April 2016

DONG A/S

Vindeby offshore wind farm
Mapping of environmentally harmful substances in regards to decommissioning
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INTRODUCTION
NIRAS has been assigned to map environmentally harmful substances in the construction materials in the structures at Vindeby offshore wind farm in regard to the planned decommissioning.

THE OFFSHORE WIND FARM
The offshore wind farm is located at Smålandsfarvandet near shore from the coastal village Vindeby on the southern Danish island Lolland. The Wind farm layout can be seen in Appendix 2.

Scope of decommissioning
The decommissioning includes removal of 11 wind turbines, their gravity based foundations and the recovery of the inter array and export cables. The mapping includes the offshore part of the wind farm which are planned for decommissioning.

Description of the offshore wind farm

General:
Capacity, total: 4.95 MW
Distance to shore: 1.5 - 3 km
Water depths: 2.1 – 5.1 m
Commissioned: 1991
Distance between turbines: 300 m (two rows of respectively 5 and 6 turbines)

Turbines:
Turbine Model: Bonus 450 kW/37
Number of turbines: 11
Rotor weight: 4.9 tons
Hub height: 37.5 m
Blade manufacturer: LM Wind Power
Blade model: LM17
Nacelle, weight: 27.6 tons
Tower weight: 20 tons

Inter array and export cables:
Inter array cable: 3 km
Export cable: 1.3 km
Cable type: 12 kV, 3x150 mm², Cobber
Buried: 1 m
Protection: Flagstones, rock stones and sandbags

Foundation:
Concrete strength: 77.9 MPa (5 concrete core DS/EN 12390-3)

See separate test report P1380-01 of April 24, 2016
Concrete bottom slap: Diameter 14 m, height 0.6m
Concrete top slap: Diameter 5.0 m
Weight incl. ballast: 710 – 1105 tons
Weight excl. ballast: 366 – 559 tons

3 MAPPING BASIS

It is assumed that materials and waste are loaded in and processed in Denmark.

Based on the year of commission it is estimated that the structures potentially could contain environmentally harmful substances in the structures such as chlorinated paraffin’s, heavy metals and asbestos.

The legislation within this field includes among other requirements as explained below (unofficial translation):

Working environment – Statutory Order regarding the builders obligations

– Work with major hazards or risks must be mapped (includes work with environmentally harmful substances and risk drowning)
– Plan for occupational health & safety must be prepared for work classified as dangerous

Waste management – Statutory order regarding waste management and Statutory order regarding residual products

– Waste and materials must be sorted at source
– Recyclable materials must be reused and must be free of harmful substances (which therefore must be separated/cleaned)
– Waste must be reported (present report attached)

The survey and mapping of the structures containing environmentally harmful substances are based on:

– Forslag til undersøgelse af miljøfarlige stoffer (Proposal for survey of environmentally harmful substances), NIRAS note of March 9, 2016 prepared for DONG A/S
– Elsams report "Erfaringer fra Vindeby Havmøllepark" (Experience from Vindeby offshore wind farm) from 1991
– Service manual for BONUS 450 kW off shore turbines

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2 Statutory Order no. 117 of 05/02/2013 (Bekendtgørelse om bygherrens pligter)
3 Statutory Order no. 1309 of 18/12/2012 (Bekendtgørelse om affald)
4 Statutory Order no. 1414 of 30/11/2015 (Bekendtgørelse om anvendelse af restprodukter og jord til bygge- og anlægsarbejder og om anvendelse af sorteret, uforurenet bygge- og anlægsaffald)
– Drawings and other background material available from NIRAS project archive from the installation and following repair projects. The drawings material are not complete and concerns exclusively the foundations.
– Inspection of and sampling from turbines 4W and 5E

4 INSPECTION AND SAMPLING

Inspection and sampling where performed on April 18, 2016 by Johan Finsteen Gjødvad og Morten Dallov Ibsen, NIRAS A/S. Strong wind and required safety precautions made the inspection and sampling challenging and rather difficult. During the operation 4 samples were taken on the two turbines and structures. The location of the samples on the structures can be seen in Appendix 2.

