About 20 to 25 wt.% of the waste input into a municipal solid waste incineration (MSWI) plant is transferred to so-called incinerator bottom ash (IBA), which represents the major solid residue from MSWI [7, 43]. It is common practice to separate ferrous and non-ferrous metals from IBA and subsequently recycle them in the metal industry [1, 9, 27, 32, 35, 39, 48, 63, 65] due to their economic value. The mineral fraction of IBA shows a much lower economic value which results in a lower financial incentive to recycle this material. It is either disposed of on landfills (including landfill construction) or utilised in the civil engineering sector [56, 66]. While some countries utilise up to 100 % of IBA in the civil engineering sector, other countries dispose of up to 100 % of this residue in landfills [14]. One of the reasons for such different utilisation rates may lie in the legal framework regulating IBA utilisation. For instance, while the Netherlands promote the use of IBA in engineering constructions, Switzerland limits its utilization for this purpose [5, 8]. The present work aims to illuminate the different legal frameworks on IBA management in the European Union (EU), Norway and Switzerland and presents requirements that have to be met in order to recycle this material as secondary raw material in the civil engineering sector.
Legal framework at EU level

At EU level, two legal documents address IBA. The first one is Directive 2010/75/EU on industrial emissions [21]. This directive applies to all member states and it has to be considered when operating a MSWI plant, by defining certain minimum requirements. Those minimum requirements include operating conditions that ensure a proper conversion of the waste in such a manner that the resulting bottom ashes show either total organic carbon contents lower than 3 % or their loss on ignition is less than 5 %. Furthermore, the plant operator is required to recycle residues where appropriate. Prior to recycling, the operator has to assess chemical and physical properties as well as the polluting potential of the material. This directive goes neither into detail which recycling options should be considered nor are parameters defined for assessing the properties and the pollution potential.

The second legal document addressing IBA is Commission Decision 2014/955/EU, which includes a List of Waste (LoW) that defines waste types and classifies waste as hazardous or non-hazardous [19]. The LoW includes three entries which concern IBA: 19 01 02 – ferrous materials removed from bottom ash, 19 01 11* – bottom ash and slag containing hazardous substances and 19 01 12 – bottom ash and slag other than those mentioned in 19 01 11. 19 01 11* and 19 01 12 are so-called mirror entries which means that IBA has to be tested if it shows (amongst others) any of the 15 hazardous properties (HP) laid down in Commission Regulation (EU) No 1357/2014 [20].

When it comes to the utilisation of IBA as secondary raw material in the construction sector however, there is no standardised procedure at EU level and countries developed their own rules to regulate this matter. A literature review revealed that requirements for utilising IBA vary significantly between countries and a fragmented picture became visible, highlighting the complex nature of IBA utilisation. But since many publications on this matter do not cover the entire EU and they do not show all the requirements regarding IBA utilisation, an up-to-date and holistic overview on the legal framework of IBA utilisation is presented.

1. Methods

1.1. Geographic system boundary

From 28 EU member states, 20 have implemented MSWI, namely: Austria, Belgium, Czech Republic, Denmark, Estonia, Finland, France, Germany, Hungary, Ireland, Italy, Lithuania, Luxembourg, Netherlands, Poland, Portugal, Slovakia, Spain, Sweden and United Kingdom. Including Norway and Switzerland, this makes in total 22 countries which are in the focus of this work.

1.2. Data collection

In order to collect data, experts in the respective countries were approached and connected within the COST action Mining the European Anthroposphere (MINEA).
The MINEA project assesses anthropogenic resources like IBA with respect to their potential to produce secondary raw materials by building up a network of competent persons (experts) for data collection and interpretation. This panel of experts is composed of specialists from scientific institutions, plant operators, waste management consultants, professionals from environmental agencies and experts on waste policy.

2. Results and discussion

2.1. General results

Results in Table 1 reveal that overall about 17.6 Mt of IBA is annually generated in the EU, Norway and Switzerland, which is 20 wt.% of the annual incineration capacity in these countries (cf. Introduction). Sixteen of the 22 observed countries permit the utilisation of IBA outside of landfills. In only eleven countries, however, utilisation of IBA is practiced. The utilisation rates range from 20 to 100 wt.% of the annual IBA amount in these countries. Within the considered system, around 9.6 Mt or 53 % of the annually generated IBA amount is utilised outside of landfills as secondary raw material.

