Waste; WEEE: Waste Electrical and Electronic Equipment

| Product category | | | Application | | Waste category |
|---|---|---|---|---|---|
| **Name** | **PC Share** | **EoL release** | **Name** | **Share** | |
| Tires | 70% | 0.850 | Tires | 1 | ELV |
| Other rubber components | 20% | 0.999 | Multiple | - | Residual waste |
| Paints and varnishes | 3% | 0.950 | Paper | 0.66 | Total paper |
| | | | Automotive | 0.21 | ELV |
| | | | Construction | 0.09 | CDW |
| | | | Electronics | 0.02 | WEEE |
| | | | Furniture | 0.02 | Residual waste |
| Inks | 3% | 1.000 | Paper | 0.85 | Paper |
| | | | Toners | 0.15 | Toners |
| Plastics | 3% | 0.999 | Multiple | - | Total plastic |
| Fillers | 0.2% | 0.700 | Fillers | 1 | Residual waste |
| Antifouling paints | 0.1% | 0.330 | Boat | 1 | Boat |

As a result, most of the carbon black ENM are collected in end-of-life vehicles (ELV, 71%) and in mixed waste (20%), as shown in Table 9.

Table 9: Transfer coefficients of carbon black to waste categories

| | |
|---|---|
| End-of-Life Vehicles | 71% |
| Mixed waste | 20% |
| Paper | 4.5% |
| Plastic | 3.0% |
| Toners | 0.5% |
| Construction and demolition waste | 0.3% |
| Boat | 0.1% |
| Electrical and electronic waste | 0.1% |

#### 4.2.1.2. Copper

Most of the nano CuO is used in catalysts (Table 10). These were assumed to be used in industrial processes; consequently all associated solid waste is considered to be collected. Electronics & Optics also constitute a high share of CuO use, but no accurate data could be found to refine this product category. Cosmetics and Medical applications are mostly released to waste water during use. A fraction of 5% was assumed to stay in the packaging and ends in this waste category. Food and beverages are more likely to be wasted before full consumption, resulting in partly full packages which are not thrown away in separate bins. Therefore, a fraction of this PC was assumed to reach the mixed waste.

The definition of the product applications and their allocations to waste categories results in high shares of nano Cu collected as industrial waste (34%) and WEEE (33%) (Table 11). Construction and boats waste are other significant portions of the nano Cu waste collection (12%).

Table 10: Allocation of nano copper to applications and waste categories. WEEE: Waste electronic and electrical waste; CDW: Construction and demolition waste; ELV: End-of-life vehicles; LHA: Large household appliances

| ENM | Product category | | | | Application | | Waste category |
|---|---|---|---|---|---|---|---|
| | Name | Share - ENM | Share - nCu | EoL release | Name | Share | |
| Copper oxide | Catalysts | 35% | 34% | 0.99 | Industrial waste | 1 | Industrial waste |
| | Electronics & Optics | 31% | 30% | 1 | Electronics | 1 | WEEE |
| | Coatings, paints and pigments | 24% | 23% | 0.96 | Wood coating | 0.5 | CDW |
| | | | | | Boats | 0.5 | Boats |
| | Energy and Environment | 4% | 3.9% | 1 | Engines | 0.5 | ELV |
| | | | | | Electronics | 0.5 | WEEE |
| | Medical | 3% | 2.9% | 0.05 | Medical | 1 | Medical |
| | Cosmetics | 3% | 2.9% | 0.05 | Packaging | 1 | Packaging |
| Metallic copper | Cosmetics | 29% | 0.6% | 0.05 | Packaging | 1 | Packaging |
| | Food and beverages | 29% | 0.6% | 0.1 | Food | 0.99 | Mixed municipal |
| | | | | | Packaging | 0.01 | Packaging |
| | Engine additive | 14% | 0.3% | 0.05 | Automotive | 1 | ELV |
| | Filters | 10% | 0.2% | 0.7 | Filter | 1 | Mixed municipal |
| | Paints | 4.8% | 0.1% | 0.96 | Walls | 1 | CDW |
| | | 4.8% | 0.1% | 1 | Fridge | 1 | LHA |
| | Welding nozzle | 4.8% | 0.1% | 1 | Welding nozzle | 1 | Metal |
| | Electronics | 4.8% | 0.1% | 1 | Chip | 1 | WEEE |

Table 11: Transfer coefficients of nano copper to waste categories

| | |
|---|---|
| Industrial waste | 34% |
| WEEE | 33% |
| CDW | 12% |
| Boats | 12% |
| Packaging waste | 5.9% |
| Medical waste | 2.9% |
| ELV | 3.0% |
| Mixed waste | 0.8% |
| Metal | 0.1% |

#### 4.2.1.3. Silver

According to Sun et al. (2014), the most significant use of nano Ag is in electronics (38.1%, Table 12). Sufficient data were found for this product category to separate the use in large household appliances (LHA) from the use in other electronics (e.g. consumer electronics or small household appliances). This enabled a better assessment of the waste flows: in contrary to other electronic waste categories, LHA cannot enter a household bin, so they were considered to be all collected separately from mixed waste. The packaging of paints, coatings and water treatment products were considered to not be recycled, as they can contain dangerous products: They were assumed to be treated in the same way as mixed municipal waste.

Table 12: Allocation of nano Ag to applications and waste categories. WEEE: Waste electronic and electrical waste; CDW: Construction and demolition waste; ELV: End-of-life vehicles; LHA: Large household appliances

| Product category | | | Application | | Waste category |
|---|---|---|---|---|---|
| **Name** | **Share** | **EoL release** | **Name** | **Share** | |
| Electronics & Appliances | 38.1% | 0.70 | Electronics | 0.84 | WEEE |
| | | | LHA | 0.16 | LHA |
| Textiles | 25.1% | 0.40 | Textiles | 1.00 | Textiles |
| Cosmetics | 10.2% | 0.05 | Cosmetics | 1.00 | Packaging |
| Food | 6.6% | 0.10 | Food | 1.00 | Packaging |
| Cleaning agents | 6.0% | 0.05 | Cosmetics | 1.00 | Packaging |
| MedTech | 3.6% | 0.95 | Medical waste | 0.41 | Medical waste |
| | | | Contact lenses, wound dressings,… | 0.28 | Mixed municipal |
| | | | Implants | 0.31 | Implants |
| Plastics | 3.3% | 0.20 | Construction | 0.06 | CDW |
| | | | Electronics | 0.02 | WEEE |
| | | | Food containers,… | 0.14 | Plastics |
| | | | Toothbrushes, brushes,… | 0.78 | Mixed municipal |
| Paints | 3.0% | 0.65 | Construction | 0.64 | CDW |
| | | | Electronics | 0.11 | WEEE |
| | | | Plastics | 0.11 | Plastics |
| | | | Watercolor palette | 0.11 | Mixed municipal |
| | | | Packaging | 0.05 | Mixed municipal |
| Metals | 2.4% | 0.95 | Pans, water softener | 1.00 | Mixed municipal |
| Glass & Ceramics | 0.6% | 0.65 | Glass | 0.33 | Glass |
| | | | Construction glass | 0.18 | CDW |
| | | | Electronics | 0.30 | WEEE |
| | | | Residual waste | 0.19 | Mixed municipal |
| Soil remediation | 0.6% | 0.02 | Soil remediation | 1.00 | Packaging |
| Filter | 0.3% | 0.70 | Filter | 1.00 | Mixed municipal |
| Diapers | 0.2% | 0.95 | Diapers | 1.00 | Mixed municipal |
| Paper | 0.1% | 1.00 | Paper | 1.00 | Paper & Cardboard |

The most significant waste categories in which nano silver is collected are electronics (39%), textiles (25%) and packaging (23%) (Table 13).

Table 13: Transfer coefficients of nano Ag to waste categories

| | |
|---|---|
| Electrical and electronic waste | 39% |
| Textiles | 25% |
| Packaging | 23% |
| Mixed municipal | 6.4% |
| Construction and demolition waste | 2.3% |
| Medical waste | 1.5% |
| Implants | 1.1% |
| Plastics | 0.8% |
| Glass | 0.2% |
| Paper & Cardboard | 0.1% |

#### 4.2.1.4. Titanium dioxide

The most important share of $TiO_2$ ENM is cosmetics (Table 14), which explains why it is mostly collected in packaging waste (Table 15).

Construction waste and electronics are also significant waste categories. However, small electronic items such as sprays and mosquito killers were assumed to not be collected separately and to be treated as mixed waste. In the same way, sporting goods consisting in products such as golf clubs and tennis rackets were considered to be treated as mixed municipal waste.

Table 14: Allocation of nano $TiO_2$ to applications and waste categories. WEEE: Waste electronic and electrical waste; CDW: Construction and demolition waste; ELV: End-of-life vehicles; LHA: Large household appliances

| Product category | | | Application | | Waste category |
|---|---|---|---|---|---|
| **Name** | **Share** | **EoL release** | **Name** | **Share** | |
| Cosmetics | 55.6% | 0.05 | Packaging | 1.00 | Plastic packaging |
| Paints | 8.4% | 0.99 | Construction | 0.87 | CDW |
| | | | Automotive | 0.08 | ELV |
| | | | Packaging | 0.05 | Mixed municipal |
| Electronics | 6.5% | 0.70 | Electronics | 0.48 | WEEE |
| | | | Large household appliances | 0.35 | LHA |
| | | | Mosquito killers, sprays,… | 0.17 | Mixed municipal |
| Cleaning agents | 5.8% | 0.05 | Packaging | 1.00 | Plastic packaging |
| Filters | 5.5% | 0.70 | Air conditioners | 1.00 | LHA |
| Plastics | 3.4% | 0.97 | Plastic | 1.00 | Plastic |
| Coatings | 3.5% | 0.65 | Construction | 0.46 | CDW |
| | | | Automotive | 0.24 | ELV |
| | | | Airplanes | 0.01 | Airplanes |
| | | | Textiles | 0.07 | Textiles |
| | | | Packaging | 0.05 | Mixed municipal |
| | | | Electronics | 0.05 | WEEE |
| | | | LHA | 0.04 | LHA |
| | | | Medical instruments | 0.004 | Medical waste |
| | | | Food | 0.03 | Mixed municipal |
| | | | Water treatment | 0.04 | Mixed municipal |
| Glass & Ceramics | 1.6% | 0.65 | Construction | 0.50 | CDW |
| | | | Air purifier | 0.50 | LHA |
| Sport goods | 1.4% | 0.96 | Golf clubs, rackets,… | 0.96 | Mixed municipal |
| | | | Textiles | 0.04 | Textiles |
| WWTP | 6.6% | 0.02 | Packaging | 1.00 | Packaging |
| Batteries | 0.4% | 0.10 | Batteries & Accumulators | 1.00 | Batteries & Accumulators |
| Food | 0.4% | 0.10 | Food | 0.99 | Mixed municipal |
| | | | Packaging | 0.01 | Packaging |
| Textiles | 0.3% | 0.97 | Textiles | 1.00 | Textiles |
| Light bulbs | 0.2% | 1.00 | Lighting equipment | 1.00 | WEEE |
| Spray | 0.2% | 0.05 | Spray | 1.00 | Mixed municipal |
| Metals | 0.1% | 0.95 | Construction | 0.50 | CDW |
| | | | Automotive | 0.50 | ELV |
| Cement | 0.1% | 0.99 | Concrete | 1.00 | CDW |
| Paper | 0.1% | 1.00 | Paper | 1.00 | Paper & cardboard |

Table 15: Transfer coefficients of nano $TiO_2$ to waste categories

| | |
|---|---|
| Packaging | 68% |
| Electrical and electronic waste | 12% |
| Construction and demolition waste | 10% |
| Mixed municipal waste | 3.9% |
| Plastic | 3.4% |
| End-of-Life Vehicles | 1.6% |
| Textiles | 0.6% |
| Batteries & Accumulators | 0.4% |
| Paper & Cardboard | 0.05% |
| Airplanes | 0.03% |
| Medical waste | 0.01% |

#### 4.2.1.5. Zinc oxide

Most of ZnO ENM are used in cosmetics and paints (Table 16). As a result, almost all ZnO ENM are collected in packaging waste (83%) and construction waste (15%) (Table 17). The management of these waste categories will thus determine to a high extent the fate of these particles.

Table 16: Allocation of nano ZnO to applications and waste categories. WEEE: Waste electronic and electrical waste; CDW: Construction and demolition waste

| Product category | | | Application | | Waste category |
|---|---|---|---|---|---|
| Name | Share | EoL release | Name | Share | |
| Cosmetics | 82.6% | 0.05 | Packaging | 1 | Packaging |
| Paints | 14.3% | 0.65 | Construction | 1 | CDW |
| Plastics | 2.0% | 0.2 | Residual and bulky waste | 1 | Mixed municipal |
| Glass | 0.7% | 0.65 | Light equipment | 0.5 | WEEE |
| | | | Construction | 0.5 | CDW |
| Electronics | 0.2% | 0.7 | WEEE | 1 | WEEE |
| Cleaning agent | 0.15% | 0.05 | Packaging | 1 | Packaging |
| Filter | 0.1% | 0.7 | Filter | 1 | Mixed municipal |
| Paper | 0.02% | 1 | Paper & Cardboard | 1 | Paper & Cardboard |
| Textiles | 0.01% | 0.4 | Textiles | 1 | Textiles |
| Wood | 0.01% | 0.7 | Construction | 1 | CDW |
| Food | 0.005% | 0.1 | Packaging | 1 | Packaging |
| Metals | 0.005% | 0.95 | Metals | 1 | Metals |

Table 17: Transfer coefficients of nano ZnO to waste categories

| | |
|---|---|
| Packaging | 83% |
| Construction and demolition waste | 15% |
| Mixed municipal | 2.1% |
| Electrical and electronic waste | 0.6% |
| Paper & Cardboard | 0.02% |
| Textiles | 0.01% |
| Metals | 0.01% |

#### 4.2.2. Flows to waste treatment

The identification of the waste categories in which the ENM are present, the data collection which allowed the spatial distribution of production, manufacture and consumption among the European countries as well as the use of country-specific waste management data enabled the assessment of the ENMs mass flows to environmental and technical compartments (Appendix 6). As mentioned earlier, part of these flows, namely the flows of the ENM out of recycling to the environmental and waste treatment compartments as well as those from incineration and landfilling to the environment will be assessed in future work: the masses entering all compartments except recycling are due to change when this step of the work is completed. It is consequently more interesting to discuss in this report the shares of ENM entering landfilling, incineration and recycling, as they already give a good approximation of the expected sources of releases.

Construction waste was assumed to be all collected for sorting and recycling. Consequently, it enters the recycling compartment and the flows of ENMs from construction waste to landfills are null at this stage of the work. The export of waste was assumed negligible at this stage of the work: the collected wastes collected separately are exported after entering the sorting plants, and no data could be found on the export of mixed municipal waste. Consequently, three waste flows remain: to reactive landfills, to incineration and to sorting/recycling plants. The shares of the flows between these three compartments will be discussed in the next sections: 100% represents the sum of landfilling, incineration and recycling (Appendix 7).

Overall, recycling is the most significant waste treatment. This is partly explained by the European legislation, which requires high rates of recycling to all Member States. Specific regulations exist regarding most of the waste categories. This fact is enhanced by the way in which the recycling compartment has been defined in this work: it includes all waste separately collected, but this waste is not necessarily be actually reprocessed into new materials. Therefore, the share of recycled waste is expected to drop after assessing the flows out of this process towards landfilling and incineration.

Among the ENM, Cu, $TiO_2$ and ZnO present shares equal to or higher than 85% of recycling. This is due to the waste categories in which they occur: Industrial, packaging, construction and electronic waste present high rates of separate collection. On the other hand, Ag presents the lowest share of recycling, because of the high fraction of consumption in textiles: This waste category is very poorly collected in some countries, such as Greece or Spain.

Geographically distributed data = …

#### 4.2.2.1. Carbon black

Carbon black ENM show relatively homogeneous waste streams across the European countries (Figure 14 and Appendix 7A). The recycling rates vary over a range of 20%: The UK recycles 55% of its carbon black waste while Switzerland recycles 75%. Incineration and landfilling rates vary between 0% (Cyprus, France, Latvia, Lithuania, Malta, Slovenia, Romania, and Switzerland, respectively) and around 30 % (Denmark and Greece, Lithuania, respectively). These homogeneous results are explained by the fact that 70% of carbon black is used in tires, which are all assumed to enter recycling plants, in all countries.

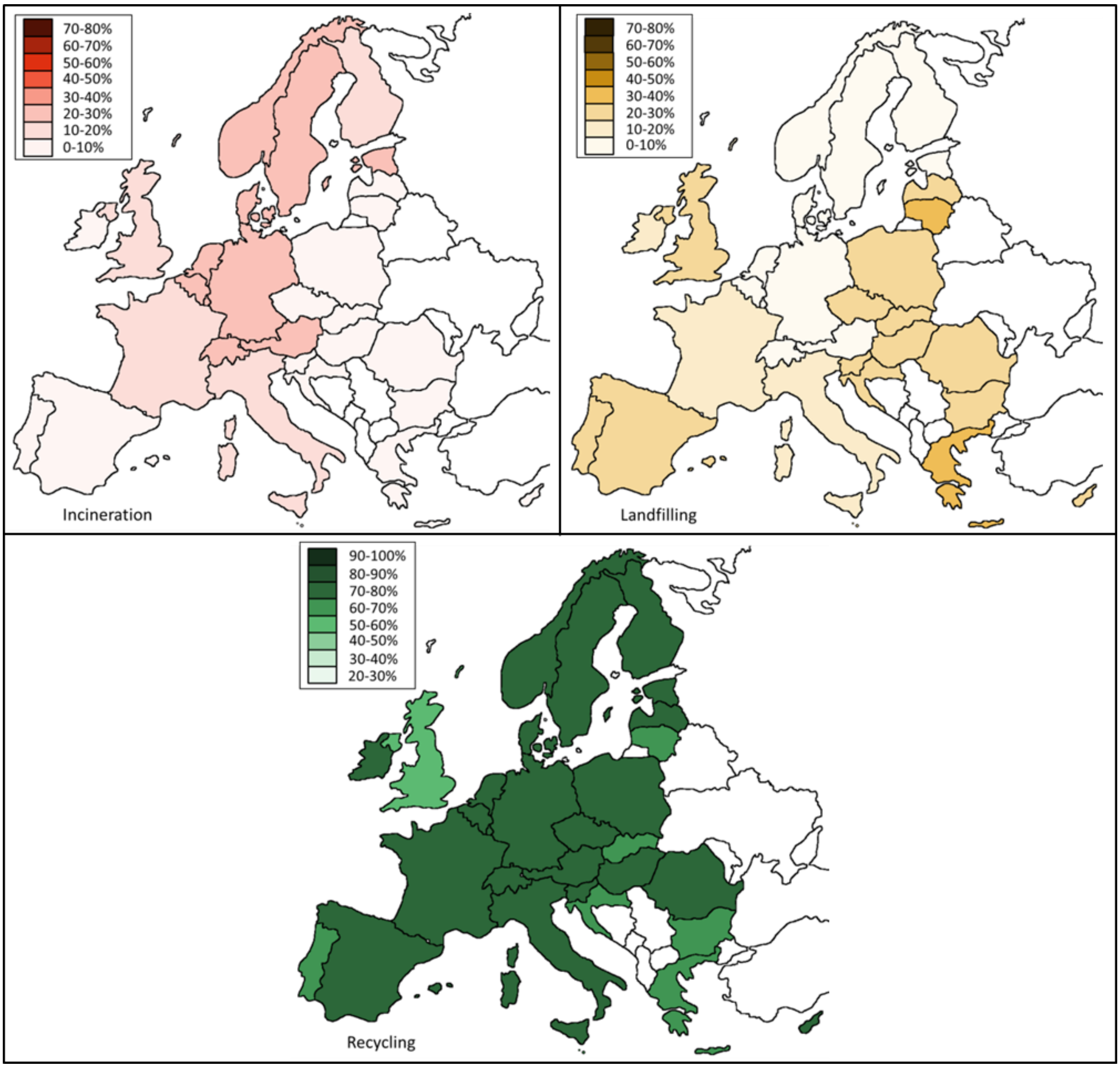



Figure 14: Carbon black ENM waste stream shares of landfilling, incineration and recycling in European countries

#### 4.2.2.2. Copper

Very low shares of Cu ENM directly enter incineration plants (Figure 15 and Appendix 7B): Most countries incinerate most than 10% of this waste. Nine countries show recycling rates higher than 90%. The highest shares occur in Finland and Austria (96%). The lowest share is attributed to Romania (52%), which landfills almost all of the remaining waste (48%).

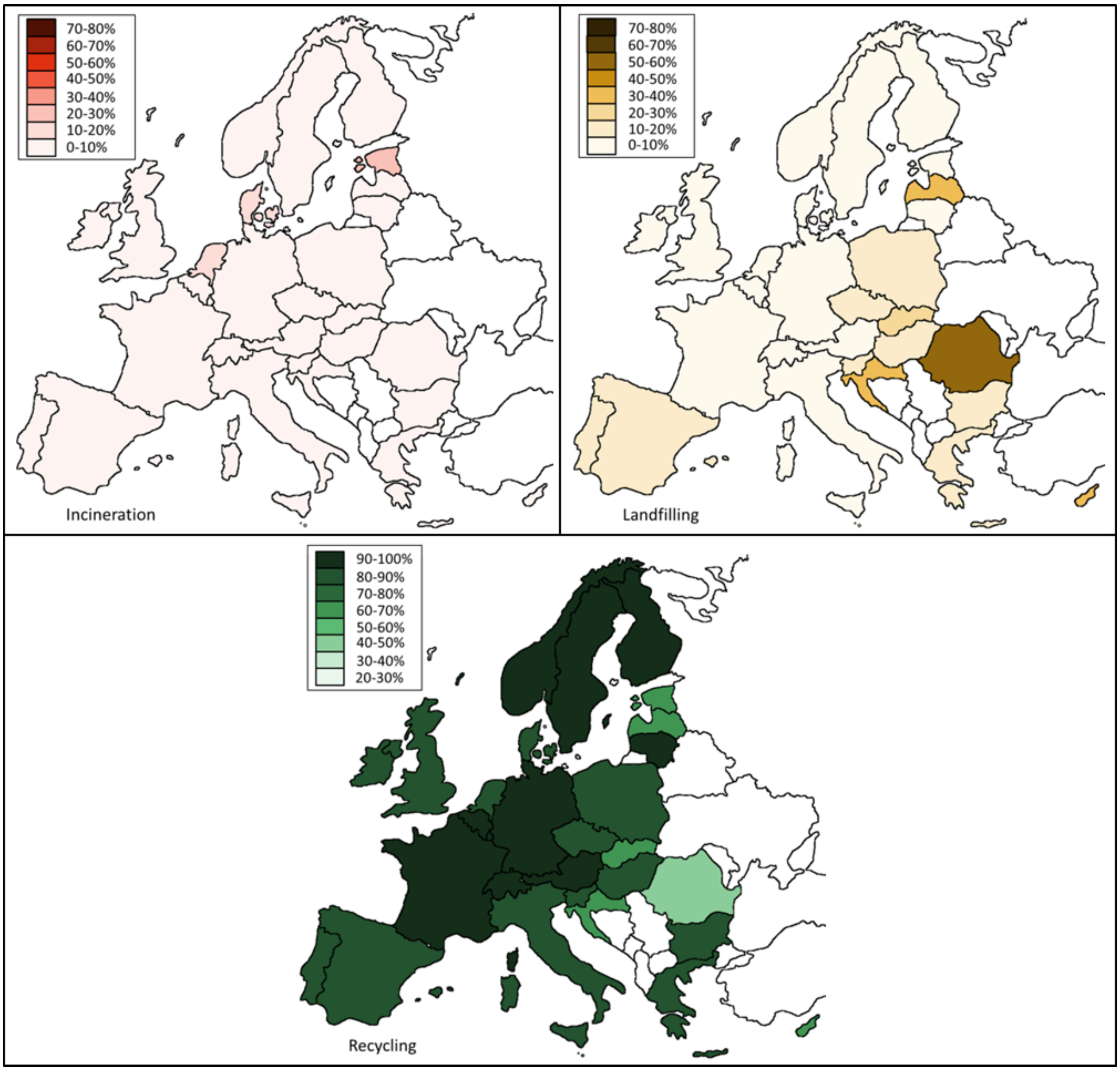



Figure 15: Cu ENM waste stream shares of landfilling, incineration and recycling in European countries

#### 4.2.2.3. Silver

The highest shares of Ag waste recycling were found in Germany and Belgium (75%; Figure 16 and Appendix 7C). Both these countries incinerate the remaining waste more than they landfill it. Romania presents the lowest share of nano Ag recycling (22%). Most of this waste is landfilled in this country (74%). Latvia and Croatia also present very high shares of landfilling (59 and 60%, respectively). The highest shares of incineration occur in Estonia and the Netherlands (53% and 46%, respectively).

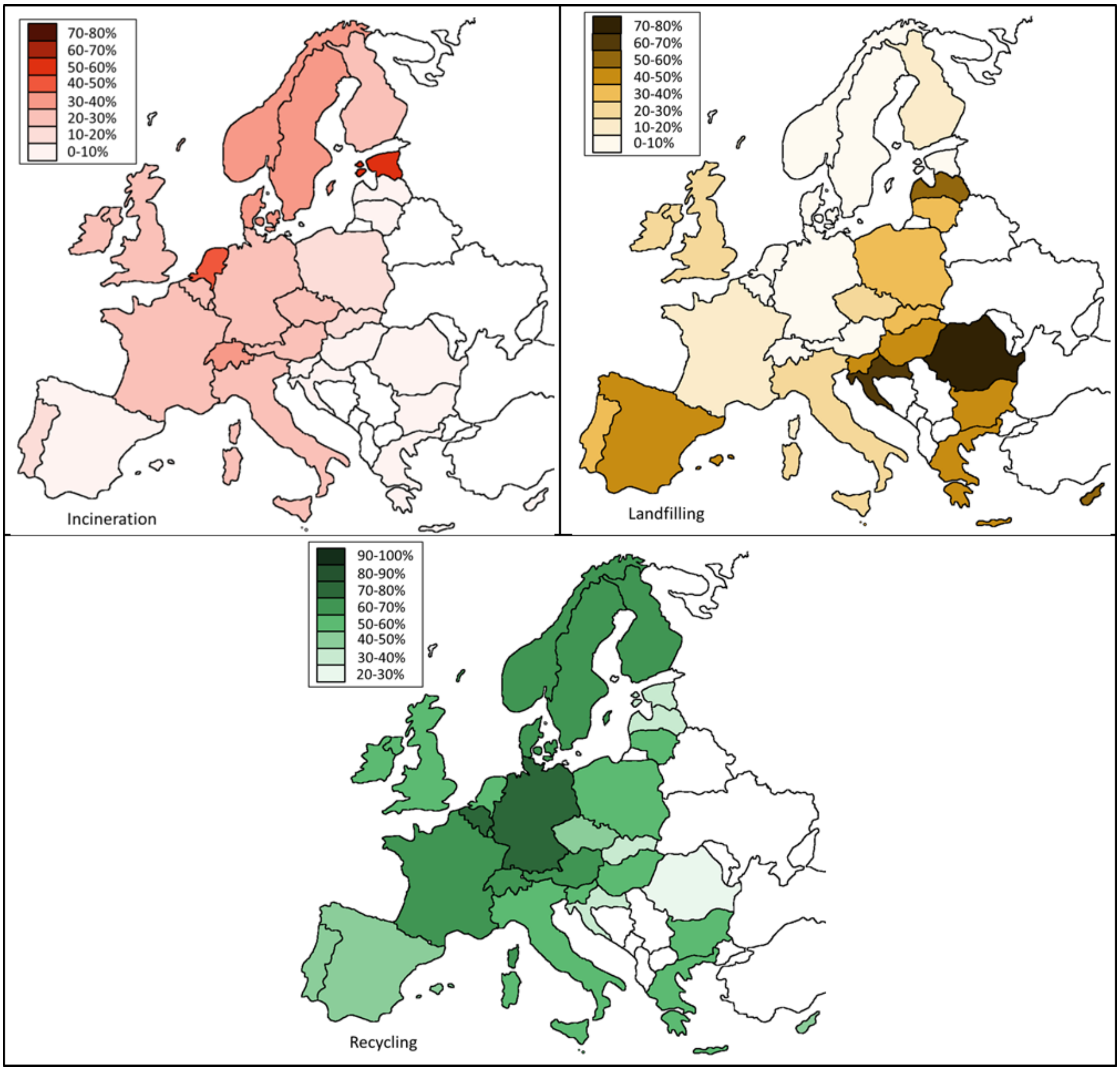



Figure 16: Ag ENM waste stream shares of landfilling, incineration and recycling in European countries

#### 4.2.2.4. Titanium dioxide

The highest shares of recycling occur in Switzerland and Luxembourg (70 to 80%, Figure 17 and Appendix 7D). These countries present very low shares of landfilling (0 and 0.5%, respectively): the remaining waste in incinerated. On the opposite side of the scale, Romania, Croatia and Latvia show among the lowest shares of recycling (67%, 67% and 68%, respectively) and the highest shares of landfilling (33%, 32% and 32%, respectively). Almost no waste is incinerated in these countries. The other countries showing low shares of recycling are Estonia (68%), the Netherlands (68%) and Hungary (69%). The Netherlands and Estonia incinerate most of the remaining waste, while Hungary mostly sends it to landfills.

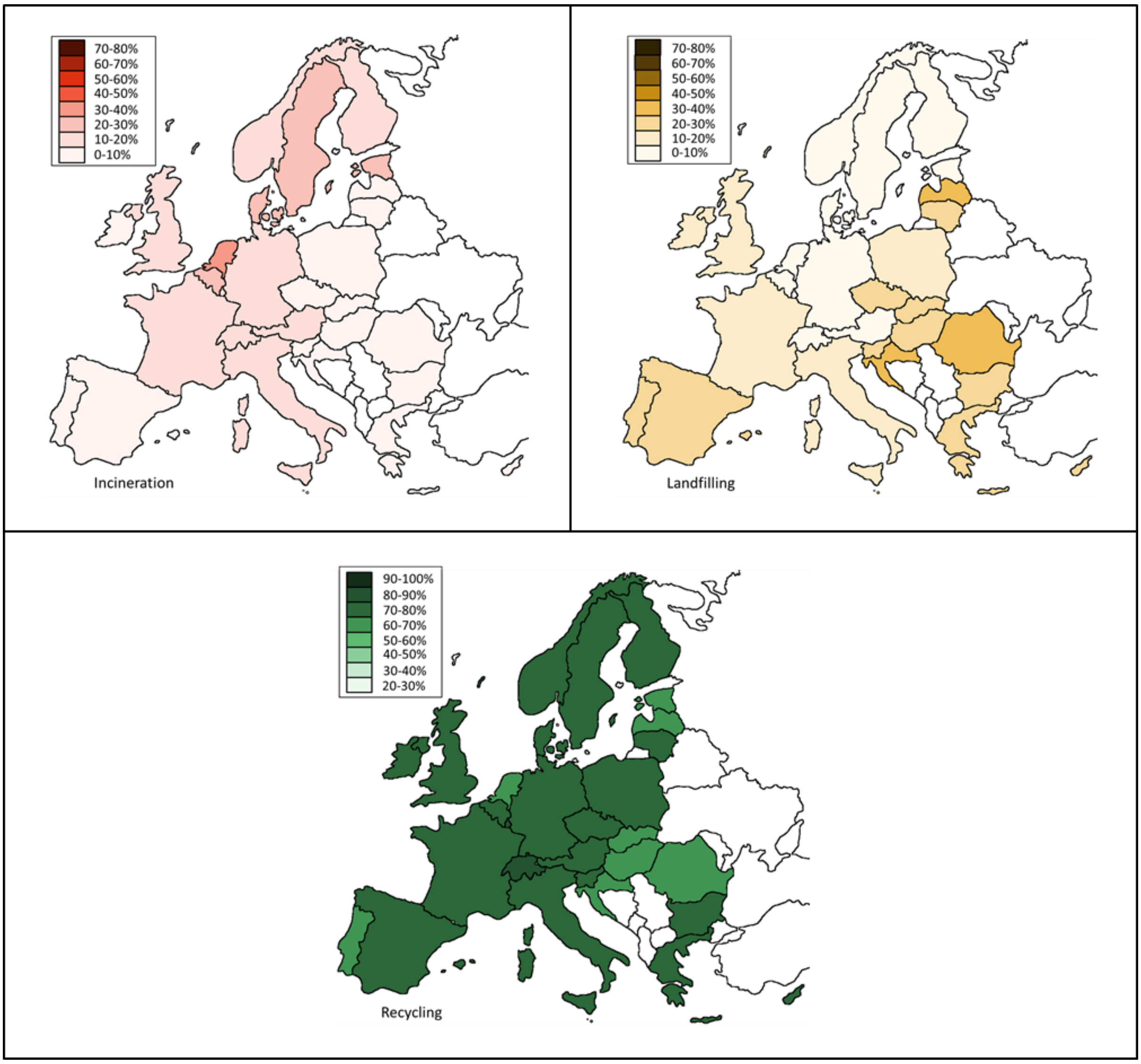



Figure 17: $TiO_2$ ENM waste stream shares of landfilling, incineration and recycling in European countries

#### 4.2.2.5. Zinc oxide

The highest recycling shares of nano ZnO waste are attributed to Finland (96%), Sweden (94%), Switzerland (94%), Ireland (93%), Germany (92%), Belgium (91%) and Italy (90%) (Figure 18 and Appendix 7E). These countries present comparable shares of nano ZnO landfilling and incineration. Czech Republic, Hungary, Spain, Portugal and Romania present the lowest shares of recycling (75%, 75%, 75%, 75% and 77%, respectively); they all mostly landfill the remaining waste.

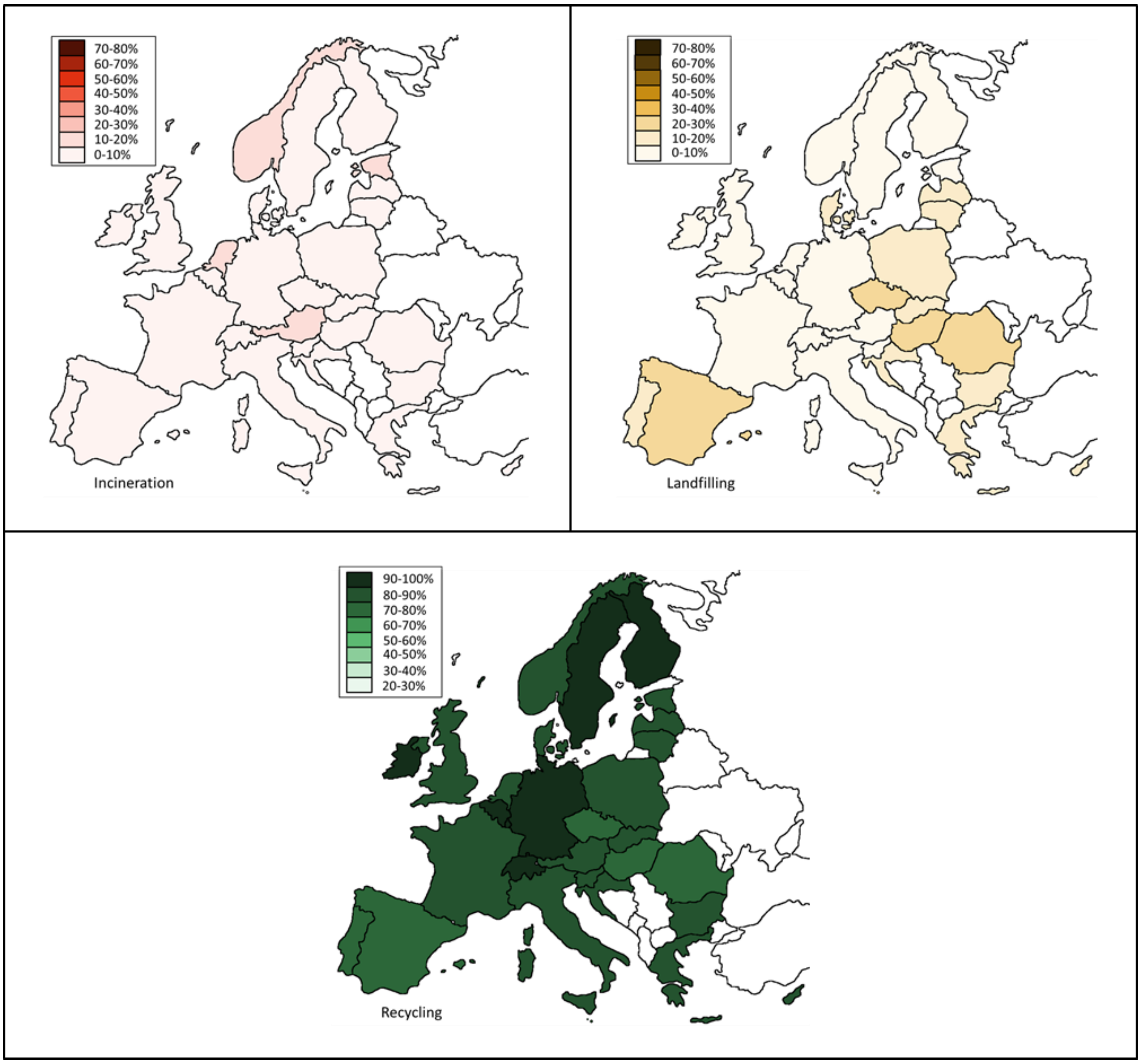



Figure 18: ZnO ENM waste stream shares of landfilling, incineration and recycling in European countries

# 5. DISCUSSION

This report presents a first country-specific ENM release model for production, manufacturing and consumption for 5 different ENMs across Europe, including the different applications. The main goal of this country specific assessment is to provide information where the ENM end up in waste management processes. Such knowledge is crucial to understand and improve the ENM release to the environment from such processes in Europe. A next step in the NanoFASE project is to go from countries as a whole to specific points or grid cells where waste treatment based release takes place.

