BE AWARE

Bonn Agreement
Accord de Bonn

Technical Sub Report 8 Maritime Oil Spill Risk Analysis

Bonn Agreement
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Co-financed by the EU –
Civil Protection Financial Instrument

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The Greater North Sea and its wider approaches is one of the busiest and most highly used maritime areas in the world. With the ever-increasing competition for space comes an increased risk of accidents that could result in marine pollution.

Currently the area has no overall risk assessment for marine pollution; risk is mapped with a variety of national risk assessments which are undertaken with differing methodologies; thus reducing comparability.

The BE-AWARE project is therefore undertaking the first area-wide risk assessment of marine pollution using a common methodology that allows the risk to be mapped and compared under different scenarios.

The project outcomes will improve disaster prevention by allowing North Sea States to better focus their resources on areas of high risk.

The project is a two year initiative (2012-2014), co-financed by the European Union, with participation and support from the Bonn Agreement Secretariat, Belgium, Denmark and the Netherlands, with co-financing from Norway.

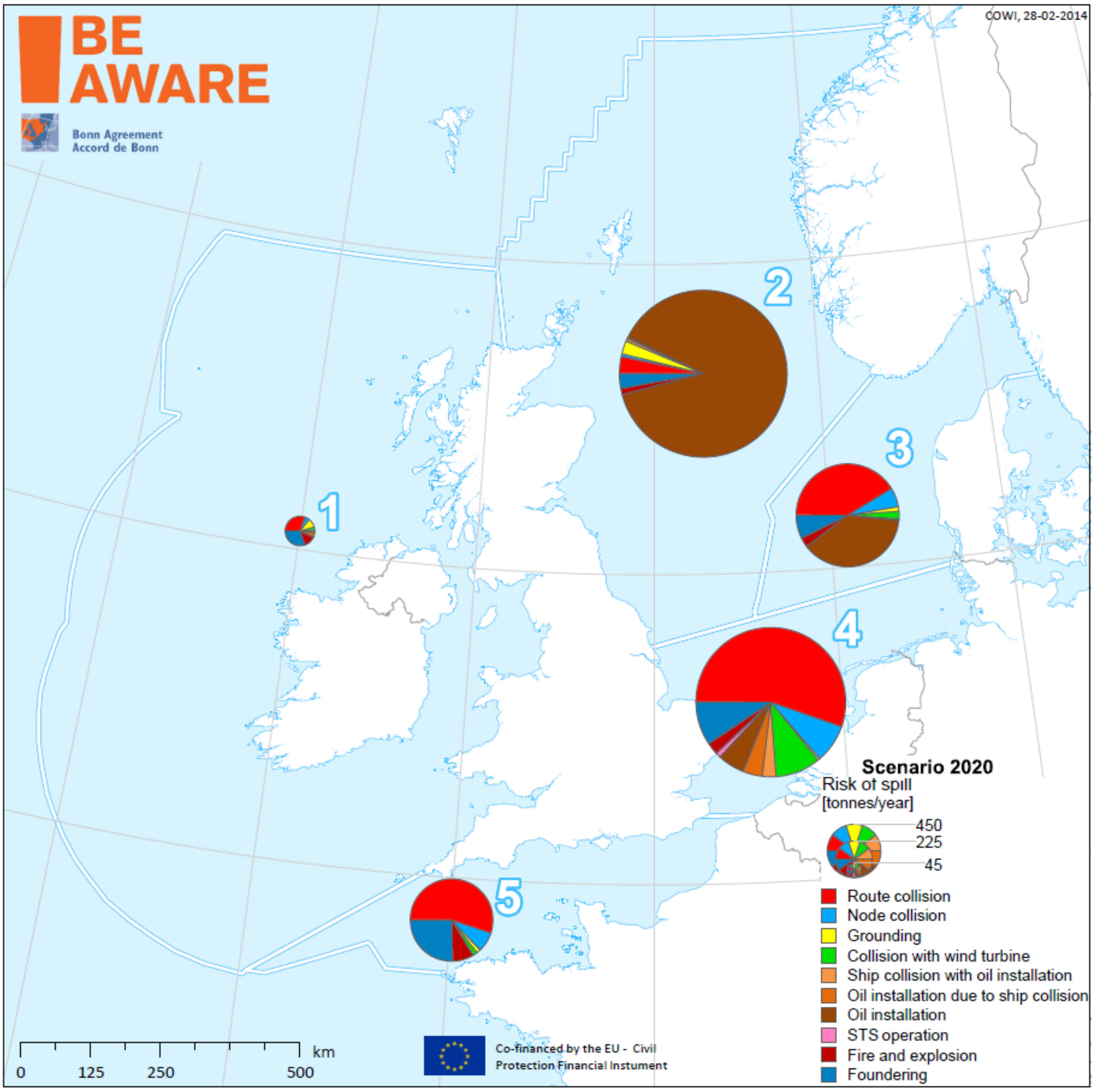
Contents

Executive Summary

This report outlines the frequencies of various types of accidents that have been estimated and the risks that have been calculated throughout the Bonn Agreement area. The results are based on a number of tasks carried out in the project.

The overall aim of BE-AWARE has been to develop an area-wide description of accidents and spill frequencies. In order to establish various local differences the area was divided into five sub-areas. Within each of these sub-areas the frequency of different accident types has been calculated for both the existing situation (based on 2011 data) and the future 2020 scenario. The frequency for individual spill sizes has also been calculated for each of the sub-areas.

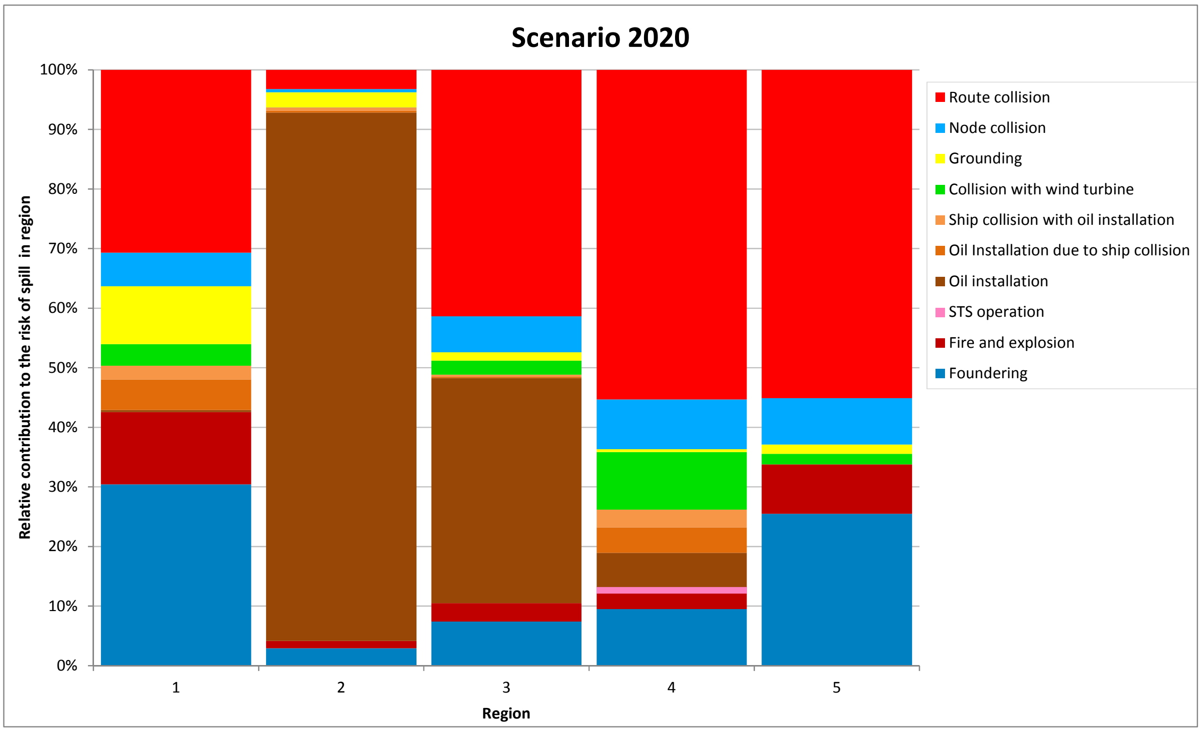
In the results significant regional differences are seen. Accidents caused by collisions are predicted to be most pronounced in areas with high intensity traffic in combination with narrow stretches or areas with crossing traffic or complex traffic patterns.