Table 1 shows the relevant documents that have to be considered for IBA utilisation outside of landfills at national level. While the majority of member states regulate IBA utilisation on the basis of legislation (decrees, regulations, and ordinances), Austria, Germany, Sweden, and the United Kingdom solely published guidelines. Guidelines usually provide less legal security as they are considered to be so-called soft law [49]. Soft law is unlike hard law (regulations etc.) not binding on those who are addressed by it [22, 49]. Portugal has an individual permit in place, issued by the independent national body Laboratório Nacional de Engenharia Civil (LNEC), exclusively for one IBA processing company. In Estonia, Hungary, Ireland, Luxembourg and Slovakia the utilisation outside of landfills is not regulated. This is also the case in the Brussels Capital Region in Belgium and in sixteen out of seventeen Spanish autonomous communities (all except Catalonia). Ireland and Luxembourg export their generated IBA to other EU countries for utilisation. While in Ireland one of the two plant operators follows this practice and sends it to the Netherlands, Luxembourg’s only plant operator sends its entire IBA to Germany for utilisation. Estonia, Hungary and Slovakia send their IBA to landfills. In Norway, utilisation outside of landfills is not permitted; therefore, it is either used as construction material in landfills or disposed of in the same.

By comparing utilisation rates with the type of rules in the respective countries, it can be investigated if a correlation between those two factors is observable. The results show that clear rules do not necessarily mean high utilisation rates. This can be observed for example in Lithuania or Switzerland where clear rules for IBA utilisation are in place, but both countries show utilisation rates of 0 wt.%. On the contrary, in Portugal and the United Kingdom utilisation rates are 56 wt.% and 99 wt.% respectively, even though no such clear rules are in place.
Table 1: Overview on annually generated amount of IBA in the observed countries, information if utilisation is permitted and practiced, how much IBA is utilised, respective documents regulating the utilisation of IBA in the observed countries, type of legal document and references