In this study, we have chosen to start from an estimate of the total of ENMs produced in Europe, and implicitly assumed that these ENMs are also manufactured (incorporated in products) and subsequently used in Europe. These ENMs are then distributed over various applications and the countries, after which release factors are applied to assess the environmental releases.

During this process, major uncertainties come in at various stages, including:

- The study starts from an estimate of the total production of each ENM in Europe. This report shows that this number is rather uncertain for most ENMs, different estimates in literature being several orders of magnitude apart are not uncommon. This starting value may be the largest uncertainty.
- The assumption that whenever the production of an ENM takes place in Europe, also the manufacturing and consumption take place within the European borders (here constituted by the EU28 countries plus Norway and Switzerland). In practice however, import and export of produced nanomaterials and also manufactured products incorporating nanomaterials will likely take place between the EU and other regions in the world (e.g. East Asia, North America, etc.)
- The distribution of production, manufacturing and consumption to the individual product categories and the individual countries is done using proxy parameters, since no actual data are available on the split. In addition, the allocation of each product category to product applications does not account for the weight of the ENM in the products.
- The quality of the data on waste collection and treatment is poor for some countries. For 16 countries, data had to be taken from other countries. Sometimes this applied to only one waste category (such as Germany and Belgium), while for other countries such as Slovakia and Hungary, the management of almost all waste categories had to be approximated.
- Finally, for the estimation of the releases of ENMs from the various applications available information from literature sources is used, which is complemented by expert judgement. These releases are also subject to distinct uncertainties.

It is important that these uncertainties are taken into account when the data presented in this report are used. It should be stressed that this is a first version of the ENM release model at the level of individual European countries, and during the course of the NanoFASE project work will continue to further improve and refine this ENM flow inventory. In this study the aim was to build on existing information and publications, rather than to repeat the work. However, in some cases the information sources available were contradicting each other, and a choice had to be made. For instance, in the case of copper, further discussion and research is needed to better understand the products in which copper and copper oxide ENMs are used.

# 6. CONCLUSION AND NEXT STEPS

This report describes a first version of a European wide country ENM release model for 5 different ENMs: $TiO_2$, ZnO, silver, copper (consisting of both elemental copper and copper oxide) and carbon black. The model provides for each stage, application and European country an estimate of the flow of ENMs and the releases to the environment. In addition, improved release factors and end-of-life pathways for the different ENMs are presented. Constant lifecycle parameters were broken down on a current one year release period, assuming that what has been emitted in previous years and eliminated again in the same years is likely to compensate each other. All of these have significant uncertainties, mostly resulting from a poor availability of data on actual production, use and releases of ENMs. The estimates presented in this report are mainly based on literature sources and expert judgements.

With this first version of the ENM release model at country level, the work is not completed. During the remainder of the NanoFASE project, work will continue to further improve the inventory and the quantification of releases to the environment.

- First, further work is needed to refine the currently used factors to split ENMs to different applications, for instance for copper. Also, the release factors may be further improved. This is clearly something requiring further discussion between the NanoFASE partners and other experts in the field, which will be taken up in the next phase of the project.
- Another issue which will be addressed in the next phase is the uptake of the updated information on release factors and end-of-life pathways as presented in Section 4.2 with the country specific PMC results shown in Section 4.1. This will not only lead to an improved ENM release model but also ensure harmonization between the different models which are used in the NanoFASE project.
- Another issue which will be addressed as further work is the flows of ENMs coming from recycling and other end-of-life pathways, and how these flows feed back into the manufacturing and/or use phase of ENMs. This will further improve the release model developed in NanoFASE WP4.
- Finally, this inventory will be used as the basis for a high resolution spatially distributed model of ENM releases, which will be used as input for the ENM fate modellers in the NanoFASE project. The exact scope and format of this model is to be discussed further in the next months.

# 7. REFERENCES

Allied Market Research (2016). Europe Nanomaterials Market: Trends, Share, Opportunities and Forecasts 2014 - 2022.

Boxall A.B.A., Chaudhry Q., Sinclair C., Jones A.D. and Aitken R. (2007): Current and future predicted environmental exposure to engineered nanoparticles; Central Science Laboratory, Sand Hutton, UK.

BRITISH GEOLOGICAL SURVEY, 2016. European mineral statistics 2010–14. Keyworth, Nottingham: British Geological Survey.

Caballero-Guzman, A., Sun, T., Nowack, B., 2015. Flows of engineered nanomaterials through the recycling process in Switzerland. Waste Manag. 36, 33–43. doi:10.1016/j.wasman.2014.11.006

Caballero-Guzman, Nowack, B., (2017), Flows of nanomaterials into the environment released from four specific applications during their life cycle: do they influence the entire system? In prepraration.

Ceresana. 2013. Market Study: Carbon Black (UC-5605). Ceresana Market Intelligence Consulting. http://www.ceresana.com/en/market-studies/chemicals/carbon-black/

EPA U. (2009) External Review Draft - Nanomaterial Case Studies: Nanoscale Titanium Dioxide in Water Treatment and in Topical Sunscreen. National Center for Environmental Assessment, Office of Research and Development, U.S. Environmental Protection Agency; Research Triangle Park, NC: p. 222. EPA/600/R-09/057.

ESIG (2015), Solvent VOC Emissions Inventories Position Paper – June 2015. European Solvents Industry Group. http://www.esig.org/layout/uploads/2016/09/voc-inventory-esvoc-position-paper-2015.pdf

European Commission (2012), Types and uses of nanomaterials, including safety aspects. Accompanying the Communication from the Commission to the European Parliament, the Council and the European Economic and Social Committee on the Second Regulatory Review on Nanomaterials, Staff working document.

European Commission, Joint Research Centre, Institute for Environment and Sustainability (2010). International Reference Life Cycle Data System (ILCD) Handbook - General guide for Life Cycle Assessment - Detailed guidance.

Eurostat (2017), PRODCOM database with statistics on the production of manufactured goods in Europe. http://ec.europa.eu/eurostat/web/prodcom. Accessed 20 January 2017.

Future Markets (2012), The global market for nanomaterials 2002–2006: production volumes, revenues and end use markets.

Giese, B., Wigger, H., Steinfeldt, M., von Gleich, A., Gottschalk, F., in prep. Dynamics of Environmental Releases and Concentrations of Engineered Nanomaterials in Germany

Global Insight (2007), A study of the European Cosmetics Industry. Final Report prepared for European Commission, DG Enterprise and Industry, October 2007. http://ec.europa.eu/DocsRoom/documents/13125/attachments/1/translations/en/renditions/native

Gottschalk F., Sonderer T., Scholz R.W. and Nowack B. (2009): Modelled environmental concentrations of engineered nanomaterials ($TiO_2$, ZnO, Ag, CNT, fullerenes) for different regions. Environmental Science and Technology, 43, 9216-9222.

Gottschalk F., R. W. Scholz, and B. Nowack (2010) "Probabilistic material flow modeling for assessing the environmental exposure to compounds: Methodology and an application to engineered nano-TiO2 particles," Environ. Model. Softw., vol. 25, no. 3, pp. 320–332.

Gottschalk, F., Ort, C., Scholz, R.W., Nowack, B. (2011). Engineered nanomaterials in rivers – exposure scenarios for Switzerland at high spatial and temporal resolution. Environmental Pollution 159, 3439-3445.

Gotttschalk F., Kost E. and Nowack B. (2013a). Engineered nanomaterials in water and soils: A risk quantification based on probabilistic exposure and effect modelling. Environmental Toxicology and Chemistry 2013, 32, (6), 1278-1287.

Gottschalk F., Sun T. and Nowack B. (2013b). Environmental concentrations of engineered nanomaterials: Review of modelling and analytical studies. Environmental Pollution 2013, 181, (0), 287-300.

Gottschalk, F.; Lassen, C.; Kjoelholt, J.; Christensen, F.; Nowack, B. (2015). Modeling Flows and Concentrations of Nine Engineered Nanomaterials in the Danish Environment. Int. J. Environ. Res. Public Health 2015, 12, 5581-5602.

Gottschalk, F.; Nowack, B.; Lassen, C.; Kjølholt, J.; Christensen, F. (2015) Nanomaterials in the Danish Environment. Modelling Exposure of the Danish Environment to Selected Nanomaterials. Environmental Project No. 1639, 2015 from the Danish Environmental Protection Agency. Available online: http://www2.Mst.Dk/udgiv/publications/2015/01/978-87-93283-60-2.Pdf (accessed on 18 May 2015).

Hedbrant, J., Sörme, L. (2001). Data Vagueness and Uncertainties in Urban Heavy-Metal Data Collection. Water Air Soil Pollut. Focus 1, 43–53. doi:10.1023/A:1017591718463

Holden, P. A., Klaessig, F., Turco, R. F., Priester, J. H., Rico, C. M., Avila-Arias, H., Mortimer, M., Pacpaco, K. & Gardea-Torresdey, J. L. (2014). Evaluation of exposure concentrations used in assessing manufactured nanomaterial environmental hazards: are they relevant?. Environmental science & technology, 48(18), 10541-10551.

IARC (2010), IARC Monographs on the evaluation of carcinogenic risks to humans Volume 93: Carbon black, Titanium dioxide and Talc. World Health Organisation, International Agency for Research on Cancer, https://monographs.iarc.fr/ENG/Monographs/vol93/mono93.pdf

Kammer F. von der, Ferguson P.L., Holden P.A., Masion A., Rogers K.R., Klaine S.J., Koelmans A.A., Horne N., Unrine J.M. (2012). Analysis of engineered nanomaterials in complex matrices (environment and biota): General considerations and conceptual case studies. Environmental Toxicology and Chemistry 2012, 31, (1), 32-49.

Keller A.A., S. McFerran, A. Lazareva, and S. Suh (2013), Global life cycle releases of engineered nanomaterials, J. Nanoparticle Res., vol. 15, no. 6, 2013.

Laner, D., Rechberger, H., Astrup, T. (2015). Applying Fuzzy and Probabilistic Uncertainty Concepts to the Material Flow Analysis of Palladium in Austria. J. Ind. Ecol. 19, 1055–1069. doi:10.1111/jiec.12235

Nanotechnology Products Database.” [Online]. Available: http://product.statnano.com/. Accessed February 2017.

Nanowerk (2012), New study shows that titanium dioxide nanoparticles are ubiquitous in food products, http://www.nanowerk.com/spotlight/spotid=24290.php

NANOWERK PRODUCT CATALOG.” [Online]. Available: http://nanowerk.com/nanocatalog/. Accessed February 2017.

Piccinno, F.; Gottschalk, F.; Seeger, S.; Nowack, B., Industrial production quantities and uses of ten engineered nanomaterials in Europe and the world. J Nanopart Res 2012, 14, (9), 1-11.

PlasticsEurope (2014), Plastics – the facts 2014/2015. Analysis of European Plastics production, demand and waste data. http://www.plasticseurope.org/cust/documentrequest.aspx?DocID=62506

Project on Emerging Nanotechnologies.” [Online]. Available: http://www.nanotechproject.org/. Accessed February 2017.

Ricardo (2016), Ricardo Energy & Environment, Support for 3rd regulatory review on nanomaterials: Interim/background Report. WORKSHOP WORKING MATERIAL Report for European Commission DG Environment, ENV.A.3/ETU/2015/0030

Sun, T. Y., Bornhöft, N. A., Hungerbühler, K., & Nowack, B. (2016). Dynamic probabilistic modeling of environmental emissions of engineered nanomaterials. Environmental science & technology, 50(9), 4701-4711.

Sun, T.Y., Gottschalk, F., Hungerbühler, K., Nowack, B., 2014. Comprehensive probabilistic modelling of environmental emissions of engineered nanomaterials. Environ. Pollut. 185, 69–76. doi:10.1016/j.envpol.2013.10.004

TDMA (2010): Industry responds to Nano-TiO2 study published in American Association for Cancer Research Journal. http://www.cefic.org/Documents/Industry%20sectors/Industry-responds-to-Nano-TiO2-study-published-in-American-Association-for-Cancer-Research-Journal.pdf

THE NANODATABASE.” [Online]. Available: http://nanodb.dk/en/. Accessed February 2017.

Turner, D.A., Williams, I.D., Kemp, S. (2015). Greenhouse gas emission factors for recycling of source-segregated waste materials. Resour. Conserv. Recycl. 105, Part A, 186–197. doi:10.1016/j.resconrec.2015.10.026

Vílchez A., E. Fernández-Rosas, D. González-Gálvez, and S. Vázquez Campos (2015), “Nanomaterials release from nano-enabled products,” in Indoor and Outdoor Nanoparticles: Determinants of Release and Exposure Scenarios, 1st ed., M. Viana, Ed. Springer International Publishing Switzerland 2015.

Walser, T., Gottschalk, F. (2014), Stochastic fate analysis of engineered nanoparticles in incineration plants. Journal of Cleaner Production. 80, 241-251.

Weidema, B.P., Wesnæs, M.S. (1996). Data quality management for life cycle inventories—an example of using data quality indicators. J. Clean. Prod. 4, 167–174. doi:10.1016/S0959-6526(96)00043-1

Weir, A., Westerhoff, P., Fabricius, L., & von Goetz, N. (2012). Titanium Dioxide Nanoparticles in Food and Personal Care Products. Environmental Science & Technology, 46(4), 2242–2250. http://doi.org/10.1021/es204168d

**Appendix 1: Smelter and refined copper production volumes distribution per country, and derived distribution of nano-CuO and nano-$Cu^0$ production per country**

| COUNTRY (ISO3) | SMELTER Cu (1000 ton) | REFINED Cu (1000 ton) | PRODUCTION VOLUMES DISTRIBUTION (%) | nano-CuO (ton) | nano-$Cu^0$ (ton) |
|---|---|---|---|---|---|
| AUT | | 83.2 | 1.85 | 0.83 | 0.018 |
| BEL | | 387.3 | 8.60 | 3.87 | 0.086 |
| BGR | 305 | 234 | 11.97 | 5.39 | 0.12 |
| CYP | | 3.088 | 0.07 | 0.03 | 1 |
| CZE | | | | | |
| DEU | 351.1 | 676.9 | 22.84 | 10.28 | 0.228 |
| DNK | | | | | |
| ESP | 294.1 | 418.5 | 15.83 | 7.12 | 0.158 |
| EST | | | | | |
| FIN | 146.542 | 146.542 | 6.51 | 2.93 | 0.065 |
| FRA | | | | | |
| GBR | | | | | |
| GRC | | | | | |
| HRV | | | | | |
| HUN | | | | | |
| IRL | | | | | |
| ITA | | 7.9 | 0.18 | 0.08 | 2 |
| LTU | | | | | |
| LUX | | | | | |
| LVA | | | | | |
| MLT | | | | | |
| NLD | | | | | |
| POL | 503.111 | 576.876 | 23.99 | 10.8 | 0.24 |
| PRT | | | | | |
| ROU | | | | | |
| SVK | | | | | |
| SVN | | | | | |
| SWE | 150 | 217.337 | 8.16 | 3.67 | 0.082 |

## Appendix 2: Release factors adopted for this inventory, per ENM, stage and application

| ENM | Stage | Application | Municipal waste water system | Surface water | Air | Soil | Waste incineration | Landfill | Recycling | Export | Other waste management | Transformation into other forms | Source / Comments |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $TiO_2$ | Production | | 0.5% | | 0.5% | | | | | | | | Gottschalk and Nowack (2011) report 0-2% release during production (1% assumed as average) split equally over air and surface water |
| | Manufacturing | Sunscreens | 2.0% | | 0.0% | | 1.0% | | | | 2.0% | | From Gottschalk et al. (2015b), photostable $TiO_2$ release during production of cosmetics |
| | | Cosmetics | 2.0% | | 0.0% | | 1.0% | | | | 2.0% | | |
| | | Paints | 0.3% | 0.3% | | | 2.0% | | | | | | From Gottschalk et al. (2015b), photostable $TiO_2$ release during production of pigments, paints, lacquers and adhesives |
| | | Electronics and appliances | 0.3% | 0.3% | | | 2.0% | | | | | | |
| | | Cleaning agents | 0.3% | 0.3% | | | 2.0% | | | | | | |
| | | Filters | 0.3% | 0.3% | | | 2.0% | | | | | | |
| | | Plastics | 0.3% | 0.3% | | | 2.0% | | | | | | |
| | | Coatings | 0.3% | 0.3% | | | 2.0% | | | | | | |
| | | Glass and ceramics | 0.3% | 0.3% | | | 2.0% | | | | | | |
| | | Sporting goods | 0.3% | 0.3% | | | 2.0% | | | | | | |
| | | Waste water treatment | 0.3% | 0.3% | | | 2.0% | | | | | | |
| | | Batteries | 0.3% | 0.3% | | | 2.0% | | | | | | |
| | | Food | 0.3% | 0.3% | | | 2.0% | | | | | | |
| | | Textiles | 0.3% | 0.3% | | | 2.0% | | | | | | |
| | | Light bulbs | 0.3% | 0.3% | | | 2.0% | | | | | | |
| | | Spray | 0.3% | 0.3% | | | 2.0% | | | | | | |
| | | Metals | 0.3% | 0.3% | | | 2.0% | | | | | | |
| | | Cement | 0.3% | 0.3% | | | 2.0% | | | | | | |
| | | Ink | 0.3% | 0.3% | | | 2.0% | | | | | | |
| | | Paper | 0.3% | 0.3% | | | 2.0% | | | | | | |
| | Consumption | Sunscreens | 85.5% | 9.5% | | | 1.3% | 1.8% | 2.0% | | | | Directly from Gottschalk et al. (2015b) |
| | | Cosmetics | 85.5% | 9.5% | | | 1.3% | 1.8% | 2.0% | | | | |
| | | Paints | 0.5% | | 0.3% | 0.3% | | 29.7% | 69.3% | | | | |
| | | Electronics and appliances | 30.0% | | | | 3.5% | 7.0% | 45.5% | 14.0% | | | |

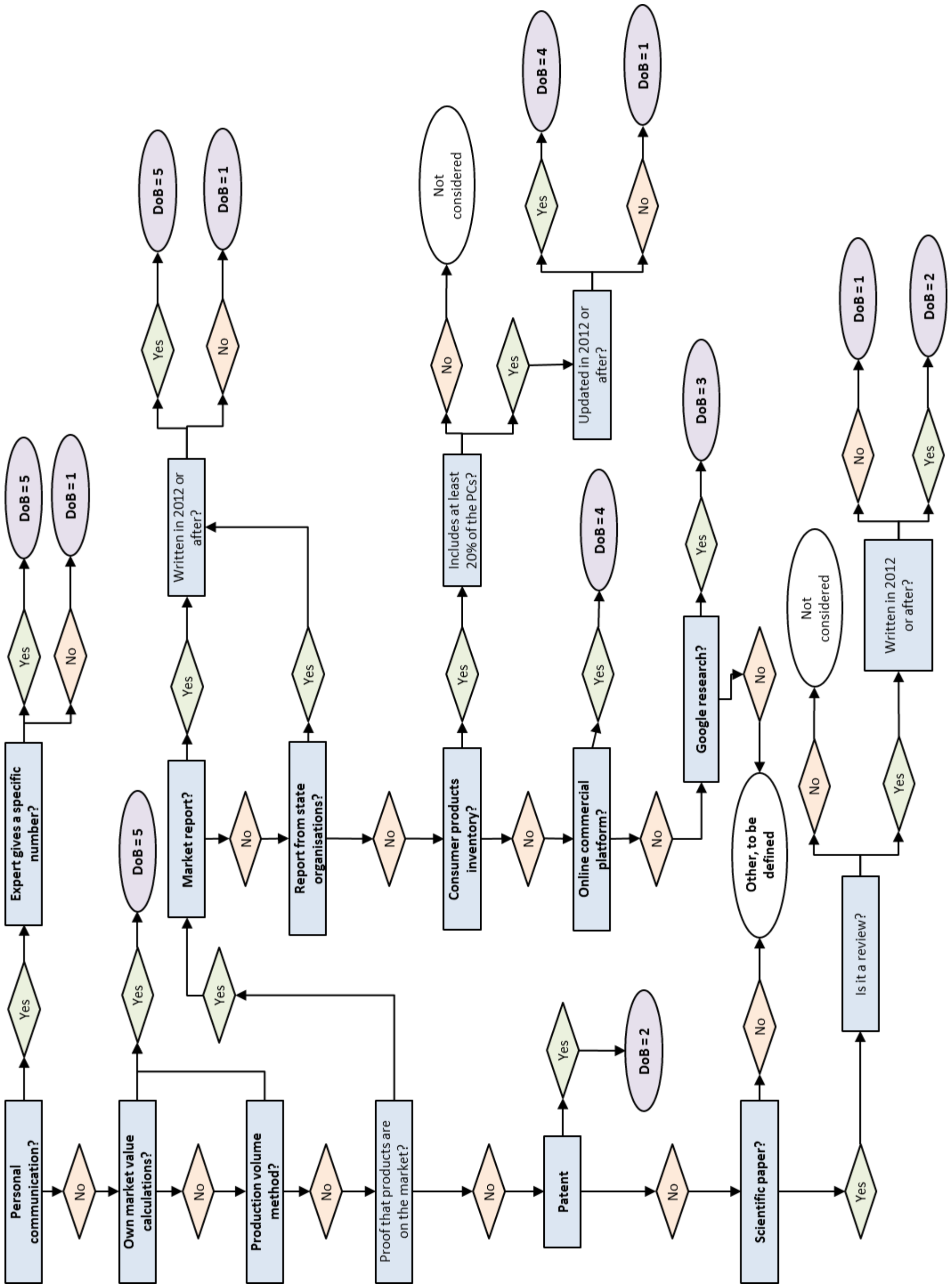
| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | **Cleaning agents** | 95.0% | | | | 1.3% | 1.8% | 2.0% | | | | |
| | | **Filters** | 24.0% | | 6.0% | | 3.5% | 7.0% | 45.5% | 14.0% | | | |
| | | **Plastics** | 3.0% | | | | 24.3% | 34.0% | 38.8% | | | | |
| | | **Coatings** | 28.0% | | 3.5% | 3.5% | 16.3% | 22.8% | 26.0% | | | | |
| | | **Glass and ceramics** | 35.0% | | | | 6.5% | 13.0% | 45.5% | | | | |
| | | **Sporting goods** | 2.8% | | 1.2% | | 24.0% | 33.6% | 38.4% | | | | |
| | | **Waste water treatment** | 98.0% | | | | 0.8% | 1.2% | | | | | |
| | | **Batteries** | | | | | 30.0% | 45.0% | 25.0% | | | | |
| | | **Food** | 90.0% | | | | 4.0% | 6.0% | | | | | |
| | | **Textiles** | 2.4% | | 0.6% | | 6.8% | 30.1% | 27.2% | 33.0% | | | |
| | | **Light bulbs** | | | | | 25.0% | 35.0% | 40.0% | | | | |
| | | **Spray** | 85.5% | | 9.5% | | 1.3% | 1.8% | 2.0% | | | | |
| | | **Metals** | 5.0% | | | | 1.9% | 2.9% | 90.3% | | | | |
| | | **Cement** | 1.0% | | | | | 29.7% | 69.3% | | | | |
| | | **Ink** | | | | | 3.0% | 7.0% | 70.0% | 20.0% | | | |
| | | **Paper** | | | | | 3.0% | 7.0% | 70.0% | 20.0% | | | |
| **ZnO** | **Production** | | 0.5% | | 0.5% | | | | | | | | Gottschalk and Nowack (2011) report 0-2% release during production (1% assumed as average) split equally over air and surface water |
| | **Manufacturing** | **Sunscreens** | 2.0% | | 0.0% | | 1.0% | | | | 2.0% | | From Gottschalk et al. (2015b), photostable $TiO_2$ release during production of cosmetics |
| | | **Cosmetics** | 2.0% | | 0.0% | | 1.0% | | | | 2.0% | | |
| | | **Paints** | 0.3% | 0.3% | | | 2.0% | | | | | | From Gottschalk et al. (2015b), photostable $TiO_2$ release during production of pigments, paints, lacquers and adhesives |
| | | **Plastics** | 0.3% | 0.3% | | | 2.0% | | | | | | |
| | | **Glass** | 0.3% | 0.3% | | | 2.0% | | | | | | |
| | | **Electronics and appliances** | 0.3% | 0.3% | | | 2.0% | | | | | | |
| | | **Filters** | 0.3% | 0.3% | | | 2.0% | | | | | | |
| | | **Cleaning agents** | 0.3% | 0.3% | | | 2.0% | | | | | | |
| | | **Food** | 0.3% | 0.3% | | | 2.0% | | | | | | |
| | | **Textiles** | 0.3% | 0.3% | | | 2.0% | | | | | | |
| | | **Metals** | 0.3% | 0.3% | | | 2.0% | | | | | | |
| | | **Wood** | 0.3% | 0.3% | | | 2.0% | | | | | | |
| | | **Paper** | 0.3% | 0.3% | | | 2.0% | | | | | | |
| | **Consumption** | **Sunscreens** | 85.5% | 9.5% | | | 1.3% | 1.8% | 2.0% | | | | Directly from Gottschalk et al. (2015b) |
| | | **Cosmetics** | 85.5% | 9.5% | | | 1.3% | 1.8% | 2.0% | | | | |
| | | **Paints** | 17.5% | | 8.8% | 8.8% | | 19.5% | 45.5% | | | | |
| | | **Plastics** | 80.0% | | | | 5.0% | 7.0% | 8.0% | | | | |

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Glass | 35.0% | | | | 6.5% | 13.0% | 45.5% | | | | |
| | | Electronics and appliances | 30.0% | | | | 3.5% | 7.0% | 45.5% | 14.0% | | | |
| | | Filters | 24.0% | | 6.0% | | 3.5% | 7.0% | 45.5% | 14.0% | | | |
| | | Cleaning agents | 95.0% | | | | 1.3% | 1.8% | 2.0% | | | | |
| | | Food | 90.0% | | | | 4.0% | 6.0% | | | | | |
| | | Textiles | 48.0% | | 12.0% | | 2.8% | 12.4% | 11.2% | 13.6% | | | |
| | | Metals | 5.0% | | | | 1.9% | 2.9% | 90.3% | | | | |
| | | Wood | 30.0% | | | | 70.0% | | | | | | |
| | | Paper | | | | | 3.0% | 7.0% | 70.0% | 20.0% | | | |
| Ag | Production | | 0.5% | | 0.5% | | | | | | | | Gottschalk and Nowack (2011) report 0-2% release during production (1% assumed as average) split equally over air and surface water |
| Ag | Manufacturing | Electronics and appliances | 0.3% | 0.3% | | | 2.0% | | | | | | From Gottschalk et al. (2015b), photostable $TiO_2$ release during production of pigments, paints, lacquers and adhesives |
| Ag | Manufacturing | Textiles | 0.3% | 0.3% | | | 2.0% | | | | | | |
| Ag | Manufacturing | Cosmetics | 0.3% | 0.3% | | | 2.0% | | | | | | |
| Ag | Manufacturing | Food | 0.3% | 0.3% | | | 2.0% | | | | | | |
| Ag | Manufacturing | Cleaning agents | 0.3% | 0.3% | | | 2.0% | | | | | | |
| Ag | Manufacturing | Medical technology | 0.3% | 0.3% | | | 2.0% | | | | | | |
| Ag | Manufacturing | Plastics | 0.3% | 0.3% | | | 2.0% | | | | | | |
| Ag | Manufacturing | Paints | 0.3% | 0.3% | | | 2.0% | | | | | | |
| Ag | Manufacturing | Metals | 0.3% | 0.3% | | | 2.0% | | | | | | |
| Ag | Manufacturing | Glass and ceramics | 0.3% | 0.3% | | | 2.0% | | | | | | |
| Ag | Manufacturing | Soil remediation | 0.3% | 0.3% | | | 2.0% | | | | | | |
| Ag | Manufacturing | Filters | 0.3% | 0.3% | | | 2.0% | | | | | | |
| Ag | Manufacturing | Diapers | 0.3% | 0.3% | | | 2.0% | | | | | | |
| Ag | Manufacturing | Paper | 0.3% | 0.3% | | | 2.0% | | | | | | |
| Ag | Consumption | Electronics and appliances | 30.0% | | | | 4.2% | 6.3% | 45.5% | 14.0% | | | Directly from Gottschalk et al. (2015b) |
| Ag | Consumption | Textiles | 48.0% | | 12.0% | | 2.8% | 12.4% | 11.2% | 13.6% | | | |
| Ag | Consumption | Cosmetics | 85.5% | 9.5% | | | 1.3% | 1.8% | 2.0% | | | | |
| Ag | Consumption | Food | 90.0% | | | | 4.0% | 6.0% | | | | | |
| Ag | Consumption | Cleaning agents | 95.0% | | | | 1.3% | 1.8% | 2.0% | | | | |
| Ag | Consumption | Medical technology | 5.0% | | | | 95.0% | | | | | | |
| Ag | Consumption | Plastics | 80.0% | | | | 5.0% | 7.0% | 8.0% | | | | |
| Ag | Consumption | Paints | 17.5% | | 8.8% | 8.8% | | 19.5% | 45.5% | | | | |
| Ag | Consumption | Metals | 5.0% | | | | 1.9% | 2.9% | 90.3% | | | | |
| Ag | Consumption | Glass and ceramics | 35.0% | | | | 6.5% | 13.0% | 45.5% | | | | |

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Soil remediation | | | | 98.0% | 0.8% | 1.2% | | | | | |
| | | Filters | 24.0% | | 6.0% | | 4.2% | 6.3% | 45.5% | 14.0% | | | |
| | | Diapers | 5.0% | | | | 95.0% | | | | | | |
| | | Paper | | | | | 3.0% | 7.0% | 70.0% | 20.0% | | | |
| Cu and CuO | Production | | 0.5% | | 0.5% | | | | | | | | Gottschalk and Nowack (2011) report 0-2% release during production (1% assumed as average) split equally over air and surface water |
| Cu and CuO | Manufacturing | Catalysts | 0.3% | 0.3% | | | 2.0% | | | | | | From Gottschalk et al. (2015b), photostable $TiO_2$ release during production of pigments, paints, lacquers and adhesives |
| Cu and CuO | Manufacturing | Electronics & Optics | 0.3% | 0.3% | | | 2.0% | | | | | | |
| Cu and CuO | Manufacturing | Coatings, paints and pigments | 0.3% | 0.3% | | | 2.0% | | | | | | |
| Cu and CuO | Manufacturing | Energy and Environment | 0.3% | 0.3% | | | 2.0% | | | | | | |
| Cu and CuO | Manufacturing | Medical | 0.3% | 0.3% | | | 2.0% | | | | | | |
| Cu and CuO | Manufacturing | Cosmetics | 0.3% | 0.3% | | | 2.0% | | | | | | |
| Cu and CuO | Manufacturing | Cosmetics | 0.3% | 0.3% | | | 2.0% | | | | | | |
| Cu and CuO | Manufacturing | Food and beverages | 0.3% | 0.3% | | | 2.0% | | | | | | |
| Cu and CuO | Manufacturing | Engine additive | 0.3% | 0.3% | | | 2.0% | | | | | | |
| Cu and CuO | Manufacturing | Filters | 0.3% | 0.3% | | | 2.0% | | | | | | |
| Cu and CuO | Manufacturing | Paints | 0.3% | 0.3% | | | 2.0% | | | | | | |
| Cu and CuO | Manufacturing | Welding nozzle | 0.3% | 0.3% | | | 2.0% | | | | | | |
| Cu and CuO | Manufacturing | Electronics | 0.3% | 0.3% | | | 2.0% | | | | | | |
| Cu and CuO | Consumption | Catalysts | 74.0% | 0.0% | 25.0% | 0.0% | | | 1.0% | 74.0% | 0.0% | 25.0% | Updated release factors from EMPA used in this study |
| Cu and CuO | Consumption | Electronics & Optics | 0.0% | 0.0% | 0.0% | 0.0% | 10.0% | 20.0% | 70.0% | 0.0% | 0.0% | 0.0% | |
| Cu and CuO | Consumption | Coatings, paints and pigments | 1.0% | 1.0% | 1.0% | 1.0% | | | 96.0% | 1.0% | 1.0% | 1.0% | |
| Cu and CuO | Consumption | Energy and Environment | 0.0% | 0.0% | 0.0% | 0.0% | 5.0% | 10.0% | 85.0% | 0.0% | 0.0% | 0.0% | |
| Cu and CuO | Consumption | Medical | 95.0% | 0.0% | 0.0% | 0.0% | | | 5.0% | 95.0% | 0.0% | 0.0% | |
| Cu and CuO | Consumption | Cosmetics | 85.0% | 0.0% | 0.0% | 10.0% | 0.5% | 1.5% | 3.0% | 85.0% | 0.0% | 0.0% | |
| Cu and CuO | Consumption | Cosmetics | 85.0% | 0.0% | 0.0% | 10.0% | 0.5% | 1.5% | 3.0% | 85.0% | 0.0% | 0.0% | |
| Cu and CuO | Consumption | Food and beverages | 90.0% | 0.0% | 0.0% | 0.0% | 1.0% | 2.5% | 6.5% | 90.0% | 0.0% | 0.0% | |
| Cu and CuO | Consumption | Engine additive | 0.0% | 0.0% | 5.0% | 0.0% | | | 95.0% | 0.0% | 0.0% | 5.0% | |
| Cu and CuO | Consumption | Filters | 24.0% | 0.0% | 6.0% | 0.0% | 30.0% | 40.0% | | 24.0% | 0.0% | 6.0% | |
| Cu and CuO | Consumption | Paints | 0.5% | 0.0% | 0.3% | 0.3% | | | 99.0% | 0.5% | 0.0% | 0.3% | |
| Cu and CuO | Consumption | Welding nozzle | 0.0% | 0.0% | 0.0% | 0.0% | 5.0% | 15.0% | 80.0% | 0.0% | 0.0% | 0.0% | |
| Cu and CuO | Consumption | Electronics | 0.0% | 0.0% | 0.0% | 0.0% | 10.0% | 20.0% | 70.0% | 0.0% | 0.0% | 0.0% | |
| Carbon | Production | | 0.5% | | 0.5% | | | | | | | | Gottschalk and Nowack (2011) report 0-2% release during |