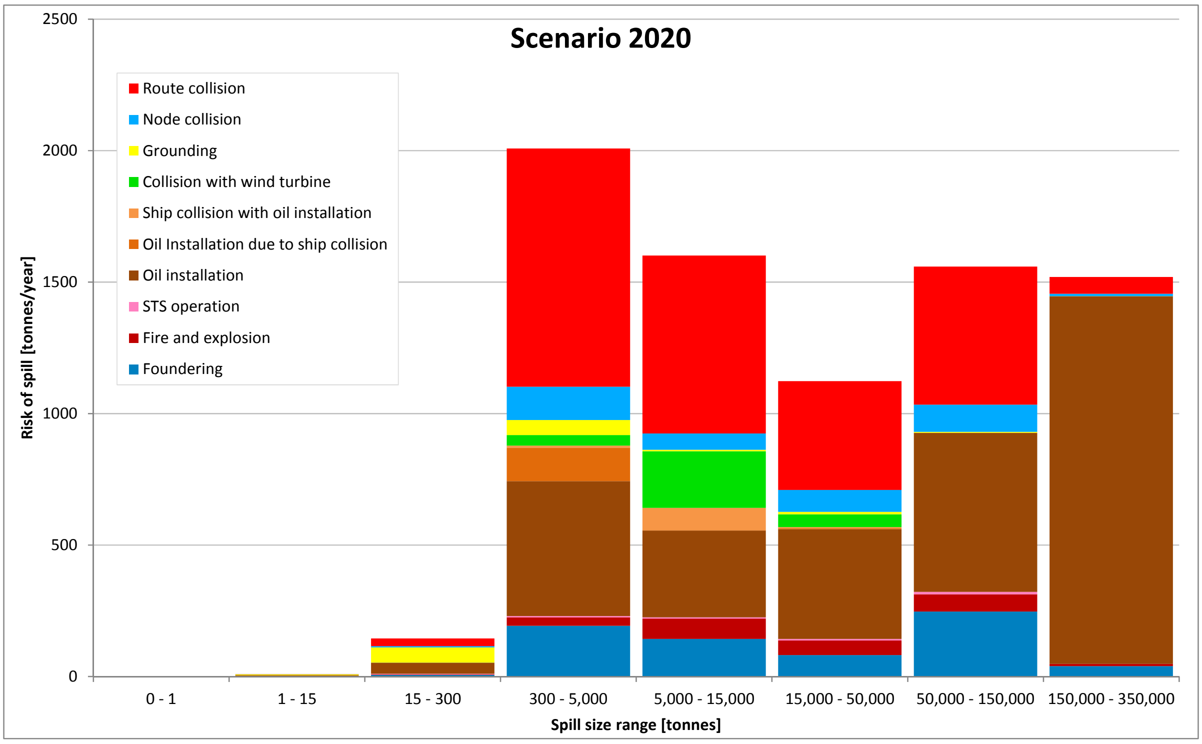
The significant regional differences are clearly seen in the figure. In the northern part of the North Sea there is limited traffic over a very large area, hence limiting the probability of ship-ship collisions. There is however a substantial number of oil platforms present and accidents at the platforms make the largest contribution to the risk in this area. In high traffic areas such as along the coast of the Netherlands, Belgium and Germany the ship-ship collisions become much more pronounced and constitute the largest contribution to the risk.

Grounding accidents are based on the grounding statistics in the period 2002-2011. There are significant local differences in the statistical background data and this is also apparent when looking at the results of the grounding accidents.

The figure below clearly shows the differences in the relative contribution to the risk from the accident types in the sub regions:



In the Bonn Agreement area the extremely large spills are dominated by rare events such as blow-outs from offshore installations. Even though the return period of such an event is high the size of an eventual spill does make these results very visible when looking at risks in terms of average annual spill.



Large spills can also come from offshore installations, but overall the largest contributor is the outflow of cargo as a result of collisions with large tankers.

Minor and medium size spills are typically from accidents where the vessels have only sustained minor damage or from a leakage. Groundings mainly contribute to the overall risk with minor and medium size spills.

The frequency of collision accidents are mainly spread along the areas of the North Sea with the highest amount of traffic. Groundings are more dependent on local weather phenomena and bathymetry and the grounding model is based on representative points prone to these accidents. Foundering and accidents with fire and explosions are assumed to be distributed evenly in the area based on the distance sailed, thus it is only dependent on the development in the traffic.

There are significant differences both overall and on a regional level between the two scenarios 2011 and 2020. This is due to changes in ship traffic, the increase in ship size and the development of risk reducing measures. The amount of traffic has increased and this general increase in the number of vessels adds to the risk. The development of offshore wind farms also increases the risk of a collision with the individual turbines significantly in the 2020 scenario compared to the 2011 scenario.

1. Introduction

1.1 Scope

The risk assessment outlined in this report was based on the methodology outlined in the BE-AWARE Method Note and has taken as its input the results for the previous technical sub-reports. The aim is to implement the chosen methodology, i.e. to process the collected data and to prepare the computational tools for the subsequent risk assessment.

The methodology is based on a similar model that has earlier been applied to the Danish and Baltic waters. Thus, the model is not created from scratch, but only modified, adapted and extended.

The present model report deals with the spill model for oil. The relevant spill scenarios have been identified and discussed in the method note. They comprise the following events occurring in the open sea with vessels of a gross tonnage of 300 and above:

- Ship accidents (ship-ship collisions, groundings, fire, foundering etc.);
- STS operations and bunkering at sea;
- Collisions with fixed objects (platforms and wind turbines).

Furthermore operational and accidental spills are treated for the following non-vessel related accidents:

- Spills from offshore oil installations.

The division into the various accident categories is done in accordance with the method note. The cause of an accident could be due to a number of factors including but not limited to defective equipment, bad weather, human error or intoxication. Regional differences could in principle give variations in the cause of accidents over the project area and this is taken into account through the applied accident statistics that are used as a basis for the risk calculation.

In the present report the basis for the calculation of the navigational oil spills are given and the results of all accidents.

The present model report deals exclusively with the question of how much cargo as well as bunker oil is expected to be spilt. The type of oil likely to be on board a vessel at any given time is based on the output of Technical Sub-report 2: Oil Cargo Model.

2. Spill size classes

2.1 Spill size classes

The model indicates a separate spill frequency for each spill size class. The following spill size classes are used in the results:

Table 2-1 Spill size classes used in the BE-AWARE results (all values in tonnes)

Spill size class	Lower limit [t]	Upper limit [t]	Representative size [t]
0	0	0	0.0
1	0	1	0.3
2	1	15	4.0

3	15	300	67.0
4	300	5,000	1,200.0
5	5,000	15,000	8,700.0
6	15,000	50,000	27,000.0
7	50,000	150,000	87,000.0
8	150,000	350,000	230,000.0

3. Ship accidents

3.1 General modelling

3.1.1 Fujii's model

In the present context, a model is understood to be a calculation method used to estimate the occurrence of sea accidents based on basic data. The present section describes how accident frequencies are calculated by means of the established models. Observed data (such as traffic statistics) are used as input in the calculation.

A generally acknowledged method for estimating the frequency of accidents where ships run into some sort of obstacle – another ship, aground, any other obstacle – was developed by the Japanese physicist Yahei Fujii (Fujii, 1984) and can be expressed in the following way:

$$F = N \times P_g \times P_c \times P_s$$

where

- F … the accident frequency, i.e. the number of accidents per year;
- N … the number of ship passages per year;
- P_g … the geometrical probability, i.e. the probability that a ship is on a collision course with a nearby obstacle (within 20 ship lengths);
- P_c … the causation probability, i.e. the probability that a ship on a collision course does not undertake successful evasive action. This probability includes both human and technical failure;
- P_s … the probability that the damage exceeds a certain limit, e.g. that the impact is violent enough to cause leakage.

The modelling consists of calculating the above equation by calculating the respective factors for each area and accident type. The aim is to describe the factors such that they describe the actual situation as well as possible. It is in the nature of such a calculation that it will always be an uncertain approximation. However, experience shows that it can be useful, especially if the calculation is a good approximation that describes the occurrence of a phenomenon in a significant way for a given area.

Since Fujii’s model gives a clear image of the influence of some of the most significant effects in question, choosing this model is a reasonable basis for establishing a more detailed model, as described below.

In the present risk analysis, the model is supposed to reflect the effect of risk-reducing measures (RRMs) which can be added by introducing an additional factor:

P_e … Effect factor, which takes the effect of RRMs upon the causation factor into account (e.g. due to increased surveillance)

and by adjusting the parameters of the traffic model in accordance with the expected effects of the RRMs (e.g. the fraction of ships using a maritime pilot, usage of ECDIS).

Fujii's model is used to calculate the occurrence of sea accidents where ships run into an "obstacle" and is therefore linear dependent upon the traffic intensity N. In the case of collision between two ships, the collision frequency depends therefore upon the traffic intensity in both sailing directions. In order to be able to handle these accidents, Fujii's model is adjusted so that the linear dependency on N is replaced by a function of the two colliding traffic intensities N_1 and N_2:

$$h(N_i) = \begin{cases} h(N) & \text{... for collision with fixed objects} \\ h(N_1; N_2) & \text{... for collision between ships} \end{cases}$$

Other parameters such as vessel speed, angles and lengths etc. are equally part of the calculation of the collision frequency (see Section 3.3).