<table>
<thead>
<tr>
<th>Country</th>
<th>IBA mass Mt/a</th>
<th>IBA utilisation</th>
<th>utilisation rate outside landfills %</th>
<th>Reference for utilisation rate</th>
<th>Original title of document regulating IBA utilisation outside of landfills</th>
<th>Type</th>
<th>Reference for legal document</th>
</tr>
</thead>
<tbody>
<tr>
<td>Austria</td>
<td>0.53</td>
<td>yes</td>
<td>no</td>
<td>0</td>
<td>Bundesabfallwirtschaftsplan 2017; Technische Grundlagen für den Einsatz von Abfällen als Ersatzrhythstoffe in Anlagen zur Zementerzeugung</td>
<td>guidance</td>
<td>[53, 54]</td>
</tr>
<tr>
<td>Belgium</td>
<td>0.47</td>
<td>yes</td>
<td>yes</td>
<td>69</td>
<td>VLAREMA-2012 (Flanders); Arrêté du Gouvernement wallon, 14/06/2001 (Wallonia)</td>
<td>legislation</td>
<td>[30, 24]</td>
</tr>
<tr>
<td>Czech Rep.</td>
<td>0.2</td>
<td>yes</td>
<td>no</td>
<td>0</td>
<td>Vyhláška c. 294/2005 Sb.</td>
<td>legislation</td>
<td>[13]</td>
</tr>
<tr>
<td>Denmark</td>
<td>0.6</td>
<td>yes</td>
<td>yes</td>
<td>99</td>
<td>Order N.1672 (2016)</td>
<td>legislation</td>
<td>[36]</td>
</tr>
<tr>
<td>Estonia</td>
<td>0.058</td>
<td>not regulated</td>
<td>-</td>
<td>0</td>
<td></td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Finland</td>
<td>0.3</td>
<td>yes</td>
<td>yes</td>
<td>20</td>
<td>Government Decree on the Recovery of Certain Wastes in Earth Construction (843/2017)</td>
<td>legislation</td>
<td>[28]</td>
</tr>
<tr>
<td>France</td>
<td>2.9</td>
<td>yes</td>
<td>yes</td>
<td>80</td>
<td>Arrêté du 18 novembre 2011 relatif au recyclage en technique routière des mâchefers d’incinération de déchets non dangereux NOR: DEVP1131516A</td>
<td>legislation</td>
<td>[25]</td>
</tr>
<tr>
<td>Germany</td>
<td>4.8</td>
<td>yes</td>
<td>yes</td>
<td>30</td>
<td>LAGA M19 (annex 6) and LAGA M20 (for leachates)</td>
<td>guidance</td>
<td>[37, 38]</td>
</tr>
<tr>
<td>Hungary</td>
<td>0.12</td>
<td>not regulated</td>
<td>-</td>
<td>0</td>
<td></td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Ireland</td>
<td>0.14</td>
<td>not regulated</td>
<td>-</td>
<td>0</td>
<td></td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Italy</td>
<td>1.03</td>
<td>yes</td>
<td>yes</td>
<td>85</td>
<td>Decreto 5 febbraio 1998 including its amendment Decreto 5 aprile 2006, n. 186</td>
<td>legislation</td>
<td>[33, 34]</td>
</tr>
<tr>
<td>Lithuania</td>
<td>0.075</td>
<td>yes</td>
<td>no</td>
<td>0</td>
<td>Įsakymas 2016 November 25 No. D1-805</td>
<td>legislation</td>
<td>[41]</td>
</tr>
<tr>
<td>Luxembourg</td>
<td>0.028</td>
<td>not regulated</td>
<td>-</td>
<td>0</td>
<td></td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Netherlands</td>
<td>1.9</td>
<td>yes (mandatory)</td>
<td>yes</td>
<td>100</td>