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | | production (1% assumed as average) split equally over air and surface water |
| | Manufacturing | **Rubber products** | 0.5% | 0.1% | | | 2.0% | | | | | | From Gottschalk et al. (2015b), carbon black release during production of paints, lacquers, pigments, cosmetics, etc. |
| | | **Rubber tyres** | 0.5% | 0.1% | | | 2.0% | | | | | | |
| | | **Antifouling paints** | 0.5% | 0.1% | | | 2.0% | | | | | | |
| | | **Filters** | 0.5% | 0.1% | | | 2.0% | | | | | | |
| | | **Inks** | 0.5% | 0.1% | | | 2.0% | | | | | | |
| | | **Others** | 0.5% | 0.1% | | | 2.0% | | | | | | |
| | | **Paints and varnishes** | 0.5% | 0.1% | | | 2.0% | | | | | | |
| | | **Plastic components** | 0.5% | 0.1% | | | 2.0% | | | | | | |
| | Consumption | **Rubber products** | 0.1% | | 0.1% | 0.1% | 94.7% | 5.0% | | | | | Directly from Gottschalk et al. (2015b) |
| | | **Rubber tyres** | 3.0% | 8.0% | 1.0% | 4.0% | 5.0% | | 79.0% | | | | |
| | | **Antifouling paints** | 1.0% | 1.0% | 1.0% | 2.0% | 50.0% | 10.0% | 35.0% | | | | |
| | | **Filters** | | 66.9% | | 0.1% | 1.0% | | 32.0% | | | | |
| | | **Inks** | | | | | 10.0% | | 80.0% | 10.0% | | | |
| | | **Others** | 0.1% | 0.1% | | 0.1% | 95.7% | 2.0% | 2.0% | | | | |
| | | **Paints and varnishes** | 25.0% | | 5.0% | | 70.0% | | | | | | |
| | | **Plastic components** | 5.0% | 5.0% | 5.0% | 5.0% | 50.0% | 20.0% | 10.0% | | | | Expert judgement |

**Appendix 3: Decision tree for assessing the quality of the references used for allocations to product applications**



## Appendix 4: References used for the management of the waste categories

| Country | Waste category | Reference |
|---|---|---|
| Autria | Batteries | Elektroaltgeräte Koordinierungsstelle Austria GmbH - 2016[1] |
| | WEEE | BLFUW - 2015[2] |
| | Textiles | BLFUW - 2015[2] |
| | Packaging | BLFUW - 2015[2] |
| | Glass | BLFUW - 2015[2] |
| | Metals | BLFUW - 2015[2]; Eurostat[3] |
| | Paper | BLFUW - 2015[2] |
| | Plastic | BLFUW - 2015[2] |
| | Mixed municipal waste | BLFUW - 2015[2] |
| Belgium | Batteries | Perchards - 2015[4] |
| | WEEE | Steiger – 2014[5]; BAFU - 2015[6] |
| | Textiles | Coberec - 2016[7] |
| | Packaging | FostPlus - 2016[8] |
| | Glass | Eurostat[3]; de Beer - 2012[9] |
| | Metals | Eurostat[3]; de Beer - 2012[9] |
| | Paper | Eurostat[3]; de Beer - 2012[9] |
| | Plastic | Eurostat[3]; de Beer - 2012[9] |
| | Mixed municipal waste | Wille et al. - 2015[10] |
| Bulgaria | Batteries | Perchards - 2015[4] |
| | WEEE | Baldé et al. - 2015[11]; Eurostat[3] |
| | Textiles | Egis International - 2011[12]; Eurostat[3] |
| | Packaging | Ministry of Environment - 2016 (Personal communication) |
| | Glass | Egis International - 2011[12]; Eurostat[3] |
| | Metals | Egis International - 2011[12]; Eurostat[3] |
| | Paper | Egis International - 2011[12]; Eurostat[3] |
| | Plastic | Egis International - 2011[12]; Eurostat[3] |
| | Mixed municipal waste | Ministry of Environment and Water - 2014[13] |
| Croatia | Batteries | Perchards - 2015[4] |
| | WEEE | Hrvatska AZO - 2016a[14] |
| | Textiles | Stanic-Maruna and Fellner - 2012[15]; Eurostat[3]; Hrvatska AZO - 2016b[16] |
| | Packaging | Hrvatska AZO - 2016a[14] |
| | Glass | Stanic-Maruna and Fellner - 2012[15]; Eurostat[3]; Hrvatska AZO - 2016b[16] |
| | Metals | Stanic-Maruna and Fellner - 2012[15]; Eurostat[3]; Hrvatska AZO - 2016b[16] |
| | Paper | Stanic-Maruna and Fellner - 2012[15]; Eurostat[3]; Hrvatska AZO - 2016b[16] |
| | Plastic | Stanic-Maruna and Fellner - 2012[15]; Eurostat[3]; Hrvatska AZO - 2016b[16] |
| | Mixed municipal waste | Hrvatska AZO - 2016b[16] |
| Cyprus | Batteries | Perchards - 2015[4] |
| | WEEE | Hrvatska AZO - 2016a[14] |
| | Textiles | Stanic-Maruna and Fellner - 2012[15]; Eurostat[3]; Hrvatska AZO - 2016b[16] |
| | Packaging | Green Dot - 2016[17] |
| | Glass | Zorpas et al - 2015[18]; Eurostat[3] |
| | Metals | Zorpas et al - 2015[18]; Eurostat[3] |
| | Paper | Zorpas et al - 2015[18]; Eurostat[3] |
| | Plastic | Static-Maruna and Fellner - 2012[15]; Eurostat[3]; Hrvatska AZO - 2016b[16] |
| | Mixed municipal waste | Department of Environment (Personal communication) |

| Country | Waste category | Reference |
|---|---|---|
| Czech Republic | Batteries | Perchards - 2015[4] |
| | WEEE | MAPAMA - 2016[19]; Eurostat[3] |
| | Textiles | MAPAMA - 2016[19]; Eurostat[3] |
| | Packaging | MAPAMA - 2016[19] |
| | Glass | MAPAMA - 2016[19]; Eurostat[3]; AFESD - 2015[20] |
| | Metals | MAPAMA - 2016[19]; Eurostat[3] |
| | Paper | MAPAMA - 2016[19]; Eurostat[3]; AFESD - 2015[20] |
| | Plastic | MAPAMA - 2016[19]; Eurostat[3] |
| | Mixed municipal waste | Ministry of the Environment - 2014[21] |
| Denmark | Batteries | Perchards - 2015[4] |
| | WEEE | Toft et al - 2016[22] |
| | Textiles | Tojo et al - 2012[23] |
| | Packaging | Petersen et al - 2014[24]; Toft et al - 2016[22] |
| | Glass | Petersen et al - 2014[24]; Toft et al - 2016[22] |
| | Metals | Petersen et al - 2014[24]; Toft et al - 2016[22] |
| | Paper | Petersen et al - 2014[24]; Toft et al - 2016[22] |
| | Plastic | Petersen et al - 2014[24]; Toft et al - 2016[22] |
| | Mixed municipal waste | Eurostat[3] |
| Estonia | Batteries | Perchards - 2015[4] |
| | WEEE | Keskkonnaagentuur - 2016[25]; Mattson - 2016[26]; RECO Baltic 21 Tech - 2012[27] |
| | Textiles | RECO Baltic 21 Tech - 2012[27]; Eurostat[3] |
| | Packaging | Estonian Institute for Sustainable Development & SEI Tallin - 2014[28]; Mattson - 2016[26] |
| | Glass | Mattson - 2016[26]; RECO Baltic 21 Tech - 2012[27] |
| | Metals | RECO Baltic 21 Tech - 2012[27]; Eurostat[3] |
| | Paper | Mattson - 2016[26]; RECO Baltic 21 Tech - 2012[27] |
| | Plastic | Mattson - 2016[26]; RECO Baltic 21 Tech - 2012[27] |
| | Mixed municipal waste | Eurostat[3] |
| Finland | Batteries | Perchards - 2015[4] |
| | WEEE | Liikanen et al - 2016[29]; Statistics Finland - 2015[30]; Seyring et al - 2015[31] |
| | Textiles | Tojo et al - 2012[23] |
| | Packaging | ymparisto.fi[32] |
| | Glass | Liikanen et al - 2016[29]; Statistics Finland - 2015[30]; Eurostat[3] |
| | Metals | Liikanen et al - 2016[29]; Statistics Finland - 2015[30]; Eurostat[3] |
| | Paper | Liikanen et al - 2016[29]; Statistics Finland - 2015[30] |
| | Plastic | Liikanen et al - 2016[29]; Statistics Finland - 2015[30] |
| | Mixed municipal waste | Statistics Finland - 2015[30] |
| France | Batteries | Perchards - 2015[4] |
| | WEEE | ADEME - 2010[33], 2015a[34]; Eurostat[3] |
| | Textiles | ADEME - 2010[33], 2015b[35]; Eurostat[3] |
| | Packaging | Eco-Emballages and Adelphe - 2015[36] |
| | Glass | ADEME - 2010[33]; Eurostat[3] |
| | Metals | ADEME - 2010[33]; Eurostat[3] |
| | Paper | ADEME - 2010[33]; Eurostat[3] |
| | Plastic | ADEME - 2010[33]; Eurostat[3] |
| | Mixed municipal waste | Eurostat[3] |

| Country | Waste category | Reference |
|---|---|---|
| Germany | Batteries | Perchards - 2015[4] |
| | WEEE | Ear - 2016[37]; Eurostat[3] |
| | Textiles | FTR - 2015[38] |
| | Packaging | Schüler et al - 2015[39]; Eurostat[3]; Toft et al - 2016[22] |
| | Glass | Plastic Zero - 2014[40]; Eurostat[3] |
| | Metals | Plastic Zero - 2014[40]; Eurostat[3] |
| | Paper | Plastic Zero - 2014[40]; Eurostat[3] |
| | Plastic | Plastic Zero - 2014[40]; Eurostat[3] |
| | Mixed municipal waste | Eurostat[3] |
| Greece | Batteries | Perchards - 2015[4] |
| | WEEE | Hrvatska AZO - 2016a[14] |
| | Textiles | Papagiorgou et al - 2009[41]; Eurostat[3] |
| | Packaging | Kalogirou and Sakalis - 2016[42] |
| | Glass | Papagiorgou et al - 2009[41]; Eurostat[3] |
| | Metals | Papagiorgou et al - 2009[41]; Eurostat[3] |
| | Paper | Papagiorgou et al - 2009[41]; Eurostat[3] |
| | Plastic | Papagiorgou et al - 2009[41]; Eurostat[3] |
| | Mixed municipal waste | Eurostat[3] |
| Hungary | Batteries | Perchards - 2015[4] |
| | WEEE | MAPAMA - 2016[19]; Eurostat[3] |
| | Textiles | MAPAMA - 2016[19]; Eurostat[3] |
| | Packaging | MAPAMA - 2016[19] |
| | Glass | MAPAMA - 2016[19]; Eurostat[3] |
| | Metals | MAPAMA - 2016[19]; Eurostat[3] |
| | Paper | MAPAMA - 2016[19]; Eurostat[3] |
| | Plastic | MAPAMA - 2016[19]; Eurostat[3] |
| | Mixed municipal waste | Eurostat[3] |
| Ireland | Batteries | Perchards - 2015[4] |
| | WEEE | McCoole et al - 2013[43]; WEEE Ireland - 2016[44]; EPA - 2014[45] |
| | Textiles | McCoole et al - 2013[43]; EPA - 2014[45]; Eurostat[3] |
| | Packaging | Personal communication from EPA |
| | Glass | McCoole et al - 2013[43]; Eurostat[3]; EPA - 2014[45] |
| | Metals | McCoole et al - 2013[43]; Eurostat[3]; EPA - 2014[45] |
| | Paper | McCoole et al - 2013[43]; Eurostat[3]; EPA - 2014[45] |
| | Plastic | McCoole et al - 2013[43]; Eurostat[3]; EPA - 2014[45] |
| | Mixed municipal waste | EPA - 2014[45] |
| Italy | Batteries | Perchards - 2015[4] |
| | WEEE | ISPRA - 2015[46]; Di Maria et al - 2015[47] |
| | Textiles | ISPRA - 2015[46]; Di Maria et al - 2015[47] |
| | Packaging | ISPRA - 2015[46] |
| | Glass | ISPRA - 2015[46]; Di Maria et al - 2015[47] |
| | Metals | ISPRA - 2015[46]; Di Maria et al - 2015; Eurostat[3] |
| | Paper | ISPRA - 2015[46]; Di Maria et al - 2015[47] |
| | Plastic | ISPRA - 2015[46]; Di Maria et al - 2015[47] |
| | Mixed municipal waste | Eurostat[3] |

| Country | Waste category | Reference |
|---|---|---|
| Latvia | Batteries | Perchards - 2015[4] |
| | WEEE | Hrvatska AZO - 2016a[14] |
| | Textiles | Teibe et al - 2013[48]; Eurostat[3] |
| | Packaging | Hrvatska AZO - 2016a[14] |
| | Glass | Teibe et al - 2013[48]; Eurostat[3] |
| | Metals | Teibe et al - 2013[48]; Eurostat[3] |
| | Paper | Teibe et al - 2013[48]; Eurostat[3] |
| | Plastic | Teibe et al - 2013[48]; Eurostat[3] |
| | Mixed municipal waste | Eurostat[3] |
| Lithuania | Batteries | Perchards - 2015[4] |
| | WEEE | MAPAMA - 2016[19]; Eurostat[3] |
| | Textiles | Teibe et al - 2013[48]; Eurostat[3] |
| | Packaging | Personal communication from Inga Latveliene, EPA; MAPAMA - 2016[19]; Eurostat[3] |
| | Glass | Teibe et al - 2013[48]; Eurostat[3] |
| | Metals | Teibe et al - 2013[48]; Eurostat[3] |
| | Paper | Teibe et al - 2013[48]; Eurostat[3] |
| | Plastic | Teibe et al - 2013[48]; Eurostat[3] |
| | Mixed municipal waste | Eurostat[3] |
| Luxembourg | Batteries | Perchards - 2015[4] |
| | WEEE | MDI - 2015[49]; MDI - 2014[50]; Eurostat[3] |
| | Textiles | Administration de l'Environnement[51]; MDI - 2014[50]; Eurostat[3] |
| | Packaging | Administration de l'Environnement[51] |
| | Glass | Administration de l'Environnement[51]; Eurostat[3]; MDI - 2014[50] |
| | Metals | MDI - 2014[50]; Eurostat[3] |
| | Paper | Administration de l'Environnement[51]; Eurostat[3]; MDI - 2014[50] |
| | Plastic | Administration de l'Environnement[51]; Eurostat[3]; MDI - 2014[50] |
| | Mixed municipal waste | Eurostat[3] |
| Malta | Batteries | Perchards - 2015[4] |
| | WEEE | RECO Baltic 21 Tech - 2012[27]; Eurostat[3]; Personal communication from the Environment and Resources Authority |
| | Textiles | Eurostat[3]; Personal communication from the Environment and Resources Authority |
| | Packaging | Eurostat[3]; Personal communication from the Environment and Resources Authority |
| | Glass | Eurostat[3]; Zorpas et al - 2015[18] |
| | Metals | Eurostat[3]; Zorpas et al - 2015[18] |
| | Paper | Eurostat[3]; Zorpas et al - 2015[18] |
| | Plastic | Teibe et al – 2013[48]; Eurostat[3] |
| | Mixed municipal waste | Eurostat[3] |
| Netherlands | Batteries | Perchards - 2015[4] |
| | WEEE | Huisman et al - 2012[52]; Rijkswaterstaat - 2016[53] |
| | Textiles | van de Wiel - 2013[54] |
| | Packaging | Afvalfonds Verpakkingen - 2016[55]; Rijkswaterstaat - 2016[53]; Eurostat[3] |
| | Glass | Rijkswaterstaat - 2016[53]; Eurostat[3] |
| | Metals | Rijkswaterstaat - 2016[53]; Eurostat[3] |
| | Paper | Rijkswaterstaat - 2016[53]; Eurostat[3] |
| | Plastic | Rijkswaterstaat - 2016[53]; Eurostat[3] |
| | Mixed municipal waste | Eurostat[3] |

| Country | Waste category | Reference |
|---|---|---|
| Norway | Batteries | Perchards - 2015[4] |
| | WEEE | Norwegian Environment Agency - 2013[56]; Ellyin - 2012[57]; Eurostat[3] |
| | Textiles | Tojo et al - 2012[23] |
| | Packaging | Petersen et al - 2014[24]; Toft et al - 2016[22] |
| | Glass | Eurostat[3]; Petersen et al - 2014[24] |
| | Metals | Eurostat[3]; Petersen et al - 2014[24] |
| | Paper | Eurostat[3]; Petersen et al – 2014[24] |
| | Plastic | Eurostat[3]; Petersen et al - 2014[24] |
| | Mixed municipal waste | Eurostat[3] |
| Poland | Batteries | Perchards - 2015[4] |
| | WEEE | Personal communication from the Executive Environmental Agency of Bulgaria |
| | Textiles | Gorska et al - 2015[58]; den Boer et al - 2010[59]; Eurostat[3] |
| | Packaging | Ministry of Environment - 2016 (Personal communication) |
| | Glass | Eurostat[3]; den Boer et al - 2010[59] |
| | Metals | Eurostat[3]; den Boer et al - 2010[59] |
| | Paper | Eurostat[3]; den Boer et al - 2010[59] |
| | Plastic | Eurostat[3]; den Boer et al - 2010[59] |
| | Mixed municipal waste | Eurostat[3] |
| Portugal | Batteries | Perchards - 2015[4] |
| | WEEE | Eurostat[3]; MAPAMA - 2016[19] |
| | Textiles | Eurostat[3] |
| | Packaging | MAPAMA - 2016[19] |
| | Glass | Magrinho and Semiao - 2008[60]; Eurostat[3] |
| | Metals | Magrinho and Semiao - 2008[60]; Eurostat[3] |
| | Paper | Magrinho and Semiao - 2008[60]; Eurostat[3] |
| | Plastic | Magrinho and Semiao - 2008[60]; Eurostat[3] |
| | Mixed municipal waste | Eurostat[3] |
| Romania | Batteries | Perchards - 2015[4] |
| | WEEE | Magalini et al - 2015[61]; Ecotic - 2015[62] |
| | Textiles | Ciuta et al - 2015[63]; Eurostat[3] |
| | Packaging | Personal communication from the Environment and Resources Authority |
| | Glass | Ciuta et al - 2015[63]; Eurostat[3] |
| | Metals | Ciuta et al - 2015[63]; Eurostat[3] |
| | Paper | Ciuta et al - 2015[63]; Eurostat[3] |
| | Plastic | Ciuta et al - 2015[63]; Eurostat[3] |
| | Mixed municipal waste | Eurostat[3] |
| Slovakia | Batteries | Perchards - 2015[4] |
| | WEEE | Hrvatska AZO - 2016a[14] |
| | Textiles | Papagiorgou et al - 2009[41]; Eurostat[3] |
| | Packaging | Kalogirou and Sakalis - 2016[42] |
| | Glass | Papagiorgou et al - 2009[41]; Eurostat[3] |
| | Metals | Papagiorgou et al - 2009[41]; Eurostat[3] |
| | Paper | Papagiorgou et al - 2009[41]; Eurostat[3] |
| | Plastic | Papagiorgou et al - 2009[41]; Eurostat[3] |
| | Mixed municipal waste | Eurostat[3] |

| Country | Waste category | Reference |
|---|---|---|
| Slovenia | Batteries | Perchards - 2015[4] |
| | WEEE | Di Maria et al - 2015[47]; Zitnik and Vidic - 2015[64]; Eurostat[3] |
| | Textiles | Di Maria et al - 2015[47]; Eurostat[3] |
| | Packaging | ISPRA - 2015[46] |
| | Glass | Di Maria et al - 2015[47]; Eurostat[3] |
| | Metals | Di Maria et al - 2015[47]; Eurostat[3] |
| | Paper | Di Maria et al - 2015[47]; Eurostat[3] |
| | Plastic | Di Maria et al - 2015[47]; Eurostat[3] |
| | Mixed municipal waste | Eurostat[3] |
| Spain | Batteries | Perchards - 2015[4] |
| | WEEE | MAPAMA - 2016[19]; Eurostat[3] |
| | Textiles | MAPAMA - 2016[19]; Eurostat[3] |
| | Packaging | MAPAMA - 2016[19] |
| | Glass | MAPAMA - 2016[19]; Eurostat[3] |
| | Metals | MAPAMA - 2016[19]; Eurostat[3] |
| | Paper | MAPAMA - 2016[19]; Eurostat[3] |
| | Plastic | MAPAMA - 2016[19]; Eurostat[3] |
| | Mixed municipal waste | Eurostat[3] |
| Sweden | Batteries | Perchards - 2015[4] |
| | WEEE | Steiger – 2014[5]; BAFU - 2015[6] |
| | Textiles | Tojo et al - 2012[23] |
| | Packaging | BAFU - 2015[6] |
| | Glass | BAFU - 2015[6]; Eurostat[3] |
| | Metals | BAFU - 2015[6]; Eurostat[3] |
| | Paper | BAFU - 2015[6]; Eurostat[3] |
| | Plastic | BAFU - 2015[6]; Eurostat[3] |
| | Mixed municipal waste | Eurostat[3] |
| Switzerland | Batteries | Perchards - 2015[4] |
| | WEEE | Steiger – 2014[5]; BAFU - 2015[6] |
| | Textiles | Steiger – 2014[5]; BAFU - 2015[6] |
| | Packaging | BAFU - 2015[6] |
| | Glass | BAFU - 2015[6] |
| | Metals | BAFU - 2015[6] |
| | Paper | BAFU - 2015[6] |
| | Plastic | BAFU - 2015[6] |
| | Mixed municipal waste | OFEV - 2016[65] |
| United Kingdom | Batteries | Perchards - 2015[4] |
| | WEEE | Personal communication from the EPA; Eurostat[3]; Personal communication from D. Turner, Empa |
| | Textiles | Thompson and Hitchen - 2015[66]; Eurostat[3]; Personal communication from D. Turner, Empa |
| | Packaging | DEFRA - 2015[67] |
| | Glass | Eurostat[3]; Personal communication from D. Turner, Empa |
| | Metals | Eurostat[3]; Personal communication from D. Turner, Empa |
| | Paper | Eurostat[3]; Personal communication from D. Turner, Empa |
| | Plastic | Eurostat[3]; Personal communication from D. Turner, Empa |
| | Mixed municipal waste | Eurostat[3] |

List of references:


(1) Elektroaltgeräte Kordinierungsstelle Austria GmbH. *Tätigkeitsbericht 2015*; Wien, 2016; p 93.

(2) Bundesministerium für Land- und Fortwirtschaft, Umwelt und Wasserwirtschaft. *Die Bestandsaufnahme der Abfallwirtschaft in Österreich Statusbericht 2015*; Wien, 2015; p 92.

(3) European Commission. Waste Generation and Treatment http://ec.europa.eu/eurostat/web/environment/waste/database (accessed Feb 15, 2017).

(4) Perchards; SagisEPR.com. *The collection of waste portable batteries in Europe in view of the achievability of the collection targets set by Batteries Directive 2006/66/EC*; European Portable Battery Association (EPBA), 2015; p 35.

(5) Steiger, U. *Erhebung der Kehrichtzusammensetzung 2012*; Bundesamt für Umwelt (BAFU), 2014; p 63.

(6) Bundesamt für Umwelt BAFU. *Abfallmengen und Recycling 2014 im Überblick*; Bern, Switzerland, 2015; p 1.

(7) Coberec. *Récupération des textiles - Rapport 2015*; 2016; p 1.

(8) FostPlus. *Annual Report 2015*; Brussels, Belgium, 2016; p 24.

(9) de Beer, H. *Gestion des déchets ménagers à Bruxelles et en Wallonie: Etat des lieux et enjeux*; Etopia, 2012; p 17.

(10) Wille, D.; Vervaet, M.; Andries, A.; Segers, N.; Van Hasselt, D.; Smeets, K. *Inventarisatie huishoudelijke afvalstoffen 2014*; OVAM: Mechelen, The Netherlands, 2015; p 67.

(11) Baldé, C. P.; Wang, F.; Kuehr, R.; Huisman, J. *The global e-waste monitor - 2014*; United Nations University, IAS - SCYCLE: Bonn, Germany, 2015; p 80.

(12) Egis International. *Sofia Waste Phase II - MBT Option Analysis - First Interim Report*; 2011; p 123.

(13) Ministry of Environment and Water. *National Waste Management Plan 2014-2020*; Sofia, Bulgaria, 2014; p 197.

(14) Hrvatska agencija za okolis i prirodu. *Pregled podataka za posebne kategorije otpada za razdoblje do 2014. Godine: Ambalazni otpad, Otpadna motorna i jestiva ulja, Elektricni i elektronicki otpad, Otpadne baterije i akumulatori*; Zagreb, Croatia, 2016; p 25.

(15) Stanic-Maruna, I.; Fellner, J. Solid waste management in Croatia in response to the European Landfill Directive. *Waste Manag. Res.* **2012**, *0*, 1–14.

(16) Hrvatska agencija za okolis i prirodu. *Izvjescé o komunalnom otpadu za 2014. godinu*; NN br. 94/13; Zagreb, Croatia, 2016; p 309.

(17) Green Dot. *Annual Report 2015*; 2016; p 94.

(18) Zorpas, A. A.; Lasaridi, K.; Voukkali, I.; Loizia, P.; Chroni, C. Household waste compositional analysis variation from insular communities in the framework of waste prevention strategy plans. *Waste Manag.* **2015**, *38*, 3–11.

(19) Ministerio de agricultura y pesca alimentación y medio ambiente. *Anuario de Estadística 2015*; Madrid, Spain, 2016; p 1047.

(20) Agriculture, Forestry and Environmental Statistics Department. *Generation, recovery and dispoal of waste*; Prague, Czech Republic, 2015; p 42.

(21) Ministry of the Environment. *Waste Management Plan of the Czech Republic for the period 2015-2024*; Prague, Czech Republic, 2014; p 189.

(22) Toft, R.; Fischer, C.; Aasted Bojesen, N. *Waste Statistics 2014*; Ministry of Environment and Food of Denmark, 2016; p 58.

(23) Tojo, N.; Kogg, B.; Kiorboe, N.; Kjaer, B.; Aalto, K. *Prevention of Textile Waste - Material flows of textiles in three Nordic countries and suggestions on policy instruments*; TemaNord 2012:545; Nordic Council of Ministers, 2012; p 124.

(24) Petersen, C.; Kaysen, O.; Manokaran, S.; Tonning, K. *Kortlaegning af dagrenovation i Danmark - Med fokus pa etageboliger og madspild*; Miljostyrelsen, 2014; p 74.

(25) Keskkonnaagentuur. Waste from Estonia https://jats.keskkonnainfo.ee/main.php?public=1 (accessed Feb 14, 2017).

(26) Mattson, T. Municipal waste removal is successfully organised, sorting needs improvement http://www.riigikontroll.ee/tabid/168/amid/557/ItemId/942/language/en-US/Default.aspx (accessed Feb 14, 2017).
(27) RECO Baltic 21 Tech. *National Waste Management Review - Estonia, Latvia, Lithuania, Poland*; 2012; p 96.
(28) Estonian Institute for Sustainable Development; Stockholm Environment Institute Tallinn Centre (SEI Tallinn). *Improving the recycling system of municipal waste in Tallinn based on the examples of best practices*; 2014; p 67.
(29) Liikanen, M.; Sahimaa, O.; Hupponen, M.; Havukainen, J.; Sorvari, J.; Horttanainen, M. Updating and testing of a Finnish method for mixed municipal solid waste composition studies. *Waste Manag.* **2016**, *52*, 25–33.
(30) Statistics Finland. *Waste Statistics 2014 - Municipal waste*; 2015; p 5.
(31) Seyring, N.; Kling, M.; Weissenbacher, J.; Hestin, M.; Lecerf, L.; Magalini, F.; Sinha Khetriwal, D.; Kuehr, R. *Study on WEEE recovery targets, preparation for re-use targets and on the method for calculation of the recovery targets - Final Report*; European Commission (EC), 2015; p 136.
(32) ymparisto.fi. Pakkausjätetilastoja vuosilta 2003-2014, materiaalit yhteensä. 2016.
(33) ADEME. *La composition des ordures ménagères et assimilées en France*; ADEME, 2010; p 31.
(34) ADEME. *Equipements électriques et électroniques - Données 2014*; Angers, France, 2015; p 16.
(35) ADEME. *Textiles d'habillement, linge de maison et chaussures des ménages - Données 2014*; Angers, France, 2015; p 13.
(36) Eco-Emballages; Adelphe. *Rapport d'activité 2014*; 2015; p 112.
(37) Stiftung Elektro-altgeräte register. Jahres-Statistik-Mitteilung https://www.stiftung-ear.de/en/service/kennzahlen/jahres-statistik-mitteilung/ (accessed Feb 14, 2017).
(38) Fachverband Textilrecycling. *Konsum, Bedarf und Wiederverwendung von Bekleidung und Textilien in Deutschland*; Bundesverband Sekundärrohstoffe und Entsorgung e.V., 2015; p 68.
(39) Schüler, K. *Aufkommen und Verwertung von Verpackungsabfällen in Deutschland im Jahr 2013*; UBA-FB 002234; Umweltbundesamtes: Dessau-Rosslau, 2015; p 177.
(40) Plastic ZERO - Public Private Cooperations for Avoiding Plastic as a Waste. *Review of plastic waste in municipal waste stream - Germany*; 2014; p 13.
(41) Papageorgiou, A.; Karagiannidis, A.; Barton, J. R.; Kalogirou, E. Municipal solid waste management scenarios for Attica and their greenhouse gas emission impact. *Waste Manag. Res.* **2009**, *27*, 928–937.
(42) Kalogirou, E.; Sakalis, A. Overview of the Waste Management Situation and Planning in Greece. *Waste Manag.* **2016**, *6*, 107–116.
(43) McCoole, F.; Kurz, I.; McDonagh, M.; O'Neill, D.; Derham, J. *National Waste Report for 2011*; Environmental Protection Agency of Ireland, 2013; p 103.
(44) WEEE Ireland. *Annual Environmental Report 2014*; Dublin, Ireland, 2015; p 88.
(45) Environmental Protection Agency. Bulletin 3: Residual waste treatment trends 2009 to 2013. 2014.
(46) Istituto Superiore per la Protezione e la Ricerca Ambientale (ISPRA). *Rapporto Rifiuti Urbani - Edizione 2015*; 2015; p 585.
(47) Di Maria, F.; Micale, C.; Morettini, E.; Sisani, L.; Damiano, R. Improvement of the management of residual waste in areas without thermal treatment facilities: A life cycle analysis of an Italian management district. *Waste Manag.* **2015**, *44*, 206–215.
(48) Teibe, I.; Bendere, R.; Arina, D. Latvian waste management modelling in view of environmental impact reduction. *Latv. J. Phys. Tech. Sci.* **2013**, No. 6, 36–47.
(49) Ministère du Développement durable et des Infrastructures. *Berichtswesen 2013 zur Bewirtschaftung von Elektround Elektronik-Altgeräten im Großherzogtum Luxemburg*; 2015; p 14.

(50) Ministère du Développement durable et des Infrastructures. Restabfallanalyse 2013/14 Ausgewählte Ergebnisse. 2014.
(51) Administration de l'Environnement. Déchets recyclables récupérés (en tonnes) 1984-2014 http://www.statistiques.public.lu/stat/TableViewer/tableView.aspx?ReportId=13940&IF_Language=fra&MainTheme=1&FldrName=3&RFPath=65 (accessed Feb 14, 2017).
(52) Huisman, J.; van der Maesen, M.; Eijsbouts, R. J. J.; Wang, F.; Baldé, C. P.; Wielenga, C. A. *The Dutch WEEE Flows*; United Nations University, ISP - SCYCLE: Bonn, Germany, 2012; p 46.
(53) Rijkswaterstaat. *Samenstelling van het huishoudelijk restafval, sorteeranalyses 2015 - Gemiddelde driejaarlijkse samenstelling 2014*; Utrecht, The Netherlands, 2016; p 46.
(54) van de Wiel, H. *Giving old clothes a second life*; Dutch Waste Management Association, 2013; p 3.
(55) Afvalfonds Verpakkingen. *Monitoring Verpakkingen - Resultaten inzameling en recycling 2015*; 2016; p 60.
(56) The Norwegian Environment Agency. Waste electrical and electronic equipment http://www.environment.no/topics/waste/waste-electrical-and-electronic-equipment/ (accessed Feb 14, 2017).
(57) Ellyin, C. *Small scale waste-to-energy technologies*; Ph.D. Dissertation; Columbia University, 2012; p 65.
(58) Górska, A.; Karczewska, K.; Kielczykowska, A.; Kowaluk, R.; Lizuraj, M.; Pawlowska, T.; Rudnicka, M.; Ruman, J.; Stefaniak, K.; Sulik, J.; et al. *Environment 2015*; CSO, Regional and Environmental Surveys Department: Varsaw, Poland, 2015; p 565.
(59) den Boer, E.; Jedrczak, A.; Kowalski, Z.; Kulcazycka, J.; Szpadt, R. A review of municipal solid waste composition and quantities in Poland. *Waste Manag.* **2010**, *30*, 369–377.
(60) Magrinho, A.; Semiao, V. Estimation of residual MSW heating value as a function of waste component recycling. *Waste Manag.* **2008**, *28*, 2675–2683.
(61) Magalini, F.; Baldé, K.; Habib, H. *Quantifying Waste of Electric and Electronic Equipment in Romania*; United Nations University, 2015; p 42.
(62) Ecotic. *Year in Review 2014*; 2015; p 32.
(63) Ciuta, S.; Apostol, T.; Rusu, V. Urban and Rural MSW Stream Characterization for Separate Collection Improvement. *Sustainability* **2015**, *7*, 916–931.
(64) Zitnik, M.; Vidic, T. *In 2013, 69% of packaging waste was recycled*; Statistical Office of the Republic of Slovenia: Ljubljana, Slovenia, 2015; p 3.
(65) Office fédéral de l'environnement (OFEV). Statistique des déchets spéciaux 2012 - Déchets suisses traités sur le territoire national. February 26, 2016.
(66) Thompson, L.; Hitchen, D. *Recycling Grade Textiles - Collection Demonstration Projects*; WRAP, 2015; p 23.
(67) Department for Environment, Food and Rural Affairs (DEFRA). *Digest of Waste and Resource Statistics - 2015 Edition*; 2015; p 84.