The risk analysis of oil and hazardous chemical spills requires calculation of the occurrence of the different incidents involving spillage depending on several conditions:

- Sea areas
- Substance groups for oil and hazardous substances, respectively
- Spill sizes
- Time-dependent scenarios (today, 2020)

Therefore, Fujii's model needs to be generalised and expressed in such a way that the spills are assumed to occur at a series of representative locations:

$$F(\text{location, substance group, spill size, scenario}) = h(N_i) \times P_g \times P_c \times P_s \times P_e$$

3.1.2 General risk analysis model

With regard to the analysis of the different pollution events it is sensible to re-formulate Fujii's model such that

F{spill size} =

F{sea accident} ×

P{hull damage with possibility of spillage | sea accident} ×

P{spill size | hull damage with possibility of spillage} ×

Effect factor{Risk reducing measures}

where

F{spill size} is the spill frequency (occurrences per year). This quantity corresponds to F in Fujii's model.

F{sea accident} is the frequency that a sea accident that can cause spillage occurs. This quantity includes the effect of the traffic intensity (N, N1 and N2 in Fujii's generalised model), geometrical conditions with respect to route, vessel, speed etc. (Pg in Fujii's model) as well as navigational conditions (Pc in Fujii's model).

P{hull damage with possibility of spillage|sea accident} is the probability of a sea accident entailing damage that breaks the containment of oil or hazardous substances and therefore can lead to an accident. Thus, it includes aspects of Fujii's factor PS. However this differentiation is necessary since the risk analysis shall be capable of handling the size of the spills.

P{spill size hull damage with possibility ofspillage} is the probability of a given spill size given hull damage and can therefore be seen as being part of Fujii's factor PS.

Effect factor {Risk reducing measures} is the reduction factor for the spill frequency that is estimated on the basis of the risk reducing measures.

F{spill size} is then calculated for the same parameters as mentioned above, i.e.

- Sea areas
- Substance groups for oil
- Spill sizes
- Time-dependent scenarios (2011, 2020)

which can be expressed as

F{spillage|location, substance group, spill size, scenario}

It is emphasized that the above description is generally so that variation will occur for the respective accident types depending on the complexity of the respective problem. It can be necessary to calculate

P{hull damage with possibility ofspillage|sea accident}

and

P{spill size|hull damage with possibility of spillage}

as random distributions instead of probabilities. Details are not described here. In this way it becomes possible to handle the fact that a given spill size can consist of contributions both from minor spills from ships with a lot of cargo and from large spills from ships with less cargo.

3.1.3 Calculation procedure

As a consequence, spill frequencies are calculated on the basis of a traffic model that reflects the distribution of the ships with respect to:

- vessel type
- vessel size
- hull configuration (single/double)
- load state (loaded/in ballast)
- draught
- operational vessel speed
- risk-reducing measures (RRMs).

The traffic model is prepared for traffic corresponding to the traffic in 2011 and in 2020.

The models for the frequency of sea accidents includes a number of risk reducing measures (RRMs), which are described in Section 3.8. Other effects *increase* the risk of accidents. They are equally described in the RRM section of this report.

3.1.4 Distribution of leakage of oil and hazardous substances between substance groups

Once the calculated spill frequencies have been obtained, the spill frequencies per substance group are calculated based on the relative distribution of the transported cargo from Technical Sub-report 2.

3.2 Ship-ship collisions

3.2.1 Collision frequency

The collision modelling is based on the route-based traffic analysis described in part 1 of the Model report.

Collision frequencies for route collisions are modelled for two situations (Figure 3-1):

- head-on collisions between ships sailing in opposite directions
- overtaking collisions between ships sailing in the same direction

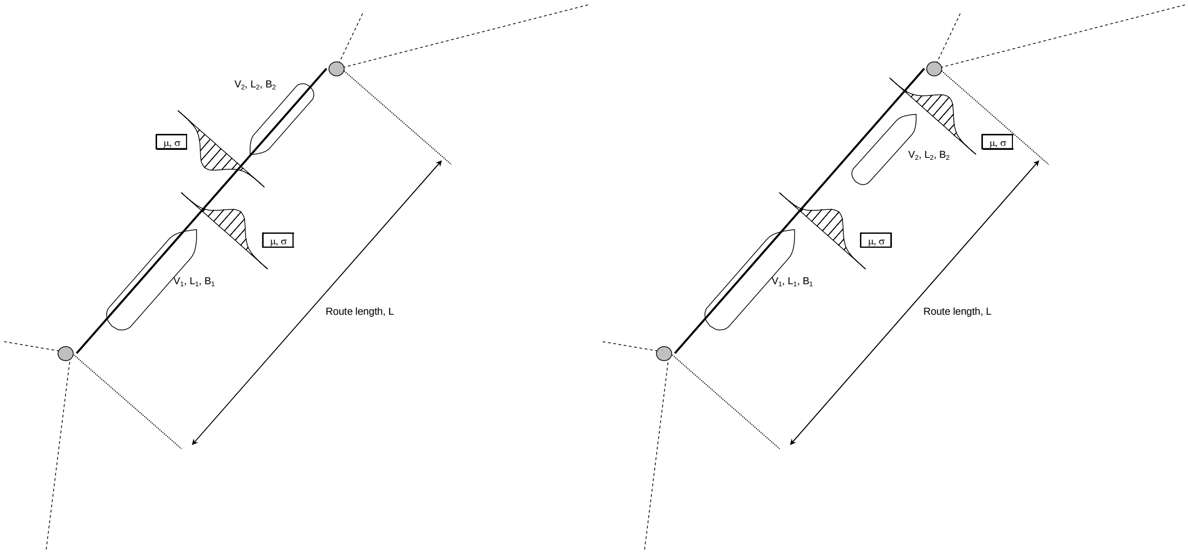


Figure 3-1 Head-on and overtaking collisions

The collision frequencies depend on:

- the length of the route segment
- the traffic intensity in each direction
- the length, breadth and speed of the ships
- the deviation of the ships from the route axis
- the causation probability Pc

Appendix 1 describes the applied model in more detail.

With the detailed route and traffic description given in Technical Sub Report 1: Ship Traffic it is possible to calculate the collision frequencies for the respective route segments.

Figure 3-3 illustrates the frequency of route collisions in the North Sea.

The frequencies of node collisions are modelled for a number of relative manoeuvres between the crossing ships. Figure 3-2 shows four frequent crossing manoeuvres.

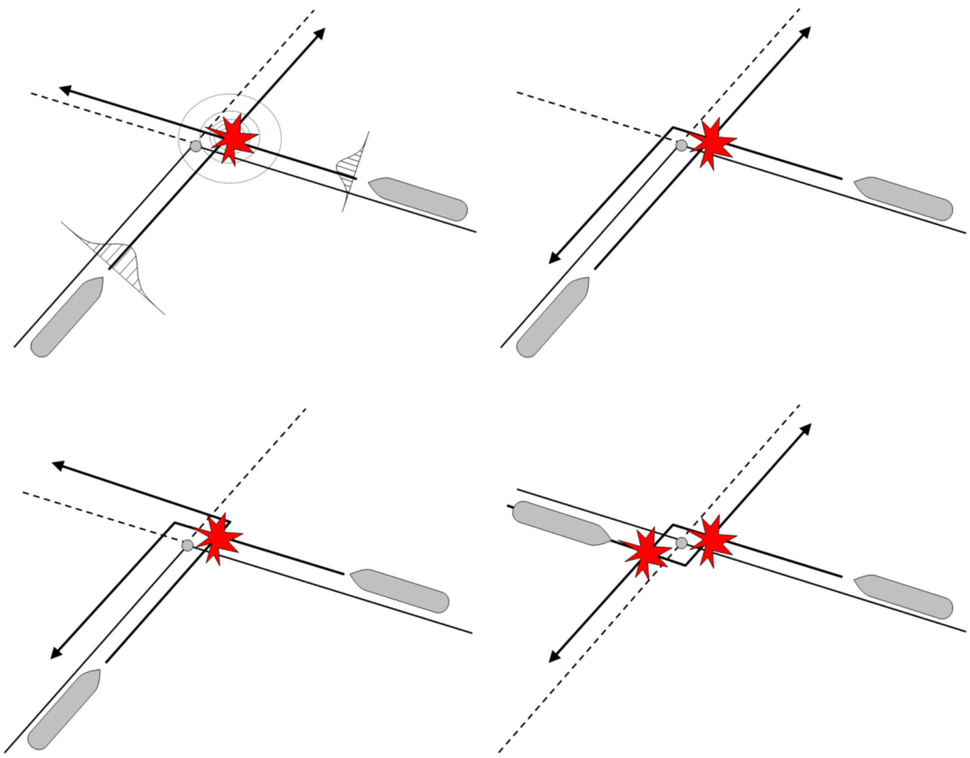


Figure 3-2 Regular crossing collisions and bending/crossing collisions

The collision frequencies depend on

- the traffic intensity in each direction
- the length, breadth and speed of the ships
- the crossing angle
- the causation probability Pc