5 RESULTS OF ANALYSIS AND WASTE CATEGORIZATION

The samples have been analysed by the external laboratory Dansk MiljøAnalyse ApS (DMA). The samples have been analysed for PCB and/or heavy metals. The results can be found in the DMA analysis report in Appendix 5.

The analysis shows occurrences of heavy metals of different concentrations in the paint on the tower structure and by the flange. No environmentally harmful substances has been detected in the concrete of the foundation.

The analysis results are furthermore summarised in Appendix 3. Each analysis result of the respective sample are stated in ppm (mg/kg). In addition the results are coloured dependent on the waste category which they fall under:

Red: Hazardous waste.
Yellow: Contaminated, not hazardous waste.
Green: Not contaminated.

The waste categorization must comply with the threshold values for waste management in the municipality of the receiving port. However at the time of writing the receiving port is not known, hence the waste categorisation stated in Table 1 this is the threshold values from the Municipality of Copenhagen, which is normative for waste threshold values:

<table>
<thead>
<tr>
<th></th>
<th>Not contaminated (mg/kg)</th>
<th>Contaminated, not hazardous (mg/kg)</th>
<th>Hazardous waste (mg/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>PCB&lt;sub&gt;total&lt;/sub&gt;</td>
<td>&lt; 0.1</td>
<td>0.1 - 50</td>
<td>&gt; 50</td>
</tr>
<tr>
<td>PAH&lt;sub&gt;total&lt;/sub&gt;</td>
<td>&lt; 4</td>
<td>4 - 1.000</td>
<td>&gt; 1.000</td>
</tr>
<tr>
<td>Benz(a)pyren</td>
<td>&lt; 0.3</td>
<td>0.3 - 1.000</td>
<td>&gt; 100</td>
</tr>
<tr>
<td>Dibenz(a,h)anthracene</td>
<td>&lt; 0.3</td>
<td>0.3 - 25</td>
<td>&gt; 25</td>
</tr>
<tr>
<td>Heavy metal - Lead (Pb)</td>
<td>&lt; 40</td>
<td>40 - 2.500</td>
<td>&gt; 2.500</td>
</tr>
<tr>
<td>Heavy metal – Cadmium (Cd)</td>
<td>&lt; 0.5</td>
<td>0.5 - 1.000</td>
<td>&gt; 1.000</td>
</tr>
</tbody>
</table>
Table 1 Threshold values for waste categorisation

<table>
<thead>
<tr>
<th>Waste component</th>
<th>Threshold values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heavy metal – Chrom (Cr)_{total}</td>
<td>&lt; 500</td>
</tr>
<tr>
<td>Heavy metal – Cobber (Cu)</td>
<td>&lt; 500</td>
</tr>
<tr>
<td>Heavy metal – Nickel (Ni)</td>
<td>&lt;30</td>
</tr>
<tr>
<td>Heavy metal Zinc (Zn)</td>
<td>&lt; 500</td>
</tr>
<tr>
<td>Mercury, organic (Hg)</td>
<td>&lt; 1</td>
</tr>
<tr>
<td>Asbestos</td>
<td>No asbestos fibers</td>
</tr>
<tr>
<td>Chlorinated paraffins short chained</td>
<td>-</td>
</tr>
</tbody>
</table>

6 MAPPING

Based on the results of the survey NIRAS has mapped the structural components which contain contaminated or hazardous waste and materials in Table 1 Table 2.

The table gives a short description of the structural component and states the respective waste categorization. In addition a proposed waste handling is given.