## Appendix 5: Municipal waste management in Europe in 2013 (adapted from Eurostat)

| | Landfilling | | Total incineration | | Material recycling | |
|---|---|---|---|---|---|---|
| | Tonnes | % | Tonnes | % | Tonnes | % |
| Belgium | 46 | 1% | 2,189 | 56% | 1,672 | 43% |
| Bulgaria | 2,167 | 72% | 49 | 2% | 787 | 26% |
| Czech Republic | 1,815 | 58% | 631 | 20% | 686 | 22% |
| Denmark | 71 | 2% | 2,315 | 65% | 1,154 | 33% |
| Germany | 684 | 2% | 17,255 | 42% | 23,091 | 56% |
| Estonia | 53 | 17% | 214 | 68% | 49 | 16% |
| Ireland | 1,028 | 45% | 427 | 19% | 829 | 36% |
| Greece | 4,507 | 84% | 0 | 0% | 869 | 16% |
| Spain | 11,801 | 67% | 2,492 | 14% | 3,284 | 19% |
| France | 8,777 | 31% | 12,099 | 43% | 7,320 | 26% |
| Croatia | 1,413 | 86% | 1 | 0% | 228 | 14% |
| Italy | 10,914 | 45% | 5,970 | 25% | 7,335 | 30% |
| Cyprus | 423 | 86% | 0 | 0% | 70 | 14% |
| Latvia | 521 | 89% | 0 | 0% | 66 | 11% |
| Lithuania | 798 | 69% | 92 | 8% | 261 | 23% |
| Luxembourg | 61 | 22% | 119 | 43% | 95 | 35% |
| Hungary | 2,415 | 68% | 336 | 9% | 799 | 23% |
| Malta | 196 | 91% | 1 | 0% | 19 | 9% |
| Netherlands | 131 | 2% | 4,305 | 66% | 2,111 | 32% |
| Austria | 199 | 6% | 1,716 | 55% | 1,202 | 39% |
| Poland | 5,979 | 73% | 766 | 9% | 1,499 | 18% |
| Portugal | 2,320 | 58% | 1,091 | 27% | 594 | 15% |
| Romania | 3,503 | 92% | 97 | 3% | 214 | 6% |
| Slovenia | 224 | 48% | 4 | 1% | 239 | 51% |
| Slovakia | 1,152 | 80% | 174 | 12% | 108 | 8% |
| Finland | 672 | 29% | 1,137 | 49% | 510 | 22% |
| Sweden | 28 | 1% | 2,192 | 60% | 1,443 | 39% |
| United Kingdom | 10,516 | 41% | 6,510 | 26% | 8,468 | 33% |
| Norway | 52 | 2% | 1,446 | 69% | 590 | 28% |
| Switzerland | 0 | 0% | 2,798 | 59% | 1,919 | 41% |

**Appendix 6: Modelling results – masses of carbon black ENM entering technical and environmental compartments**

| | Flows of CB in Austria | | | | | Flows of CB in Belgium | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Q15 | Mode | Mean | Q85 | **Mean TC** | Q15 | Mode | Mean | Q85 | **Mean TC** |
| To | In tonnes | | | | | In tonnes | | | | |
| Waste water | 1,481.57 | 1,787.93 | 2,024.22 | 2,579.30 | **2.7%** | 1,075.55 | 1,290.68 | 1,334.88 | 1,596.37 | **2.0%** |
| Air | 601.17 | 750.13 | 811.20 | 1,025.44 | **1.1%** | 470.66 | 539.17 | 563.84 | 657.57 | **0.8%** |
| Surface water | 2,923.36 | 3,776.52 | 4,233.14 | 5,577.64 | **5.7%** | 1,818.55 | 2,382.36 | 2,472.77 | 3,135.63 | **3.7%** |
| Soil | 1,454.96 | 1,842.15 | 2,132.24 | 2,824.58 | **2.9%** | 906.24 | 1,126.14 | 1,243.04 | 1,582.36 | **1.8%** |
| Landfill - CDW | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** |
| Landfill - RW | 316.30 | 402.92 | 429.31 | 544.65 | **0.6%** | 201.90 | 238.36 | 251.90 | 303.25 | **0.4%** |
| Incineration | 12,573.34 | 15,275.30 | 17,335.67 | 22,218.58 | **23.3%** | 7,958.81 | 9,466.94 | 10,156.46 | 12,394.42 | **15.1%** |
| Recycling | 37,265.17 | 48,332.07 | 47,572.17 | 57,896.78 | **63.8%** | 25,063.72 | 27,796.68 | 27,838.37 | 30,602.38 | **41.3%** |
| Export | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** | 20,800.04 | 23,073.85 | 23,611.95 | 26,480.09 | **35.0%** |

| | Flows of CB in Bulgaria | | | | | Flows of CB in Croatia | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Q15 | Mode | Mean | Q85 | **Mean TC** | Q15 | Mode | Mean | Q85 | **Mean TC** |
| To | In tonnes | | | | | In tonnes | | | | |
| Waste water | 490.57 | 716.92 | 900.89 | 1,313.99 | **2.5%** | 168.78 | 197.97 | 203.18 | 237.56 | **0.4%** |
| Air | 194.74 | 231.57 | 358.70 | 522.34 | **1.0%** | 122.26 | 149.83 | 153.70 | 184.95 | **0.3%** |
| Surface water | 1,081.55 | 1,643.70 | 2,049.40 | 3,037.48 | **5.7%** | 58.25 | 74.53 | 84.02 | 110.08 | **0.2%** |
| Soil | 542.36 | 669.32 | 1,031.12 | 1,531.57 | **2.9%** | 29.17 | 36.69 | 42.27 | 55.64 | **0.1%** |
| Landfill - CDW | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** |
| Landfill - RW | 5,151.54 | 7,261.51 | 9,483.48 | 13,789.20 | **26.4%** | 286.58 | 345.62 | 387.16 | 489.78 | **0.8%** |
| Incineration | 0.56 | 0.74 | 1.11 | 1.67 | **0.0%** | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** |
| Recycling | 12,431.77 | 18,912.86 | 22,156.27 | 31,778.79 | **61.6%** | 736.25 | 877.25 | 912.69 | 1,091.66 | **1.8%** |
| Export | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** | 47,664.65 | 49,556.70 | 49,475.03 | 51,278.58 | **96.5%** |

**Modelling results – masses of carbon black ENM entering technical and environmental compartments (continued)**

| To | Flows of CB in Cyprus | | | | | Flows of CB in Czech Republic | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Q15 | Mode | Mean | Q85 | Mean TC | Q15 | Mode | Mean | Q85 | Mean TC |
| | In tonnes | | | | | In tonnes | | | | |
| Waste water | 268.65 | 389.05 | 665.08 | 1,055.84 | **2.5%** | 933.57 | 1,101.24 | 1,210.65 | 1,492.15 | **0.5%** |
| Air | 109.89 | 108.07 | 270.76 | 427.80 | **1.0%** | 530.86 | 639.19 | 668.04 | 806.94 | **0.3%** |
| Surface water | 581.24 | 477.04 | 1,514.92 | 2,438.28 | **5.7%** | 1,474.31 | 1,988.16 | 2,140.85 | 2,817.69 | **1.0%** |
| Soil | 292.12 | 416.01 | 761.88 | 1,229.21 | **2.9%** | 737.12 | 923.25 | 1,076.74 | 1,422.05 | **0.5%** |
| Landfill - CDW | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** |
| Landfill - RW | 2,275.24 | 1,901.08 | 5,810.31 | 9,288.84 | **21.8%** | 6,121.69 | 7,405.04 | 7,502.18 | 8,873.49 | **3.4%** |
| Incineration | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** | 1,535.28 | 1,903.51 | 1,882.57 | 2,228.14 | **0.9%** |
| Recycling | 7,174.32 | 6,213.58 | 17,605.16 | 27,861.23 | **66.1%** | 20,563.98 | 25,048.33 | 25,153.00 | 29,669.04 | **11.4%** |
| Export | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** | 169,894.13 | 179,657.55 | 180,697.98 | 191,480.96 | **82.0%** |

| To | Flows of CB in Denmark | | | | | Flows of CB in Estonia | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Q15 | Mode | Mean | Q85 | Mean TC | Q15 | Mode | Mean | Q85 | Mean TC |
| | In tonnes | | | | | In tonnes | | | | |
| Waste water | 918.66 | 1,149.33 | 1,372.27 | 1,836.58 | **2.6%** | 272.79 | 278.88 | 671.30 | 1,062.38 | **2.5%** |
| Air | 368.03 | 462.94 | 545.34 | 725.81 | **1.0%** | 109.61 | 113.69 | 271.23 | 429.29 | **1.0%** |
| Surface water | 1,932.63 | 2,572.64 | 3,022.13 | 4,160.17 | **5.7%** | 615.64 | 735.39 | 1,553.67 | 2,479.87 | **5.7%** |
| Soil | 962.52 | 1,220.28 | 1,520.06 | 2,099.85 | **2.9%** | 307.94 | 476.97 | 780.34 | 1,248.84 | **2.9%** |
| Landfill - CDW | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** |
| Landfill - RW | 163.38 | 215.78 | 246.75 | 331.05 | **0.5%** | 340.78 | 444.75 | 839.44 | 1,328.00 | **3.1%** |
| Incineration | 8,934.59 | 11,827.52 | 13,394.76 | 17,930.50 | **25.2%** | 2,499.47 | 2,694.23 | 6,128.15 | 9,682.55 | **22.5%** |
| Recycling | 23,048.72 | 35,551.58 | 32,992.11 | 42,783.53 | **62.1%** | 7,121.21 | 22,244.49 | 17,015.62 | 26,726.90 | **62.4%** |
| Export | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** |

## Modelling results – masses of carbon black ENM entering technical and environmental compartments (continued)

| To | Flows of CB in Finland Q15 | Mode | Mean | Q85 | Mean TC | Flows of CB in France Q15 | Mode | Mean | Q85 | Mean TC |
|---|---|---|---|---|---|---|---|---|---|---|
| | In tonnes | | | | | In tonnes | | | | |
| Waste water | 850.53 | 1,054.50 | 1,294.97 | 1,753.71 | **2.6%** | 5,951.13 | 7,479.40 | 7,671.06 | 9,402.14 | **1.6%** |
| Air | 338.62 | 432.90 | 512.92 | 689.96 | **1.0%** | 2,764.36 | 3,230.49 | 3,396.95 | 4,037.67 | **0.7%** |
| Surface water | 1,807.22 | 2,305.85 | 2,879.44 | 3,986.42 | **5.7%** | 11,954.36 | 15,044.59 | 16,377.64 | 20,843.66 | **3.5%** |
| Soil | 905.78 | 1,140.71 | 1,449.10 | 2,013.69 | **2.9%** | 5,985.85 | 7,626.97 | 8,251.77 | 10,530.96 | **1.7%** |
| Landfill - CDW | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** |
| Landfill - RW | 2,635.34 | 3,352.55 | 4,029.92 | 5,454.33 | **8.0%** | 23,610.82 | 28,696.24 | 30,364.84 | 37,216.96 | **6.4%** |
| Incineration | 5,509.57 | 7,025.20 | 8,434.25 | 11,407.76 | **16.7%** | 31,663.07 | 38,415.17 | 40,660.77 | 49,796.26 | **8.6%** |
| Recycling | 21,870.32 | 26,848.70 | 31,953.26 | 41,941.07 | **63.2%** | 162,051.76 | 184,109.48 | 182,905.36 | 203,563.07 | **38.6%** |
| Export | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** | 161,622.20 | 178,759.55 | 183,616.91 | 205,906.46 | **38.8%** |

| To | Flows of CB in Germany Q15 | Mode | Mean | Q85 | Mean TC | Flows of CB in Greece Q15 | Mode | Mean | Q85 | Mean TC |
|---|---|---|---|---|---|---|---|---|---|---|
| | In tonnes | | | | | In tonnes | | | | |
| Waste water | 7,307.75 | 8,914.13 | 9,661.36 | 12,042.97 | **1.8%** | 1,160.39 | 1,373.86 | 1,648.17 | 2,148.83 | **2.7%** |
| Air | 3,291.57 | 3,951.56 | 4,155.53 | 5,031.28 | **0.8%** | 471.85 | 567.78 | 659.93 | 851.68 | **1.1%** |
| Surface water | 15,787.93 | 19,687.77 | 21,760.33 | 27,836.43 | **4.0%** | 2,340.90 | 2,936.66 | 3,519.73 | 4,743.45 | **5.7%** |
| Soil | 7,875.21 | 9,759.90 | 10,942.69 | 14,049.68 | **2.0%** | 1,168.54 | 1,511.64 | 1,771.92 | 2,395.81 | **2.9%** |
| Landfill - CDW | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** |
| Landfill - RW | 290.48 | 351.41 | 366.09 | 441.93 | **0.1%** | 11,853.37 | 15,154.92 | 16,847.14 | 21,959.88 | **27.1%** |
| Incineration | 71,995.30 | 86,863.41 | 89,673.53 | 107,385.14 | **16.4%** | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** |
| Recycling | 218,668.42 | 249,228.29 | 248,011.62 | 277,201.13 | **45.3%** | 27,874.99 | 34,847.25 | 37,609.55 | 47,380.27 | **60.6%** |
| Export | 141,489.38 | 156,515.17 | 162,456.70 | 183,816.73 | **29.7%** | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** |

**Modelling results – masses of carbon black ENM entering technical and environmental compartments (continued)**

| To | Flows of CB in Hungary | | | | | Flows of CB in Ireland | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Q15 | Mode | Mean | Q85 | **Mean TC** | Q15 | Mode | Mean | Q85 | **Mean TC** |
| | In tonnes | | | | | In tonnes | | | | |
| Waste water | 593.62 | 721.56 | 779.17 | 969.03 | **0.5%** | 665.06 | 931.76 | 1,084.32 | 1,512.77 | **2.6%** |
| Air | 317.62 | 377.82 | 399.87 | 483.05 | **0.3%** | 269.69 | 353.57 | 436.86 | 605.60 | **1.0%** |
| Surface water | 1,035.03 | 1,348.17 | 1,498.48 | 1,970.29 | **1.1%** | 1,369.67 | 1,725.31 | 2,369.41 | 3,399.01 | **5.7%** |
| Soil | 518.33 | 676.03 | 753.60 | 994.99 | **0.5%** | 687.73 | 923.49 | 1,193.57 | 1,715.90 | **2.9%** |
| Landfill - CDW | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** |
| Landfill - RW | 4,478.33 | 5,427.87 | 5,500.78 | 6,510.88 | **3.9%** | 4,194.70 | 5,316.80 | 7,021.60 | 9,858.68 | **16.8%** |
| Incineration | 790.37 | 977.57 | 979.78 | 1,167.30 | **0.7%** | 1,920.31 | 2,649.51 | 3,221.50 | 4,533.27 | **7.7%** |
| Recycling | 14,136.68 | 17,463.06 | 17,315.16 | 20,442.97 | **12.1%** | 16,410.91 | 28,597.65 | 26,451.60 | 36,349.98 | **63.3%** |
| Export | 108,717.10 | 115,648.50 | 115,479.13 | 122,219.64 | **80.9%** | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** |

| To | Flows of CB in Italy | | | | | Flows of CB in Latvia | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Q15 | Mode | Mean | Q85 | **Mean TC** | Q15 | Mode | Mean | Q85 | **Mean TC** |
| | In tonnes | | | | | In tonnes | | | | |
| Waste water | 5,225.46 | 6,166.45 | 6,692.73 | 8,173.27 | **1.5%** | 334.44 | 526.93 | 734.87 | 1,131.33 | **2.5%** |
| Air | 2,445.71 | 2,901.52 | 2,991.91 | 3,542.45 | **0.7%** | 136.89 | 220.38 | 298.35 | 457.40 | **1.0%** |
| Surface water | 10,113.13 | 12,839.75 | 13,864.54 | 17,645.53 | **3.2%** | 717.40 | 1,182.50 | 1,660.97 | 2,602.45 | **5.7%** |
| Soil | 5,046.47 | 6,326.49 | 6,964.12 | 8,899.80 | **1.6%** | 359.52 | 584.16 | 835.91 | 1,313.57 | **2.9%** |
| Landfill - CDW | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** |
| Landfill - RW | 24,137.90 | 29,132.80 | 30,990.87 | 37,947.71 | **7.2%** | 3,288.66 | 3,575.03 | 7,387.74 | 11,424.12 | **25.3%** |
| Incineration | 23,442.28 | 28,354.46 | 30,070.95 | 36,820.43 | **7.0%** | 19.69 | 22.86 | 44.38 | 68.71 | **0.2%** |
| Recycling | 135,255.16 | 153,278.76 | 153,209.69 | 171,183.74 | **35.5%** | 8,364.36 | 24,619.04 | 18,256.63 | 28,018.62 | **62.5%** |
| Export | 166,503.73 | 182,600.26 | 187,064.87 | 207,978.75 | **43.3%** | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** |

**Modelling results – masses of carbon black ENM entering technical and environmental compartments (continued)**

| To | Flows of CB in Lithuania | | | | | Flows of CB in Luxembourg | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Q15 | Mode | Mean | Q85 | Mean TC | Q15 | Mode | Mean | Q85 | Mean TC |
| | In tonnes | | | | | In tonnes | | | | |
| Waste water | 393.99 | 416.64 | 796.42 | 1,194.54 | **2.5%** | 497.12 | 762.37 | 901.32 | 1,311.83 | **2.6%** |
| Air | 159.85 | 229.11 | 321.92 | 481.33 | **1.0%** | 202.87 | 291.19 | 365.68 | 527.55 | **1.0%** |
| Surface water | 839.33 | 1,300.31 | 1,791.19 | 2,745.61 | **5.7%** | 1,035.41 | 1,560.91 | 1,994.24 | 2,968.68 | **5.7%** |
| Soil | 420.32 | 655.39 | 900.01 | 1,381.77 | **2.9%** | 518.24 | 724.61 | 1,004.72 | 1,498.52 | **2.9%** |
| Landfill - CDW | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** |
| Landfill - RW | 4,065.39 | 6,351.20 | 8,435.24 | 12,709.59 | **26.8%** | 799.48 | 1,365.33 | 1,504.90 | 2,211.26 | **4.3%** |
| Incineration | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** | 3,575.73 | 5,881.23 | 6,701.85 | 9,838.02 | **19.1%** |
| Recycling | 9,565.64 | 17,879.37 | 19,244.19 | 28,761.92 | **61.1%** | 12,546.44 | 16,957.93 | 22,660.20 | 32,678.25 | **64.5%** |
| Export | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** |

| To | Flows of CB in Malta | | | | | Flows of CB in the Netherlands | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Q15 | Mode | Mean | Q85 | Mean TC | Q15 | Mode | Mean | Q85 | Mean TC |
| | In tonnes | | | | | In tonnes | | | | |
| Waste water | 191.96 | 588.19 | 584.06 | 969.19 | **2.5%** | 915.94 | 1,046.83 | 1,085.75 | 1,256.17 | **0.6%** |
| Air | 79.05 | 217.06 | 238.83 | 394.66 | **1.0%** | 543.36 | 644.45 | 657.41 | 771.71 | **0.4%** |
| Surface water | 430.93 | 1,272.82 | 1,350.20 | 2,260.04 | **5.7%** | 690.46 | 873.02 | 986.35 | 1,286.61 | **0.6%** |
| Soil | 215.97 | 578.29 | 679.76 | 1,137.23 | **2.9%** | 345.35 | 430.63 | 495.88 | 648.88 | **0.3%** |
| Landfill - CDW | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** |
| Landfill - RW | 2,056.63 | 6,028.47 | 6,242.81 | 10,307.87 | **26.3%** | 51.18 | 63.65 | 69.53 | 88.24 | **0.0%** |
| Incineration | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** | 3,172.87 | 3,924.77 | 4,266.42 | 5,383.85 | **2.4%** |
| Recycling | 4,941.60 | 21,980.44 | 14,659.46 | 24,240.04 | **61.7%** | 8,950.70 | 10,692.97 | 10,942.97 | 12,930.74 | **6.2%** |
| Export | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** | 151,425.65 | 156,503.81 | 156,675.21 | 161,941.38 | **89.4%** |

**Modelling results – masses of carbon black ENM entering technical and environmental compartments (continued)**

| To | Flows of CB in Norway | | | | | Flows of CB in Poland | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Q15 | Mode | Mean | Q85 | **Mean TC** | Q15 | Mode | Mean | Q85 | **Mean TC** |
| | In tonnes | | | | | In tonnes | | | | |
| Waste water | 944.02 | 1,175.76 | 1,396.58 | 1,860.80 | **2.6%** | 1,969.48 | 2,537.16 | 2,699.58 | 3,439.80 | **1.4%** |
| Air | 383.21 | 474.80 | 560.03 | 741.16 | **1.0%** | 722.36 | 908.51 | 969.43 | 1,220.90 | **0.5%** |
| Surface water | 1,939.43 | 2,568.85 | 3,031.03 | 4,167.51 | **5.7%** | 4,929.15 | 6,409.35 | 6,840.53 | 8,763.67 | **3.5%** |
| Soil | 968.29 | 1,258.30 | 1,522.56 | 2,096.22 | **2.9%** | 2,468.21 | 3,088.63 | 3,440.05 | 4,422.26 | **1.7%** |
| Landfill - CDW | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** |
| Landfill - RW | 227.45 | 284.16 | 345.08 | 465.84 | **0.6%** | 19,081.85 | 23,066.39 | 23,303.20 | 27,538.30 | **11.8%** |
| Incineration | 7,936.65 | 10,141.64 | 11,954.74 | 16,060.13 | **22.4%** | 5,455.77 | 6,566.41 | 6,718.89 | 7,988.29 | **3.4%** |
| Recycling | 24,228.58 | 23,798.71 | 34,565.07 | 44,777.91 | **64.8%** | 64,235.77 | 75,178.55 | 74,117.53 | 83,792.86 | **37.6%** |
| Export | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** | 70,248.88 | 76,867.70 | 78,789.69 | 87,524.20 | **40.0%** |

| To | Flows of CB in Portugal | | | | | Flows of CB in Romania | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Q15 | Mode | Mean | Q85 | **Mean TC** | Q15 | Mode | Mean | Q85 | **Mean TC** |
| | In tonnes | | | | | In tonnes | | | | |
| Waste water | 774.63 | 958.76 | 1,043.10 | 1,315.11 | **0.9%** | 552.31 | 689.99 | 765.44 | 981.95 | **0.5%** |
| Air | 351.56 | 428.16 | 448.77 | 547.89 | **0.4%** | 234.57 | 293.57 | 308.92 | 384.37 | **0.2%** |
| Surface water | 1,655.40 | 2,174.92 | 2,345.89 | 3,046.46 | **2.1%** | 1,249.43 | 1,640.31 | 1,804.03 | 2,367.04 | **1.2%** |
| Soil | 826.70 | 1,045.98 | 1,180.27 | 1,538.32 | **1.1%** | 626.43 | 845.89 | 906.98 | 1,191.12 | **0.6%** |
| Landfill - CDW | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** |
| Landfill - RW | 6,326.42 | 7,620.42 | 7,651.48 | 8,969.41 | **6.9%** | 6,067.68 | 7,381.15 | 7,475.14 | 8,871.20 | **5.1%** |
| Incineration | 2,605.49 | 3,128.27 | 3,169.20 | 3,732.83 | **2.9%** | 47.93 | 59.33 | 59.93 | 71.88 | **0.0%** |
| Recycling | 21,216.39 | 25,781.42 | 25,487.04 | 29,660.71 | **23.1%** | 16,488.21 | 20,233.38 | 20,172.32 | 23,812.19 | **13.9%** |
| Export | 63,715.80 | 68,349.05 | 69,056.02 | 74,463.90 | **62.6%** | 107,370.65 | 113,440.63 | 113,866.06 | 120,358.53 | **78.3%** |

**Modelling results – masses of carbon black ENM entering technical and environmental compartments (continued)**

| To | Flows of CB in the Slovakia | | | | | Flows of CB in Slovenia | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Q15 | Mode | Mean | Q85 | **Mean TC** | Q15 | Mode | Mean | Q85 | **Mean TC** |
| | In tonnes | | | | | In tonnes | | | | |
| Waste water | 315.33 | 381.23 | 399.40 | 484.50 | **1.7%** | 303.46 | 347.37 | 701.11 | 1,094.64 | **2.5%** |
| Air | 144.83 | 168.98 | 175.69 | 206.75 | **0.7%** | 121.04 | 246.12 | 282.68 | 441.18 | **1.0%** |
| Surface water | 588.03 | 740.10 | 803.41 | 1,021.17 | **3.3%** | 672.33 | 762.33 | 1,612.15 | 2,548.79 | **5.7%** |
| Soil | 293.58 | 371.42 | 403.90 | 515.52 | **1.7%** | 337.39 | 463.16 | 811.00 | 1,284.95 | **2.9%** |
| Landfill - CDW | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** |
| Landfill - RW | 2,540.33 | 2,969.44 | 3,217.96 | 3,916.95 | **13.3%** | 3,092.15 | 5,715.94 | 7,210.31 | 11,251.94 | **25.5%** |
| Incineration | 413.06 | 490.07 | 527.84 | 646.17 | **2.2%** | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** |
| Recycling | 7,698.62 | 8,659.45 | 8,693.72 | 9,686.62 | **36.0%** | 7,821.04 | 20,272.50 | 17,702.41 | 27,414.54 | **62.5%** |
| Export | 8,797.04 | 9,770.08 | 9,895.52 | 11,020.10 | **41.0%** | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** |

| To | Flows of CB in Spain | | | | | Flows of CB in Sweden | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Q15 | Mode | Mean | Q85 | **Mean TC** | Q15 | Mode | Mean | Q85 | **Mean TC** |
| | In tonnes | | | | | In tonnes | | | | |
| Waste water | 4,508.13 | 5,426.24 | 5,758.71 | 7,025.99 | **2.6%** | 627.29 | 718.51 | 756.26 | 887.35 | **0.8%** |
| Air | 1,861.74 | 2,204.51 | 2,309.12 | 2,759.56 | **1.1%** | 350.38 | 419.02 | 421.74 | 493.47 | **0.4%** |
| Surface water | 9,260.83 | 11,886.67 | 12,484.47 | 15,728.95 | **5.7%** | 683.84 | 896.58 | 968.41 | 1,258.20 | **1.0%** |
| Soil | 4,615.08 | 5,826.44 | 6,269.64 | 7,946.94 | **2.9%** | 341.76 | 443.49 | 487.34 | 635.07 | **0.5%** |
| Landfill - CDW | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** |
| Landfill - RW | 36,649.79 | 44,933.94 | 46,043.15 | 55,607.64 | **20.9%** | 31.00 | 38.00 | 41.90 | 53.04 | **0.0%** |
| Incineration | 6,233.70 | 7,540.46 | 7,896.36 | 9,597.58 | **3.6%** | 3,093.47 | 3,848.91 | 4,129.12 | 5,184.72 | **4.1%** |
| Recycling | 128,146.46 | 140,340.57 | 139,140.28 | 150,071.09 | **63.3%** | 8,984.35 | 10,500.37 | 10,821.68 | 12,664.84 | **10.8%** |
| Export | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** | 78,603.85 | 81,801.35 | 82,157.61 | 85,706.66 | **82.3%** |

**Modelling results – masses of carbon black ENM entering technical and environmental compartments (continued)**

| | Flows of CB in Switzerland | | | | | Flows of CB in the United Kingdom | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Q15 | Mode | Mean | Q85 | **Mean TC** | Q15 | Mode | Mean | Q85 | **Mean TC** |
| To | In tonnes | | | | | In tonnes | | | | |
| Waste water | 939.43 | 1,194.73 | 1,351.22 | 1,769.98 | **1.3%** | 5,465.24 | 6,361.78 | 6,546.06 | 7,636.43 | **1.7%** |
| Air | 343.06 | 447.37 | 496.33 | 652.44 | **0.5%** | 2,340.24 | 2,711.04 | 2,735.89 | 3,133.27 | **0.7%** |
| Surface water | 2,345.24 | 3,074.02 | 3,370.52 | 4,418.22 | **3.3%** | 15,135.19 | 17,851.21 | 18,706.11 | 22,291.78 | **4.8%** |
| Soil | 1,171.15 | 1,579.50 | 1,696.94 | 2,232.30 | **1.7%** | 3,166.94 | 3,991.12 | 4,320.76 | 5,487.92 | **1.1%** |
| Landfill - CDW | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** |
| Landfill - RW | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** | 42,955.57 | 50,200.93 | 50,807.74 | 58,714.52 | **13.1%** |
| Incineration | 9,597.67 | 11,768.32 | 12,639.20 | 15,730.69 | **12.4%** | 32,992.66 | 38,090.12 | 39,046.54 | 45,164.55 | **10.1%** |
| Recycling | 31,696.42 | 36,891.92 | 38,883.27 | 46,324.49 | **38.1%** | 98,222.38 | 110,113.93 | 111,992.52 | 125,822.31 | **28.9%** |
| Export | 36,014.21 | 42,957.49 | 43,493.52 | 50,948.38 | **42.7%** | 135,652.33 | 149,461.60 | 153,286.48 | 171,299.06 | **39.6%** |

## Modelling results – masses of copper ENM entering technical and environmental compartments

| | Flows of Cu in Austria | | | | | Flows of Cu in Belgium | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Q15 | Mode | Mean | Q85 | **Mean TC** | Q15 | Mode | Mean | Q85 | **Mean TC** |
| To | In tonnes | | | | | In tonnes | | | | |
| Waste water | 0.17 | 0.22 | 0.23 | 0.30 | **16.0%** | 0.16 | 0.21 | 0.22 | 0.28 | **3.3%** |
| Air | 0.05 | 0.06 | 0.07 | 0.09 | **4.6%** | 0.05 | 0.07 | 0.07 | 0.10 | **1.1%** |
| Surface water | 0.00 | 0.00 | 0.00 | 0.00 | **0.1%** | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** |
| Soil | 0.00 | 0.00 | 0.00 | 0.01 | **0.3%** | 0.00 | 0.00 | 0.00 | 0.01 | **0.1%** |
| Landfill - CDW | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** |
| Landfill - RW | 0.00 | 0.00 | 0.00 | 0.00 | **0.1%** | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** |
| Incineration | 0.01 | 0.01 | 0.02 | 0.02 | **1.1%** | 0.02 | 0.02 | 0.02 | 0.03 | **0.4%** |
| Recycling | 0.30 | 0.40 | 0.40 | 0.51 | **27.7%** | 0.25 | 0.33 | 0.34 | 0.44 | **5.1%** |
| Export | 0.56 | 0.71 | 0.73 | 0.90 | **50.0%** | 4.65 | 6.06 | 6.04 | 7.42 | **90.1%** |

| | Flows of Cu in Bulgaria | | | | | Flows of Cu in Croatia | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Q15 | Mode | Mean | Q85 | **Mean TC** | Q15 | Mode | Mean | Q85 | **Mean TC** |
| To | In tonnes | | | | | In tonnes | | | | |
| Waste water | 0.03 | 0.04 | 0.04 | 0.05 | **1.0%** | 0.09 | 0.10 | 0.20 | 0.31 | **31.9%** |
| Air | 0.01 | 0.02 | 0.02 | 0.02 | **0.5%** | 0.02 | 0.03 | 0.06 | 0.09 | **9.1%** |
| Surface water | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** | 0.00 | 0.00 | 0.00 | 0.00 | **0.2%** |
| Soil | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** | 0.00 | 0.00 | 0.00 | 0.01 | **0.6%** |
| Landfill - CDW | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** |
| Landfill - RW | 0.01 | 0.01 | 0.01 | 0.01 | **0.2%** | 0.06 | 0.06 | 0.13 | 0.20 | **19.8%** |
| Incineration | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** |
| Recycling | 0.03 | 0.04 | 0.05 | 0.06 | **1.1%** | 0.11 | 0.15 | 0.24 | 0.38 | **38.4%** |
| Export | 2.99 | 3.95 | 3.89 | 4.78 | **97.1%** | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** |

**Modelling results – masses of copper ENM entering technical and environmental compartments (continued)**

| | Flows of Cu in Cyprus | | | | | Flows of Cu in Czech Republic | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Q15 | Mode | Mean | Q85 | **Mean TC** | Q15 | Mode | Mean | Q85 | **Mean TC** |
| To | In tonnes | | | | | In tonnes | | | | |
| Waste water | 0.01 | 0.01 | 0.01 | 0.01 | **11.8%** | 0.20 | 0.25 | 0.32 | 0.45 | **31.9%** |
| Air | 0.00 | 0.00 | 0.00 | 0.00 | **3.5%** | 0.05 | 0.07 | 0.09 | 0.13 | **9.1%** |
| Surface water | 0.00 | 0.00 | 0.00 | 0.00 | **0.1%** | 0.00 | 0.00 | 0.00 | 0.00 | **0.2%** |
| Soil | 0.00 | 0.00 | 0.00 | 0.00 | **0.2%** | 0.00 | 0.00 | 0.01 | 0.01 | **0.6%** |
| Landfill - CDW | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** |
| Landfill - RW | 0.00 | 0.01 | 0.01 | 0.01 | **7.1%** | 0.05 | 0.06 | 0.08 | 0.11 | **7.8%** |
| Incineration | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** | 0.01 | 0.02 | 0.02 | 0.03 | **2.0%** |
| Recycling | 0.01 | 0.01 | 0.01 | 0.02 | **13.8%** | 0.31 | 0.38 | 0.49 | 0.68 | **48.4%** |
| Export | 0.04 | 0.06 | 0.06 | 0.07 | **63.5%** | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** |

| | Flows of Cu in Denmark | | | | | Flows of Cu in Estonia | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Q15 | Mode | Mean | Q85 | **Mean TC** | Q15 | Mode | Mean | Q85 | **Mean TC** |
| To | In tonnes | | | | | In tonnes | | | | |
| Waste water | 0.13 | 0.17 | 0.20 | 0.27 | **14.1%** | 0.05 | 0.06 | 0.13 | 0.22 | **25.5%** |
| Air | 0.03 | 0.05 | 0.06 | 0.08 | **4.0%** | 0.01 | 0.02 | 0.04 | 0.06 | **7.3%** |
| Surface water | 0.00 | 0.00 | 0.00 | 0.00 | **0.1%** | 0.00 | 0.00 | 0.00 | 0.00 | **0.2%** |
| Soil | 0.00 | 0.00 | 0.00 | 0.01 | **0.3%** | 0.00 | 0.00 | 0.00 | 0.00 | **0.5%** |
| Landfill - CDW | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** |
| Landfill - RW | 0.00 | 0.00 | 0.00 | 0.00 | **0.1%** | 0.00 | 0.00 | 0.01 | 0.02 | **1.9%** |
| Incineration | 0.03 | 0.04 | 0.05 | 0.06 | **3.3%** | 0.03 | 0.03 | 0.07 | 0.12 | **14.0%** |
| Recycling | 0.21 | 0.28 | 0.31 | 0.42 | **22.3%** | 0.06 | 0.07 | 0.16 | 0.27 | **30.8%** |
| Export | 0.55 | 0.69 | 0.78 | 1.03 | **55.8%** | 0.04 | 0.05 | 0.11 | 0.17 | **19.9%** |

**Modelling results – masses of copper ENM entering technical and environmental compartments (continued)**

| | Flows of Cu in Finland | | | | | Flows of Cu in France | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Q15 | Mode | Mean | Q85 | **Mean TC** | Q15 | Mode | Mean | Q85 | **Mean TC** |
| To | In tonnes | | | | | In tonnes | | | | |
| Waste water | 0.09 | 0.11 | 0.13 | 0.16 | **5.1%** | 1.82 | 2.38 | 2.48 | 3.15 | **24.8%** |
| Air | 0.03 | 0.03 | 0.04 | 0.05 | **1.6%** | 0.46 | 0.60 | 0.70 | 0.94 | **7.0%** |
| Surface water | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** | 0.01 | 0.02 | 0.02 | 0.03 | **0.2%** |
| Soil | 0.00 | 0.00 | 0.00 | 0.00 | **0.1%** | 0.03 | 0.05 | 0.05 | 0.06 | **0.5%** |
| Landfill - CDW | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** |
| Landfill - RW | 0.00 | 0.00 | 0.00 | 0.00 | **0.1%** | 0.08 | 0.11 | 0.12 | 0.16 | **1.2%** |
| Incineration | 0.00 | 0.01 | 0.01 | 0.01 | **0.3%** | 0.11 | 0.14 | 0.17 | 0.22 | **1.7%** |
| Recycling | 0.16 | 0.20 | 0.21 | 0.27 | **8.6%** | 3.18 | 4.18 | 4.22 | 5.26 | **42.3%** |
| Export | 1.59 | 2.01 | 2.07 | 2.54 | **84.1%** | 1.69 | 2.17 | 2.23 | 2.78 | **22.4%** |

| | Flows of Cu in Germany | | | | | Flows of Cu in Greece | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Q15 | Mode | Mean | Q85 | **Mean TC** | Q15 | Mode | Mean | Q85 | **Mean TC** |
| To | In tonnes | | | | | In tonnes | | | | |
| Waste water | 1.45 | 1.87 | 1.99 | 2.53 | **17.6%** | 0.21 | 0.26 | 0.33 | 0.46 | **31.9%** |
| Air | 0.38 | 0.50 | 0.58 | 0.78 | **5.1%** | 0.05 | 0.08 | 0.09 | 0.14 | **9.1%** |
| Surface water | 0.01 | 0.01 | 0.01 | 0.02 | **0.1%** | 0.00 | 0.00 | 0.00 | 0.00 | **0.2%** |
| Soil | 0.03 | 0.03 | 0.04 | 0.05 | **0.3%** | 0.00 | 0.01 | 0.01 | 0.01 | **0.6%** |
| Landfill - CDW | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** |
| Landfill - RW | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** | 0.04 | 0.06 | 0.08 | 0.11 | **7.2%** |
| Incineration | 0.21 | 0.26 | 0.29 | 0.37 | **2.6%** | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** |
| Recycling | 2.52 | 3.16 | 3.35 | 4.18 | **29.6%** | 0.34 | 0.41 | 0.53 | 0.73 | **50.9%** |
| Export | 3.87 | 4.88 | 5.06 | 6.25 | **44.7%** | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** |