<td>Regeling van 13 december 2007, nr. DJZZ2007124397, houdende regels voor de uitvoering van de kwaliteit van de bodem (Regeling bodemkwaliteit)</td>
<td>legislation</td>
<td>[29]</td>
</tr>
<tr>
<td>Norway</td>
<td>0.25</td>
<td>not permitted</td>
<td>-</td>
<td>0</td>
<td></td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Poland</td>
<td>0.21</td>
<td>yes</td>
<td>yes</td>
<td>60%</td>
<td>Poz. 796 - Rozporzadzenie Ministra Środowiska z dnia 11 maja 2015 r. w sprawie odzysku odpadów poza instalacjami i urządzeniami</td>
<td>legislation</td>
<td>[55]</td>
</tr>
</tbody>
</table>
Utilisation of IBA and Respective Legal Requirements in the EU, Norway and Switzerland

Table 1: Overview on annually generated amount of IBA in the observed countries, information if utilisation is permitted and practiced, how much IBA is utilised, respective documents regulating the utilisation of IBA in the observed countries, type of legal document and references\textsuperscript{b} – continuation

<table>
<thead>
<tr>
<th>Country</th>
<th>IBA mass Mt/a</th>
<th>IBA utilisation permitted</th>
<th>IBA utilisation practised</th>
<th>utilisation rate outside landfills (%)</th>
<th>Reference for utilisation rate</th>
<th>Original title of document regulating IBA utilisation outside of landfills</th>
<th>Type</th>
<th>Reference for legal document</th>
</tr>
</thead>
<tbody>
<tr>
<td>Portugal</td>
<td>0.22</td>
<td>yes</td>
<td>yes</td>
<td>56</td>
<td>Individual permit issued by independent national body (LNEC – Laboratório Nacional de Engenharia Civil)</td>
<td>individual permit [62]</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Slovakia</td>
<td>0.062</td>
<td>not regulated</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Spain</td>
<td>0.44</td>
<td>Catalonia: yes Rest of Spain: not regulated</td>
<td>yes</td>
<td>58</td>
<td>Ordre de 15 de febrer de 1996 (Catalonia)</td>
<td>legislation [26]</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sweden</td>
<td>0.99</td>
<td>yes</td>
<td>no</td>
<td>0</td>
<td>Återvinning av avfall i anläggningsarbeten Handbok</td>
<td>guidance [44]</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Switzerland</td>
<td>0.82</td>
<td>yes</td>
<td>no</td>
<td>0</td>
<td>Verordnung über die Vermeidung und Entsorgung von Abfällen (VVEA)</td>
<td>legislation [57]</td>
<td></td>
<td></td>
</tr>
<tr>
<td>United Kingdom</td>
<td>1.5</td>
<td>yes</td>
<td>yes</td>
<td>99</td>
<td>Guidance - Use of unbound municipal Incinerator Bottom Ash Aggregate (IBAA) in construction activities: RPS 206</td>
<td>guidance [60]</td>
<td></td>
<td></td>
</tr>
<tr>
<td>SUM</td>
<td>17.6</td>
<td>16</td>
<td>11</td>
<td>54 (or 9.6 Mt/a)</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
</tbody>
</table>