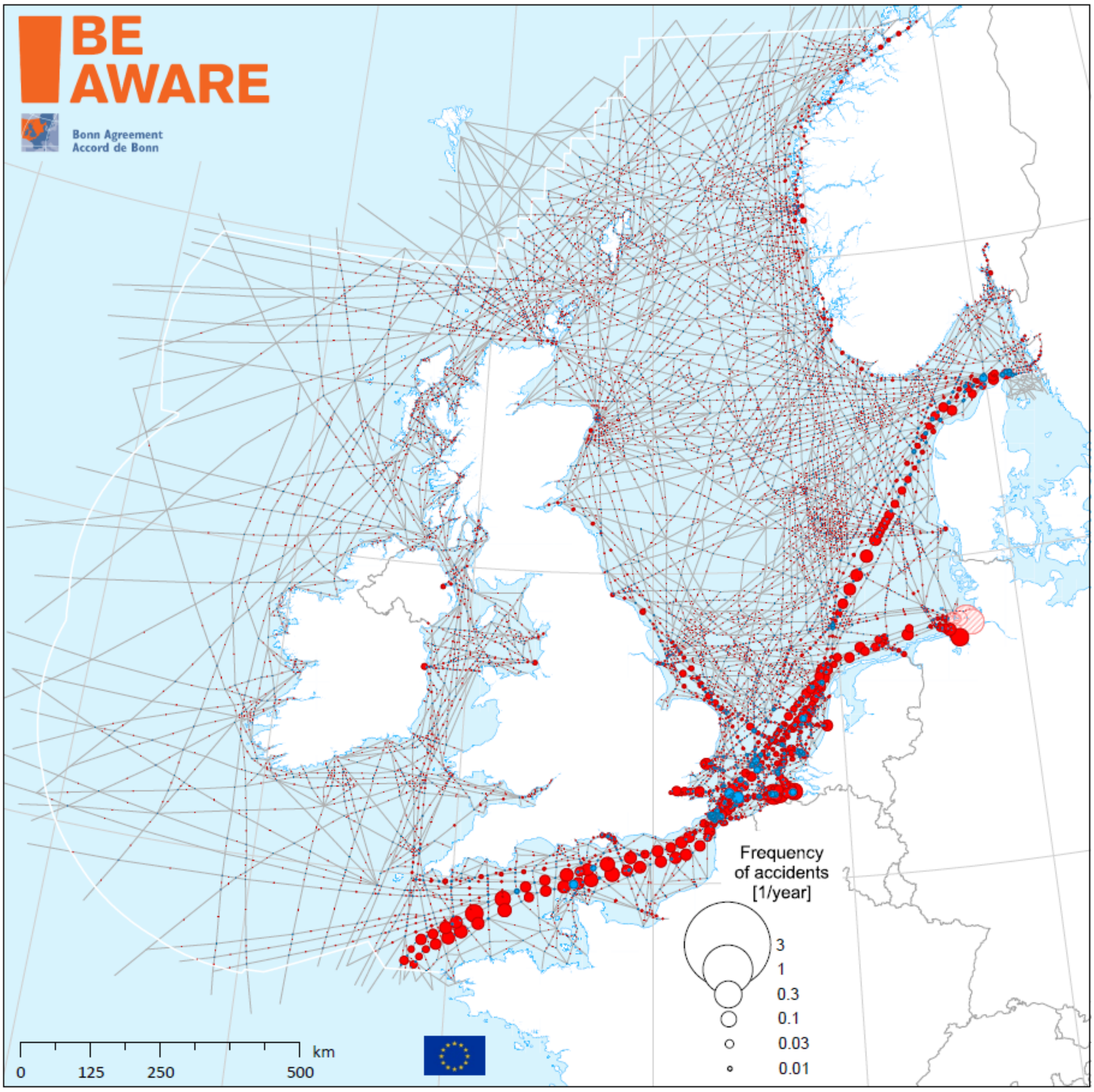


Figure 3-3 **Expected frequency[1] of route collisions (red) and node collisions (blue) in the North Sea**

Based on the detailed traffic description described in Technical Sub Report 1: Ship Traffic it is possible to calculate the collision frequencies for the respective nodes in the route net.

Following the establishment of the collision model, the total number of collisions in the North Sea has been estimated. This number has been compared to the accident statistics described in Section 3.1 which resulted in a moderate adjustment to the model, see Appendix 1.

Figure 3-3 illustrates the frequency of collisions in the North Sea.

[1] In calculatingthe frequency of accidents at the entrance to the Elbe in the German Bight the effect of pilotage was not included.The frequencies in this area have therefore been hatched to indicate this omission. These frequencies will be recalculated in the BE-AWARE II project.

3.2.2 Collision consequences

In order to assess the consequences of ship-ship collisions, a series of idealised ship designs have been developed. The damage size in case of a collision is described in accordance with work performed by Erik Sonne Ravn and Peter Friis-Hansen at the Technical University of Denmark, who elaborated routines simulating large numbers of representative collision scenarios. A neural network is applied in order to:

- determine the penetration at the hit vessel (both for bulb-shaped and conventional ship bows);
- the damage length at the hit vessel;
- the damage height at the hit vessel;
- the vertical position of the damage.

These results are calculated based on data about the colliding ships:

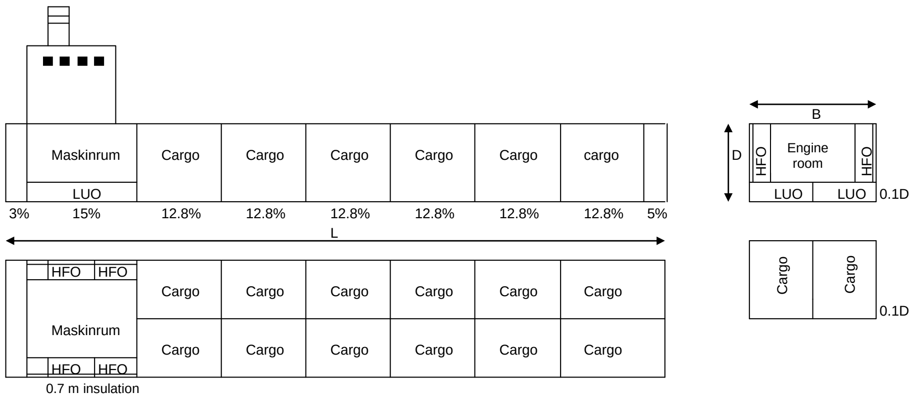
- vessel speeds;
- collision angle and draught;
- bow shape (bulb or conventional).

The results from these simulations are used in order to estimate the possible spill in case of collision.

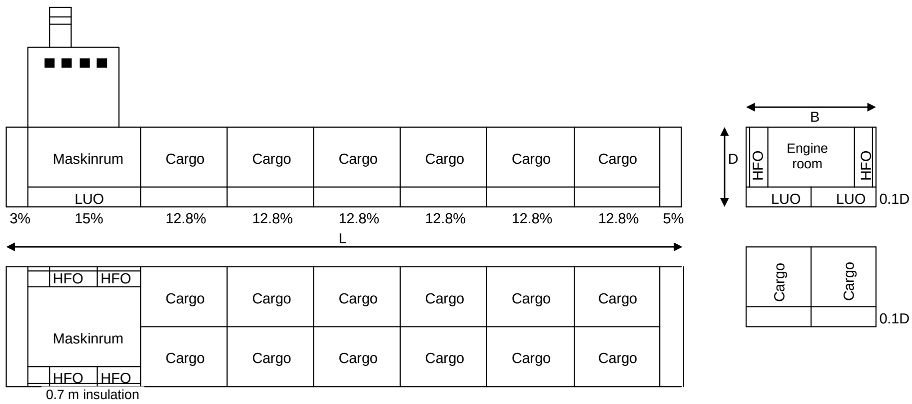
A number of assumptions need to be made in order to determine the amount of bunker oil and eventual cargo leaking from vessels with hull damage:

- The ships are categorised into seven ship types
    - tankers with single and double hull
    - chemical tankers
    - bulk carriers
    - container ships
    - general cargo ships / packed goods
    - Ro-Ro ships
    - Ro-Pax ferries
- Size of the bunker tank
- Division into cargo compartments of equal size
- Triangular distribution of the collision speed from 0 to vmax with 2/3 vmax as the most probable case
- Collision angles in the interval 30 to 150°
- Ship types are represented by rectangular boxes with rectangular cargo compartments, i.e. as idealised vessels (Figure 3-4 illustrates the case of tank ships):

Single hull



Single hull with double bottom



Double hull

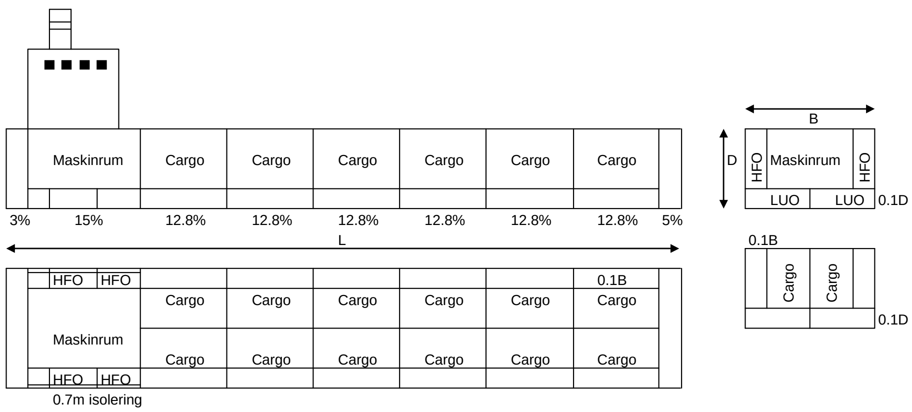


Figure 3-4 Idealised tankers used for determining the spill in case of hull damage (HFO = heavy fuel oil, LUO = lubricating oil)

- the spill size depends on the position of the damage relative to the water line:

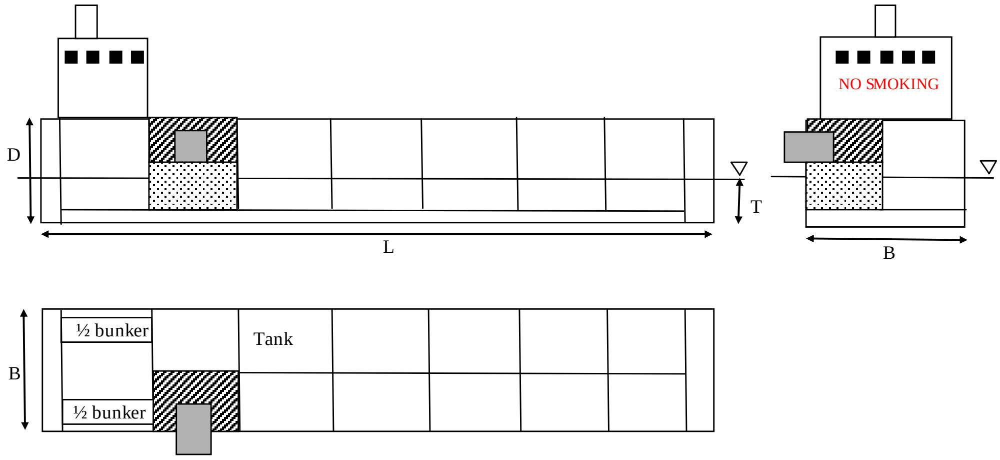


Figure 3-5 Example of a penetration above the water line. The shaded part is spilt. The dotted part remains in the tank.

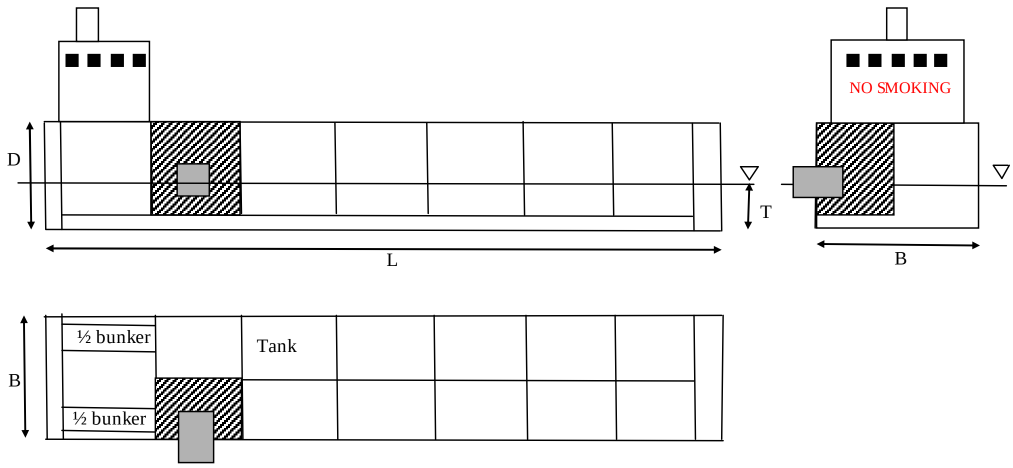


Figure 3-6 Example of a penetration below the water line. The entire shaded part is spilt.

For each collision, 250 simulations with varying angles, collision point relative to the ship length and speed are performed. Cargo and bunker spills from each simulation are stored in the intervals indicated in Table 3-1. For each interval, a probability is indicated.

Table 3-1 Relative spill intervals for which the respective probabilities are calculated in the simulation

Cargo spill size classes (fraction of cargo capacity)	***Bunker spill size classes (fraction of bunker capacity)***
[0-1/1000] (no spillage)	[0-1/1000] (no spillage)
]1/1000-1/18]	]1/1000-1/6]
]1/18-1/9]	]1/6-1/4]
]1/9-1/6]	]1/4-1/3]
]1/6-1/3]	]1/3-1/2]
]1/3-1/2]	]1/2-1]
]1/2-1]	

The spills are calculated for a number of different scenarios, where

- the impacting ship is
  - loaded/not loaded
  - hitting diagonally from the front/back
- the impacted ship is
  - loaded/not loaded
  - double-hulled/single-hulled
  - bunker-protected (double hull at bunker)/not bunker-protected

In addition, all combinations between the representative ships used in the simulations are analysed. This yields a very large number of combinations (>100,000). The results are stored in a database table.

When it comes to the consequences of route collisions, some adaptations to the model are necessary as described above. In general, the model implies that ships do not penetrate each other, if the collision occurs at a very acute (<30°) or very obtuse angle (>150°). Instead, they just grind alongside each other. This, however, does not mean that parallel collisions are by any means harmless:

- Routes are an idealisation of reality. In many cases, ships that have been allocated to one route leg do not move perfectly parallel.
- Two ships in a head-on situation having failed to make an evasive manoeuvre in good time will typically try to change their direction as a last resort prior to impact. This means that one or both ships “open up” and present their side to the other ship. If the evasive manoeuvre fails, one of the two ships will be struck in a vulnerable constellation (angel between 30° and 150°).
- In an overtaking situation, it is less likely that a ship "opens up" than with head-on situations. Assuming that this behaviour nevertheless occurs in 10 % of all cases was deemed to be very conservative by the nautical experts consulted during an earlier analysis (Bornholmsgat, 2008). This conservative assumption is used in the BRISK model.

3.3 Groundings

3.3.1 Grounding frequency

The approach for calculating the grounding frequency is simple and based upon the available data and statistics.

1. The Bonn Agreement area has been divided into several traffic areas. For each of these areas, a number of representative grounding points (grounding locations) are identified.
2. For each traffic area, the grounding frequency is calculated, based on historical accident data and divided with the number of nautical miles sailed per year. The result is a grounding frequency per sailed nautical mile. Each traffic area has a different frequency.
3. The grounding frequency is corrected for the effect of risk reduction measures (see Technical Sub- report 5) in order to obtain a "basic" grounding frequency per sailed nautical mile.
4. Present and future grounding frequencies are calculated on an annual basis by multiplying the distance sailed by different ships with the basic grounding frequency per nautical mile and with various risk-reducing factors representing the effect of the RRMs. This step is performed separately for each ship type and ship size, since not every ship is subject to the same RRMs.

Table 3-2 provides an overview of the grounding frequencies in the different traffic areas. It is apparent that the risk-reduction efforts have been strongest in areas with high grounding frequencies (Note: A low risk-reduction factor corresponds to a high level of risk reduction).