**Modelling results – masses of copper ENM entering technical and environmental compartments (continued)**

| | Flows of Cu in Hungary | | | | | Flows of Cu in Ireland | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Q15 | Mode | Mean | Q85 | **Mean TC** | Q15 | Mode | Mean | Q85 | **Mean TC** |
| To | In tonnes | | | | | In tonnes | | | | |
| Waste water | 0.13 | 0.17 | 0.24 | 0.34 | **28.7%** | 0.13 | 0.15 | 0.24 | 0.36 | **32.0%** |
| Air | 0.03 | 0.04 | 0.07 | 0.10 | **8.1%** | 0.03 | 0.04 | 0.07 | 0.10 | **9.0%** |
| Surface water | 0.00 | 0.00 | 0.00 | 0.00 | **0.2%** | 0.00 | 0.00 | 0.00 | 0.00 | **0.2%** |
| Soil | 0.00 | 0.00 | 0.00 | 0.01 | **0.5%** | 0.00 | 0.00 | 0.00 | 0.01 | **0.6%** |
| Landfill - CDW | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** |
| Landfill - RW | 0.03 | 0.04 | 0.06 | 0.09 | **7.0%** | 0.02 | 0.03 | 0.03 | 0.05 | **4.1%** |
| Incineration | 0.01 | 0.01 | 0.01 | 0.02 | **1.3%** | 0.01 | 0.01 | 0.01 | 0.02 | **1.9%** |
| Recycling | 0.21 | 0.27 | 0.36 | 0.53 | **44.0%** | 0.21 | 0.32 | 0.40 | 0.58 | **52.2%** |
| Export | 0.05 | 0.06 | 0.08 | 0.12 | **10.1%** | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** |

| | Flows of Cu in Italy | | | | | Flows of Cu in Latvia | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Q15 | Mode | Mean | Q85 | **Mean TC** | Q15 | Mode | Mean | Q85 | **Mean TC** |
| To | In tonnes | | | | | In tonnes | | | | |
| Waste water | 1.61 | 2.18 | 2.18 | 2.75 | **32.0%** | 0.06 | 0.09 | 0.17 | 0.28 | **31.9%** |
| Air | 0.41 | 0.52 | 0.61 | 0.83 | **9.0%** | 0.02 | 0.02 | 0.05 | 0.08 | **9.1%** |
| Surface water | 0.01 | 0.01 | 0.02 | 0.02 | **0.2%** | 0.00 | 0.00 | 0.00 | 0.00 | **0.2%** |
| Soil | 0.03 | 0.04 | 0.04 | 0.05 | **0.6%** | 0.00 | 0.00 | 0.00 | 0.01 | **0.6%** |
| Landfill - CDW | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** |
| Landfill - RW | 0.21 | 0.28 | 0.30 | 0.38 | **4.4%** | 0.04 | 0.07 | 0.10 | 0.17 | **19.6%** |
| Incineration | 0.21 | 0.28 | 0.29 | 0.37 | **4.2%** | 0.00 | 0.00 | 0.00 | 0.00 | **0.1%** |
| Recycling | 2.56 | 3.26 | 3.37 | 4.19 | **49.5%** | 0.08 | 0.11 | 0.20 | 0.33 | **38.4%** |
| Export | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** |

**Modelling results – masses of copper ENM entering technical and environmental compartments (continued)**

| To | Flows of Cu in Lithuania | | | | | Flows of Cu in Luxembourg | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Q15 | Mode | Mean | Q85 | Mean TC | Q15 | Mode | Mean | Q85 | Mean TC |
| | In tonnes | | | | | In tonnes | | | | |
| Waste water | 0.07 | 0.07 | 0.18 | 0.29 | **31.9%** | 0.06 | 0.09 | 0.17 | 0.28 | **31.9%** |
| Air | 0.02 | 0.03 | 0.05 | 0.08 | **9.1%** | 0.02 | 0.03 | 0.05 | 0.08 | **9.1%** |
| Surface water | 0.00 | 0.00 | 0.00 | 0.00 | **0.2%** | 0.00 | 0.00 | 0.00 | 0.00 | **0.2%** |
| Soil | 0.00 | 0.00 | 0.00 | 0.01 | **0.6%** | 0.00 | 0.00 | 0.00 | 0.01 | **0.6%** |
| Landfill - CDW | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** |
| Landfill - RW | 0.01 | 0.02 | 0.02 | 0.04 | **4.3%** | 0.00 | 0.00 | 0.00 | 0.01 | **0.9%** |
| Incineration | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** | 0.01 | 0.01 | 0.02 | 0.03 | **3.9%** |
| Recycling | 0.13 | 0.28 | 0.31 | 0.49 | **53.8%** | 0.11 | 0.15 | 0.29 | 0.47 | **53.5%** |
| Export | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** |

| To | Flows of Cu in Malta | | | | | Flows of Cu in the Netherlands | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Q15 | Mode | Mean | Q85 | Mean TC | Q15 | Mode | Mean | Q85 | Mean TC |
| | In tonnes | | | | | In tonnes | | | | |
| Waste water | 0.05 | 0.11 | 0.15 | 0.26 | **31.9%** | 0.38 | 0.48 | 0.54 | 0.71 | **31.9%** |
| Air | 0.01 | 0.02 | 0.04 | 0.07 | **9.1%** | 0.10 | 0.12 | 0.15 | 0.21 | **9.0%** |
| Surface water | 0.00 | 0.00 | 0.00 | 0.00 | **0.2%** | 0.00 | 0.00 | 0.00 | 0.01 | **0.2%** |
| Soil | 0.00 | 0.00 | 0.00 | 0.00 | **0.6%** | 0.01 | 0.01 | 0.01 | 0.01 | **0.6%** |
| Landfill - CDW | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** |
| Landfill - RW | 0.02 | 0.07 | 0.08 | 0.14 | **17.0%** | 0.00 | 0.00 | 0.00 | 0.00 | **0.2%** |
| Incineration | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** | 0.13 | 0.17 | 0.19 | 0.25 | **11.0%** |
| Recycling | 0.06 | 0.18 | 0.20 | 0.33 | **41.2%** | 0.57 | 0.74 | 0.80 | 1.03 | **47.0%** |
| Export | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** |

**Modelling results – masses of copper ENM entering technical and environmental compartments (continued)**

| | Flows of Cu in Norway | | | | | Flows of Cu in Poland | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Q15 | Mode | Mean | Q85 | **Mean TC** | Q15 | Mode | Mean | Q85 | **Mean TC** |
| To | In tonnes | | | | | In tonnes | | | | |
| Waste water | 0.24 | 0.30 | 0.37 | 0.51 | **32.0%** | 0.33 | 0.42 | 0.45 | 0.58 | **4.5%** |
| Air | 0.06 | 0.08 | 0.11 | 0.15 | **9.1%** | 0.10 | 0.13 | 0.15 | 0.19 | **1.5%** |
| Surface water | 0.00 | 0.00 | 0.00 | 0.00 | **0.2%** | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** |
| Soil | 0.00 | 0.01 | 0.01 | 0.01 | **0.6%** | 0.01 | 0.01 | 0.01 | 0.01 | **0.1%** |
| Landfill - CDW | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** |
| Landfill - RW | 0.00 | 0.00 | 0.00 | 0.00 | **0.1%** | 0.07 | 0.09 | 0.10 | 0.14 | **1.0%** |
| Incineration | 0.03 | 0.04 | 0.05 | 0.06 | **4.0%** | 0.02 | 0.03 | 0.03 | 0.04 | **0.3%** |
| Recycling | 0.41 | 0.53 | 0.63 | 0.84 | **54.0%** | 0.48 | 0.65 | 0.65 | 0.83 | **6.5%** |
| Export | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** | 6.62 | 8.62 | 8.60 | 10.58 | **86.0%** |

| | Flows of Cu in Portugal | | | | | Flows of Cu in Romania | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Q15 | Mode | Mean | Q85 | **Mean TC** | Q15 | Mode | Mean | Q85 | **Mean TC** |
| To | In tonnes | | | | | In tonnes | | | | |
| Waste water | 0.19 | 0.25 | 0.30 | 0.42 | **29.1%** | 0.22 | 0.30 | 0.34 | 0.48 | **32.0%** |
| Air | 0.05 | 0.07 | 0.08 | 0.12 | **8.2%** | 0.06 | 0.08 | 0.10 | 0.14 | **9.1%** |
| Surface water | 0.00 | 0.00 | 0.00 | 0.00 | **0.2%** | 0.00 | 0.00 | 0.00 | 0.00 | **0.2%** |
| Soil | 0.00 | 0.00 | 0.01 | 0.01 | **0.6%** | 0.00 | 0.01 | 0.01 | 0.01 | **0.6%** |
| Landfill - CDW | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** |
| Landfill - RW | 0.04 | 0.05 | 0.07 | 0.09 | **6.3%** | 0.20 | 0.26 | 0.32 | 0.45 | **29.9%** |
| Incineration | 0.02 | 0.02 | 0.03 | 0.04 | **2.6%** | 0.00 | 0.00 | 0.00 | 0.00 | **0.2%** |
| Recycling | 0.29 | 0.36 | 0.46 | 0.63 | **44.1%** | 0.19 | 0.24 | 0.30 | 0.42 | **28.0%** |
| Export | 0.06 | 0.07 | 0.09 | 0.13 | **8.9%** | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** |

**Modelling results – masses of copper ENM entering technical and environmental compartments (continued)**

| | Flows of Cu in the Slovakia | | | | | Flows of Cu in Slovenia | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Q15 | Mode | Mean | Q85 | **Mean TC** | Q15 | Mode | Mean | Q85 | **Mean TC** |
| To | In tonnes | | | | | In tonnes | | | | |
| Waste water | 0.12 | 0.16 | 0.23 | 0.35 | **31.9%** | 0.07 | 0.10 | 0.18 | 0.29 | **31.9%** |
| Air | 0.03 | 0.04 | 0.07 | 0.10 | **9.1%** | 0.02 | 0.02 | 0.05 | 0.08 | **9.1%** |
| Surface water | 0.00 | 0.00 | 0.00 | 0.00 | **0.2%** | 0.00 | 0.00 | 0.00 | 0.00 | **0.2%** |
| Soil | 0.00 | 0.00 | 0.00 | 0.01 | **0.6%** | 0.00 | 0.00 | 0.00 | 0.01 | **0.6%** |
| Landfill - CDW | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** |
| Landfill - RW | 0.06 | 0.08 | 0.12 | 0.19 | **17.0%** | 0.02 | 0.03 | 0.04 | 0.07 | **7.4%** |
| Incineration | 0.01 | 0.01 | 0.02 | 0.03 | **2.8%** | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** |
| Recycling | 0.15 | 0.18 | 0.28 | 0.42 | **38.4%** | 0.12 | 0.18 | 0.29 | 0.46 | **50.8%** |
| Export | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** |

| | Flows of Cu in Spain | | | | | Flows of Cu in Sweden | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Q15 | Mode | Mean | Q85 | **Mean TC** | Q15 | Mode | Mean | Q85 | **Mean TC** |
| To | In tonnes | | | | | In tonnes | | | | |
| Waste water | 0.68 | 0.89 | 0.93 | 1.18 | **13.2%** | 0.20 | 0.26 | 0.27 | 0.35 | **6.6%** |
| Air | 0.18 | 0.24 | 0.27 | 0.37 | **3.9%** | 0.06 | 0.07 | 0.08 | 0.11 | **2.0%** |
| Surface water | 0.00 | 0.01 | 0.01 | 0.01 | **0.1%** | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** |
| Soil | 0.01 | 0.02 | 0.02 | 0.02 | **0.2%** | 0.00 | 0.00 | 0.01 | 0.01 | **0.1%** |
| Landfill - CDW | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** |
| Landfill - RW | 0.17 | 0.23 | 0.24 | 0.31 | **3.4%** | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** |
| Incineration | 0.03 | 0.04 | 0.04 | 0.05 | **0.6%** | 0.02 | 0.03 | 0.03 | 0.04 | **0.8%** |
| Recycling | 1.06 | 1.36 | 1.41 | 1.76 | **20.2%** | 0.33 | 0.43 | 0.45 | 0.57 | **10.9%** |
| Export | 3.14 | 4.03 | 4.08 | 5.03 | **58.4%** | 2.52 | 3.25 | 3.28 | 4.03 | **79.5%** |

**Modelling results – masses of copper ENM entering technical and environmental compartments (continued)**

| | Flows of Cu in Switzerland | | | | | Flows of Cu in the United Kingdom | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Q15 | Mode | Mean | Q85 | **Mean TC** | Q15 | Mode | Mean | Q85 | **Mean TC** |
| To | In tonnes | | | | | In tonnes | | | | |
| Waste water | 0.35 | 0.45 | 0.49 | 0.64 | **23.5%** | 2.55 | 3.28 | 3.46 | 4.37 | **32.0%** |
| Air | 0.09 | 0.12 | 0.14 | 0.19 | **6.6%** | 0.65 | 0.84 | 0.98 | 1.32 | **9.1%** |
| Surface water | 0.00 | 0.00 | 0.00 | 0.01 | **0.2%** | 0.02 | 0.02 | 0.03 | 0.04 | **0.2%** |
| Soil | 0.01 | 0.01 | 0.01 | 0.01 | **0.5%** | 0.05 | 0.06 | 0.07 | 0.09 | **0.6%** |
| Landfill - CDW | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** |
| Landfill - RW | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** | 0.29 | 0.37 | 0.40 | 0.52 | **3.7%** |
| Incineration | 0.04 | 0.06 | 0.06 | 0.08 | **2.9%** | 0.22 | 0.29 | 0.31 | 0.39 | **2.9%** |
| Recycling | 0.61 | 0.81 | 0.83 | 1.07 | **39.8%** | 4.22 | 5.35 | 5.56 | 6.90 | **51.5%** |
| Export | 0.41 | 0.53 | 0.56 | 0.71 | **26.6%** | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** |

**Modelling results – masses of silver ENM entering technical and environmental compartments**

| | Flows of Ag in Austria | | | | | Flows of Ag in Belgium | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Q15 | Mode | Mean | Q85 | **Mean TC** | Q15 | Mode | Mean | Q85 | **Mean TC** |
| To | In tonnes | | | | | In tonnes | | | | |
| Waste water | 0.43 | 0.53 | 0.57 | 0.71 | **46.7%** | 0.33 | 0.39 | 0.41 | 0.49 | **4.6%** |
| Air | 0.03 | 0.04 | 0.04 | 0.06 | **3.4%** | 0.04 | 0.05 | 0.05 | 0.06 | **0.6%** |
| Surface water | 0.01 | 0.01 | 0.01 | 0.02 | **1.0%** | 0.01 | 0.01 | 0.01 | 0.01 | **0.1%** |
| Soil | 0.01 | 0.01 | 0.01 | 0.01 | **0.8%** | 0.01 | 0.01 | 0.01 | 0.01 | **0.1%** |
| Landfill - CDW | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** |
| Landfill - RW | 0.01 | 0.01 | 0.01 | 0.02 | **1.2%** | 0.01 | 0.01 | 0.01 | 0.01 | **0.1%** |
| Incineration | 0.15 | 0.18 | 0.20 | 0.25 | **16.0%** | 0.08 | 0.09 | 0.10 | 0.12 | **1.1%** |
| Recycling | 0.28 | 0.33 | 0.38 | 0.48 | **31.0%** | 0.25 | 0.30 | 0.32 | 0.38 | **3.5%** |
| Export | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** | 6.84 | 8.03 | 8.05 | 9.25 | **90.0%** |

| | Flows of Ag in Bulgaria | | | | | Flows of Ag in Croatia | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Q15 | Mode | Mean | Q85 | **Mean TC** | Q15 | Mode | Mean | Q85 | **Mean TC** |
| To | In tonnes | | | | | In tonnes | | | | |
| Waste water | 0.18 | 0.24 | 0.30 | 0.42 | **45.7%** | 0.15 | 0.23 | 0.27 | 0.38 | **45.7%** |
| Air | 0.01 | 0.02 | 0.02 | 0.03 | **3.4%** | 0.01 | 0.01 | 0.02 | 0.03 | **3.4%** |
| Surface water | 0.00 | 0.00 | 0.01 | 0.01 | **1.0%** | 0.00 | 0.00 | 0.01 | 0.01 | **1.0%** |
| Soil | 0.00 | 0.00 | 0.01 | 0.01 | **0.8%** | 0.00 | 0.00 | 0.00 | 0.01 | **0.8%** |
| Landfill - CDW | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** |
| Landfill - RW | 0.09 | 0.13 | 0.15 | 0.21 | **22.4%** | 0.09 | 0.14 | 0.17 | 0.24 | **29.4%** |
| Incineration | 0.00 | 0.01 | 0.01 | 0.01 | **1.4%** | 0.00 | 0.01 | 0.01 | 0.01 | **1.4%** |
| Recycling | 0.10 | 0.16 | 0.17 | 0.23 | **25.3%** | 0.06 | 0.08 | 0.11 | 0.16 | **18.3%** |
| Export | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** |

**Modelling results – masses of silver ENM entering technical and environmental compartments (continued)**

| | Flows of Ag in Cyprus | | | | | Flows of Ag in Czech Republic | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Q15 | Mode | Mean | Q85 | **Mean TC** | Q15 | Mode | Mean | Q85 | **Mean TC** |
| To | In tonnes | | | | | In tonnes | | | | |
| Waste water | 0.06 | 0.20 | 0.18 | 0.29 | **45.5%** | 0.32 | 0.41 | 0.45 | 0.58 | **46.2%** |
| Air | 0.00 | 0.01 | 0.01 | 0.02 | **3.4%** | 0.02 | 0.03 | 0.03 | 0.05 | **3.4%** |
| Surface water | 0.00 | 0.00 | 0.00 | 0.01 | **1.0%** | 0.01 | 0.01 | 0.01 | 0.01 | **1.0%** |
| Soil | 0.00 | 0.00 | 0.00 | 0.01 | **0.8%** | 0.01 | 0.01 | 0.01 | 0.01 | **0.8%** |
| Landfill - CDW | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** |
| Landfill - RW | 0.04 | 0.10 | 0.11 | 0.18 | **27.6%** | 0.08 | 0.11 | 0.12 | 0.15 | **12.2%** |
| Incineration | 0.00 | 0.00 | 0.01 | 0.01 | **1.4%** | 0.08 | 0.10 | 0.12 | 0.15 | **12.0%** |
| Recycling | 0.03 | 0.08 | 0.08 | 0.13 | **20.4%** | 0.16 | 0.21 | 0.24 | 0.31 | **24.5%** |
| Export | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** |

| | Flows of Ag in Denmark | | | | | Flows of Ag in Estonia | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Q15 | Mode | Mean | Q85 | **Mean TC** | Q15 | Mode | Mean | Q85 | **Mean TC** |
| To | In tonnes | | | | | In tonnes | | | | |
| Waste water | 0.26 | 0.33 | 0.36 | 0.47 | **38.7%** | 0.08 | 0.11 | 0.20 | 0.31 | **45.6%** |
| Air | 0.02 | 0.02 | 0.03 | 0.04 | **2.8%** | 0.01 | 0.01 | 0.01 | 0.02 | **3.4%** |
| Surface water | 0.00 | 0.01 | 0.01 | 0.01 | **0.8%** | 0.00 | 0.00 | 0.00 | 0.01 | **1.0%** |
| Soil | 0.00 | 0.01 | 0.01 | 0.01 | **0.7%** | 0.00 | 0.00 | 0.00 | 0.01 | **0.8%** |
| Landfill - CDW | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** |
| Landfill - RW | 0.01 | 0.01 | 0.01 | 0.02 | **1.5%** | 0.01 | 0.02 | 0.02 | 0.03 | **4.4%** |
| Incineration | 0.08 | 0.11 | 0.12 | 0.15 | **12.7%** | 0.05 | 0.13 | 0.11 | 0.18 | **26.2%** |
| Recycling | 0.17 | 0.22 | 0.25 | 0.32 | **26.2%** | 0.03 | 0.03 | 0.08 | 0.13 | **18.6%** |
| Export | 0.11 | 0.14 | 0.16 | 0.20 | **16.6%** | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** |

**Modelling results – masses of silver ENM entering technical and environmental compartments (continued)**

| | Flows of Ag in Finland | | | | | Flows of Ag in France | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Q15 | Mode | Mean | Q85 | **Mean TC** | Q15 | Mode | Mean | Q85 | **Mean TC** |
| To | In tonnes | | | | | In tonnes | | | | |
| Waste water | 0.24 | 0.29 | 0.35 | 0.47 | **43.8%** | 1.93 | 2.28 | 2.31 | 2.69 | **42.4%** |
| Air | 0.02 | 0.02 | 0.03 | 0.04 | **3.2%** | 0.12 | 0.15 | 0.16 | 0.21 | **3.0%** |
| Surface water | 0.00 | 0.01 | 0.01 | 0.01 | **0.9%** | 0.03 | 0.04 | 0.05 | 0.07 | **0.9%** |
| Soil | 0.00 | 0.01 | 0.01 | 0.01 | **0.8%** | 0.03 | 0.04 | 0.04 | 0.05 | **0.8%** |
| Landfill - CDW | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** |
| Landfill - RW | 0.03 | 0.04 | 0.04 | 0.05 | **5.0%** | 0.30 | 0.36 | 0.36 | 0.43 | **6.7%** |
| Incineration | 0.05 | 0.06 | 0.08 | 0.10 | **9.7%** | 0.40 | 0.47 | 0.49 | 0.58 | **8.9%** |
| Recycling | 0.16 | 0.22 | 0.25 | 0.34 | **31.1%** | 1.19 | 1.48 | 1.48 | 1.78 | **27.3%** |
| Export | 0.03 | 0.04 | 0.04 | 0.06 | **5.5%** | 0.45 | 0.54 | 0.55 | 0.64 | **10.0%** |

| | Flows of Ag in Germany | | | | | Flows of Ag in Greece | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Q15 | Mode | Mean | Q85 | **Mean TC** | Q15 | Mode | Mean | Q85 | **Mean TC** |
| To | In tonnes | | | | | In tonnes | | | | |
| Waste water | 2.30 | 2.80 | 2.82 | 3.33 | **15.7%** | 0.33 | 0.41 | 0.46 | 0.59 | **46.2%** |
| Air | 0.17 | 0.21 | 0.24 | 0.30 | **1.3%** | 0.02 | 0.03 | 0.03 | 0.05 | **3.4%** |
| Surface water | 0.04 | 0.05 | 0.06 | 0.08 | **0.3%** | 0.01 | 0.01 | 0.01 | 0.01 | **1.0%** |
| Soil | 0.04 | 0.05 | 0.05 | 0.06 | **0.3%** | 0.01 | 0.01 | 0.01 | 0.01 | **0.8%** |
| Landfill - CDW | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** |
| Landfill - RW | 0.05 | 0.06 | 0.07 | 0.09 | **0.4%** | 0.15 | 0.19 | 0.21 | 0.27 | **21.0%** |
| Incineration | 0.58 | 0.69 | 0.71 | 0.84 | **4.0%** | 0.01 | 0.01 | 0.01 | 0.02 | **1.4%** |
| Recycling | 1.84 | 2.23 | 2.28 | 2.71 | **12.7%** | 0.18 | 0.23 | 0.26 | 0.34 | **26.3%** |
| Export | 9.86 | 11.66 | 11.69 | 13.51 | **65.3%** | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** |

**Modelling results – masses of silver ENM entering technical and environmental compartments (continued)**

| To | Flows of Ag in Hungary | | | | | Flows of Ag in Ireland | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Q15 | Mode | Mean | Q85 | **Mean TC** | Q15 | Mode | Mean | Q85 | **Mean TC** |
| | In tonnes | | | | | In tonnes | | | | |
| Waste water | 0.26 | 0.34 | 0.38 | 0.51 | **46.1%** | 0.26 | 0.31 | 0.35 | 0.45 | **34.8%** |
| Air | 0.02 | 0.02 | 0.03 | 0.04 | **3.4%** | 0.02 | 0.02 | 0.03 | 0.04 | **2.5%** |
| Surface water | 0.00 | 0.01 | 0.01 | 0.01 | **1.0%** | 0.00 | 0.01 | 0.01 | 0.01 | **0.7%** |
| Soil | 0.00 | 0.01 | 0.01 | 0.01 | **0.8%** | 0.00 | 0.01 | 0.01 | 0.01 | **0.6%** |
| Landfill - CDW | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** |
| Landfill - RW | 0.11 | 0.13 | 0.16 | 0.21 | **19.0%** | 0.06 | 0.08 | 0.08 | 0.11 | **8.2%** |
| Incineration | 0.03 | 0.03 | 0.04 | 0.05 | **4.6%** | 0.06 | 0.07 | 0.08 | 0.11 | **8.3%** |
| Recycling | 0.14 | 0.16 | 0.21 | 0.28 | **25.2%** | 0.14 | 0.17 | 0.20 | 0.27 | **19.9%** |
| Export | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** | 0.18 | 0.23 | 0.25 | 0.32 | **24.9%** |

| To | Flows of Ag in Italy | | | | | Flows of Ag in Latvia | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Q15 | Mode | Mean | Q85 | **Mean TC** | Q15 | Mode | Mean | Q85 | **Mean TC** |
| | In tonnes | | | | | In tonnes | | | | |
| Waste water | 1.75 | 2.05 | 2.10 | 2.44 | **35.2%** | 0.09 | 0.11 | 0.21 | 0.32 | **45.6%** |
| Air | 0.10 | 0.13 | 0.15 | 0.19 | **2.5%** | 0.01 | 0.01 | 0.02 | 0.02 | **3.4%** |
| Surface water | 0.03 | 0.04 | 0.04 | 0.06 | **0.7%** | 0.00 | 0.00 | 0.00 | 0.01 | **1.0%** |
| Soil | 0.03 | 0.04 | 0.04 | 0.05 | **0.6%** | 0.00 | 0.00 | 0.00 | 0.01 | **0.8%** |
| Landfill - CDW | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** |
| Landfill - RW | 0.41 | 0.48 | 0.50 | 0.58 | **8.4%** | 0.06 | 0.08 | 0.13 | 0.21 | **29.0%** |
| Incineration | 0.41 | 0.49 | 0.50 | 0.59 | **8.4%** | 0.00 | 0.01 | 0.01 | 0.01 | **1.5%** |
| Recycling | 0.89 | 1.10 | 1.13 | 1.36 | **18.9%** | 0.04 | 0.04 | 0.09 | 0.14 | **18.7%** |
| Export | 1.25 | 1.47 | 1.51 | 1.77 | **25.3%** | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** |

**Modelling results – masses of silver ENM entering technical and environmental compartments (continued)**

| | Flows of Ag in Lithuania | | | | | Flows of Ag in Luxembourg | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Q15 | Mode | Mean | Q85 | **Mean TC** | Q15 | Mode | Mean | Q85 | **Mean TC** |
| To | In tonnes | | | | | In tonnes | | | | |
| Waste water | 0.12 | 0.17 | 0.23 | 0.35 | **45.8%** | 0.08 | 0.13 | 0.20 | 0.31 | **45.7%** |
| Air | 0.01 | 0.01 | 0.02 | 0.03 | **3.4%** | 0.01 | 0.01 | 0.01 | 0.02 | **3.4%** |
| Surface water | 0.00 | 0.00 | 0.00 | 0.01 | **1.0%** | 0.00 | 0.00 | 0.00 | 0.01 | **1.0%** |
| Soil | 0.00 | 0.00 | 0.00 | 0.01 | **0.8%** | 0.00 | 0.00 | 0.00 | 0.01 | **0.8%** |
| Landfill - CDW | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** |
| Landfill - RW | 0.05 | 0.05 | 0.09 | 0.14 | **18.3%** | 0.01 | 0.01 | 0.02 | 0.02 | **3.5%** |
| Incineration | 0.00 | 0.00 | 0.01 | 0.01 | **1.4%** | 0.02 | 0.03 | 0.05 | 0.08 | **12.2%** |
| Recycling | 0.07 | 0.08 | 0.15 | 0.23 | **29.4%** | 0.06 | 0.08 | 0.15 | 0.23 | **33.5%** |
| Export | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** |

| | Flows of Ag in Malta | | | | | Flows of Ag in the Netherlands | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Q15 | Mode | Mean | Q85 | **Mean TC** | Q15 | Mode | Mean | Q85 | **Mean TC** |
| To | In tonnes | | | | | In tonnes | | | | |
| Waste water | 0.06 | 0.17 | 0.17 | 0.29 | **45.4%** | 0.63 | 0.76 | 0.78 | 0.94 | **43.5%** |
| Air | 0.00 | 0.01 | 0.01 | 0.02 | **3.4%** | 0.04 | 0.05 | 0.06 | 0.07 | **3.1%** |
| Surface water | 0.00 | 0.00 | 0.00 | 0.01 | **1.0%** | 0.01 | 0.01 | 0.02 | 0.02 | **0.9%** |
| Soil | 0.00 | 0.00 | 0.00 | 0.01 | **0.8%** | 0.01 | 0.01 | 0.01 | 0.02 | **0.8%** |
| Landfill - CDW | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** |
| Landfill - RW | 0.02 | 0.04 | 0.07 | 0.12 | **18.7%** | 0.02 | 0.02 | 0.02 | 0.03 | **1.2%** |
| Incineration | 0.00 | 0.00 | 0.01 | 0.01 | **1.4%** | 0.30 | 0.35 | 0.37 | 0.44 | **20.4%** |
| Recycling | 0.04 | 0.06 | 0.11 | 0.19 | **29.4%** | 0.32 | 0.39 | 0.41 | 0.51 | **22.9%** |
| Export | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** | 0.10 | 0.12 | 0.13 | 0.16 | **7.2%** |

**Modelling results – masses of silver ENM entering technical and environmental compartments (continued)**

| To | Flows of Ag in Norway Q15 (In tonnes) | Mode | Mean | Q85 | Mean TC | Flows of Ag in Poland Q15 (In tonnes) | Mode | Mean | Q85 | Mean TC |
|---|---|---|---|---|---|---|---|---|---|---|
| Waste water | 0.31 | 0.37 | 0.43 | 0.56 | **43.9%** | 0.50 | 0.61 | 0.63 | 0.75 | **6.6%** |
| Air | 0.02 | 0.03 | 0.03 | 0.04 | **3.2%** | 0.05 | 0.06 | 0.07 | 0.08 | **0.7%** |
| Surface water | 0.01 | 0.01 | 0.01 | 0.01 | **0.9%** | 0.01 | 0.01 | 0.01 | 0.02 | **0.1%** |
| Soil | 0.01 | 0.01 | 0.01 | 0.01 | **0.8%** | 0.01 | 0.01 | 0.01 | 0.01 | **0.1%** |
| Landfill - CDW | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** |
| Landfill - RW | 0.01 | 0.01 | 0.01 | 0.02 | **1.3%** | 0.17 | 0.21 | 0.22 | 0.27 | **2.3%** |
| Incineration | 0.10 | 0.12 | 0.13 | 0.17 | **13.5%** | 0.06 | 0.07 | 0.08 | 0.09 | **0.8%** |
| Recycling | 0.21 | 0.27 | 0.30 | 0.40 | **30.7%** | 0.28 | 0.34 | 0.36 | 0.45 | **3.8%** |
| Export | 0.04 | 0.05 | 0.06 | 0.07 | **5.7%** | 6.95 | 8.03 | 8.18 | 9.41 | **85.6%** |

| To | Flows of Ag in Portugal Q15 (In tonnes) | Mode | Mean | Q85 | Mean TC | Flows of Ag in Romania Q15 (In tonnes) | Mode | Mean | Q85 | Mean TC |
|---|---|---|---|---|---|---|---|---|---|---|
| Waste water | 0.31 | 0.39 | 0.42 | 0.54 | **41.8%** | 0.41 | 0.50 | 0.54 | 0.68 | **45.9%** |
| Air | 0.02 | 0.03 | 0.03 | 0.04 | **3.0%** | 0.03 | 0.03 | 0.04 | 0.05 | **3.4%** |
| Surface water | 0.01 | 0.01 | 0.01 | 0.01 | **0.9%** | 0.01 | 0.01 | 0.01 | 0.02 | **1.0%** |
| Soil | 0.01 | 0.01 | 0.01 | 0.01 | **0.8%** | 0.01 | 0.01 | 0.01 | 0.01 | **0.8%** |
| Landfill - CDW | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** |
| Landfill - RW | 0.11 | 0.15 | 0.15 | 0.20 | **15.1%** | 0.32 | 0.39 | 0.43 | 0.54 | **36.3%** |
| Incineration | 0.05 | 0.06 | 0.07 | 0.09 | **7.1%** | 0.01 | 0.02 | 0.02 | 0.03 | **1.6%** |
| Recycling | 0.14 | 0.19 | 0.21 | 0.28 | **21.0%** | 0.09 | 0.12 | 0.13 | 0.17 | **11.0%** |
| Export | 0.08 | 0.09 | 0.10 | 0.13 | **10.4%** | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** |

**Modelling results – masses of silver ENM entering technical and environmental compartments (continued)**

| | **Flows of Ag in the Slovakia** | | | | | **Flows of Ag in Slovenia** | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Q15 | Mode | Mean | Q85 | **Mean TC** | Q15 | Mode | Mean | Q85 | **Mean TC** |
| To | In tonnes | | | | | In tonnes | | | | |
| Waste water | 0.19 | 0.25 | 0.31 | 0.42 | **45.8%** | 0.11 | 0.15 | 0.22 | 0.34 | **45.8%** |
| Air | 0.01 | 0.02 | 0.02 | 0.03 | **3.4%** | 0.01 | 0.01 | 0.02 | 0.03 | **3.4%** |
| Surface water | 0.00 | 0.00 | 0.01 | 0.01 | **1.0%** | 0.00 | 0.00 | 0.00 | 0.01 | **1.0%** |
| Soil | 0.00 | 0.00 | 0.01 | 0.01 | **0.8%** | 0.00 | 0.00 | 0.00 | 0.01 | **0.8%** |
| Landfill - CDW | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** |
| Landfill - RW | 0.10 | 0.11 | 0.17 | 0.23 | **24.9%** | 0.05 | 0.09 | 0.10 | 0.15 | **20.2%** |
| Incineration | 0.02 | 0.03 | 0.04 | 0.05 | **5.3%** | 0.00 | 0.00 | 0.01 | 0.01 | **1.4%** |
| Recycling | 0.07 | 0.10 | 0.13 | 0.18 | **18.8%** | 0.06 | 0.10 | 0.13 | 0.21 | **27.5%** |
| Export | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** |

| | **Flows of Ag in Spain** | | | | | **Flows of Ag in Sweden** | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Q15 | Mode | Mean | Q85 | **Mean TC** | Q15 | Mode | Mean | Q85 | **Mean TC** |
| To | In tonnes | | | | | In tonnes | | | | |
| Waste water | 1.36 | 1.60 | 1.63 | 1.91 | **46.9%** | 0.43 | 0.53 | 0.57 | 0.71 | **46.7%** |
| Air | 0.08 | 0.10 | 0.12 | 0.15 | **3.3%** | 0.03 | 0.04 | 0.04 | 0.06 | **3.4%** |
| Surface water | 0.02 | 0.03 | 0.03 | 0.05 | **1.0%** | 0.01 | 0.01 | 0.01 | 0.02 | **1.0%** |
| Soil | 0.02 | 0.03 | 0.03 | 0.04 | **0.9%** | 0.01 | 0.01 | 0.01 | 0.01 | **0.8%** |
| Landfill - CDW | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** |
| Landfill - RW | 0.57 | 0.68 | 0.70 | 0.82 | **20.0%** | 0.01 | 0.01 | 0.01 | 0.02 | **1.2%** |
| Incineration | 0.13 | 0.16 | 0.16 | 0.19 | **4.6%** | 0.15 | 0.18 | 0.20 | 0.25 | **16.0%** |
| Recycling | 0.64 | 0.76 | 0.81 | 0.98 | **23.2%** | 0.28 | 0.33 | 0.38 | 0.48 | **31.0%** |
| Export | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** |

**Modelling results – masses of silver ENM entering technical and environmental compartments (continued)**

| | Flows of Ag in Switzerland | | | | | Flows of Ag in the United Kingdom | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Q15 | Mode | Mean | Q85 | **Mean TC** | Q15 | Mode | Mean | Q85 | **Mean TC** |
| To | In tonnes | | | | | In tonnes | | | | |
| Waste water | 0.43 | 0.51 | 0.54 | 0.65 | **33.4%** | 2.14 | 2.55 | 2.56 | 2.98 | **47.0%** |
| Air | 0.03 | 0.03 | 0.04 | 0.05 | **2.4%** | 0.13 | 0.17 | 0.18 | 0.23 | **3.3%** |
| Surface water | 0.01 | 0.01 | 0.01 | 0.02 | **0.7%** | 0.03 | 0.04 | 0.05 | 0.07 | **1.0%** |
| Soil | 0.01 | 0.01 | 0.01 | 0.01 | **0.6%** | 0.03 | 0.04 | 0.05 | 0.06 | **0.9%** |
| Landfill - CDW | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** |
| Landfill - RW | 0.01 | 0.01 | 0.01 | 0.02 | **0.8%** | 0.55 | 0.65 | 0.67 | 0.79 | **12.3%** |
| Incineration | 0.14 | 0.16 | 0.17 | 0.21 | **10.8%** | 0.45 | 0.53 | 0.54 | 0.64 | **10.0%** |
| Recycling | 0.28 | 0.35 | 0.37 | 0.46 | **23.0%** | 1.10 | 1.33 | 1.38 | 1.67 | **25.5%** |
| Export | 0.36 | 0.44 | 0.46 | 0.55 | **28.3%** | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** |