\textsuperscript{a} One Irish incinerator exports its entire IBA (approx. 0.14 Mt/a) to the Netherlands for utilisation.

\textsuperscript{b} Luxembourg export its entire IBA to Germany for utilisation.

\begin{itemize}
  \item The most widely permitted field of application is the construction of roads, followed by different forms of earth works (noise barriers, levelling of terrain, etc.), cement manufacturing process, use in bound and unbound form as granulate, and for foundations of structures (Table 2). In order to be in line with the requirements for utilisation, chemical and/or physiochemical parameters have to be assessed and compared with related limit values defined in the documents shown in Table 1. The respective limit values regarding total and leaching content for the related field of application and region are presented in Table 2. Overall 51 different parameters for the total content and 36 different parameters for the leaching content are defined in the observed countries. Both organic, as well as inorganic parameters, have to be complied with. It can be seen that out of 51 total content parameters, 36 concern organic substances and out of 36 leaching parameters only two are related to organic substances, while 29 are inorganic parameters and 4 are physiochemical parameters.
\end{itemize}
### Table 2: Parameters for total and leaching content that have to be considered in order to utilise IBA in the permitted fields of application

<table>
<thead>
<tr>
<th>Country</th>
<th>Permitted field of application</th>
<th>Requirements on total content</th>
<th>leaching content</th>
<th>type of values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Austria</td>
<td>Base layer in road construction (bound and unbound)</td>
<td>Cd, Cr (total), Ni, Pb, TOC</td>
<td>As, Cr (total), Cu, Mo, Ni, Pb, Sb, chloride, sulphate, pH</td>
<td>guideline values</td>
</tr>
<tr>
<td></td>
<td>Secondary raw material in cement production</td>
<td>As, Cd, Co, Cr (total), Hg, Ni, Pb, Sb, Ti</td>
<td>no requirements</td>
<td>guideline values</td>
</tr>
<tr>
<td>Flanders: bound and unbound construction material</td>
<td>As, Cd, Cr (total), Cu, Hg, Ni, Pb, Zn, asbestos, benzene, ethylbenzene, styrene, toluene, xylene, benzo(a) anthracene, benzo(a)pyrene, benzo(g,h,i)perylene, benzo(b) fluoranthene, benzo(k)fluoranthene, chrysene, phenanthrene, fluoranthene, indeno(1,2,3-cd)pyrene, naphthalene, hexane, heptane, petroleum, octane, PCB</td>
<td>As, Cd, Cr (total), Cu, Hg, Ni, Pb, Zn</td>
<td>limit values</td>
<td></td>
</tr>
<tr>
<td>Belgium</td>
<td>Wallonia: Certification test (base layer and hydraulic bound material)</td>
<td>petroleum, PCB, BTEx, EOX, PAH</td>
<td>Al, As, Cd, Co, Cr (total), Cr (VI), Cu, Hg, K, Mo, Ni, Pb, Sb, Ti, Zn, chloride, cyanide, fluoride, sulphate</td>
<td>limit values</td>
</tr>
<tr>
<td></td>
<td>Wallonia: Regular quality assurance test (base layer and possibly hydraulic bound material)</td>
<td>petroleum, EOX</td>
<td>Al, As, Cd, Co, Cr (total), Cr (VI), Cu, Hg, K, Mo, Ni, Pb, Sb, Ti, Zn, chloride, cyanide, fluoride, sulphate</td>
<td>limit values</td>
</tr>
<tr>
<td>Czech Republic</td>
<td>application of waste on soil surface</td>
<td>As, Cd, Cr (total), Hg, Ni, Pb, V, hydrocarbons (C10-40), PCB, BTX, EOX, PAH</td>
<td>no requirements</td>
<td>limit values</td>
</tr>
<tr>
<td>Denmark</td>
<td>Category 1: unrestricted use in specific construction applications (no IBA will meet Cat. 1 requirements), Category 2&amp;3: subbase layer in road construction</td>
<td>As, Cd, Cr (total), Cr (VI), Cu, Ni, Pb, Zn</td>
<td>As, Ba, Cd, Cr (total), Cu, Hg, Mn, Na, Ni, Pb, Se, Zn, chloride, sulphate-</td>
<td>limit values</td>
</tr>
<tr>
<td></td>
<td>Category 2: maximum 3 m high road embankment or shoulder infrastructures, under the condition to be covered road structures</td>
<td>TOC, hydrocarbons (C10-40), PCB (sum of 28, 52, 101, 118, 138, 153, 180), BTEx, PAH, TEQ</td>
<td>As, Ba, Cd, Cr (total), Cu, Hg, Mo, Ni, Pb, Sb, Se, Zn, chloride, fluoride, sulphate, total dissolved solids</td>
<td>limit values</td>
</tr>
<tr>
<td></td>
<td>Estonia</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Finland</td>
<td>no requirements</td>
<td>As, Ba, Cd, Cr (total), Cu, Hg, Mo, Ni, Pb, Sb, Se, Zn, chloride, sulphate, DOx</td>
<td>limit values</td>
</tr>
<tr>
<td></td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Type 1: maximum 6 m high road embankment or shoulder infrastructures under the condition to be covered road structures</td>
<td>TOC, hydrocarbons (C10-40), PCB (sum of 28, 52, 101, 118, 138, 153, 180), BTEx, PAH, TEQ</td>
<td>As, Ba, Cd, Cr (total), Cu, Hg, Mo, Ni, Pb, Sb, Se, Zn, chloride, fluoride, sulphate, total dissolved solids</td>
<td>limit values</td>
</tr>
<tr>
<td></td>
<td>France</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Germany</td>
<td>Cd, Cr (total), Cu, Ni, Pb, Zn, TOC, PCDD/PCDF, EOX</td>
<td>Cd, Cr (total), Cu, Hg, Ni, Pb, Zn, chloride, sulphate, pH, electric conductivity</td>
<td>guideline values</td>
</tr>
<tr>
<td></td>
<td>Hungary</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Ireland</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>Italy</td>
<td>no requirements</td>
<td>As, Ba, Be, Cd, Co, Cr (total), Cu, Hg, Ni, Pb, V, Zn, chloride, cyanide, fluoride, sulphate, nitrate, asbestos, chemical oxygen demand, pH</td>
<td>limit values</td>
</tr>
<tr>
<td></td>
<td>Lithuania</td>
<td>TOC, loss on ignition</td>
<td>Cd, Cr (total), Cu, Hg, Ni, Pb, Zn, chloride, cyanide, sulphate, pH, electric conductivity</td>
<td>limit values</td>
</tr>
</tbody>
</table>
### Parameters for total and leaching content that have to be considered in order to utilise IBA in the permitted fields of application – continuation