Table 2 NIRAS mapping of structural components

<table>
<thead>
<tr>
<th>Description of structural component</th>
<th>Mapping</th>
<th>Håndtering</th>
</tr>
</thead>
<tbody>
<tr>
<td>PCB</td>
<td>Heavy metals</td>
<td>PVC</td>
</tr>
<tr>
<td>Tower + nacelle</td>
<td>Paint, internal</td>
<td>Disposal for recycling at a licensed recycling site.</td>
</tr>
<tr>
<td>Concrete grout at flange</td>
<td>Paint</td>
<td>Removal and cleaning of paint and disposal at licensed e.g. Ekokem. Underlying concrete for recycling.</td>
</tr>
<tr>
<td>Top slap</td>
<td>Paint</td>
<td>Removal and cleaning of paint and disposal at licensed e.g. Ekokem. Underlying concrete for recycling.</td>
</tr>
<tr>
<td>Railing, machine parts etc.</td>
<td>Paint^2</td>
<td>Disposal for recycling at a licensed recycling site.</td>
</tr>
</tbody>
</table>

^1 If offshore removal and cleaning is unfeasible without spreading of the hazardous paint removal of the concrete with the paint for disposal as contaminated waste could be considered as the safer method.

^2 It is assumed that the paint contain heavy metals in concentration equal to hazardous waste.
7 FURTHER SURVEYS
During the survey it was not possible to access all structural components which potentially contains environmentally harmful substances.

When the turbines and cables are loaded ashore it is therefore recommended to investigate the following components:

- **Inter array and export cables.** The cables contain asphalt. Asphalt can potentially contain PAH (tars), which might limit the possibilities for recycling of the materials.
- **Soft joints** potentially contains chlorinated paraffin. Soft joints are registered in the service manual sealant (labyrinthtætning) shown at a drawing on page 68 and a joint strip by the cable entry to the foundation and between the top slab and the floating caisson on the drawing ‘Sænkekasser, beton- og armeringsplan’. 18/12-1989.
- **There might be brake blocks in the yawing system and possibly other similar systems which contains asbestos.** Asbestos-containing brake blocks have been excepted the prohibition of products containing asbestos until 2005. Furthermore practice has been to use old products containing asbestos from storages or from outside Denmark, where prohibition was not introduced until later. Hence the end year for the use of products containing asbestos cannot be precisely established.
- **Blades.** The foam might contains isocyanates, which can produce hazardous substances when cut.

8 WASTE QUANTITIES AND HANDLING PROPOSAL
Wherever possible the mapping of waste quantities and structural components is based on the accessible data. Besides structural components equipment and removable inventory is briefly included in the estimation.

Where no information have been accessible quantities and fractions are assessed on basis of information from other turbine models. Hence the stated waste quantities are guiding and should be used with caution.

<table>
<thead>
<tr>
<th>Substances</th>
<th>Structural component</th>
<th>Tons</th>
<th>Handling proposal</th>
</tr>
</thead>
<tbody>
<tr>
<td>Steel</td>
<td>Tower, machinery, concrete reinforcement</td>
<td>1020</td>
<td>If possible repaired for reuse otherwise recycled. Disposal only at licensed recycling sites due to heavy metals in paint.</td>
</tr>
<tr>
<td>Aluminium</td>
<td>Ladders and alloys</td>
<td>1</td>
<td>Recycling (remelting)</td>
</tr>
<tr>
<td>Cobber + epoxy</td>
<td>Windings on transformer</td>
<td>7</td>
<td>Recycling (remelting)</td>
</tr>
<tr>
<td>Fibre glass + polyester (resin, glue, gelcoat)</td>
<td>Blades</td>
<td>20+23</td>
<td>If possible repaired for reuse as blades or other structures (e.g.</td>
</tr>
</tbody>
</table>
Table 3 Waste quantities and proposal for handling of 11 turbines including foundations and cables.

General comments:

Foamed materials must be handled according to instructions of receiving municipality (until known the rules of the Municipality of Copenhagen). The materials must be handled in as large pieces as practicable possible.