### Modelling results – masses of $TiO_2$ ENM entering technical and environmental compartments

| | Flows of $TiO_2$ in Austria | | | | | Flows of $TiO_2$ in Belgium | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Q15 | Mode | Mean | Q85 | **Mean TC** | Q15 | Mode | Mean | Q85 | **Mean TC** |
| To | In tonnes | | | | | In tonnes | | | | |
| Waste water | 112.81 | 163.98 | 187.54 | 264.50 | **61.9%** | 136.07 | 195.93 | 221.54 | 308.94 | **61.9%** |
| Air | 1.24 | 1.80 | 2.23 | 3.25 | **0.7%** | 1.47 | 2.13 | 2.58 | 3.73 | **0.7%** |
| Surface water | 8.98 | 12.60 | 17.05 | 25.42 | **5.6%** | 10.85 | 15.67 | 20.11 | 29.71 | **5.6%** |
| Soil | 0.26 | 0.36 | 0.49 | 0.74 | **0.2%** | 0.31 | 0.46 | 0.58 | 0.86 | **0.2%** |
| Landfill - CDW | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** |
| Landfill - RW | 1.35 | 2.07 | 2.29 | 3.25 | **0.8%** | 0.26 | 0.39 | 0.44 | 0.63 | **0.1%** |
| Incineration | 10.66 | 15.94 | 18.06 | 25.70 | **6.0%** | 13.75 | 21.16 | 23.06 | 32.50 | **6.4%** |
| Recycling | 44.30 | 64.15 | 75.47 | 107.89 | **24.9%** | 53.78 | 80.48 | 89.32 | 125.49 | **25.0%** |
| Export | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** |

| | Flows of $TiO_2$ in Bulgaria | | | | | Flows of $TiO_2$ in Croatia | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Q15 | Mode | Mean | Q85 | **Mean TC** | Q15 | Mode | Mean | Q85 | **Mean TC** |
| To | In tonnes | | | | | In tonnes | | | | |
| Waste water | 48.75 | 64.82 | 101.39 | 157.25 | **61.7%** | 52.19 | 67.50 | 105.47 | 162.48 | **61.7%** |
| Air | 0.63 | 0.85 | 1.35 | 2.12 | **0.8%** | 0.68 | 0.93 | 1.40 | 2.18 | **0.8%** |
| Surface water | 3.98 | 5.51 | 9.19 | 14.66 | **5.6%** | 4.25 | 5.95 | 9.57 | 15.14 | **5.6%** |
| Soil | 0.11 | 0.16 | 0.27 | 0.43 | **0.2%** | 0.12 | 0.18 | 0.28 | 0.44 | **0.2%** |
| Landfill - CDW | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** |
| Landfill - RW | 6.62 | 8.66 | 14.07 | 21.93 | **8.6%** | 8.57 | 11.69 | 17.60 | 27.19 | **10.3%** |
| Incineration | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** |
| Recycling | 17.87 | 23.06 | 38.00 | 59.27 | **23.1%** | 17.73 | 26.05 | 36.66 | 56.71 | **21.4%** |
| Export | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** |

## Modelling results – masses of $TiO_2$ ENM entering technical and environmental compartments (continued)

| | Flows of $TiO_2$ in Cyprus | | | | | Flows of $TiO_2$ in Czech Republic | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Q15 | Mode | Mean | Q85 | **Mean TC** | Q15 | Mode | Mean | Q85 | **Mean TC** |
| To | In tonnes | | | | | In tonnes | | | | |
| Waste water | 32.43 | 36.39 | 82.22 | 134.71 | **61.6%** | 108.78 | 164.12 | 181.56 | 257.23 | **61.7%** |
| Air | 0.44 | 0.56 | 1.11 | 1.81 | **0.8%** | 1.39 | 1.98 | 2.43 | 3.50 | **0.8%** |
| Surface water | 2.70 | 3.19 | 7.46 | 12.40 | **5.6%** | 8.69 | 13.15 | 16.45 | 24.44 | **5.6%** |
| Soil | 0.08 | 0.11 | 0.22 | 0.36 | **0.2%** | 0.25 | 0.36 | 0.48 | 0.71 | **0.2%** |
| Landfill - CDW | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** |
| Landfill - RW | 3.53 | 4.09 | 9.04 | 14.91 | **6.8%** | 12.19 | 19.00 | 20.69 | 29.48 | **7.0%** |
| Incineration | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** | 3.79 | 5.83 | 6.44 | 9.18 | **2.2%** |
| Recycling | 13.02 | 14.93 | 33.35 | 54.94 | **25.0%** | 38.60 | 60.79 | 66.04 | 94.70 | **22.5%** |
| Export | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** |

| | Flows of $TiO_2$ in Denmark | | | | | Flows of $TiO_2$ in Estonia | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Q15 | Mode | Mean | Q85 | **Mean TC** | Q15 | Mode | Mean | Q85 | **Mean TC** |
| To | In tonnes | | | | | In tonnes | | | | |
| Waste water | 75.07 | 107.21 | 134.95 | 198.66 | **61.8%** | 26.48 | 25.23 | 75.66 | 126.63 | **61.6%** |
| Air | 0.82 | 1.14 | 1.62 | 2.44 | **0.7%** | 0.33 | 0.33 | 0.99 | 1.68 | **0.8%** |
| Surface water | 6.09 | 8.55 | 12.31 | 18.81 | **5.6%** | 2.24 | 2.46 | 6.85 | 11.62 | **5.6%** |
| Soil | 0.17 | 0.25 | 0.36 | 0.54 | **0.2%** | 0.06 | 0.08 | 0.20 | 0.34 | **0.2%** |
| Landfill - CDW | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** |
| Landfill - RW | 1.57 | 2.13 | 2.92 | 4.34 | **1.3%** | 0.51 | 0.52 | 1.48 | 2.49 | **1.2%** |
| Incineration | 8.00 | 10.89 | 14.88 | 22.11 | **6.8%** | 3.73 | 3.74 | 10.79 | 18.08 | **8.8%** |
| Recycling | 27.93 | 39.04 | 51.33 | 76.02 | **23.5%** | 9.23 | 9.11 | 26.82 | 45.08 | **21.8%** |
| Export | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** |

**Modelling results – masses of $TiO_2$ ENM entering technical and environmental compartments (continued)**

| To | Flows of $TiO_2$ in Finland Q15 (In tonnes) | Mode | Mean | Q85 | Mean TC | Flows of $TiO_2$ in France Q15 (In tonnes) | Mode | Mean | Q85 | Mean TC |
|---|---|---|---|---|---|---|---|---|---|---|
| Waste water | 70.98 | 104.85 | 129.98 | 192.64 | **61.9%** | 482.19 | 720.17 | 764.96 | 1,049.09 | **28.2%** |
| Air | 0.72 | 0.98 | 1.49 | 2.29 | **0.7%** | 7.09 | 10.69 | 11.49 | 15.96 | **0.4%** |
| Surface water | 5.75 | 7.60 | 11.82 | 18.19 | **5.6%** | 37.84 | 56.53 | 69.52 | 102.05 | **2.6%** |
| Soil | 0.17 | 0.24 | 0.34 | 0.53 | **0.2%** | 1.12 | 1.71 | 1.99 | 2.89 | **0.1%** |
| Landfill - CDW | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** |
| Landfill - RW | 2.75 | 3.67 | 5.15 | 7.67 | **2.5%** | 26.57 | 40.81 | 42.05 | 57.67 | **1.6%** |
| Incineration | 5.79 | 8.02 | 10.86 | 16.18 | **5.2%** | 35.87 | 54.26 | 56.74 | 77.85 | **2.1%** |
| Recycling | 26.86 | 38.97 | 50.44 | 75.33 | **24.0%** | 190.21 | 280.67 | 297.28 | 406.22 | **11.0%** |
| Export | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** | 949.06 | 1,373.80 | 1,468.85 | 1,993.02 | **54.1%** |

| To | Flows of $TiO_2$ in Germany Q15 (In tonnes) | Mode | Mean | Q85 | Mean TC | Flows of $TiO_2$ in Greece Q15 (In tonnes) | Mode | Mean | Q85 | Mean TC |
|---|---|---|---|---|---|---|---|---|---|---|
| Waste water | 533.42 | 828.20 | 848.76 | 1,165.86 | **20.3%** | 121.58 | 180.10 | 200.20 | 280.92 | **61.8%** |
| Air | 11.10 | 16.41 | 18.07 | 25.05 | **0.4%** | 1.39 | 1.99 | 2.44 | 3.54 | **0.8%** |
| Surface water | 41.46 | 61.68 | 76.61 | 112.72 | **1.8%** | 9.68 | 13.95 | 18.16 | 26.86 | **5.6%** |
| Soil | 1.22 | 1.79 | 2.20 | 3.20 | **0.1%** | 0.28 | 0.41 | 0.53 | 0.78 | **0.2%** |
| Landfill - CDW | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** |
| Landfill - RW | 0.19 | 0.29 | 0.31 | 0.43 | **0.0%** | 16.81 | 24.76 | 28.42 | 40.43 | **8.8%** |
| Incineration | 54.39 | 80.88 | 87.24 | 120.31 | **2.1%** | 0.06 | 0.09 | 0.11 | 0.16 | **0.0%** |
| Recycling | 221.66 | 342.69 | 351.50 | 482.03 | **8.4%** | 43.71 | 67.69 | 73.85 | 105.06 | **22.8%** |
| Export | 1,800.85 | 2,760.75 | 2,788.92 | 3,781.56 | **66.8%** | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** |

**Modelling results – masses of $TiO_2$ ENM entering technical and environmental compartments (continued)**

| | Flows of $TiO_2$ in Hungary | | | | | Flows of $TiO_2$ in Ireland | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Q15 | Mode | Mean | Q85 | **Mean TC** | Q15 | Mode | Mean | Q85 | **Mean TC** |
| To | In tonnes | | | | | In tonnes | | | | |
| Waste water | 63.40 | 85.86 | 119.61 | 179.70 | **61.8%** | 54.48 | 80.25 | 106.28 | 161.15 | **57.8%** |
| Air | 0.74 | 0.97 | 1.50 | 2.30 | **0.8%** | 0.54 | 0.73 | 1.22 | 1.93 | **0.7%** |
| Surface water | 5.12 | 7.13 | 10.89 | 16.90 | **5.6%** | 4.46 | 5.88 | 9.65 | 15.08 | **5.2%** |
| Soil | 0.15 | 0.20 | 0.31 | 0.49 | **0.2%** | 0.13 | 0.18 | 0.28 | 0.44 | **0.2%** |
| Landfill - CDW | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** |
| Landfill - RW | 8.12 | 10.97 | 15.68 | 23.67 | **8.1%** | 4.24 | 5.84 | 8.44 | 12.90 | **4.6%** |
| Incineration | 1.50 | 2.05 | 2.90 | 4.37 | **1.5%** | 1.97 | 2.71 | 3.92 | 5.98 | **2.1%** |
| Recycling | 22.07 | 30.43 | 42.76 | 64.60 | **22.1%** | 21.14 | 29.51 | 42.06 | 64.10 | **22.9%** |
| Export | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** | 6.16 | 8.60 | 12.17 | 18.51 | **6.6%** |

| | Flows of $TiO_2$ in Italy | | | | | Flows of $TiO_2$ in Latvia | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Q15 | Mode | Mean | Q85 | **Mean TC** | Q15 | Mode | Mean | Q85 | **Mean TC** |
| To | In tonnes | | | | | In tonnes | | | | |
| Waste water | 563.57 | 838.76 | 866.27 | 1,170.66 | **61.9%** | 29.11 | 31.93 | 78.59 | 130.17 | **61.7%** |
| Air | 6.21 | 8.96 | 10.21 | 14.26 | **0.7%** | 0.37 | 0.40 | 1.03 | 1.72 | **0.8%** |
| Surface water | 44.74 | 65.41 | 78.87 | 113.61 | **5.6%** | 2.45 | 2.93 | 7.13 | 11.96 | **5.6%** |
| Soil | 1.28 | 1.96 | 2.28 | 3.30 | **0.2%** | 0.07 | 0.08 | 0.21 | 0.35 | **0.2%** |
| Landfill - CDW | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** |
| Landfill - RW | 34.74 | 52.22 | 55.17 | 75.73 | **3.9%** | 4.55 | 4.64 | 12.54 | 20.75 | **9.8%** |
| Incineration | 34.07 | 52.91 | 54.10 | 74.21 | **3.9%** | 0.04 | 0.04 | 0.12 | 0.20 | **0.1%** |
| Recycling | 211.98 | 321.81 | 333.59 | 455.27 | **23.8%** | 10.13 | 10.68 | 27.84 | 46.14 | **21.8%** |
| Export | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** |

**Modelling results – masses of $TiO_2$ ENM entering technical and environmental compartments (continued)**

| | Flows of $TiO_2$ in Lithuania | | | | | Flows of $TiO_2$ in Luxembourg | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Q15 | Mode | Mean | Q85 | **Mean TC** | Q15 | Mode | Mean | Q85 | **Mean TC** |
| To | In tonnes | | | | | In tonnes | | | | |
| Waste water | 33.36 | 35.04 | 83.59 | 136.24 | **61.7%** | 25.30 | 24.66 | 74.19 | 124.66 | **61.6%** |
| Air | 0.42 | 0.51 | 1.09 | 1.79 | **0.8%** | 0.32 | 0.37 | 0.97 | 1.65 | **0.8%** |
| Surface water | 2.79 | 3.33 | 7.58 | 12.58 | **5.6%** | 2.14 | 2.40 | 6.74 | 11.49 | **5.6%** |
| Soil | 0.08 | 0.11 | 0.22 | 0.36 | **0.2%** | 0.06 | 0.07 | 0.20 | 0.34 | **0.2%** |
| Landfill - CDW | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** |
| Landfill - RW | 4.45 | 5.09 | 11.28 | 18.34 | **8.3%** | 0.42 | 0.44 | 1.26 | 2.13 | **1.0%** |
| Incineration | 0.02 | 0.02 | 0.05 | 0.08 | **0.0%** | 1.90 | 1.98 | 5.67 | 9.57 | **4.7%** |
| Recycling | 12.44 | 13.69 | 31.65 | 51.64 | **23.4%** | 10.59 | 10.95 | 31.41 | 53.06 | **26.1%** |
| Export | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** |

| | Flows of $TiO_2$ in Malta | | | | | Flows of $TiO_2$ in the Netherlands | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Q15 | Mode | Mean | Q85 | **Mean TC** | Q15 | Mode | Mean | Q85 | **Mean TC** |
| To | In tonnes | | | | | In tonnes | | | | |
| Waste water | 21.59 | 20.48 | 69.76 | 119.37 | **61.6%** | 109.81 | 161.86 | 172.91 | 236.53 | **25.4%** |
| Air | 0.29 | 0.30 | 0.93 | 1.60 | **0.8%** | 2.07 | 3.17 | 3.35 | 4.65 | **0.5%** |
| Surface water | 1.82 | 1.86 | 6.34 | 11.00 | **5.6%** | 8.61 | 12.15 | 15.59 | 22.73 | **2.3%** |
| Soil | 0.05 | 0.05 | 0.18 | 0.32 | **0.2%** | 0.25 | 0.35 | 0.45 | 0.66 | **0.1%** |
| Landfill - CDW | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** |
| Landfill - RW | 3.39 | 3.19 | 11.14 | 19.13 | **9.8%** | 0.28 | 0.41 | 0.45 | 0.62 | **0.1%** |
| Incineration | 0.01 | 0.01 | 0.04 | 0.07 | **0.0%** | 17.75 | 27.66 | 28.32 | 39.02 | **4.2%** |
| Recycling | 7.55 | 7.50 | 24.79 | 42.56 | **21.9%** | 37.03 | 54.71 | 59.91 | 83.01 | **8.8%** |
| Export | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** | 257.97 | 393.01 | 398.71 | 540.93 | **58.7%** |

**Modelling results – masses of $TiO_2$ ENM entering technical and environmental compartments (continued)**

| To | Flows of $TiO_2$ in Norway | | | | | Flows of $TiO_2$ in Poland | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Q15 | Mode | Mean | Q85 | **Mean TC** | Q15 | Mode | Mean | Q85 | **Mean TC** |
| | In tonnes | | | | | In tonnes | | | | |
| Waste water | 85.44 | 126.67 | 149.54 | 216.29 | **61.7%** | 218.96 | 336.76 | 343.21 | 468.87 | **51.7%** |
| Air | 1.10 | 1.47 | 2.00 | 2.93 | **0.8%** | 1.96 | 3.07 | 3.38 | 4.84 | **0.5%** |
| Surface water | 6.88 | 10.18 | 13.51 | 20.43 | **5.6%** | 17.30 | 25.31 | 31.27 | 45.48 | **4.7%** |
| Soil | 0.20 | 0.29 | 0.39 | 0.60 | **0.2%** | 0.50 | 0.74 | 0.91 | 1.32 | **0.1%** |
| Landfill - CDW | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** |
| Landfill - RW | 0.25 | 0.37 | 0.44 | 0.65 | **0.2%** | 21.97 | 33.55 | 35.02 | 48.24 | **5.3%** |
| Incineration | 8.65 | 13.32 | 15.44 | 22.47 | **6.4%** | 5.94 | 9.20 | 9.61 | 13.34 | **1.4%** |
| Recycling | 34.23 | 51.89 | 60.93 | 88.83 | **25.1%** | 81.03 | 122.50 | 129.37 | 178.13 | **19.5%** |
| Export | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** | 70.07 | 101.85 | 111.25 | 152.76 | **16.8%** |

| To | Flows of $TiO_2$ in Portugal | | | | | Flows of $TiO_2$ in Romania | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Q15 | Mode | Mean | Q85 | **Mean TC** | Q15 | Mode | Mean | Q85 | **Mean TC** |
| | In tonnes | | | | | In tonnes | | | | |
| Waste water | 116.96 | 171.22 | 194.04 | 273.28 | **61.8%** | 83.05 | 120.56 | 145.87 | 212.69 | **61.8%** |
| Air | 1.52 | 2.25 | 2.63 | 3.75 | **0.8%** | 1.02 | 1.41 | 1.89 | 2.79 | **0.8%** |
| Surface water | 9.29 | 14.23 | 17.56 | 26.03 | **5.6%** | 6.63 | 9.99 | 13.19 | 20.03 | **5.6%** |
| Soil | 0.27 | 0.40 | 0.51 | 0.76 | **0.2%** | 0.19 | 0.27 | 0.38 | 0.58 | **0.2%** |
| Landfill - CDW | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** |
| Landfill - RW | 12.99 | 19.25 | 21.97 | 31.22 | **7.0%** | 13.60 | 18.26 | 24.34 | 35.65 | **10.3%** |
| Incineration | 5.41 | 8.22 | 9.21 | 13.10 | **2.9%** | 0.15 | 0.21 | 0.27 | 0.39 | **0.1%** |
| Recycling | 39.99 | 57.22 | 68.21 | 97.33 | **21.7%** | 27.82 | 38.53 | 50.15 | 73.88 | **21.2%** |
| Export | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** |

### Modelling results – masses of $TiO_2$ ENM entering technical and environmental compartments (continued)

| To | Flows of $TiO_2$ in the Slovakia: Q15 (In tonnes) | Mode (In tonnes) | Mean (In tonnes) | Q85 (In tonnes) | Mean TC | Flows of $TiO_2$ in Slovenia: Q15 (In tonnes) | Mode (In tonnes) | Mean (In tonnes) | Q85 (In tonnes) | Mean TC |
|---|---|---|---|---|---|---|---|---|---|---|
| Waste water | 86.81 | 130.05 | 151.49 | 219.45 | **61.7%** | 36.36 | 42.80 | 86.91 | 140.44 | **61.7%** |
| Air | 1.18 | 1.74 | 2.11 | 3.07 | **0.9%** | 0.48 | 0.62 | 1.16 | 1.88 | **0.8%** |
| Surface water | 6.99 | 9.66 | 13.70 | 20.62 | **5.6%** | 3.02 | 3.94 | 7.86 | 12.95 | **5.6%** |
| Soil | 0.20 | 0.29 | 0.40 | 0.60 | **0.2%** | 0.09 | 0.11 | 0.23 | 0.38 | **0.2%** |
| Landfill - CDW | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** |
| Landfill - RW | 11.13 | 15.86 | 19.82 | 28.95 | **8.1%** | 4.60 | 5.63 | 11.18 | 18.11 | **7.9%** |
| Incineration | 1.87 | 2.85 | 3.35 | 4.89 | **1.4%** | 0.02 | 0.03 | 0.05 | 0.08 | **0.0%** |
| Recycling | 30.83 | 42.55 | 54.76 | 79.66 | **22.3%** | 13.88 | 16.81 | 33.51 | 54.26 | **23.8%** |
| Export | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** |

| To | Flows of $TiO_2$ in Spain: Q15 (In tonnes) | Mode (In tonnes) | Mean (In tonnes) | Q85 (In tonnes) | Mean TC | Flows of $TiO_2$ in Sweden: Q15 (In tonnes) | Mode (In tonnes) | Mean (In tonnes) | Q85 (In tonnes) | Mean TC |
|---|---|---|---|---|---|---|---|---|---|---|
| Waste water | 512.33 | 756.04 | 784.53 | 1,056.03 | **61.7%** | 105.66 | 154.75 | 177.04 | 251.81 | **61.8%** |
| Air | 6.41 | 9.91 | 10.35 | 14.34 | **0.8%** | 1.33 | 1.83 | 2.33 | 3.37 | **0.8%** |
| Surface water | 40.43 | 59.60 | 70.96 | 102.34 | **5.6%** | 8.38 | 12.21 | 16.04 | 23.91 | **5.6%** |
| Soil | 1.16 | 1.67 | 2.06 | 2.99 | **0.2%** | 0.24 | 0.34 | 0.46 | 0.70 | **0.2%** |
| Landfill - CDW | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** |
| Landfill - RW | 63.67 | 92.87 | 99.04 | 134.70 | **7.8%** | 0.11 | 0.16 | 0.19 | 0.28 | **0.1%** |
| Incineration | 11.20 | 16.76 | 17.42 | 23.69 | **1.4%** | 11.50 | 16.04 | 20.05 | 28.93 | **7.0%** |
| Recycling | 182.24 | 267.76 | 286.42 | 391.14 | **22.5%** | 41.14 | 61.44 | 70.45 | 101.16 | **24.6%** |
| Export | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** |

**Modelling results – masses of $TiO_2$ ENM entering technical and environmental compartments (continued)**

| | Flows of $TiO_2$ in Switzerland | | | | | Flows of $TiO_2$ in the United Kingdom | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Q15 | Mode | Mean | Q85 | **Mean TC** | Q15 | Mode | Mean | Q85 | **Mean TC** |
| To | In tonnes | | | | | In tonnes | | | | |
| Waste water | 97.13 | 145.31 | 156.89 | 217.35 | **34.5%** | 554.78 | 841.54 | 869.97 | 1,183.87 | **28.8%** |
| Air | 0.94 | 1.32 | 1.67 | 2.42 | **0.4%** | 10.00 | 14.27 | 16.09 | 22.29 | **0.5%** |
| Surface water | 7.71 | 11.41 | 14.31 | 21.13 | **3.2%** | 43.58 | 63.99 | 78.47 | 113.91 | **2.6%** |
| Soil | 0.23 | 0.34 | 0.41 | 0.60 | **0.1%** | 1.25 | 1.94 | 2.27 | 3.32 | **0.1%** |
| Landfill - CDW | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** |
| Landfill - RW | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** | 38.00 | 59.81 | 60.80 | 83.77 | **2.0%** |
| Incineration | 6.78 | 10.41 | 10.90 | 15.09 | **2.4%** | 29.27 | 44.56 | 46.87 | 64.58 | **1.6%** |
| Recycling | 42.69 | 64.89 | 68.45 | 94.73 | **15.1%** | 211.90 | 310.84 | 338.20 | 466.38 | **11.2%** |
| Export | 126.80 | 193.17 | 201.57 | 277.96 | **44.4%** | 1,035.64 | 1,620.00 | 1,603.17 | 2,173.92 | **53.2%** |

**Modelling results – masses of ZnO ENM entering technical and environmental compartments**

| To | Flows of ZnO in Austria | | | | |
|---|---|---|---|---|---|
| | Q15 | Mode | Mean | Q85 | **Mean TC** |
| | In tonnes | | | | |
| Waste water | 2.17 | 19.27 | 18.47 | 34.72 | **57.2%** |
| Air | 0.04 | 0.36 | 0.41 | 0.78 | **1.3%** |
| Surface water | 0.21 | 1.64 | 1.98 | 3.77 | **6.1%** |
| Soil | 0.03 | 0.22 | 0.32 | 0.61 | **1.0%** |
| Landfill - CDW | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** |
| Landfill - RW | 0.01 | 0.05 | 0.05 | 0.09 | **0.1%** |
| Incineration | 0.04 | 0.37 | 0.36 | 0.67 | **1.1%** |
| Recycling | 0.38 | 3.17 | 3.33 | 6.31 | **10.3%** |
| Export | 0.84 | 7.37 | 7.40 | 13.95 | **22.9%** |

| To | Flows of ZnO in Belgium | | | | |
|---|---|---|---|---|---|
| | Q15 | Mode | Mean | Q85 | **Mean TC** |
| | In tonnes | | | | |
| Waste water | 2.61 | 21.56 | 22.40 | 42.22 | **41.6%** |
| Air | 0.05 | 0.45 | 0.49 | 0.93 | **0.9%** |
| Surface water | 0.26 | 2.03 | 2.39 | 4.57 | **4.4%** |
| Soil | 0.04 | 0.29 | 0.39 | 0.75 | **0.7%** |
| Landfill - CDW | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** |
| Landfill - RW | 0.00 | 0.01 | 0.01 | 0.02 | **0.0%** |
| Incineration | 0.04 | 0.38 | 0.38 | 0.72 | **0.7%** |
| Recycling | 0.47 | 3.84 | 4.15 | 7.85 | **7.7%** |
| Export | 2.74 | 24.90 | 23.58 | 44.31 | **43.8%** |

| To | Flows of ZnO in Bulgaria | | | | |
|---|---|---|---|---|---|
| | Q15 | Mode | Mean | Q85 | **Mean TC** |
| | In tonnes | | | | |
| Waste water | 1.75 | 11.17 | 18.41 | 36.78 | **74.2%** |
| Air | 0.03 | 0.19 | 0.38 | 0.76 | **1.5%** |
| Surface water | 0.17 | 0.91 | 1.98 | 3.97 | **8.0%** |
| Soil | 0.03 | 0.14 | 0.32 | 0.64 | **1.3%** |
| Landfill - CDW | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** |
| Landfill - RW | 0.05 | 0.31 | 0.55 | 1.11 | **2.2%** |
| Incineration | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** |
| Recycling | 0.29 | 1.70 | 3.17 | 6.35 | **12.8%** |
| Export | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** |

| To | Flows of ZnO in Croatia | | | | |
|---|---|---|---|---|---|
| | Q15 | Mode | Mean | Q85 | **Mean TC** |
| | In tonnes | | | | |
| Waste water | 2.13 | 13.73 | 20.42 | 40.17 | **74.2%** |
| Air | 0.04 | 0.29 | 0.43 | 0.85 | **1.6%** |
| Surface water | 0.21 | 1.14 | 2.19 | 4.33 | **8.0%** |
| Soil | 0.03 | 0.16 | 0.35 | 0.70 | **1.3%** |
| Landfill - CDW | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** |
| Landfill - RW | 0.08 | 0.44 | 0.74 | 1.45 | **2.7%** |
| Incineration | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** |
| Recycling | 0.34 | 2.16 | 3.40 | 6.68 | **12.3%** |
| Export | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** |

**Modelling results – masses of ZnO ENM entering technical and environmental compartments (continued)**

| | Flows of ZnO in Cyprus | | | | | Flows of ZnO in Czech Republic | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Q15 | Mode | Mean | Q85 | **Mean TC** | Q15 | Mode | Mean | Q85 | **Mean TC** |
| To | In tonnes | | | | | In tonnes | | | | |
| Waste water | 1.50 | 7.30 | 16.21 | 33.01 | **74.2%** | 4.15 | 31.16 | 35.48 | 67.11 | **74.2%** |
| Air | 0.03 | 0.15 | 0.34 | 0.70 | **1.6%** | 0.08 | 0.59 | 0.75 | 1.44 | **1.6%** |
| Surface water | 0.15 | 0.68 | 1.74 | 3.52 | **7.9%** | 0.41 | 2.63 | 3.79 | 7.29 | **7.9%** |
| Soil | 0.02 | 0.10 | 0.28 | 0.57 | **1.3%** | 0.06 | 0.43 | 0.61 | 1.19 | **1.3%** |
| Landfill - CDW | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** |
| Landfill - RW | 0.04 | 0.18 | 0.44 | 0.89 | **2.0%** | 0.16 | 1.09 | 1.41 | 2.69 | **3.0%** |
| Incineration | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** | 0.04 | 0.29 | 0.36 | 0.68 | **0.7%** |
| Recycling | 0.26 | 1.30 | 2.85 | 5.79 | **13.0%** | 0.60 | 4.50 | 5.40 | 10.30 | **11.3%** |
| Export | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** |

| | Flows of ZnO in Denmark | | | | | Flows of ZnO in Estonia | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Q15 | Mode | Mean | Q85 | **Mean TC** | Q15 | Mode | Mean | Q85 | **Mean TC** |
| To | In tonnes | | | | | In tonnes | | | | |
| Waste water | 2.65 | 19.49 | 24.10 | 46.63 | **74.2%** | 0.03 | 0.18 | 0.20 | 0.37 | **0.3%** |
| Air | 0.05 | 0.28 | 0.49 | 0.96 | **1.5%** | 0.00 | 0.01 | 0.01 | 0.01 | **0.0%** |
| Surface water | 0.26 | 1.70 | 2.58 | 5.03 | **8.0%** | 0.00 | 0.01 | 0.02 | 0.04 | **0.0%** |
| Soil | 0.04 | 0.23 | 0.42 | 0.82 | **1.3%** | 0.00 | 0.00 | 0.00 | 0.01 | **0.0%** |
| Landfill - CDW | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** |
| Landfill - RW | 0.05 | 0.35 | 0.51 | 0.98 | **1.6%** | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** |
| Incineration | 0.02 | 0.13 | 0.20 | 0.39 | **0.6%** | 0.00 | 0.01 | 0.01 | 0.01 | **0.0%** |
| Recycling | 0.44 | 2.82 | 4.16 | 8.09 | **12.8%** | 0.00 | 0.02 | 0.03 | 0.06 | **0.0%** |
| Export | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** | 9.48 | 65.44 | 70.24 | 131.01 | **99.6%** |

**Modelling results – masses of ZnO ENM entering technical and environmental compartments (continued)**

| | Flows of ZnO in Finland | | | | | Flows of ZnO in France | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Q15 | Mode | Mean | Q85 | Mean TC | Q15 | Mode | Mean | Q85 | Mean TC |
| To | In tonnes | | | | | In tonnes | | | | |
| Waste water | 2.71 | 16.21 | 23.40 | 45.32 | **74.3%** | 15.59 | 131.14 | 138.25 | 262.73 | **26.6%** |
| Air | 0.05 | 0.28 | 0.48 | 0.93 | **1.5%** | 0.37 | 2.99 | 3.40 | 6.49 | **0.7%** |
| Surface water | 0.27 | 1.61 | 2.51 | 4.90 | **8.0%** | 1.55 | 10.70 | 14.81 | 28.49 | **2.8%** |
| Soil | 0.04 | 0.23 | 0.40 | 0.79 | **1.3%** | 0.24 | 1.62 | 2.34 | 4.52 | **0.4%** |
| Landfill - CDW | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** |
| Landfill - RW | 0.01 | 0.04 | 0.06 | 0.12 | **0.2%** | 0.19 | 1.58 | 1.69 | 3.21 | **0.3%** |
| Incineration | 0.01 | 0.08 | 0.13 | 0.25 | **0.4%** | 0.26 | 2.17 | 2.28 | 4.33 | **0.4%** |
| Recycling | 0.50 | 2.98 | 4.53 | 8.77 | **14.4%** | 2.77 | 22.77 | 24.37 | 46.43 | **4.7%** |
| Export | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** | 38.52 | 315.81 | 333.46 | 630.71 | **64.1%** |

| | Flows of ZnO in Germany | | | | | Flows of ZnO in Greece | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Q15 | Mode | Mean | Q85 | Mean TC | Q15 | Mode | Mean | Q85 | Mean TC |
| To | In tonnes | | | | | In tonnes | | | | |
| Waste water | 15.55 | 121.89 | 138.24 | 260.71 | **43.7%** | 4.66 | 38.59 | 40.20 | 76.06 | **74.3%** |
| Air | 0.26 | 1.93 | 2.51 | 4.80 | **0.8%** | 0.08 | 0.57 | 0.80 | 1.53 | **1.5%** |
| Surface water | 1.55 | 11.94 | 14.90 | 28.48 | **4.7%** | 0.47 | 3.20 | 4.31 | 8.25 | **8.0%** |
| Soil | 0.25 | 1.78 | 2.38 | 4.56 | **0.8%** | 0.07 | 0.43 | 0.70 | 1.34 | **1.3%** |
| Landfill - CDW | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** |
| Landfill - RW | 0.00 | 0.00 | 0.00 | 0.01 | **0.0%** | 0.15 | 1.04 | 1.27 | 2.40 | **2.3%** |
| Incineration | 0.26 | 2.09 | 2.31 | 4.36 | **0.7%** | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** |
| Recycling | 2.80 | 22.66 | 25.20 | 47.73 | **8.0%** | 0.77 | 5.06 | 6.83 | 13.02 | **12.6%** |
| Export | 14.90 | 108.89 | 131.01 | 246.32 | **41.4%** | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** |

### Modelling results – masses of ZnO ENM entering technical and environmental compartments (continued)

| | Flows of ZnO in Hungary | | | | | Flows of ZnO in Ireland | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Q15 | Mode | Mean | Q85 | **Mean TC** | Q15 | Mode | Mean | Q85 | **Mean TC** |
| To | In tonnes | | | | | In tonnes | | | | |
| Waste water | 2.17 | 13.92 | 21.29 | 41.76 | **74.2%** | 1.75 | 10.82 | 16.29 | 31.90 | **54.7%** |
| Air | 0.04 | 0.26 | 0.45 | 0.88 | **1.6%** | 0.03 | 0.16 | 0.32 | 0.64 | **1.1%** |
| Surface water | 0.21 | 1.32 | 2.28 | 4.49 | **8.0%** | 0.17 | 1.08 | 1.75 | 3.45 | **5.9%** |
| Soil | 0.03 | 0.20 | 0.37 | 0.73 | **1.3%** | 0.03 | 0.15 | 0.28 | 0.55 | **0.9%** |
| Landfill - CDW | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** |
| Landfill - RW | 0.09 | 0.58 | 0.90 | 1.76 | **3.1%** | 0.02 | 0.10 | 0.15 | 0.28 | **0.5%** |
| Incineration | 0.02 | 0.09 | 0.16 | 0.32 | **0.6%** | 0.01 | 0.04 | 0.07 | 0.13 | **0.2%** |
| Recycling | 0.32 | 2.02 | 3.25 | 6.37 | **11.3%** | 0.32 | 2.12 | 3.07 | 6.04 | **10.3%** |
| Export | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** | 0.85 | 5.53 | 7.84 | 15.30 | **26.3%** |

| | Flows of ZnO in Italy | | | | | Flows of ZnO in Latvia | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Q15 | Mode | Mean | Q85 | **Mean TC** | Q15 | Mode | Mean | Q85 | **Mean TC** |
| To | In tonnes | | | | | In tonnes | | | | |
| Waste water | 19.58 | 166.73 | 168.31 | 317.01 | **71.9%** | 1.23 | 5.56 | 14.74 | 30.48 | **74.2%** |
| Air | 0.38 | 2.70 | 3.58 | 6.81 | **1.5%** | 0.02 | 0.10 | 0.31 | 0.63 | **1.5%** |
| Surface water | 1.95 | 13.89 | 18.03 | 34.33 | **7.7%** | 0.12 | 0.49 | 1.58 | 3.25 | **7.9%** |
| Soil | 0.30 | 2.10 | 2.91 | 5.61 | **1.2%** | 0.02 | 0.07 | 0.25 | 0.52 | **1.3%** |
| Landfill - CDW | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** |
| Landfill - RW | 0.20 | 1.45 | 1.73 | 3.25 | **0.7%** | 0.04 | 0.19 | 0.53 | 1.09 | **2.7%** |
| Incineration | 0.19 | 1.43 | 1.69 | 3.18 | **0.7%** | 0.00 | 0.00 | 0.00 | 0.01 | **0.0%** |
| Recycling | 3.45 | 26.10 | 30.73 | 58.09 | **13.1%** | 0.20 | 0.84 | 2.45 | 5.08 | **12.3%** |
| Export | 0.79 | 6.56 | 7.01 | 13.21 | **3.0%** | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** |