<table>
<thead>
<tr>
<th>Country</th>
<th>Permitted field of application</th>
<th>Requirements on total content</th>
<th>leaching content</th>
<th>type of values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Luxembourg</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Netherlands</td>
<td>bound and unbound construction material, IBC construction material</td>
<td>benzene, ethylbenzene, toluene, xylene, benzo(a)anthracene, benzo(a)pyrene, benzo(ghi)perylene, benzo(k)fluoranthene, indeno(1,2,3-cd)pyrene, petroleum, PCB (sum of 28, 52, 101, 118, 138, 153, 180), PAH, asbestos</td>
<td>As, Ba, Cd, Co, Cr (total), Cu, Hg, Mo, Ni, Pb, Sb, Se, Sn, V, Zn, bromide, chloride, fluoride, sulphate</td>
<td>limit values</td>
</tr>
<tr>
<td>Norway</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Poland</td>
<td>subbase layer in road construction</td>
<td>TOC, hydrocarbons (sum of C10-40), PCB, BTEX, PAH</td>
<td>As, Ba, Cd, Cr (total), Cu, Hg, Mo, Ni, Pb, Sb, Se, Zn, chloride, fluoride, sulphate, phenol index, dissolved organic carbon, total dissolved solids</td>
<td>limit values</td>
</tr>
<tr>
<td>Portugal</td>
<td>Aggregates for unbound and hydraulically bound materials for use in civil engineering work and road construction</td>
<td>Based on individual permit from LNEC: no requirements</td>
<td>Based on individual permit from LNEC: compliance with NP EN 13242:2002 + A1:2010</td>
<td>Based on individual permit from LNEC: limit values</td>
</tr>
<tr>
<td>Slovakia</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Spain</td>
<td>Catalonia: road subbase, levelling of terrain and embankments, filling and restoration of degradable areas from extractive activities, others</td>
<td>loss on ignition, unburned material</td>
<td>As, Cd, Cr (VI), Cu, Pb, Zn, total dissolved solids</td>
<td>limit values</td>
</tr>
<tr>
<td>Sweden</td>
<td>general use - unbound material</td>
<td>As, Cd, Cr (total), Cu, Hg, Ni, Pb, Zn, PAH low ring number, PAH medium ring number, PAH high ring number</td>
<td>As, Cd, Cr (total), Cu, Hg, Ni, Pb, Zn, chloride, sulphate</td>
<td>guideline values</td>
</tr>
<tr>
<td>Switzerland</td>
<td>Use of waste as raw material and raw meal correction material in the cement industry</td>
<td>As, Cd, Co, Cr (total), Cu, Hg, Ni, Pb, Sb, Sn, Ti, Zn, TOC, hydrocarbons (sum of C5-10), hydrocarbons (sum C10-40), benzene, benzo(a)pyrene, PCB, BTEX, PAH, VOC</td>
<td>no requirements</td>
<td>limit values</td>
</tr>
<tr>
<td></td>
<td>Use of waste as grinding additives and aggregates in the cement industry</td>
<td>As, Cd, Cr (total), Cr (VI), Cu, Hg, Ni, Pb, Sb, Zn, TOC, hydrocarbons (sum of C5-10), hydrocarbons (sum C10-40), benzene, benzo(a)pyrene, PCB, BTEX, PAH, VOC</td>
<td>no requirements</td>
<td>limit values</td>
</tr>
<tr>
<td>United Kingdom</td>
<td>road, construction of structural platforms, pipe bedding</td>
<td>individual decision</td>
<td>individual decision</td>
<td>individual decision</td>
</tr>
</tbody>
</table>