Table 3-2 Basic grounding frequency per sailed nautical mile (corrected for risk-reducing measures)

Traffic area	Raw grounding frequency per mile (incl. RRMs)	Implied risk reduction factor	Basic grounding frequency per mile (without RRMs)
1 Atlantic	3.8 × 10-7	0.7	5.5 × 10-7
2 Northern North Sea	7.2 × 10-7	0.6	1.2 × 10-6
3 Eastern North Sea	3.0 × 10-7	0.7	4.5 × 10-7
4 Southern North Sea	1.9 × 10-7	0.7	2.6 × 10-7
5 Channel	1.1 × 10-7	0.6	1.8 × 10-7
Average (weighted)	3.07 × 10-7	0.7	4.77 × 10-7

3.3.2 Grounding consequences

Probability of spill given grounding

The probability and quantity of spill in case of grounding is derived from the results in (Rømer, 1996). Separate models are indicated for cargo and bunker spillage, respectively.

Cargo spill

Rømer proposes a spill probability of 0.25 in case of a grounding for single hull tankers. A recent analysis performed at Aalto University in Espoo, Finland supports this number (Ylitalo et al., 2010). As in an earlier Danish analysis (Oil spill DK, 2007) a value of 0.15 is chosen for the specific case of soft grounds. With rocky grounds, a value of 0.3 is chosen which is also in agreement with DNV's probabilities (DNV, 2003).

In the case of double-hull tankers, Rømer proposes a spill probability of 0.03 in case of a grounding. The earlier Danish analysis (Oil spill DK, 2007) utilised a value of 0.02, which is reasonable considering the prevailingly soft Danish grounds. BRISK uses the same number for soft grounds. In the case of rocky grounds, a value of 0.06 is chosen based on numerical simulations at Aalto University in Espoo, Finland (Ylitalo et al., 2010).

The used probabilities of cargo spill following grounding are indicated in Table 3-3 below

Table 3-3 Probability of cargo spill following grounding

Vessel type	Ground type	*P{cargo spill | grounding}*
Single hull cargo ship (bulk)	Soft	0.15
	Rock	0.30
Double hull cargo ship (bulk)	Soft	0.02
	Rock	0.06
Not loaded ships	Soft/Rock	0.00
Ships carrying packed goods (containers, general cargo, Ro-Ro)	Soft/Rock	0.00

Bunker spill

In Risk analysis: Oil and chemicals pollution in Danish waters (Oil Spill DK, 2007), a general bunker spill probability of 0.01 in case of grounding of a loaded ship is used. This number is adapted to the Danish situation with prevailingly soft grounds. Michel and Winslow (Michel & Winslow, 2000) calculate the probability as 0.01 to 0.08 for container ships and bulk carriers, and 0.22 for loaded very large crude carriers (VLCCs). However, some of these model-based results appear rather high when taking the actual accident statistics into account (see Section 3.1) as well as the probability of cargo spill given grounding (see above).

The used probabilities of bunker spill following grounding are indicated in Table 3-4. The numbers are based on engineering judgement and apply only to loaded vessels. Grounding of unloaded vessels is unlikely to result in bunker spill. This is due to geometrical reasons (less draught in combination with the fact that bunker tanks are usually located at the rear of the ship) and the fact that the vertical forces between the ship and the ground are lower if the ship is not loaded.

Table 3-4 Probability of bunker spill following grounding of a loaded ship

Vessel type	**Ground type**	**Bunker protection**	***P{bunker spill|grounding}***
All	Soft	Yes	0.01
		No	0.02
	Rock	Yes	0.05
		No	0.10

Spill size

Also here, separate models are indicated for cargo and bunker spillage, respectively.

Cargo spill

Two scenarios are used:

Scenario 1:

Spill of less than 100 t cargo: *P{scenario 1 | spill single hull}* = 0.974

P{scenario 1 | spill double hull} = 0.94

Scenario 2:

Spill of more than 100 t cargo: *P{scenario 2 | spill single hull}* = 0.026

P{scenario 2 | spill double hull} = 0.06

In Scenario 1, the spill is set to either 30 t or 0.1 % of the cargo, whichever is less. In this way, ships with a DWT of less than 30,000 t are assumed to spill less than 30 t and the other ships are assumed to spill 30 t.

The spillage in Scenario 2 is distributed as in Table 3-5.

Table 3-5 Probability distribution for the fraction of the cargo spilt in case of a tanker, bulk carrier or other loaded ship running aground (only spills larger than 100 t). Source: CHEMAX

Spilt fraction of the total cargo in case of a grounding accident	Probability
5 %	0.5000
15 %	0.2500
25 %	0.1250
35 %	0.0625
45 %	0.0313
55 %	0.0156
65 %	0.0078
75 %	0.0039
85 %	0.0020
95 %	0.0020

Bunker spill

There is a difference between the actual bunker tanks (fuel for vessel propulsion) and the smaller lubricant tanks, since the regulations for double-hull at bunker tanks do not apply to lubricant tanks. A part of the presently existing vessels are equally double-hulled next to the bunker tanks, but not next to the lubricant tanks. In the analysis of spill consequences, no difference is made between oil bunker and lubricant spillage, since both substances are covered by the same goods group in the goods transport model.

The bunker spill size model shown in Table 3-6 has been chosen to be the same as in previous Danish studies (Oil spill DK, 2007). A spill of 0 to 1/200 of the total bunker capacity corresponds to a leakage of the lubricant tanks. Spill between 1/6 and 1/2 are not considered very probable and therefore not modelled in a separate scenario.

Table 3-6 Probability distribution for the fraction of the bunker fuel spilt in case of a grounding

Expected fraction of total bunker volume released in case of a leakage	General cargo and Ro-Ro ships incl. work vessels and Ro-Pax ferries		Oil and chemical tankers, bulk carriers, container ships
	Single hull at the bunker tanks	Double hull at the bunker tanks	Double hull at the bunker tanks
0 to 1/200	0.0	0.875	0.875
0 to 1/6	0.95	0.11875	0.11875

Ground properties

Information on the ground properties around the North Sea was taken from the European Environment Agency (EEA) coastal morphology dataset. The model uses this information in order to determine the likelihood of meeting soft or rocky ground in case of groundings at a specific location.

3.4 Fire and explosions

3.4.1 Frequency of fire and explosion events

The number of fires on board registered during the observation period 2004-2011 average at 9.5 fires per year. This number refers to events outside ports with ships of 300 GT and above. During the reference period, i.e. 1 January 2011 to 31 December 2011, the total sailed distance in the project area with ships matching the same criteria amounted to 109.4 million nautical miles. This corresponds to 8.6 × 10-8 events per sailed nautical mile.

An earlier investigation by DNV (DNV, 2003) used a frequency of 1.5 × 10-8 fire events per sailed nautical mile in one of the cargo compartments of a tanker. This number is lower by a factor of six which can be explained by the fact that only a small part of all fires involves the cargo compartment.

The frequency of fire and explosions is thus estimated as

P{Fire in cargo compartment of a tanker} = 1.5 × 10-8 / nautical mile sailed with tankers

This is comparable to the approach adopted in the BRISK project

3.4.2 Consequences of fire and explosions

It is assumed that

P{Spill | fire in a cargo compartment of a tank ship} = 1.0

The probabilities of relative spill sizes are derived from (DNV, 2003) and (Oil spill DK, 2007) and are indicated in Table 3-7.

Table 3-7 Probabilities of the relative spill sizes in case of fire aboard a tanker

Spill size	Probability
0-0.1 % of the cargo	0.12
0.1-0.4 % of the cargo	0.24
0.4-12 % of the cargo	0.58
12-100 % of the cargo	0.06

3.5 Foundering and other potentially polluting accidents

3.5.1 General considerations

Accidents other than those described above can also be the cause of a spillage. The number of foundering accidents registered during the observation period 2004-2011 average at 8 per year. The causes have not been specified for these events. Typical causes are expected to be severe weather conditions, structural fatigue and shifting cargo.

Spill from physical damage which has not been caused by other accidents (grounding, collision, fire) is considered to be relatively insignificant. Therefore, the model only takes foundering into account.

3.5.2 Modelling

Frequency

The yearly average of 8 foundering accidents together and a yearly total of 109.4 million nautical miles sailed in 2011 correspond to 7.3 × 10-8 occurrences per nautical mile. An earlier Danish analysis led to an accident rate per nautical mile that was approximately one-fifth of this, however this was using data from 1993 - 2006. The analysis of the Baltic Sea in the BRISK project had an accident frequency of approximately one-tenth of the current analysis. However, the sheltered waters of the Baltic Sea are not directly comparable to the much harsher weather conditions in the North Sea and in the Atlantic.

The frequency of foundering is therefore modelled as:

P{Foundering} = 7.3 × 10-8 / nautical mile sailed

It is noted that foundering accidents typically have involved small ships. Using the estimated frequency for all ships including large ships may cause an overestimation of the spill sizes.