Electronic waste must be handled according to Statutory order no. 130 (elektronikaffaldsbekendtgørelsen) 06/02/2014 concerning electronic waste.

Equipment such as transmission system and removable inventory can be handed over to scrap dealers according to their standard cost.

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<table>
<thead>
<tr>
<th>Material</th>
<th>Handling and Disposal</th>
<th>Quantity</th>
<th>Proposed Handling</th>
</tr>
</thead>
<tbody>
<tr>
<td>PVC foam 1</td>
<td>Shoring in blades</td>
<td>0.5</td>
<td>Separation and disposal for recycling</td>
</tr>
<tr>
<td>Lead 1</td>
<td>Blade balancing</td>
<td>0.2</td>
<td>Recycling (remelting)</td>
</tr>
<tr>
<td>Cobber</td>
<td>Cables 3x150 mm²</td>
<td>17</td>
<td>Recycling (remelting)</td>
</tr>
<tr>
<td>Asphalt</td>
<td>Cables</td>
<td>1</td>
<td>Recycling (remelting)</td>
</tr>
<tr>
<td>Steel wires</td>
<td>Cables</td>
<td>3</td>
<td>Recycling</td>
</tr>
<tr>
<td>PEX insulation</td>
<td>Cables</td>
<td>5</td>
<td>Recycling or incineration</td>
</tr>
<tr>
<td>Concrete</td>
<td>Foundation, grout and flagstone (cable protection)</td>
<td>4880</td>
<td>Recycling (e.g. as crushed concrete used in road construction)</td>
</tr>
<tr>
<td>Concrete</td>
<td>Grout with hazardous paint</td>
<td>4</td>
<td>Hazardous waste e.g. to Ekokem</td>
</tr>
<tr>
<td>Magnets</td>
<td>Nacelle</td>
<td>&gt;1</td>
<td>Possible reuse or recycling otherwise for deposit</td>
</tr>
<tr>
<td>Electronics</td>
<td>Cables and boards</td>
<td>3</td>
<td>Recycling (remelting)</td>
</tr>
<tr>
<td>Rubber</td>
<td>Nacelle (hoses)</td>
<td>3</td>
<td>Recycling or incineration</td>
</tr>
<tr>
<td>Sand, gravel</td>
<td>Ballast, sandbags on cables</td>
<td>9980</td>
<td>Reuse on land or to dredging site (ballast is assumed to be marine materials)</td>
</tr>
<tr>
<td>Mineral oil and hydraulic oil</td>
<td>Transformer og hydraulic system</td>
<td>2</td>
<td>Recycling (refining) or incineration</td>
</tr>
<tr>
<td>Marine growth</td>
<td>(on foundation)</td>
<td>14</td>
<td>Possible use on crop field as fertilizer or in biogas facility. If contaminated with herbicides (anti-growth agent) it must be disposed.</td>
</tr>
</tbody>
</table>

1 Information from LM Wind power
Appendix 1 Layout offshore wind farm
Appendix 2 Photos marked with sampling positions

Sample 1, Turbine 4W
Paint on tower, inside facing south

Sampling 2, Turbine 4W
Paint on tower, outside facing north
Sampling 3. Turbine 5E

Paint on grout at flange facing north.

Sampling 4. Turbine 5E

Concrete foundation. Sampled from drilling core for strength test.
### Appendix 3 Overview analysis results