A closer look at the parameters shows that if a country allows the utilisation in road construction or some application where precipitation potentially may reach IBA, the focus is on the leaching behaviour of IBA, as soluble components can be washed out to the environment. If IBA is applied in a more general application in bound or unbound form and it is not just limited to road construction, requirements for the total content are additionally obliged. In order to avoid/limit the dispersion of pollutants (e.g. heavy metals, persistent organic pollutants (POPs)), Austria and Switzerland defined specific limit values for utilisation of secondary raw materials in the cement process, thereby not apriori limiting the use of IBA. However, the limit values in Switzerland are quite strict and they limit the use of IBA in cement production. If IBA serves as replacement of primary raw material in the cement kiln, leaching behaviour can be neglected and
the concentration (= total content) of volatile components (such as Hg and other heavy metals) comes into focus. While Austria applies similar limit values for secondary raw materials in cement production like Switzerland, it allows exceeding these values in the case that the total content of heavy metals in the final product cement does not exceed another limit value. Even though Italy defined limit values for total as well as leaching contents for IBA utilisation in general, the introduction of IBA in the cement kiln has the consequence that the leaching behaviour does not have to be assessed anymore. A similar approach can be made when IBA is used as grinding additive or aggregate after the cement kiln. If cement that contains IBA is used in constructions, potential pollutants are included in the cement matrix and leaching is therefore significantly decreased. All applications that use IBA as secondary raw material are confronted by one issue – the demolition of such structures. While pollutants may be bound in the material or leaching is significantly decreased due to technical measures, the pollutants are still present in the construction and demolition (C&D) waste. In countries (e.g. Austria) where legislation is in place that specifically addresses the recycling of C&D waste, more strict parameters (limit values) for recycling of such a waste may apply and therefore high pollutant contents could prevent the recycling of materials of different origin than C&D waste.

2.3. Leaching tests

In order to assess the leaching behaviour, nine different standardised test methods are in place (Table 3). The two main types of test setups are the batch test (or shaking test) and the up-flow percolation test (or column test).

<table>
<thead>
<tr>
<th>Leaching test</th>
<th>Test setup</th>
<th>liquid to solid ratio (l/kg)</th>
<th>particle size (mm)</th>
<th>Test duration (h)</th>
<th>Applying Countries</th>
</tr>
</thead>
<tbody>
<tr>
<td>EN 12457-1a</td>
<td>batch test</td>
<td>2</td>
<td>&lt;4</td>
<td>24</td>
<td>Denmark, Poland</td>
</tr>
<tr>
<td>EN 12457-2a</td>
<td>batch test</td>
<td>10</td>
<td>&lt;4</td>
<td>24</td>
<td>France, Italy, Lithuania, Portugal</td>
</tr>
<tr>
<td>EN 12457-3a</td>
<td>batch test</td>
<td>2 &amp; 8</td>
<td>&lt;4</td>
<td>24</td>
<td>Finland</td>
</tr>
<tr>
<td>EN 12457-4a</td>
<td>batch test</td>
<td>10</td>
<td>&lt;10</td>
<td>24</td>
<td>Austria, Belgium (Wallonia – regular quality assurance test), Germany, Spain (Catalonia)</td>
</tr>
<tr>
<td>CEN/TS 14405</td>
<td>percolation test</td>
<td>0.1-10</td>
<td>not specified</td>
<td>not specified</td>
<td>Finland, Sweden</td>
</tr>
<tr>
<td>CMA2/II/A.9.1.</td>
<td>percolation test</td>
<td>0.1-10</td>
<td>&lt;4</td>
<td>not specified</td>
<td>Belgium (Flanders)</td>
</tr>
<tr>
<td>NEN 7343:1995</td>
<td>percolation test</td>
<td>0.1-10</td>
<td>&lt;4</td>
<td>not specified</td>
<td>Belgium (Wallonia – certification test)</td>
</tr>
<tr>
<td>NEN 7383:2004</td>
<td>percolation test</td>
<td>1-10</td>
<td>&lt;4</td>
<td>not specified</td>
<td>Netherlands</td>
</tr>
<tr>
<td>NEN 7375:2004</td>
<td>monolith in water containment</td>
<td>depending on surface area of monolith</td>
<td>not specified</td>
<td>64 days</td>
<td>Netherlands</td>
</tr>
</tbody>
</table>

* Note: Most countries translated the standard into national versions, e.g. Austria: ÖNORM EN 12457-4, Finland: SFS-EN 12457-3.
A third type of test in place in the Netherlands is used to observe the leaching behaviour due to diffusion from a monolithic material. The shaking test is characterised by a fixed liquid to solid (L/S) ratio, fixed test duration and a maximum particle size. Depending on the standard used (EN 12457-1, 2, 3 or 4) the L/S is 2, 8 or 10 l/kg [15-18]. The duration in all of these tests is 24 h and the maximum particle size can vary between 4 and 10 mm. The column test (CEN/TS 14405, CMA2/II/A.9.1., NEN 7343:1995 or NEN 7383:2004) is characterised by an increasing L/S starting at 0.1 l/kg or 1 l/kg and ending at 10 l/kg [10, 12, 45, 47]. The particle size is either not specified or set to maximum 4 mm. Leachate samples are taken in defined L/S intervals. In the diffusion test (NEN 7375:2004) a monolith containing the tested material (e.g. IBA) is placed into a tank filled with water over a period of 64 days and the concentration of elements mobilized (due to diffusion) is measured [46]. The L/S depends on the surface area of the monolith. Samples are taken in defined time intervals, at which the water is completely changed.