**Modelling results – masses of ZnO ENM entering technical and environmental compartments (continued)**

| To | Flows of ZnO in Lithuania | | | | | Flows of ZnO in Luxembourg | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Q15 | Mode | Mean | Q85 | **Mean TC** | Q15 | Mode | Mean | Q85 | **Mean TC** |
| | In tonnes | | | | | In tonnes | | | | |
| Waste water | 1.32 | 6.37 | 15.53 | 31.89 | **74.2%** | 0.98 | 3.89 | 13.75 | 28.96 | **74.1%** |
| Air | 0.03 | 0.12 | 0.32 | 0.66 | **1.6%** | 0.02 | 0.07 | 0.29 | 0.60 | **1.5%** |
| Surface water | 0.13 | 0.57 | 1.67 | 3.41 | **8.0%** | 0.10 | 0.37 | 1.48 | 3.09 | **8.0%** |
| Soil | 0.02 | 0.09 | 0.27 | 0.55 | **1.3%** | 0.02 | 0.05 | 0.24 | 0.50 | **1.3%** |
| Landfill - CDW | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** |
| Landfill - RW | 0.04 | 0.20 | 0.53 | 1.08 | **2.5%** | 0.00 | 0.01 | 0.03 | 0.06 | **0.2%** |
| Incineration | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** | 0.01 | 0.03 | 0.12 | 0.26 | **0.7%** |
| Recycling | 0.21 | 0.99 | 2.62 | 5.34 | **12.5%** | 0.18 | 0.68 | 2.64 | 5.55 | **14.2%** |
| Export | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** |

| To | Flows of ZnO in Malta | | | | | Flows of ZnO in the Netherlands | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Q15 | Mode | Mean | Q85 | **Mean TC** | Q15 | Mode | Mean | Q85 | **Mean TC** |
| | In tonnes | | | | | In tonnes | | | | |
| Waste water | 0.96 | 3.27 | 13.42 | 28.36 | **74.2%** | 2.78 | 24.14 | 24.72 | 46.79 | **15.7%** |
| Air | 0.02 | 0.06 | 0.28 | 0.59 | **1.6%** | 0.06 | 0.42 | 0.53 | 1.02 | **0.3%** |
| Surface water | 0.10 | 0.35 | 1.44 | 3.03 | **8.0%** | 0.28 | 2.03 | 2.65 | 5.07 | **1.7%** |
| Soil | 0.01 | 0.05 | 0.23 | 0.48 | **1.3%** | 0.04 | 0.30 | 0.43 | 0.83 | **0.3%** |
| Landfill - CDW | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** |
| Landfill - RW | 0.04 | 0.15 | 0.60 | 1.26 | **3.3%** | 0.00 | 0.01 | 0.01 | 0.02 | **0.0%** |
| Incineration | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** | 0.06 | 0.46 | 0.54 | 1.02 | **0.3%** |
| Recycling | 0.15 | 0.53 | 2.13 | 4.47 | **11.8%** | 0.49 | 4.36 | 4.46 | 8.47 | **2.8%** |
| Export | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** | 14.37 | 124.71 | 124.34 | 234.03 | **78.9%** |

**Modelling results – masses of ZnO ENM entering technical and environmental compartments (continued)**

| | Flows of ZnO in Norway | | | | | Flows of ZnO in Poland | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Q15 | Mode | Mean | Q85 | Mean TC | Q15 | Mode | Mean | Q85 | Mean TC |
| To | In tonnes | | | | | In tonnes | | | | |
| Waste water | 2.84 | 18.78 | 25.94 | 50.09 | **74.2%** | 7.00 | 53.21 | 61.90 | 116.98 | **52.4%** |
| Air | 0.06 | 0.35 | 0.55 | 1.07 | **1.6%** | 0.12 | 0.81 | 1.11 | 2.14 | **0.9%** |
| Surface water | 0.28 | 1.82 | 2.78 | 5.39 | **7.9%** | 0.71 | 5.21 | 6.67 | 12.78 | **5.6%** |
| Soil | 0.04 | 0.24 | 0.45 | 0.88 | **1.3%** | 0.11 | 0.83 | 1.07 | 2.05 | **0.9%** |
| Landfill - CDW | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** |
| Landfill - RW | 0.00 | 0.01 | 0.02 | 0.04 | **0.1%** | 0.19 | 1.52 | 1.75 | 3.32 | **1.5%** |
| Incineration | 0.08 | 0.51 | 0.72 | 1.39 | **2.1%** | 0.01 | 0.10 | 0.12 | 0.23 | **0.1%** |
| Recycling | 0.48 | 3.00 | 4.51 | 8.72 | **12.9%** | 1.15 | 8.60 | 10.47 | 19.82 | **8.9%** |
| Export | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** | 3.97 | 33.13 | 35.11 | 66.47 | **29.7%** |

| | Flows of ZnO in Portugal | | | | | Flows of ZnO in Romania | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Q15 | Mode | Mean | Q85 | Mean TC | Q15 | Mode | Mean | Q85 | Mean TC |
| To | In tonnes | | | | | In tonnes | | | | |
| Waste water | 2.11 | 15.06 | 16.42 | 30.80 | **39.4%** | 2.58 | 17.58 | 23.56 | 45.69 | **74.2%** |
| Air | 0.05 | 0.26 | 0.38 | 0.71 | **0.9%** | 0.05 | 0.33 | 0.49 | 0.96 | **1.5%** |
| Surface water | 0.21 | 1.31 | 1.75 | 3.33 | **4.2%** | 0.26 | 1.48 | 2.52 | 4.92 | **7.9%** |
| Soil | 0.03 | 0.20 | 0.28 | 0.54 | **0.7%** | 0.04 | 0.24 | 0.41 | 0.80 | **1.3%** |
| Landfill - CDW | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** |
| Landfill - RW | 0.07 | 0.45 | 0.58 | 1.09 | **1.4%** | 0.11 | 0.74 | 1.09 | 2.11 | **3.4%** |
| Incineration | 0.03 | 0.20 | 0.24 | 0.45 | **0.6%** | 0.00 | 0.00 | 0.01 | 0.01 | **0.0%** |
| Recycling | 0.31 | 1.84 | 2.50 | 4.73 | **6.0%** | 0.38 | 2.60 | 3.67 | 7.14 | **11.6%** |
| Export | 2.52 | 19.05 | 19.51 | 36.51 | **46.8%** | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** |

## Modelling results – masses of ZnO ENM entering technical and environmental compartments (continued)

| To | Flows of ZnO in the Slovakia | | | | | Flows of ZnO in Slovenia | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Q15 | Mode | Mean | Q85 | Mean TC | Q15 | Mode | Mean | Q85 | Mean TC |
| | In tonnes | | | | | In tonnes | | | | |
| Waste water | 3.36 | 27.87 | 31.50 | 60.27 | **74.1%** | 1.47 | 8.16 | 16.47 | 33.57 | **74.1%** |
| Air | 0.07 | 0.47 | 0.68 | 1.32 | **1.6%** | 0.03 | 0.16 | 0.35 | 0.71 | **1.6%** |
| Surface water | 0.33 | 2.70 | 3.37 | 6.51 | **7.9%** | 0.15 | 0.73 | 1.77 | 3.60 | **8.0%** |
| Soil | 0.05 | 0.35 | 0.55 | 1.06 | **1.3%** | 0.02 | 0.11 | 0.28 | 0.58 | **1.3%** |
| Landfill - CDW | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** |
| Landfill - RW | 0.09 | 0.79 | 0.91 | 1.74 | **2.1%** | 0.03 | 0.15 | 0.33 | 0.67 | **1.5%** |
| Incineration | 0.02 | 0.13 | 0.15 | 0.28 | **0.3%** | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** |
| Recycling | 0.55 | 4.34 | 5.33 | 10.27 | **12.5%** | 0.26 | 1.31 | 3.01 | 6.11 | **13.6%** |
| Export | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** |

| To | Flows of ZnO in Spain | | | | | Flows of ZnO in Sweden | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Q15 | Mode | Mean | Q85 | Mean TC | Q15 | Mode | Mean | Q85 | Mean TC |
| | In tonnes | | | | | In tonnes | | | | |
| Waste water | 16.56 | 134.95 | 152.27 | 288.36 | **62.6%** | 3.29 | 26.23 | 30.29 | 57.91 | **74.2%** |
| Air | 0.33 | 2.80 | 3.31 | 6.34 | **1.4%** | 0.06 | 0.44 | 0.64 | 1.23 | **1.6%** |
| Surface water | 1.64 | 12.56 | 16.23 | 31.06 | **6.7%** | 0.33 | 2.17 | 3.24 | 6.26 | **7.9%** |
| Soil | 0.25 | 1.94 | 2.63 | 5.08 | **1.1%** | 0.05 | 0.31 | 0.52 | 1.02 | **1.3%** |
| Landfill - CDW | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** |
| Landfill - RW | 0.69 | 5.58 | 6.47 | 12.31 | **2.7%** | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** |
| Incineration | 0.12 | 1.02 | 1.11 | 2.11 | **0.5%** | 0.04 | 0.27 | 0.34 | 0.66 | **0.8%** |
| Recycling | 2.41 | 19.09 | 23.27 | 44.31 | **9.6%** | 0.61 | 4.48 | 5.78 | 11.07 | **14.2%** |
| Export | 4.00 | 33.98 | 38.12 | 72.20 | **15.7%** | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** |

**Modelling results – masses of ZnO ENM entering technical and environmental compartments (continued)**

| | Flows of ZnO in Switzerland | | | | | Flows of ZnO in the United Kingdom | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Q15 | Mode | Mean | Q85 | **Mean TC** | Q15 | Mode | Mean | Q85 | **Mean TC** |
| To | In tonnes | | | | | In tonnes | | | | |
| Waste water | 2.79 | 24.48 | 23.99 | 45.40 | **34.2%** | 18.50 | 156.52 | 155.38 | 294.07 | **22.4%** |
| Air | 0.05 | 0.30 | 0.45 | 0.87 | **0.6%** | 0.38 | 2.83 | 3.38 | 6.42 | **0.5%** |
| Surface water | 0.28 | 1.83 | 2.58 | 4.94 | **3.7%** | 1.83 | 12.02 | 16.68 | 31.84 | **2.4%** |
| Soil | 0.04 | 0.29 | 0.41 | 0.79 | **0.6%** | 0.28 | 2.08 | 2.68 | 5.16 | **0.4%** |
| Landfill - CDW | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** |
| Landfill - RW | 0.00 | 0.00 | 0.00 | 0.00 | **0.0%** | 0.31 | 2.51 | 2.72 | 5.13 | **0.4%** |
| Incineration | 0.03 | 0.24 | 0.27 | 0.51 | **0.4%** | 0.24 | 1.88 | 2.03 | 3.82 | **0.3%** |
| Recycling | 0.52 | 4.39 | 4.51 | 8.55 | **6.4%** | 3.10 | 22.81 | 26.75 | 50.65 | **3.9%** |
| Export | 4.44 | 32.27 | 37.88 | 71.53 | **54.0%** | 58.87 | 493.26 | 484.16 | 909.56 | **69.8%** |

## Appendix 7: Modelling results – Fractions of carbon black ENM entering landfilling, incineration and recycling

| | Flows of CB in Austria | | | | | Flows of CB in Belgium | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Q15 | Mode | Mean | Q85 | **Mean TC** | Q15 | Mode | Mean | Q85 | **Mean TC** |
| To | In tonnes | | | | | In tonnes | | | | |
| Landfill - RW | 316.30 | 402.92 | 429.31 | 544.65 | **0.66%** | 201.90 | 238.36 | 251.90 | 303.25 | **0.66%** |
| Incineration | 12,573.34 | 15,275.30 | 17,335.67 | 22,218.58 | **26.53%** | 7,958.81 | 9,466.94 | 10,156.46 | 12,394.42 | **26.56%** |
| Recycling | 37,265.17 | 48,332.07 | 47,572.17 | 57,896.78 | **72.81%** | 25,063.72 | 27,796.68 | 27,838.37 | 30,602.38 | **72.79%** |

| | Flows of CB in Bulgaria | | | | | Flows of CB in Croatia | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Q15 | Mode | Mean | Q85 | **Mean TC** | Q15 | Mode | Mean | Q85 | **Mean TC** |
| To | In tonnes | | | | | In tonnes | | | | |
| Landfill - RW | 5,151.54 | 7,261.51 | 9,483.48 | 13,789.20 | **29.97%** | 286.58 | 345.62 | 387.16 | 489.78 | **29.78%** |
| Incineration | 0.56 | 0.74 | 1.11 | 1.67 | **0.00%** | 0.00 | 0.00 | 0.00 | 0.00 | **0.00%** |
| Recycling | 12,431.77 | 18,912.86 | 22,156.27 | 31,778.79 | **70.02%** | 736.25 | 877.25 | 912.69 | 1,091.66 | **70.22%** |

| | Flows of CB in Cyprus | | | | | Flows of CB in Czech Republic | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| To | In tonnes | | | | | In tonnes | | | | |
| Landfill - RW | 2,275.24 | 1,901.08 | 5,810.31 | 9,288.84 | **24.81%** | 6,121.69 | 7,405.04 | 7,502.18 | 8,873.49 | **21.72%** |
| Incineration | 0.00 | 0.00 | 0.00 | 0.00 | **0.00%** | 1,535.28 | 1,903.51 | 1,882.57 | 2,228.14 | **5.45%** |
| Recycling | 7,174.32 | 6,213.58 | 17,605.16 | 27,861.23 | **75.19%** | 20,563.98 | 25,048.33 | 25,153.00 | 29,669.04 | **72.83%** |

| | Flows of CB in Denmark | | | | | Flows of CB in Estonia | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Q15 | Mode | Mean | Q85 | **Mean TC** | Q15 | Mode | Mean | Q85 | **Mean TC** |
| To | In tonnes | | | | | In tonnes | | | | |
| Landfill - RW | 163.38 | 215.78 | 246.75 | 331.05 | **0.53%** | 340.78 | 444.75 | 839.44 | 1,328.00 | **3.50%** |
| Incineration | 8,934.59 | 11,827.52 | 13,394.76 | 17,930.50 | **28.72%** | 2,499.47 | 2,694.23 | 6,128.15 | 9,682.55 | **25.55%** |
| Recycling | 23,048.72 | 35,551.58 | 32,992.11 | 42,783.53 | **70.75%** | 7,121.21 | 22,244.49 | 17,015.62 | 26,726.90 | **70.95%** |

**Modelling results – Fractions of carbon black ENM entering landfilling, incineration and recycling (continued)**

| | Flows of CB in Finland | | | | | Flows of CB in France | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Q15 | Mode | Mean | Q85 | Mean TC | Q15 | Mode | Mean | Q85 | Mean TC |
| To | In tonnes | | | | | In tonnes | | | | |
| Landfill - RW | 2,635.34 | 3,352.55 | 4,029.92 | 5,454.33 | **9.07%** | 23,610.82 | 28,696.24 | 30,364.84 | 37,216.96 | **11.96%** |
| Incineration | 5,509.57 | 7,025.20 | 8,434.25 | 11,407.76 | **18.99%** | 31,663.07 | 38,415.17 | 40,660.77 | 49,796.26 | **16.01%** |
| Recycling | 21,870.32 | 26,848.70 | 31,953.26 | 41,941.07 | **71.94%** | 162,051.76 | 184,109.48 | 182,905.36 | 203,563.07 | **72.03%** |

| | Flows of CB in Germany | | | | | Flows of CB in Greece | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Q15 | Mode | Mean | Q85 | Mean TC | Q15 | Mode | Mean | Q85 | Mean TC |
| To | In tonnes | | | | | In tonnes | | | | |
| Landfill - RW | 290.48 | 351.41 | 366.09 | 441.93 | **0.11%** | 11,853.37 | 15,154.92 | 16,847.14 | 21,959.88 | **30.94%** |
| Incineration | 71,995.30 | 86,863.41 | 89,673.53 | 107,385.14 | **26.53%** | 0.00 | 0.00 | 0.00 | 0.00 | **0.00%** |
| Recycling | 218,668.42 | 249,228.29 | 248,011.62 | 277,201.13 | **73.37%** | 27,874.99 | 34,847.25 | 37,609.55 | 47,380.27 | **69.06%** |

| | Flows of CB in Hungary | | | | | Flows of CB in Ireland | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| To | In tonnes | | | | | In tonnes | | | | |
| Landfill - RW | 4,478.33 | 5,427.87 | 5,500.78 | 6,510.88 | **23.12%** | 4,194.70 | 5,316.80 | 7,021.60 | 9,858.68 | **19.14%** |
| Incineration | 790.37 | 977.57 | 979.78 | 1,167.30 | **4.12%** | 1,920.31 | 2,649.51 | 3,221.50 | 4,533.27 | **8.78%** |
| Recycling | 14,136.68 | 17,463.06 | 17,315.16 | 20,442.97 | **72.77%** | 16,410.91 | 28,597.65 | 26,451.60 | 36,349.98 | **72.09%** |

| | Flows of CB in Italy | | | | | Flows of CB in Latvia | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Q15 | Mode | Mean | Q85 | Mean TC | Q15 | Mode | Mean | Q85 | Mean TC |
| To | In tonnes | | | | | In tonnes | | | | |
| Landfill - RW | 24,137.90 | 29,132.80 | 30,990.87 | 37,947.71 | **14.46%** | 3,288.66 | 3,575.03 | 7,387.74 | 11,424.12 | **28.76%** |
| Incineration | 23,442.28 | 28,354.46 | 30,070.95 | 36,820.43 | **14.03%** | 19.69 | 22.86 | 44.38 | 68.71 | **0.17%** |
| Recycling | 135,255.16 | 153,278.76 | 153,209.69 | 171,183.74 | **71.50%** | 8,364.36 | 24,619.04 | 18,256.63 | 28,018.62 | **71.07%** |

**Modelling results – Fractions of carbon black ENM entering landfilling, incineration and recycling (continued)**

| | Flows of CB in Lithuania | | | | | Flows of CB in Luxembourg | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Q15 | Mode | Mean | Q85 | Mean TC | Q15 | Mode | Mean | Q85 | Mean TC |
| To | In tonnes | | | | | In tonnes | | | | |
| Landfill - RW | 4,065.39 | 6,351.20 | 8,435.24 | 12,709.59 | **30.47%** | 799.48 | 1,365.33 | 1,504.90 | 2,211.26 | **4.88%** |
| Incineration | 0.00 | 0.00 | 0.00 | 0.00 | **0.00%** | 3,575.73 | 5,881.23 | 6,701.85 | 9,838.02 | **21.71%** |
| Recycling | 9,565.64 | 17,879.37 | 19,244.19 | 28,761.92 | **69.53%** | 12,546.44 | 16,957.93 | 22,660.20 | 32,678.25 | **73.41%** |

| | Flows of CB in Malta | | | | | Flows of CB in the Netherlands | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Q15 | Mode | Mean | Q85 | Mean TC | Q15 | Mode | Mean | Q85 | Mean TC |
| To | In tonnes | | | | | In tonnes | | | | |
| Landfill - RW | 2,056.63 | 6,028.47 | 6,242.81 | 10,307.87 | **29.87%** | 51.18 | 63.65 | 69.53 | 88.24 | **0.46%** |
| Incineration | 0.00 | 0.00 | 0.00 | 0.00 | **0.00%** | 3,172.87 | 3,924.77 | 4,266.42 | 5,383.85 | **27.92%** |
| Recycling | 4,941.60 | 21,980.44 | 14,659.46 | 24,240.04 | **70.13%** | 8,950.70 | 10,692.97 | 10,942.97 | 12,930.74 | **71.62%** |

| | Flows of CB in Norway | | | | | Flows of CB in Poland | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| To | In tonnes | | | | | In tonnes | | | | |
| Landfill - RW | 227.45 | 284.16 | 345.08 | 465.84 | **0.74%** | 19,081.85 | 23,066.39 | 23,303.20 | 27,538.30 | **22.38%** |
| Incineration | 7,936.65 | 10,141.64 | 11,954.74 | 16,060.13 | **25.51%** | 5,455.77 | 6,566.41 | 6,718.89 | 7,988.29 | **6.45%** |
| Recycling | 24,228.58 | 23,798.71 | 34,565.07 | 44,777.91 | **73.75%** | 64,235.77 | 75,178.55 | 74,117.53 | 83,792.86 | **71.17%** |

| | Flows of CB in Portugal | | | | | Flows of CB in Romania | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Q15 | Mode | Mean | Q85 | Mean TC | Q15 | Mode | Mean | Q85 | Mean TC |
| To | In tonnes | | | | | In tonnes | | | | |
| Landfill - RW | 6,326.42 | 7,620.42 | 7,651.48 | 8,969.41 | **21.07%** | 6,067.68 | 7,381.15 | 7,475.14 | 8,871.20 | **26.98%** |
| Incineration | 2,605.49 | 3,128.27 | 3,169.20 | 3,732.83 | **8.73%** | 47.93 | 59.33 | 59.93 | 71.88 | **0.22%** |
| Recycling | 21,216.39 | 25,781.42 | 25,487.04 | 29,660.71 | **70.20%** | 16,488.21 | 20,233.38 | 20,172.32 | 23,812.19 | **72.80%** |

**Modelling results – Fractions of carbon black ENM entering landfilling, incineration and recycling (continued)**

| | Flows of CB in the Slovakia | | | | | Flows of CB in Slovenia | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Q15 | Mode | Mean | Q85 | **Mean TC** | Q15 | Mode | Mean | Q85 | **Mean TC** |
| To | In tonnes | | | | | In tonnes | | | | |
| Landfill - RW | 2,540.33 | 2,969.44 | 3,217.96 | 3,916.95 | **25.87%** | 3,092.15 | 5,715.94 | 7,210.31 | 11,251.94 | **28.94%** |
| Incineration | 413.06 | 490.07 | 527.84 | 646.17 | **4.24%** | 0.00 | 0.00 | 0.00 | 0.00 | **0.00%** |
| Recycling | 7,698.62 | 8,659.45 | 8,693.72 | 9,686.62 | **69.89%** | 7,821.04 | 20,272.50 | 17,702.41 | 27,414.54 | **71.06%** |

| | Flows of CB in Spain | | | | | Flows of CB in Sweden | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Q15 | Mode | Mean | Q85 | **Mean TC** | Q15 | Mode | Mean | Q85 | **Mean TC** |
| To | In tonnes | | | | | In tonnes | | | | |
| Landfill - RW | 36,649.79 | 44,933.94 | 46,043.15 | 55,607.64 | **23.85%** | 31.00 | 38.00 | 41.90 | 53.04 | **0.28%** |
| Incineration | 6,233.70 | 7,540.46 | 7,896.36 | 9,597.58 | **4.09%** | 3,093.47 | 3,848.91 | 4,129.12 | 5,184.72 | **27.54%** |
| Recycling | 128,146.46 | 140,340.57 | 139,140.28 | 150,071.09 | **72.06%** | 8,984.35 | 10,500.37 | 10,821.68 | 12,664.84 | **72.18%** |

| | Flows of CB in Switzerland | | | | | Flows of CB in the United Kingdom | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Q15 | Mode | Mean | Q85 | **Mean TC** | Q15 | Mode | Mean | Q85 | **Mean TC** |
| To | In tonnes | | | | | In tonnes | | | | |
| Landfill - RW | 0.00 | 0.00 | 0.00 | 0.00 | **0.00%** | 42,955.57 | 50,200.93 | 50,807.74 | 58,714.52 | **25.17%** |
| Incineration | 9,597.67 | 11,768.32 | 12,639.20 | 15,730.69 | **24.53%** | 32,992.66 | 38,090.12 | 39,046.54 | 45,164.55 | **19.34%** |
| Recycling | 31,696.42 | 36,891.92 | 38,883.27 | 46,324.49 | **75.47%** | 98,222.38 | 110,113.93 | 111,992.52 | 125,822.31 | **55.48%** |

## Modelling results – Fractions of copper ENM entering landfilling, incineration and recycling (continued)

| | **Flows of Cu in Austria** | | | | | **Flows of Cu in Belgium** | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Q15 | Mode | Mean | Q85 | **Mean TC** | Q15 | Mode | Mean | Q85 | **Mean TC** |
| To | In tonnes | | | | | In tonnes | | | | |
| Landfill - RW | 0.00 | 0.00 | 0.00 | 0.00 | **0.47%** | 0.00 | 0.00 | 0.00 | 0.00 | **0.13%** |
| Incineration | 0.01 | 0.01 | 0.02 | 0.02 | **3.70%** | 0.02 | 0.02 | 0.02 | 0.03 | **6.69%** |
| Recycling | 0.30 | 0.40 | 0.40 | 0.51 | **95.83%** | 0.25 | 0.33 | 0.34 | 0.44 | **93.18%** |

| | **Flows of Cu in Bulgaria** | | | | | **Flows of Cu in Croatia** | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Q15 | Mode | Mean | Q85 | **Mean TC** | Q15 | Mode | Mean | Q85 | **Mean TC** |
| To | In tonnes | | | | | In tonnes | | | | |
| Landfill - RW | 0.01 | 0.01 | 0.01 | 0.01 | **16.82%** | 0.06 | 0.06 | 0.13 | 0.20 | **34.03%** |
| Incineration | 0.00 | 0.00 | 0.00 | 0.00 | **0.00%** | 0.00 | 0.00 | 0.00 | 0.00 | **0.00%** |
| Recycling | 0.03 | 0.04 | 0.05 | 0.06 | **83.18%** | 0.11 | 0.15 | 0.24 | 0.38 | **65.97%** |

| | **Flows of Cu in Cyprus** | | | | | **Flows of Cu in Czech Republic** | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| To | In tonnes | | | | | In tonnes | | | | |
| Landfill - RW | 0.00 | 0.01 | 0.01 | 0.01 | **33.84%** | 0.05 | 0.06 | 0.08 | 0.11 | **13.37%** |
| Incineration | 0.00 | 0.00 | 0.00 | 0.00 | **0.00%** | 0.01 | 0.02 | 0.02 | 0.03 | **3.37%** |
| Recycling | 0.01 | 0.01 | 0.01 | 0.02 | **66.16%** | 0.31 | 0.38 | 0.49 | 0.68 | **83.26%** |

| | **Flows of Cu in Denmark** | | | | | **Flows of Cu in Estonia** | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Q15 | Mode | Mean | Q85 | **Mean TC** | Q15 | Mode | Mean | Q85 | **Mean TC** |
| To | In tonnes | | | | | In tonnes | | | | |
| Landfill - RW | 0.00 | 0.00 | 0.00 | 0.00 | **0.39%** | 0.00 | 0.00 | 0.01 | 0.02 | **4.10%** |
| Incineration | 0.03 | 0.04 | 0.05 | 0.06 | **13.00%** | 0.03 | 0.03 | 0.07 | 0.12 | **29.90%** |
| Recycling | 0.21 | 0.28 | 0.31 | 0.42 | **86.60%** | 0.06 | 0.07 | 0.16 | 0.27 | **66.00%** |

**Modelling results – Fractions of copper ENM entering landfilling, incineration and recycling (continued)**

| | **Flows of Cu in Finland** | | | | | **Flows of Cu in France** | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Q15 | Mode | Mean | Q85 | **Mean TC** | Q15 | Mode | Mean | Q85 | **Mean TC** |
| To | In tonnes | | | | | In tonnes | | | | |
| Landfill - RW | 0.00 | 0.00 | 0.00 | 0.00 | **1.35%** | 0.08 | 0.11 | 0.12 | 0.16 | **2.73%** |
| Incineration | 0.00 | 0.01 | 0.01 | 0.01 | **2.83%** | 0.11 | 0.14 | 0.17 | 0.22 | **3.67%** |
| Recycling | 0.16 | 0.20 | 0.21 | 0.27 | **95.82%** | 3.18 | 4.18 | 4.22 | 5.26 | **93.60%** |
| | **Flows of Cu in Germany** | | | | | **Flows of Cu in Greece** | | | | |
| | Q15 | Mode | Mean | Q85 | **Mean TC** | Q15 | Mode | Mean | Q85 | **Mean TC** |
| To | In tonnes | | | | | In tonnes | | | | |
| Landfill - RW | 0.00 | 0.00 | 0.00 | 0.00 | **0.03%** | 0.04 | 0.06 | 0.08 | 0.11 | **12.39%** |
| Incineration | 0.21 | 0.26 | 0.29 | 0.37 | **7.93%** | 0.00 | 0.00 | 0.00 | 0.00 | **0.00%** |
| Recycling | 2.52 | 3.16 | 3.35 | 4.18 | **92.04%** | 0.34 | 0.41 | 0.53 | 0.73 | **87.61%** |
| | **Flows of Cu in Hungary** | | | | | **Flows of Cu in Ireland** | | | | |
| To | In tonnes | | | | | In tonnes | | | | |
| Landfill - RW | 0.03 | 0.04 | 0.06 | 0.09 | **13.45%** | 0.02 | 0.03 | 0.03 | 0.05 | **7.05%** |
| Incineration | 0.01 | 0.01 | 0.01 | 0.02 | **2.44%** | 0.01 | 0.01 | 0.01 | 0.02 | **3.23%** |
| Recycling | 0.21 | 0.27 | 0.36 | 0.53 | **84.11%** | 0.21 | 0.32 | 0.40 | 0.58 | **89.72%** |
| | **Flows of Cu in Italy** | | | | | **Flows of Cu in Latvia** | | | | |
| | Q15 | Mode | Mean | Q85 | **Mean TC** | Q15 | Mode | Mean | Q85 | **Mean TC** |
| To | In tonnes | | | | | In tonnes | | | | |
| Landfill - RW | 0.21 | 0.28 | 0.30 | 0.38 | **7.49%** | 0.04 | 0.07 | 0.10 | 0.17 | **33.75%** |
| Incineration | 0.21 | 0.28 | 0.29 | 0.37 | **7.28%** | 0.00 | 0.00 | 0.00 | 0.00 | **0.21%** |
| Recycling | 2.56 | 3.26 | 3.37 | 4.19 | **85.23%** | 0.08 | 0.11 | 0.20 | 0.33 | **66.04%** |

**Modelling results – Fractions of copper ENM entering landfilling, incineration and recycling (continued)**

| | **Flows of Cu in Lithuania** | | | | | **Flows of Cu in Luxembourg** | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Q15 | Mode | Mean | Q85 | **Mean TC** | Q15 | Mode | Mean | Q85 | **Mean TC** |
| To | In tonnes | | | | | In tonnes | | | | |
| Landfill - RW | 0.01 | 0.02 | 0.02 | 0.04 | **7.45%** | 0.00 | 0.00 | 0.00 | 0.01 | **1.49%** |
| Incineration | 0.00 | 0.00 | 0.00 | 0.00 | **0.00%** | 0.01 | 0.01 | 0.02 | 0.03 | **6.64%** |
| Recycling | 0.13 | 0.28 | 0.31 | 0.49 | **92.55%** | 0.11 | 0.15 | 0.29 | 0.47 | **91.88%** |

| | **Flows of Cu in Malta** | | | | | **Flows of Cu in the Netherlands** | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Q15 | Mode | Mean | Q85 | **Mean TC** | Q15 | Mode | Mean | Q85 | **Mean TC** |
| To | In tonnes | | | | | In tonnes | | | | |
| Landfill - RW | 0.02 | 0.07 | 0.08 | 0.14 | **29.21%** | 0.00 | 0.00 | 0.00 | 0.00 | **0.31%** |
| Incineration | 0.00 | 0.00 | 0.00 | 0.00 | **0.00%** | 0.13 | 0.17 | 0.19 | 0.25 | **18.96%** |
| Recycling | 0.06 | 0.18 | 0.20 | 0.33 | **70.79%** | 0.57 | 0.74 | 0.80 | 1.03 | **80.73%** |

| | **Flows of Cu in Norway** | | | | | **Flows of Cu in Poland** | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| To | In tonnes | | | | | In tonnes | | | | |
| Landfill - RW | 0.00 | 0.00 | 0.00 | 0.00 | **0.20%** | 0.07 | 0.09 | 0.10 | 0.14 | **13.25%** |
| Incineration | 0.03 | 0.04 | 0.05 | 0.06 | **6.96%** | 0.02 | 0.03 | 0.03 | 0.04 | **3.77%** |
| Recycling | 0.41 | 0.53 | 0.63 | 0.84 | **92.84%** | 0.48 | 0.65 | 0.65 | 0.83 | **82.98%** |

| | **Flows of Cu in Portugal** | | | | | **Flows of Cu in Romania** | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Q15 | Mode | Mean | Q85 | **Mean TC** | Q15 | Mode | Mean | Q85 | **Mean TC** |
| To | In tonnes | | | | | In tonnes | | | | |
| Landfill - RW | 0.04 | 0.05 | 0.07 | 0.09 | **11.88%** | 0.20 | 0.26 | 0.32 | 0.45 | **51.45%** |
| Incineration | 0.02 | 0.02 | 0.03 | 0.04 | **4.93%** | 0.00 | 0.00 | 0.00 | 0.00 | **0.40%** |
| Recycling | 0.29 | 0.36 | 0.46 | 0.63 | **83.20%** | 0.19 | 0.24 | 0.30 | 0.42 | **48.15%** |

**Modelling results – Fractions of copper ENM entering landfilling, incineration and recycling (continued)**

| | Flows of Cu in the Slovakia | | | | | Flows of Cu in Slovenia | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Q15 | Mode | Mean | Q85 | **Mean TC** | Q15 | Mode | Mean | Q85 | **Mean TC** |
| To | In tonnes | | | | | In tonnes | | | | |
| Landfill - RW | 0.06 | 0.08 | 0.12 | 0.19 | **29.15%** | 0.02 | 0.03 | 0.04 | 0.07 | **12.76%** |
| Incineration | 0.01 | 0.01 | 0.02 | 0.03 | **4.82%** | 0.00 | 0.00 | 0.00 | 0.00 | **0.00%** |
| Recycling | 0.15 | 0.18 | 0.28 | 0.42 | **66.03%** | 0.12 | 0.18 | 0.29 | 0.46 | **87.24%** |

| | Flows of Cu in Spain | | | | | Flows of Cu in Sweden | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Q15 | Mode | Mean | Q85 | **Mean TC** | Q15 | Mode | Mean | Q85 | **Mean TC** |
| To | In tonnes | | | | | In tonnes | | | | |
| Landfill - RW | 0.17 | 0.23 | 0.24 | 0.31 | **14.05%** | 0.00 | 0.00 | 0.00 | 0.00 | **0.07%** |
| Incineration | 0.03 | 0.04 | 0.04 | 0.05 | **2.40%** | 0.02 | 0.03 | 0.03 | 0.04 | **6.82%** |
| Recycling | 1.06 | 1.36 | 1.41 | 1.76 | **83.55%** | 0.33 | 0.43 | 0.45 | 0.57 | **93.11%** |

| | Flows of Cu in Switzerland | | | | | Flows of Cu in the United Kingdom | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Q15 | Mode | Mean | Q85 | **Mean TC** | Q15 | Mode | Mean | Q85 | **Mean TC** |
| To | In tonnes | | | | | In tonnes | | | | |
| Landfill - RW | 0.00 | 0.00 | 0.00 | 0.00 | **0.00%** | 0.29 | 0.37 | 0.40 | 0.52 | **6.42%** |
| Incineration | 0.04 | 0.06 | 0.06 | 0.08 | **6.83%** | 0.22 | 0.29 | 0.31 | 0.39 | **4.92%** |
| Recycling | 0.61 | 0.81 | 0.83 | 1.07 | **93.17%** | 4.22 | 5.35 | 5.56 | 6.90 | **88.66%** |