Consequences

The probability of spill given foundering is estimated as:

P{Spill|Foundering} = 0.5

The size of the spill relative to the cargo and bunker capacity of the respective ship is estimated as:

Spill size = 50-100 % of the cargo/bunker volume (uniformly distributed)

3.6 Risk-reducing measures (RRMs)

The accident model components described earlier in this chapter treat all vessels in an idealised way that ignores many ship-specific and regional characteristics. Most of these characteristics have a risk-reducing effect, whereas some others can lead to additional risk. This section describes the most relevant risk-reducing measures (RRMs) and the way they are modelled. Relevant phenomena that increase risk are equally described. This is described in detail in Technical Sub report 5.

4. Offshore oil transfer

4.1 STS operations

When cargo is transferred from one ship to another at the open sea, this action is referred to as ship-to-ship transfer (STS). STS operations normally involve the transfer of oil cargoes by hose.

The UK is the only country where such operations occur on a regular basis. In the Southwold area between 141 and 370 STS operations were carried out annually in the period 2009-2012. A total volume of between 9.2-12.6 million tonnes of oil was annually transferred in this period.

The following major hazards can be identified:

- Operational spill due to hose rupture or overfilling;
- Spill due to collision with the feeder ship;
- Spill due to collision with a passing vessels.

The analysis of the ship impact frequency is based on Fujii's model (see Section 3.2.1) in combination with other considerations and previously existing risk analyses.

The risk of small and medium-sized spills is largest for operational spills, whereas operational spills and spills due to ship collisions contribute in a comparable way to the risk of large spills (i.e. spills of 300 to 5,000 tonnes). Exceptionally large spills of more than 5,000 tonnes are only expected as a result of ship collisions.

As for ship collisions, collisions with the feeder ships are the main risk contributor, whereas collisions with passing vessels mean very little in comparison.

The extent of the spill risk is mostly smaller than the risk of ship-ship collisions not related to oil transfers in the respective area. Nevertheless, STS operations contribute significantly to the overall risk in the area off Southwold.

5. Spills related to offshore installations

The model of spills related to offshore installations is presented in Technical Sub Report 7: Offshore Installation Oil Spill Risk Analysis. For the sake of convenience the general approach is described in the following chapter and the results have been included in order to see the full risk picture in the Bonn Agreement area.

5.1 General

A significant number of offshore installations are exposed to potential ship collisions:

- Offshore oil platforms
- FSPOs
- Offshore loading buys
- Offshore wind farms

If a ship hits an offshore oil installation, oil can leak both from the installation and from the involved ship. Other impacts such as a collision with an offshore wind farm can only lead to a possible leak from the impacting vessel itself.

Accidents on offshore oil platforms themselves can also lead to spills, e.g. in the event of a blow-out or similar event. Although these types of accident are very seldom they have been included in the results as the possible magnitude of these spills are considerable.

5.2 Spills due to ship impact

If a ship hits an offshore oil installation, oil can leak both from the installation and from the involved ship. The risk of oil spills due to ship collisions against offshore installations is analysed in detail in Technical Sub Report 7: Offshore Installation Oil Spill Risk Analysis.

All accidents related both to navigational oil spills and spills from platforms are for the sake of convenience included in the following chapter. The accidents are all described in section 2-5. The results are shown for two different traffic scenarios. The traffic scenarios are described in more detail in Technical Sub-report 1: Ship traffic. The two traffic scenarios represent the years 2011 and 2020.

5.3 Scenario 2011

The observed traffic in 2011 has been applied as a basis for the present scenario. The frequencies of the various accidents can be seen in Figure 5-1.

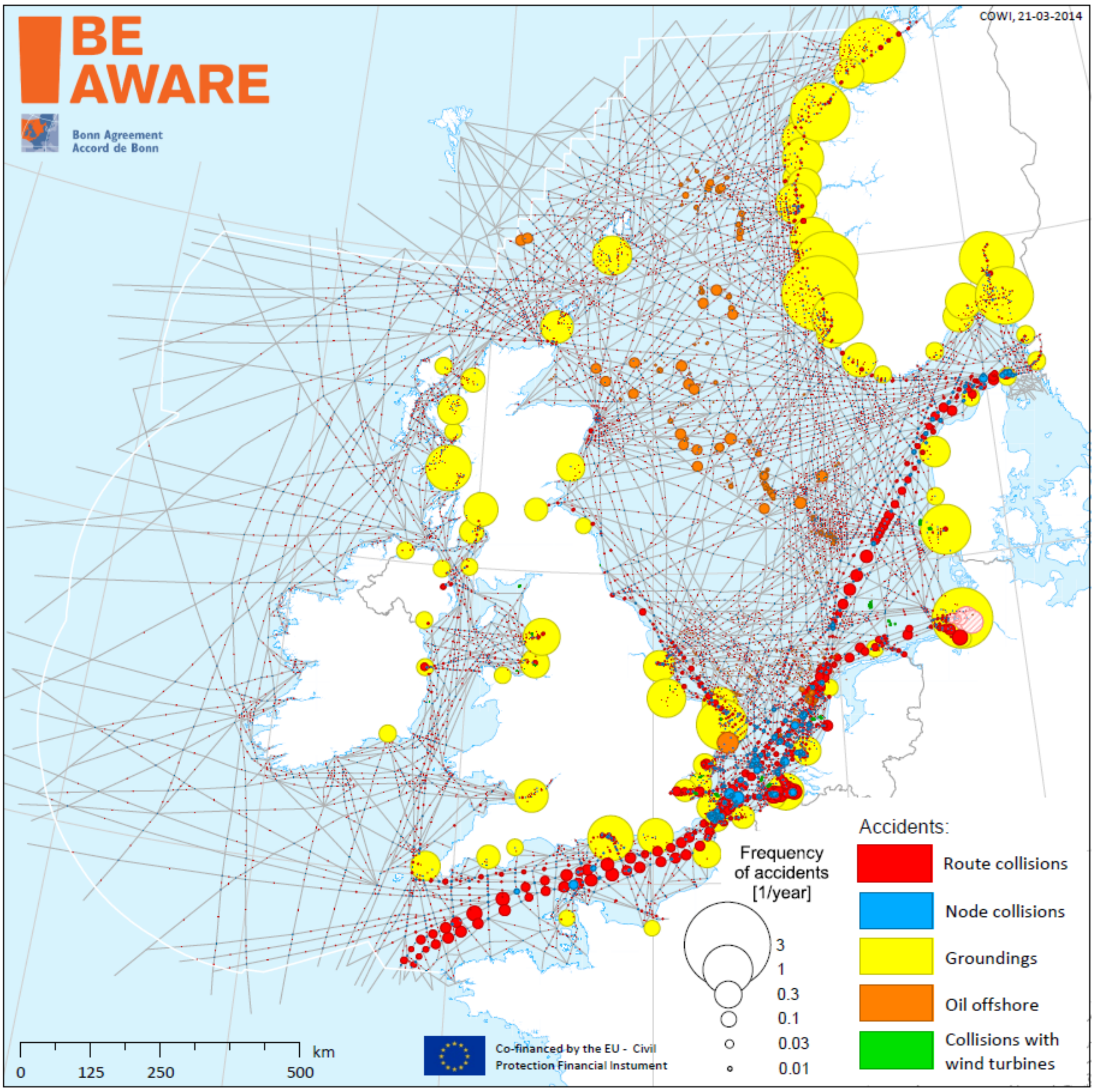


Figure 5-1 Frequency[2] of accidents for scenario 2011

From Figure 5-1 it is seen that the largest probability for route collisions are located along the main traffic routes in the Channel and then diagonally across the North Sea and along the coastline of Belgium and the Netherlands into the German Bight. Node collisions are crossing collisions and the largest probabilities can be found around the Dover Strait and in high traffic areas further north, close to the harbours at Antwerp, Rotterdam and Amsterdam. The frequency of groundings along the Norwegian coastline is relatively large compared to other areas. The accident frequencies related to offshore oil installations are primarily located far from coastlines in the middle and northern part of the North Sea. Ship collisions with wind farms have a relative low probability of occurring compared to the other types of accidents considered.

[2] In calculating the frequency of accidents at the entrance to the Elbe in the German Bight the effect of pilotage was not included.The frequencies in this area have therefore been hatched to indicate this omission. These frequencies will be recalculated in the BE-AWARE II project.

5.4 Scenario 2020

The predicted traffic in 2020 has been applied as a basis for the present scenario. The frequencies of the various accidents can be seen in Figure 5-2.