3. Conclusion

The paper at hand provided an overview on the legal framework for IBA utilisation in the European Union, Norway and Switzerland. The hypothesis that these requirements vary significantly within Europe is confirmed, and a harmonisation of national regulations seems to be in a distant prospect. Even though it cannot be concluded that legal security automatically leads to higher utilisation rates, a uniform regulatory framework for IBA utilisation may be beneficial. If the establishment of limit values for both total and leaching content follows a uniform protocol by using for example a risk based assessment, local conditions like soil types and climatic conditions can be considered. A harmonised framework could include: defined fields of application for IBA as secondary raw material, the same set of parameters that have to be tested with respect to the field of application and consistent test methods – especially for assessing the leaching behaviour. This ensures that the quality of the material meets the same high level of environmental protection in all member states. Furthermore, potential scepticism towards the utilisation of IBA may be decreased and utilisation rates may increase if this matter is uniformly regulated at EU level.

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List of abbreviations

Chemical elements and compounds
Al Aluminium
As Arsenic
Ba Barium
Be Beryllium
Cd Cadmium
Co Cobalt
Cr (total) Total chromium
Cr (VI) Hexavalent chromium
Cu Copper
Hg Mercury
K Potassium
Mn Manganese
Mo Molybdenum
Na Sodium
Ni Nickel
Pb Lead
Sb Antimony
Se Selenium
Sn Tin
Ti Titanium
Tl Tellurium
V Vanadium
Zn Zinc
BTX benzene, toluene, xylene
BTEX benzene, toluene, ethylbenzene, xylene
EOX extractable halogens inorganic bonding
PAH polycyclic aromatic hydrocarbon
PCB polychlorinated biphenyl
PCDD/PCDF polychlorinated dibenzodioxins/-furans
**Acronyms**

COD  chemical oxygen demand  
C&D  construction and demolition  
DM  dry matter  
DOC  dissolved organic carbon  
EU  European Union  
HP  hazardous properties  
IBA  incinerator bottom ash  
LNEC  Laboratório Nacional de Engenharia Civil  
LOI  loss on ignition  
LoW  List of Waste  
LV  limit value  
MSWI  municipal solid waste incineration  
POPs  persistent organic pollutants  
TOC  total organic carbon  
TEQ  toxic equivalent  
VOC  volatile organic compounds  
wt.%  weight-percent

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4. Sources


[16] EN, EN 12457-2:2002-09 – Characterisation of waste – Leaching; Compliance test for leaching of granular waste materials and sludges – Part 2: One stage batch test at a liquid to solid ratio of 10 l/kg for material with particle size below 4 mm (without or with size reduction), 2002.

[17] EN, EN 12457-3:2003-01 – Characterization of waste – Leaching; Compliance test for leaching of granular waste materials and sludges – Part 3: Two stage batch test at a liquid to solid ratio of 2 l/kg and 8 l/kg for materials with high solid content with particle size below 4 mm (without or with size reduction); German version EN 12457-3:2002, 2003.

[18] EN, EN 12457-4:2002 – Characterisation of waste – Leaching – Compliance test for leaching of granular waste materials and sludges – Part 4: One stage batch test at a liquid to solid ratio of 10 l/kg for materials with particle size below 10 mm (without or with size reduction) 2002.


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Incineration Residues


[50] Pająk, T.: AGH University of Science and Technology in Kraków, Department of Power Systems and Environmental Protection Facilities, Personal communication (email) on 8th January 2019, 2019.


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