## Modelling results – Fractions of silver ENM entering landfilling, incineration and recycling

| | **Flows of Ag in Austria** | | | | | **Flows of Ag in Belgium** | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Q15 | Mode | Mean | Q85 | **Mean TC** | Q15 | Mode | Mean | Q85 | **Mean TC** |
| To | In tonnes | | | | | In tonnes | | | | |
| Landfill - RW | 0.02 | 0.03 | 0.03 | 0.04 | **5.35%** | 0.01 | 0.01 | 0.01 | 0.01 | **2.44%** |
| Incineration | 0.11 | 0.13 | 0.15 | 0.19 | **27.90%** | 0.08 | 0.09 | 0.10 | 0.12 | **22.94%** |
| Recycling | 0.25 | 0.30 | 0.35 | 0.46 | **66.75%** | 0.25 | 0.30 | 0.32 | 0.38 | **74.63%** |

| | **Flows of Ag in Bulgaria** | | | | | **Flows of Ag in Croatia** | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Q15 | Mode | Mean | Q85 | **Mean TC** | Q15 | Mode | Mean | Q85 | **Mean TC** |
| To | In tonnes | | | | | In tonnes | | | | |
| Landfill - RW | 0.09 | 0.13 | 0.15 | 0.21 | **45.63%** | 0.09 | 0.14 | 0.17 | 0.24 | **59.88%** |
| Incineration | 0.00 | 0.01 | 0.01 | 0.01 | **2.77%** | 0.00 | 0.01 | 0.01 | 0.01 | **2.77%** |
| Recycling | 0.10 | 0.16 | 0.17 | 0.23 | **51.60%** | 0.06 | 0.08 | 0.11 | 0.16 | **37.35%** |

| | **Flows of Ag in Cyprus** | | | | | **Flows of Ag in Czech Republic** | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| To | In tonnes | | | | | In tonnes | | | | |
| Landfill - RW | 0.04 | 0.10 | 0.11 | 0.18 | **55.92%** | 0.08 | 0.11 | 0.12 | 0.15 | **25.00%** |
| Incineration | 0.00 | 0.00 | 0.01 | 0.01 | **2.74%** | 0.08 | 0.10 | 0.12 | 0.15 | **24.58%** |
| Recycling | 0.03 | 0.08 | 0.08 | 0.13 | **41.34%** | 0.16 | 0.21 | 0.24 | 0.31 | **50.43%** |

| | **Flows of Ag in Denmark** | | | | | **Flows of Ag in Estonia** | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Q15 | Mode | Mean | Q85 | **Mean TC** | Q15 | Mode | Mean | Q85 | **Mean TC** |
| To | In tonnes | | | | | In tonnes | | | | |
| Landfill - RW | 0.01 | 0.01 | 0.01 | 0.02 | **3.83%** | 0.01 | 0.02 | 0.02 | 0.03 | **9.01%** |
| Incineration | 0.08 | 0.11 | 0.12 | 0.15 | **31.46%** | 0.05 | 0.13 | 0.11 | 0.18 | **53.26%** |
| Recycling | 0.17 | 0.22 | 0.25 | 0.32 | **64.71%** | 0.03 | 0.03 | 0.08 | 0.13 | **37.73%** |

**Modelling results – Fractions of silver ENM entering landfilling, incineration and recycling (continued)**

| | Flows of Ag in Finland | | | | | Flows of Ag in France | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Q15 | Mode | Mean | Q85 | **Mean TC** | Q15 | Mode | Mean | Q85 | **Mean TC** |
| To | In tonnes | | | | | In tonnes | | | | |
| Landfill - RW | 0.03 | 0.04 | 0.04 | 0.05 | **10.91%** | 0.30 | 0.36 | 0.36 | 0.43 | **15.58%** |
| Incineration | 0.05 | 0.06 | 0.08 | 0.10 | **21.20%** | 0.40 | 0.47 | 0.49 | 0.58 | **20.84%** |
| Recycling | 0.16 | 0.22 | 0.25 | 0.34 | **67.89%** | 1.19 | 1.48 | 1.48 | 1.78 | **63.58%** |
| | **Flows of Ag in Germany** | | | | | **Flows of Ag in Greece** | | | | |
| | Q15 | Mode | Mean | Q85 | **Mean TC** | Q15 | Mode | Mean | Q85 | **Mean TC** |
| To | In tonnes | | | | | In tonnes | | | | |
| Landfill - RW | 0.05 | 0.06 | 0.07 | 0.09 | **2.14%** | 0.15 | 0.19 | 0.21 | 0.27 | **43.10%** |
| Incineration | 0.58 | 0.69 | 0.71 | 0.84 | **23.23%** | 0.01 | 0.01 | 0.01 | 0.02 | **2.81%** |
| Recycling | 1.84 | 2.23 | 2.28 | 2.71 | **74.63%** | 0.18 | 0.23 | 0.26 | 0.34 | **54.08%** |
| | **Flows of Ag in Hungary** | | | | | **Flows of Ag in Ireland** | | | | |
| To | In tonnes | | | | | In tonnes | | | | |
| Landfill - RW | 0.11 | 0.13 | 0.16 | 0.21 | **38.94%** | 0.06 | 0.08 | 0.08 | 0.11 | **22.60%** |
| Incineration | 0.03 | 0.03 | 0.04 | 0.05 | **9.44%** | 0.06 | 0.07 | 0.08 | 0.11 | **22.72%** |
| Recycling | 0.14 | 0.16 | 0.21 | 0.28 | **51.63%** | 0.14 | 0.17 | 0.20 | 0.27 | **54.67%** |
| | **Flows of Ag in Italy** | | | | | **Flows of Ag in Latvia** | | | | |
| | Q15 | Mode | Mean | Q85 | **Mean TC** | Q15 | Mode | Mean | Q85 | **Mean TC** |
| To | In tonnes | | | | | In tonnes | | | | |
| Landfill - RW | 0.41 | 0.48 | 0.50 | 0.58 | **23.45%** | 0.06 | 0.08 | 0.13 | 0.21 | **58.86%** |
| Incineration | 0.41 | 0.49 | 0.50 | 0.59 | **23.55%** | 0.00 | 0.01 | 0.01 | 0.01 | **3.10%** |
| Recycling | 0.89 | 1.10 | 1.13 | 1.36 | **53.00%** | 0.04 | 0.04 | 0.09 | 0.14 | **38.04%** |

**Modelling results – Fractions of silver ENM entering landfilling, incineration and recycling (continued)**

| | Flows of Ag in Lithuania | | | | | Flows of Ag in Luxembourg | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Q15 | Mode | Mean | Q85 | **Mean TC** | Q15 | Mode | Mean | Q85 | **Mean TC** |
| To | In tonnes | | | | | In tonnes | | | | |
| Landfill - RW | 0.05 | 0.05 | 0.09 | 0.14 | **37.30%** | 0.01 | 0.01 | 0.02 | 0.02 | **7.05%** |
| Incineration | 0.00 | 0.00 | 0.01 | 0.01 | **2.77%** | 0.02 | 0.03 | 0.05 | 0.08 | **24.89%** |
| Recycling | 0.07 | 0.08 | 0.15 | 0.23 | **59.93%** | 0.06 | 0.08 | 0.15 | 0.23 | **68.06%** |
| | **Flows of Ag in Malta** | | | | | **Flows of Ag in the Netherlands** | | | | |
| | Q15 | Mode | Mean | Q85 | **Mean TC** | Q15 | Mode | Mean | Q85 | **Mean TC** |
| To | In tonnes | | | | | In tonnes | | | | |
| Landfill - RW | 0.02 | 0.04 | 0.07 | 0.12 | **37.87%** | 0.02 | 0.02 | 0.02 | 0.03 | **2.68%** |
| Incineration | 0.00 | 0.00 | 0.01 | 0.01 | **2.73%** | 0.30 | 0.35 | 0.37 | 0.44 | **45.89%** |
| Recycling | 0.04 | 0.06 | 0.11 | 0.19 | **59.40%** | 0.32 | 0.39 | 0.41 | 0.51 | **51.43%** |
| | **Flows of Ag in Norway** | | | | | **Flows of Ag in Poland** | | | | |
| To | In tonnes | | | | | In tonnes | | | | |
| Landfill - RW | 0.01 | 0.01 | 0.01 | 0.02 | **2.95%** | 0.17 | 0.21 | 0.22 | 0.27 | **33.46%** |
| Incineration | 0.10 | 0.12 | 0.13 | 0.17 | **29.56%** | 0.06 | 0.07 | 0.08 | 0.09 | **11.44%** |
| Recycling | 0.21 | 0.27 | 0.30 | 0.40 | **67.48%** | 0.28 | 0.34 | 0.36 | 0.45 | **55.09%** |
| | **Flows of Ag in Portugal** | | | | | **Flows of Ag in Romania** | | | | |
| | Q15 | Mode | Mean | Q85 | **Mean TC** | Q15 | Mode | Mean | Q85 | **Mean TC** |
| To | In tonnes | | | | | In tonnes | | | | |
| Landfill - RW | 0.11 | 0.15 | 0.15 | 0.20 | **34.97%** | 0.32 | 0.39 | 0.43 | 0.54 | **74.24%** |
| Incineration | 0.05 | 0.06 | 0.07 | 0.09 | **16.43%** | 0.01 | 0.02 | 0.02 | 0.03 | **3.35%** |
| Recycling | 0.14 | 0.19 | 0.21 | 0.28 | **48.60%** | 0.09 | 0.12 | 0.13 | 0.17 | **22.41%** |

**Modelling results – Fractions of silver ENM entering landfilling, incineration and recycling (continued)**

| | Flows of Ag in the Slovakia | | | | | Flows of Ag in Slovenia | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Q15 | Mode | Mean | Q85 | **Mean TC** | Q15 | Mode | Mean | Q85 | **Mean TC** |
| To | In tonnes | | | | | In tonnes | | | | |
| Landfill - RW | 0.10 | 0.11 | 0.17 | 0.23 | **50.78%** | 0.05 | 0.09 | 0.10 | 0.15 | **41.08%** |
| Incineration | 0.02 | 0.03 | 0.04 | 0.05 | **10.78%** | 0.00 | 0.00 | 0.01 | 0.01 | **2.76%** |
| Recycling | 0.07 | 0.10 | 0.13 | 0.18 | **38.43%** | 0.06 | 0.10 | 0.13 | 0.21 | **56.15%** |

| | Flows of Ag in Spain | | | | | Flows of Ag in Sweden | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Q15 | Mode | Mean | Q85 | **Mean TC** | Q15 | Mode | Mean | Q85 | **Mean TC** |
| To | In tonnes | | | | | In tonnes | | | | |
| Landfill - RW | 0.57 | 0.68 | 0.70 | 0.82 | **41.81%** | 0.01 | 0.01 | 0.01 | 0.02 | **2.49%** |
| Incineration | 0.13 | 0.16 | 0.16 | 0.19 | **9.71%** | 0.15 | 0.18 | 0.20 | 0.25 | **33.21%** |
| Recycling | 0.64 | 0.76 | 0.81 | 0.98 | **48.48%** | 0.28 | 0.33 | 0.38 | 0.48 | **64.30%** |

| | Flows of Ag in Switzerland | | | | | Flows of Ag in the United Kingdom | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Q15 | Mode | Mean | Q85 | **Mean TC** | Q15 | Mode | Mean | Q85 | **Mean TC** |
| To | In tonnes | | | | | In tonnes | | | | |
| Landfill - RW | 0.01 | 0.01 | 0.01 | 0.02 | **2.19%** | 0.55 | 0.65 | 0.67 | 0.79 | **25.74%** |
| Incineration | 0.14 | 0.16 | 0.17 | 0.21 | **31.28%** | 0.45 | 0.53 | 0.54 | 0.64 | **20.95%** |
| Recycling | 0.28 | 0.35 | 0.37 | 0.46 | **66.53%** | 1.10 | 1.33 | 1.38 | 1.67 | **53.30%** |

## Modelling results – Fractions of $TiO_2$ ENM entering landfilling, incineration and recycling

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | **Flows of $TiO_2$ in Austria** | | | | | **Flows of $TiO_2$ in Belgium** | | | | |
| | Q15 | Mode | Mean | Q85 | **Mean TC** | Q15 | Mode | Mean | Q85 | **Mean TC** |
| To | In tonnes | | | | | In tonnes | | | | |
| Landfill - RW | 1.35 | 2.07 | 2.29 | 3.25 | **2.39%** | 0.26 | 0.39 | 0.44 | 0.63 | **0.39%** |
| Incineration | 10.66 | 15.94 | 18.06 | 25.70 | **18.85%** | 13.75 | 21.16 | 23.06 | 32.50 | **20.44%** |
| Recycling | 44.30 | 64.15 | 75.47 | 107.89 | **78.77%** | 53.78 | 80.48 | 89.32 | 125.49 | **79.17%** |
| | **Flows of $TiO_2$ in Bulgaria** | | | | | **Flows of $TiO_2$ in Croatia** | | | | |
| | Q15 | Mode | Mean | Q85 | **Mean TC** | Q15 | Mode | Mean | Q85 | **Mean TC** |
| To | In tonnes | | | | | In tonnes | | | | |
| Landfill - RW | 6.62 | 8.66 | 14.07 | 21.93 | **27.02%** | 8.57 | 11.69 | 17.60 | 27.19 | **32.44%** |
| Incineration | 0.00 | 0.00 | 0.00 | 0.00 | **0.00%** | 0.00 | 0.00 | 0.00 | 0.00 | **0.00%** |
| Recycling | 17.87 | 23.06 | 38.00 | 59.27 | **72.98%** | 17.73 | 26.05 | 36.66 | 56.71 | **67.56%** |
| | **Flows of $TiO_2$ in Cyprus** | | | | | **Flows of $TiO_2$ in Czech Republic** | | | | |
| To | In tonnes | | | | | In tonnes | | | | |
| Landfill - RW | 3.53 | 4.09 | 9.04 | 14.91 | **21.33%** | 12.19 | 19.00 | 20.69 | 29.48 | **22.21%** |
| Incineration | 0.00 | 0.00 | 0.00 | 0.00 | **0.00%** | 3.79 | 5.83 | 6.44 | 9.18 | **6.91%** |
| Recycling | 13.02 | 14.93 | 33.35 | 54.94 | **78.67%** | 38.60 | 60.79 | 66.04 | 94.70 | **70.88%** |
| | **Flows of $TiO_2$ in Denmark** | | | | | **Flows of $TiO_2$ in Estonia** | | | | |
| | Q15 | Mode | Mean | Q85 | **Mean TC** | Q15 | Mode | Mean | Q85 | **Mean TC** |
| To | In tonnes | | | | | In tonnes | | | | |
| Landfill - RW | 1.57 | 2.13 | 2.92 | 4.34 | **4.23%** | 0.35 | 0.43 | 0.86 | 1.40 | **3.86%** |
| Incineration | 8.00 | 10.89 | 14.88 | 22.11 | **21.52%** | 2.56 | 3.12 | 6.29 | 10.22 | **28.16%** |
| Recycling | 27.93 | 39.04 | 51.33 | 76.02 | **74.25%** | 6.21 | 7.62 | 15.18 | 24.61 | **67.98%** |

**Modelling results – Fractions of $TiO_2$ ENM entering landfilling, incineration and recycling (continued)**

| | Flows of $TiO_2$ in Finland | | | | | Flows of $TiO_2$ in France | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Q15 | Mode | Mean | Q85 | **Mean TC** | Q15 | Mode | Mean | Q85 | **Mean TC** |
| To | In tonnes | | | | | In tonnes | | | | |
| Landfill - RW | 2.29 | 3.36 | 3.88 | 5.51 | **7.84%** | 26.57 | 40.81 | 42.05 | 57.67 | **10.62%** |
| Incineration | 4.82 | 7.03 | 8.18 | 11.64 | **16.54%** | 35.87 | 54.26 | 56.74 | 77.85 | **14.33%** |
| Recycling | 22.08 | 31.52 | 37.41 | 53.03 | **75.61%** | 190.21 | 280.67 | 297.28 | 406.22 | **75.06%** |

| | Flows of $TiO_2$ in Germany | | | | | Flows of $TiO_2$ in Greece | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Q15 | Mode | Mean | Q85 | **Mean TC** | Q15 | Mode | Mean | Q85 | **Mean TC** |
| To | In tonnes | | | | | In tonnes | | | | |
| Landfill - RW | 0.19 | 0.29 | 0.31 | 0.43 | **0.07%** | 16.81 | 24.76 | 28.42 | 40.43 | **27.76%** |
| Incineration | 54.39 | 80.88 | 87.24 | 120.31 | **19.87%** | 0.06 | 0.09 | 0.11 | 0.16 | **0.11%** |
| Recycling | 221.66 | 342.69 | 351.50 | 482.03 | **80.06%** | 43.71 | 67.69 | 73.85 | 105.06 | **72.13%** |

| | Flows of $TiO_2$ in Hungary | | | | | Flows of $TiO_2$ in Ireland | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| To | In tonnes | | | | | In tonnes | | | | |
| Landfill - RW | 8.12 | 10.97 | 15.68 | 23.67 | **25.57%** | 4.24 | 5.84 | 8.44 | 12.90 | **15.51%** |
| Incineration | 1.50 | 2.05 | 2.90 | 4.37 | **4.72%** | 1.97 | 2.71 | 3.92 | 5.98 | **7.20%** |
| Recycling | 22.07 | 30.43 | 42.76 | 64.60 | **69.71%** | 21.14 | 29.51 | 42.06 | 64.10 | **77.28%** |

| | Flows of $TiO_2$ in Italy | | | | | Flows of $TiO_2$ in Latvia | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Q15 | Mode | Mean | Q85 | **Mean TC** | Q15 | Mode | Mean | Q85 | **Mean TC** |
| To | In tonnes | | | | | In tonnes | | | | |
| Landfill - RW | 34.74 | 52.22 | 55.17 | 75.73 | **12.46%** | 4.55 | 4.64 | 12.54 | 20.75 | **30.97%** |
| Incineration | 34.07 | 52.91 | 54.10 | 74.21 | **12.22%** | 0.04 | 0.04 | 0.12 | 0.20 | **0.29%** |
| Recycling | 211.98 | 321.81 | 333.59 | 455.27 | **75.33%** | 10.13 | 10.68 | 27.84 | 46.14 | **68.74%** |

**Modelling results – Fractions of $TiO_2$ ENM entering landfilling, incineration and recycling (continued)**

| | Flows of $TiO_2$ in Lithuania | | | | | Flows of $TiO_2$ in Luxembourg | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Q15 | Mode | Mean | Q85 | **Mean TC** | Q15 | Mode | Mean | Q85 | **Mean TC** |
| To | In tonnes | | | | | In tonnes | | | | |
| Landfill - RW | 4.45 | 5.09 | 11.28 | 18.34 | **26.24%** | 0.42 | 0.44 | 1.26 | 2.13 | **3.30%** |
| Incineration | 0.02 | 0.02 | 0.05 | 0.08 | **0.11%** | 1.90 | 1.98 | 5.67 | 9.57 | **14.79%** |
| Recycling | 12.44 | 13.69 | 31.65 | 51.64 | **73.65%** | 10.59 | 10.95 | 31.41 | 53.06 | **81.91%** |
| | **Flows of $TiO_2$ in Malta** | | | | | **Flows of $TiO_2$ in the Netherlands** | | | | |
| | Q15 | Mode | Mean | Q85 | **Mean TC** | Q15 | Mode | Mean | Q85 | **Mean TC** |
| To | In tonnes | | | | | In tonnes | | | | |
| Landfill - RW | 3.39 | 3.19 | 11.14 | 19.13 | **30.98%** | 0.28 | 0.41 | 0.45 | 0.62 | **0.51%** |
| Incineration | 0.01 | 0.01 | 0.04 | 0.07 | **0.11%** | 17.75 | 27.66 | 28.32 | 39.02 | **31.94%** |
| Recycling | 7.55 | 7.50 | 24.79 | 42.56 | **68.91%** | 37.03 | 54.71 | 59.91 | 83.01 | **67.55%** |
| | **Flows of $TiO_2$ in Norway** | | | | | **Flows of $TiO_2$ in Poland** | | | | |
| To | In tonnes | | | | | In tonnes | | | | |
| Landfill - RW | 0.25 | 0.37 | 0.44 | 0.65 | **0.58%** | 21.97 | 33.55 | 35.02 | 48.24 | **20.12%** |
| Incineration | 8.65 | 13.32 | 15.44 | 22.47 | **20.10%** | 5.94 | 9.20 | 9.61 | 13.34 | **5.52%** |
| Recycling | 34.23 | 51.89 | 60.93 | 88.83 | **79.32%** | 81.03 | 122.50 | 129.37 | 178.13 | **74.35%** |
| | **Flows of $TiO_2$ in Portugal** | | | | | **Flows of $TiO_2$ in Romania** | | | | |
| | Q15 | Mode | Mean | Q85 | **Mean TC** | Q15 | Mode | Mean | Q85 | **Mean TC** |
| To | In tonnes | | | | | In tonnes | | | | |
| Landfill - RW | 12.99 | 19.25 | 21.97 | 31.22 | **22.11%** | 11.41 | 16.29 | 19.05 | 26.77 | **32.87%** |
| Incineration | 5.41 | 8.22 | 9.21 | 13.10 | **9.27%** | 0.12 | 0.18 | 0.21 | 0.30 | **0.36%** |
| Recycling | 39.99 | 57.22 | 68.21 | 97.33 | **68.62%** | 23.08 | 34.28 | 38.70 | 54.55 | **66.77%** |

**Modelling results – Fractions of $TiO_2$ ENM entering landfilling, incineration and recycling (continued)**

| | Flows of $TiO_2$ in the Slovakia | | | | | Flows of $TiO_2$ in Slovenia | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Q15 | Mode | Mean | Q85 | **Mean TC** | Q15 | Mode | Mean | Q85 | **Mean TC** |
| To | In tonnes | | | | | In tonnes | | | | |
| Landfill - RW | 11.13 | 15.86 | 19.82 | 28.95 | **25.43%** | 4.60 | 5.63 | 11.18 | 18.11 | **25.00%** |
| Incineration | 1.87 | 2.85 | 3.35 | 4.89 | **4.30%** | 0.02 | 0.03 | 0.05 | 0.08 | **0.11%** |
| Recycling | 30.83 | 42.55 | 54.76 | 79.66 | **70.27%** | 13.88 | 16.81 | 33.51 | 54.26 | **74.89%** |

| | Flows of $TiO_2$ in Spain | | | | | Flows of $TiO_2$ in Sweden | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Q15 | Mode | Mean | Q85 | **Mean TC** | Q15 | Mode | Mean | Q85 | **Mean TC** |
| To | In tonnes | | | | | In tonnes | | | | |
| Landfill - RW | 63.59 | 95.71 | 98.88 | 134.74 | **24.58%** | 0.11 | 0.16 | 0.19 | 0.28 | **0.21%** |
| Incineration | 11.17 | 16.86 | 17.39 | 23.69 | **4.32%** | 11.50 | 16.04 | 20.05 | 28.93 | **22.11%** |
| Recycling | 181.34 | 287.61 | 286.08 | 390.75 | **71.10%** | 41.14 | 61.44 | 70.45 | 101.16 | **77.68%** |

| | Flows of $TiO_2$ in Switzerland | | | | | Flows of $TiO_2$ in the United Kingdom | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Q15 | Mode | Mean | Q85 | **Mean TC** | Q15 | Mode | Mean | Q85 | **Mean TC** |
| To | In tonnes | | | | | In tonnes | | | | |
| Landfill - RW | 0.00 | 0.00 | 0.00 | 0.00 | **0.00%** | 38.00 | 59.81 | 60.80 | 83.77 | **13.64%** |
| Incineration | 6.78 | 10.41 | 10.90 | 15.09 | **13.73%** | 29.27 | 44.56 | 46.87 | 64.58 | **10.51%** |
| Recycling | 42.69 | 64.89 | 68.45 | 94.73 | **86.27%** | 211.90 | 310.84 | 338.20 | 466.38 | **75.85%** |

**Modelling results – Fractions of ZnO ENM entering landfilling, incineration and recycling**

| | Flows of ZnO in Austria | | | | | Flows of ZnO in Belgium | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Q15 | Mode | Mean | Q85 | **Mean TC** | Q15 | Mode | Mean | Q85 | **Mean TC** |
| To | In tonnes | | | | | In tonnes | | | | |
| Landfill - RW | 0.01 | 0.05 | 0.05 | 0.09 | **1.23%** | 0.00 | 0.01 | 0.01 | 0.02 | **0.18%** |
| Incineration | 0.04 | 0.37 | 0.36 | 0.67 | **9.54%** | 0.04 | 0.38 | 0.38 | 0.72 | **8.40%** |
| Recycling | 0.38 | 3.17 | 3.33 | 6.31 | **89.23%** | 0.47 | 3.84 | 4.15 | 7.85 | **91.42%** |

| | Flows of ZnO in Bulgaria | | | | | Flows of ZnO in Croatia | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Q15 | Mode | Mean | Q85 | **Mean TC** | Q15 | Mode | Mean | Q85 | **Mean TC** |
| To | In tonnes | | | | | In tonnes | | | | |
| Landfill - RW | 0.05 | 0.31 | 0.55 | 1.11 | **14.86%** | 0.08 | 0.44 | 0.74 | 1.45 | **17.88%** |
| Incineration | 0.00 | 0.00 | 0.00 | 0.00 | **0.06%** | 0.00 | 0.00 | 0.00 | 0.00 | **0.00%** |
| Recycling | 0.29 | 1.70 | 3.17 | 6.35 | **85.08%** | 0.34 | 2.16 | 3.40 | 6.68 | **82.12%** |

| | Flows of ZnO in Cyprus | | | | | Flows of ZnO in Czech Republic | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Q15 | Mode | Mean | Q85 | **Mean TC** | Q15 | Mode | Mean | Q85 | **Mean TC** |
| To | In tonnes | | | | | In tonnes | | | | |
| Landfill - RW | 0.04 | 0.18 | 0.44 | 0.89 | **13.41%** | 0.16 | 1.09 | 1.41 | 2.69 | **19.68%** |
| Incineration | 0.00 | 0.00 | 0.00 | 0.00 | **0.00%** | 0.04 | 0.29 | 0.36 | 0.68 | **4.99%** |
| Recycling | 0.26 | 1.30 | 2.85 | 5.79 | **86.59%** | 0.60 | 4.50 | 5.40 | 10.30 | **75.33%** |

| | Flows of ZnO in Denmark | | | | | Flows of ZnO in Estonia | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Q15 | Mode | Mean | Q85 | **Mean TC** | Q15 | Mode | Mean | Q85 | **Mean TC** |
| To | In tonnes | | | | | In tonnes | | | | |
| Landfill - RW | 0.05 | 0.35 | 0.51 | 0.98 | **10.41%** | 0.00 | 0.00 | 0.00 | 0.00 | **2.32%** |
| Incineration | 0.02 | 0.13 | 0.20 | 0.39 | **4.06%** | 0.00 | 0.01 | 0.01 | 0.01 | **16.77%** |
| Recycling | 0.44 | 2.82 | 4.16 | 8.09 | **85.52%** | 0.00 | 0.02 | 0.03 | 0.06 | **80.90%** |

**Modelling results – Fractions of ZnO ENM entering landfilling, incineration and recycling (continued)**

| | Flows of ZnO in Finland | | | | | Flows of ZnO in France | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Q15 | Mode | Mean | Q85 | **Mean TC** | Q15 | Mode | Mean | Q85 | **Mean TC** |
| To | In tonnes | | | | | In tonnes | | | | |
| Landfill - RW | 0.01 | 0.04 | 0.06 | 0.12 | **1.31%** | 0.19 | 1.58 | 1.69 | 3.21 | **5.97%** |
| Incineration | 0.01 | 0.08 | 0.13 | 0.25 | **2.73%** | 0.26 | 2.17 | 2.28 | 4.33 | **8.03%** |
| Recycling | 0.50 | 2.98 | 4.53 | 8.77 | **95.96%** | 2.77 | 22.77 | 24.37 | 46.43 | **85.99%** |

| | Flows of ZnO in Germany | | | | | Flows of ZnO in Greece | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Q15 | Mode | Mean | Q85 | **Mean TC** | Q15 | Mode | Mean | Q85 | **Mean TC** |
| To | In tonnes | | | | | In tonnes | | | | |
| Landfill - RW | 0.00 | 0.00 | 0.00 | 0.01 | **0.01%** | 0.15 | 1.04 | 1.27 | 2.40 | **15.69%** |
| Incineration | 0.26 | 2.09 | 2.31 | 4.36 | **8.39%** | 0.00 | 0.00 | 0.00 | 0.00 | **0.00%** |
| Recycling | 2.80 | 22.66 | 25.20 | 47.73 | **91.60%** | 0.77 | 5.06 | 6.83 | 13.02 | **84.31%** |

| | Flows of ZnO in Hungary | | | | | Flows of ZnO in Ireland | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Q15 | Mode | Mean | Q85 | **Mean TC** | Q15 | Mode | Mean | Q85 | **Mean TC** |
| To | In tonnes | | | | | In tonnes | | | | |
| Landfill - RW | 0.09 | 0.58 | 0.90 | 1.76 | **20.89%** | 0.02 | 0.10 | 0.15 | 0.28 | **4.42%** |
| Incineration | 0.02 | 0.09 | 0.16 | 0.32 | **3.75%** | 0.01 | 0.04 | 0.07 | 0.13 | **1.99%** |
| Recycling | 0.32 | 2.02 | 3.25 | 6.37 | **75.36%** | 0.32 | 2.12 | 3.07 | 6.04 | **93.60%** |

| | Flows of ZnO in Italy | | | | | Flows of ZnO in Latvia | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Q15 | Mode | Mean | Q85 | **Mean TC** | Q15 | Mode | Mean | Q85 | **Mean TC** |
| To | In tonnes | | | | | In tonnes | | | | |
| Landfill - RW | 0.20 | 1.45 | 1.73 | 3.25 | **5.05%** | 0.04 | 0.19 | 0.53 | 1.09 | **17.71%** |
| Incineration | 0.19 | 1.43 | 1.69 | 3.18 | **4.94%** | 0.00 | 0.00 | 0.00 | 0.01 | **0.09%** |
| Recycling | 3.45 | 26.10 | 30.73 | 58.09 | **90.01%** | 0.20 | 0.84 | 2.45 | 5.08 | **82.21%** |

**Modelling results – Fractions of ZnO ENM entering landfilling, incineration and recycling (continued)**

| | Flows of ZnO in Lithuania | | | | | Flows of ZnO in Luxembourg | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Q15 | Mode | Mean | Q85 | **Mean TC** | Q15 | Mode | Mean | Q85 | **Mean TC** |
| To | In tonnes | | | | | In tonnes | | | | |
| Landfill - RW | 0.04 | 0.20 | 0.53 | 1.08 | **16.73%** | 0.00 | 0.01 | 0.03 | 0.06 | **1.01%** |
| Incineration | 0.00 | 0.00 | 0.00 | 0.00 | **0.00%** | 0.01 | 0.03 | 0.12 | 0.26 | **4.41%** |
| Recycling | 0.21 | 0.99 | 2.62 | 5.34 | **83.27%** | 0.18 | 0.68 | 2.64 | 5.55 | **94.58%** |

| | Flows of ZnO in Malta | | | | | Flows of ZnO in the Netherlands | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Q15 | Mode | Mean | Q85 | **Mean TC** | Q15 | Mode | Mean | Q85 | **Mean TC** |
| To | In tonnes | | | | | In tonnes | | | | |
| Landfill - RW | 0.04 | 0.15 | 0.60 | 1.26 | **21.94%** | 0.00 | 0.01 | 0.01 | 0.02 | **0.18%** |
| Incineration | 0.00 | 0.00 | 0.00 | 0.00 | **0.00%** | 0.06 | 0.46 | 0.54 | 1.02 | **10.75%** |
| Recycling | 0.15 | 0.53 | 2.13 | 4.47 | **78.06%** | 0.49 | 4.36 | 4.46 | 8.47 | **89.07%** |

| | Flows of ZnO in Norway | | | | | Flows of ZnO in Poland | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Q15 | Mode | Mean | Q85 | **Mean TC** | Q15 | Mode | Mean | Q85 | **Mean TC** |
| To | In tonnes | | | | | In tonnes | | | | |
| Landfill - RW | 0.00 | 0.01 | 0.02 | 0.04 | **0.38%** | 0.19 | 1.52 | 1.75 | 3.32 | **14.16%** |
| Incineration | 0.08 | 0.51 | 0.72 | 1.39 | **13.72%** | 0.01 | 0.10 | 0.12 | 0.23 | **0.99%** |
| Recycling | 0.48 | 3.00 | 4.51 | 8.72 | **85.90%** | 1.15 | 8.60 | 10.47 | 19.82 | **84.85%** |

| | Flows of ZnO in Portugal | | | | | Flows of ZnO in Romania | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Q15 | Mode | Mean | Q85 | **Mean TC** | Q15 | Mode | Mean | Q85 | **Mean TC** |
| To | In tonnes | | | | | In tonnes | | | | |
| Landfill - RW | 0.07 | 0.45 | 0.58 | 1.09 | **17.43%** | 0.11 | 0.74 | 1.09 | 2.11 | **22.84%** |
| Incineration | 0.03 | 0.20 | 0.24 | 0.45 | **7.18%** | 0.00 | 0.00 | 0.01 | 0.01 | **0.16%** |
| Recycling | 0.31 | 1.84 | 2.50 | 4.73 | **75.38%** | 0.38 | 2.60 | 3.67 | 7.14 | **77.00%** |

**Modelling results – Fractions of ZnO ENM entering landfilling, incineration and recycling (continued)**

| | Flows of ZnO in the Slovakia | | | | | Flows of ZnO in Slovenia | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Q15 | Mode | Mean | Q85 | **Mean TC** | Q15 | Mode | Mean | Q85 | **Mean TC** |
| To | In tonnes | | | | | In tonnes | | | | |
| Landfill - RW | 0.09 | 0.79 | 0.91 | 1.74 | **14.20%** | 0.03 | 0.15 | 0.33 | 0.67 | **9.92%** |
| Incineration | 0.02 | 0.13 | 0.15 | 0.28 | **2.32%** | 0.00 | 0.00 | 0.00 | 0.00 | **0.00%** |
| Recycling | 0.55 | 4.34 | 5.33 | 10.27 | **83.48%** | 0.26 | 1.31 | 3.01 | 6.11 | **90.08%** |

| | Flows of ZnO in Spain | | | | | Flows of ZnO in Sweden | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Q15 | Mode | Mean | Q85 | **Mean TC** | Q15 | Mode | Mean | Q85 | **Mean TC** |
| To | In tonnes | | | | | In tonnes | | | | |
| Landfill - RW | 0.69 | 5.58 | 6.47 | 12.31 | **20.96%** | 0.00 | 0.00 | 0.00 | 0.00 | **0.04%** |
| Incineration | 0.12 | 1.02 | 1.11 | 2.11 | **3.61%** | 0.04 | 0.27 | 0.34 | 0.66 | **5.57%** |
| Recycling | 2.41 | 19.09 | 23.27 | 44.31 | **75.42%** | 0.61 | 4.48 | 5.78 | 11.07 | **94.40%** |

| | Flows of ZnO in Switzerland | | | | | Flows of ZnO in the United Kingdom | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Q15 | Mode | Mean | Q85 | **Mean TC** | Q15 | Mode | Mean | Q85 | **Mean TC** |
| To | In tonnes | | | | | In tonnes | | | | |
| Landfill - RW | 0.00 | 0.00 | 0.00 | 0.00 | **0.00%** | 0.31 | 2.51 | 2.72 | 5.13 | **8.63%** |
| Incineration | 0.03 | 0.24 | 0.27 | 0.51 | **5.60%** | 0.24 | 1.88 | 2.03 | 3.82 | **6.44%** |
| Recycling | 0.52 | 4.39 | 4.51 | 8.55 | **94.40%** | 3.10 | 22.81 | 26.75 | 50.65 | **84.93%** |