<table>
<thead>
<tr>
<th>No.</th>
<th>Tower</th>
<th>Description</th>
<th>Date</th>
<th>PCB</th>
<th>Cd</th>
<th>Cr</th>
<th>Cu</th>
<th>Ni</th>
<th>Pb</th>
<th>Zn</th>
<th>Hg</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>4W</td>
<td>Paint on tower, inside</td>
<td>18-Apr</td>
<td>I.D.</td>
<td>84</td>
<td>30</td>
<td>37</td>
<td>19</td>
<td>256</td>
<td>I.D.</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>4W</td>
<td>Paint on tower, outside</td>
<td>18-Apr</td>
<td>I.D.</td>
<td>0.54</td>
<td>11</td>
<td>17</td>
<td>11</td>
<td>168</td>
<td>40800</td>
<td>I.D.</td>
</tr>
<tr>
<td>3</td>
<td>5E</td>
<td>Paint on grout at flange</td>
<td>18-Apr</td>
<td>I.D.</td>
<td>5.6</td>
<td>137</td>
<td>361</td>
<td>140</td>
<td>48</td>
<td>11500</td>
<td>I.D.</td>
</tr>
<tr>
<td>4</td>
<td>5E</td>
<td>Concrete foundation</td>
<td>18-Apr</td>
<td>I.D.</td>
<td>0.06</td>
<td>11</td>
<td>15</td>
<td>9</td>
<td>9</td>
<td>54</td>
<td>I.D.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Not contaminated</td>
<td></td>
<td></td>
<td>&lt;0.1</td>
<td>&lt;0.5</td>
<td>&lt;20</td>
<td>&lt;30</td>
<td>&lt;40</td>
<td>&lt;500</td>
<td>&lt;1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Contaminated, not hazardous</td>
<td></td>
<td></td>
<td>0.1</td>
<td>0.5</td>
<td>500</td>
<td>500</td>
<td>30</td>
<td>40</td>
<td>500</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Hazardous</td>
<td></td>
<td></td>
<td>50</td>
<td>1000</td>
<td>1000</td>
<td>2500</td>
<td>1000</td>
<td>2500</td>
<td>2500</td>
</tr>
</tbody>
</table>
Appendix 4 Other photos
Vindeby offshore wind farm – Mapping of environmentally harmful substances in regard to decommissioning
Appendix 5 Analysis report from Dansk Miljøanalyse, Journal no. 23252
### ANALYSERAPPORT

**Rekvirent**
NIRAS A/S  
Sortemosevej 19  
3450 Allerød  
Att.: Morten D. Ibsen

**Sagsnavn/ref.**  
Sag: 224148

**Vor Journal nr.**  
23252

<table>
<thead>
<tr>
<th>Antal prøver og typer</th>
<th>Type</th>
<th>Antal</th>
<th>Type</th>
<th>Antal</th>
</tr>
</thead>
<tbody>
<tr>
<td>PCB / 7 Metaller – fast stof (ikke jord)</td>
<td>(DMA102/DMA101)</td>
<td>3 (Haste)</td>
<td>7 Metaller (6 met. + Hg)</td>
<td>(DMA101)</td>
</tr>
</tbody>
</table>

**Dato for modtagelse**  
2016-04-19

**Rapport version**  
Version 1.0

### Resultater – PCB i fast stof

<table>
<thead>
<tr>
<th>Lab nr.</th>
<th>Prøve navn</th>
<th>PCB koncentration i mg/kg</th>
<th>Kommentar til prøvemateriale</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1, 4 vest (4W), maling på tårn, udvendig</td>
<td>I.D.</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>2, 4 vest (4W), maling på tårn, indvendig</td>
<td>I.D.</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>3, 5 øst (5E), maling på understøbning</td>
<td>I.D.</td>
<td></td>
</tr>
</tbody>
</table>

**Metode**  
DMA102 (Udført akkrediteret, Akk. nr. 549)

**Bemærkning**  
Normalt anvendes følgende grænseværdier:
- PCB indhold < 0,1 mg/kg betragtes som ikke PCB forurenet
- PCB indhold 0,1-50 mg/kg betragtes som forurenet, men ikke farligt affald
- PCB indhold > 50 mg/kg betragtes som farligt affald

I.D.: ikke detekteret over detektionsgrænsen for den enkelte kongener

### Detaljeret PCB resultatskema

<table>
<thead>
<tr>
<th>PCB Kongener (mg/kg)</th>
<th>Lab nr.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>28</td>
</tr>
<tr>
<td>1</td>
<td>I.D.</td>
</tr>
</tbody>
</table>

**Bemærkning**  
Der benyttes en omregningsfaktor på 5 ifølge MST-7543-00007, 5. juli 2011.

Detektionsgrænsen for den enkelte kongener: 0,01 mg/kg
Den ekspanderede usikkerhed på den enkelte kongener er 25 %.

Ved koncentrationer tæt på detektionsgrænsen kan den ekspanderede usikkerhed dog være op til 35 %

Den ekspanderede usikkerhed på den enkelte kongener er 35 % for beton

Ved koncentrationer tæt på detektionsgrænsen, kan den ekspanderede usikkerhed på den enkelte kongener være op til 55 % for beton
### Resultater - 7 metaller (Cd, Cr, Cu, Ni, Pb, Zn, Hg) i fast stof

<table>
<thead>
<tr>
<th>Lab nr.</th>
<th>Prøve navn</th>
<th>Koncentration mg/kg</th>
<th>Kommentar til prøvemateriale</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Cd</td>
<td>Cr</td>
</tr>
<tr>
<td>1</td>
<td>1, 4 vest (4W), maling på tårn, udvendig</td>
<td>I.D.</td>
<td>84</td>
</tr>
<tr>
<td>2</td>
<td>2, 4 vest (4W), maling på tørn, indvendig</td>
<td>0,34</td>
<td>57</td>
</tr>
<tr>
<td>3</td>
<td>3, 5 øst (5E), maling på understøbning</td>
<td>5,60</td>
<td>137</td>
</tr>
<tr>
<td>4</td>
<td>4, 5 øst (5E), beton på fundament</td>
<td>0,06</td>
<td>11</td>
</tr>
</tbody>
</table>

**Metode** DMA101 (Udført akkrediteret, Akk. nr. 549)

**Bemærkning**
- Normalt anvendes følgende grænseværdier for deponi/forbrænding. Indhold over disse niveauer betragtes som farligt affald:
  - Cadmium (Cd): 0,5 - 1000 mg/kg
  - Krom (Cr): 500 - 10000 mg/kg
  - Kobber (Cu): 500 - 2500 mg/kg
  - Nikkel (Ni): 30 - 1000 mg/kg
  - Bly (Pb): 40 - 2500 mg/kg
  - Zink (Zn): 500 - 2500 mg/kg
  - Kviksølv (Hg): 1-500 mg/kg

**Detektionsgrænsen for det enkelte metal:**
- Cadmium (Cd): 0,05 mg/kg
- Krom (Cr): 5 mg/kg
- Kobber (Cu): 5 mg/kg
- Nikkel (Ni): 3 mg/kg
- Bly (Pb): 4 mg/kg
- Zink (Zn): 50 mg/kg
- Kviksølv (Hg): 0,1 mg/kg

Den ekspanderede usikkerhed på analysen er 20 %. Ved koncentrationer tæt på detektionsgrænsen kan den ekspanderede usikkerhed dog være op til 50 %

**Bemærkning til grænseværdier:** Hvis ikke andet er nævnt er de oplyste grænseværdier de værdier der anvendes i Københavns kommune. Andre kommuner kan anvende andre grænseværdier.

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2016-04-20
Venlig hilsen

Tobias Hansen

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**Ansvar:** Ved indleverede prøver til analyse er DMA kun ansvarlig for selve laboratorieanalysen af den enkelte prøve. Således har DMA ikke ansvar for prøveudtagningen, dvs. om prøven er repræsentativt for det specifikke materiale den er udtaget af eller om prøveantallet er tilstrækkeligt til at kunne drage konklusioner om materialetyperne i det område hvor prøven/prøverne er udtaget. DMA er heller ikke ansvarlig for de praktiske handlinger på byggepladsen som modtageren af analyseresultatet udfører som konsekvens af resultatet.