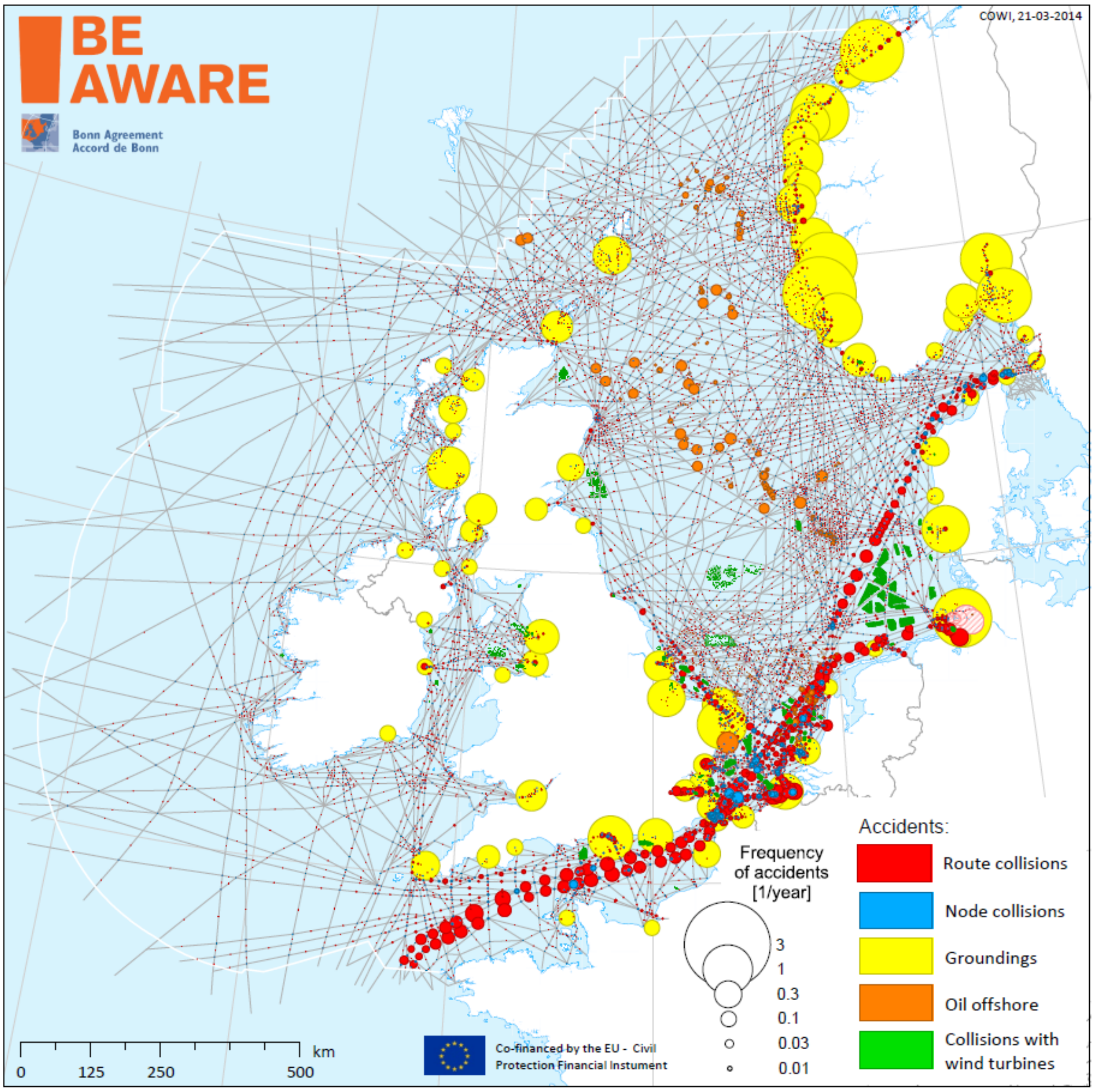


Figure 5-2 Frequency[3] of accidents for scenario 2020

The overview of the accident frequencies in the project area for scenario 2020 shows in Figure 5-2 the same tendencies as the results for scenario 2011 shown in Figure 5-1. The largest probability from route collisions is still located along the main traffic routes in the Channel and further east diagonally across the North Sea and along the coastline of Belgium and the Netherlands into the German Bight. The largest contribution from node collisions can be found around the Dover Strait and in the dense traffic areas further north close to the harbours at Antwerp, Rotterdam and Amsterdam. Some local variation is seen between the scenarios and this is primarily caused by the different developments in the number of vessels and the development in size for various types of ship. Furthermore risk reducing measures such as development in the Traffic Separation Schemes influence the accident frequency on a regional level.

[3] In calculating the frequency of accidents at the entrance to the Elbe in the German Bight the effect of pilotage was not included.The frequencies in this area have therefore been hatched to indicate this omission. These frequencies will be recalculated in the BE-AWARE II project.

6. Resulting risk

In order to differentiate between the regional differences over the project area results are shown in the various regions of the area. There are 5 regions as can be seen in Figure 6-1.

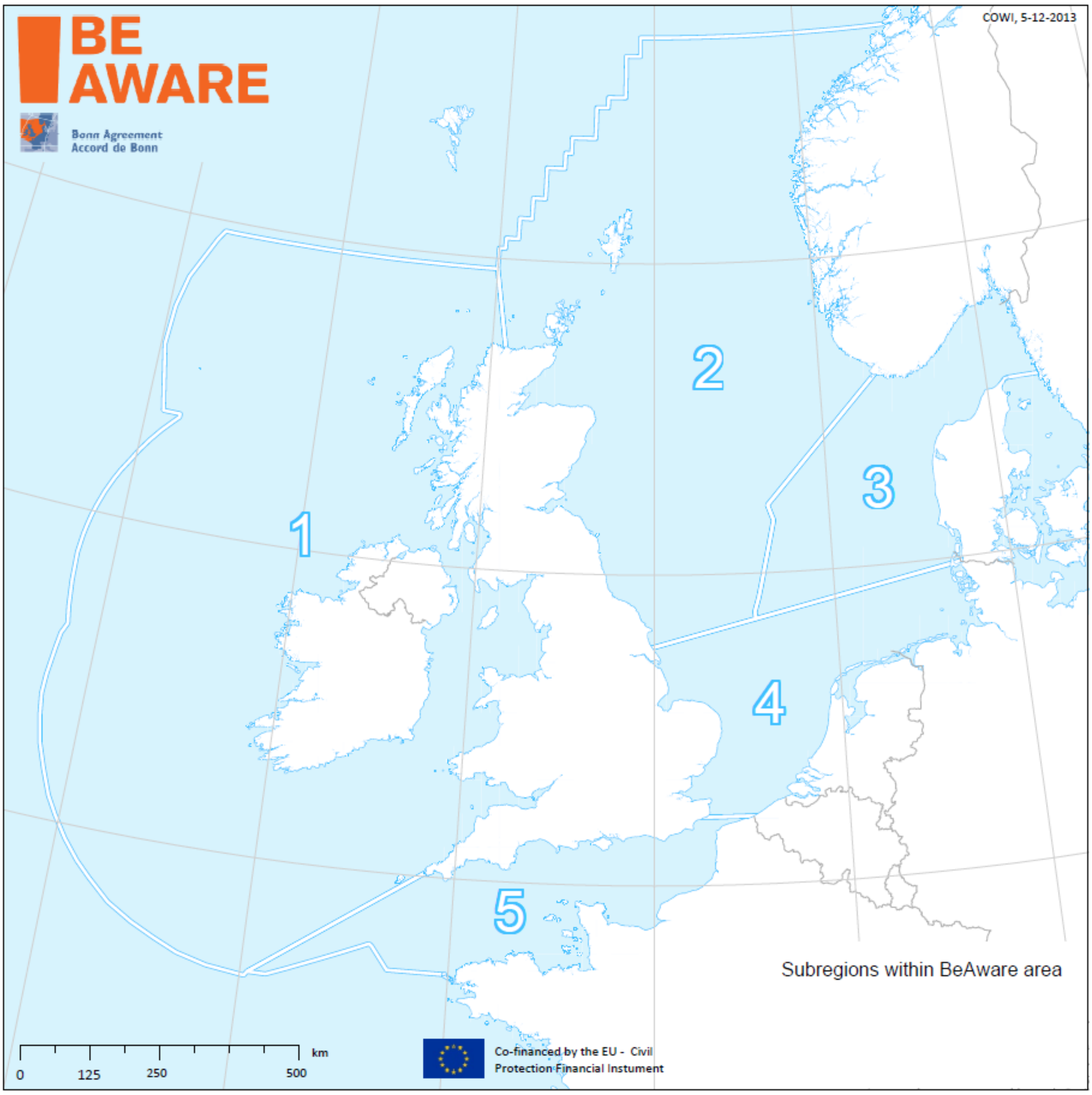


Figure 6-1 Regions within the Be-Aware area

The regions are made up of the following countries:

1. UK, IE
2. UK, NO
3. NO, SE, DK
4. DE, NL, BE, UK
5. UK, FR

6.1 Scenario 2011

For the traffic scenario 2011 the resulting risks for small/medium spills, in tonnes per year, is shown in Figure 6-2.

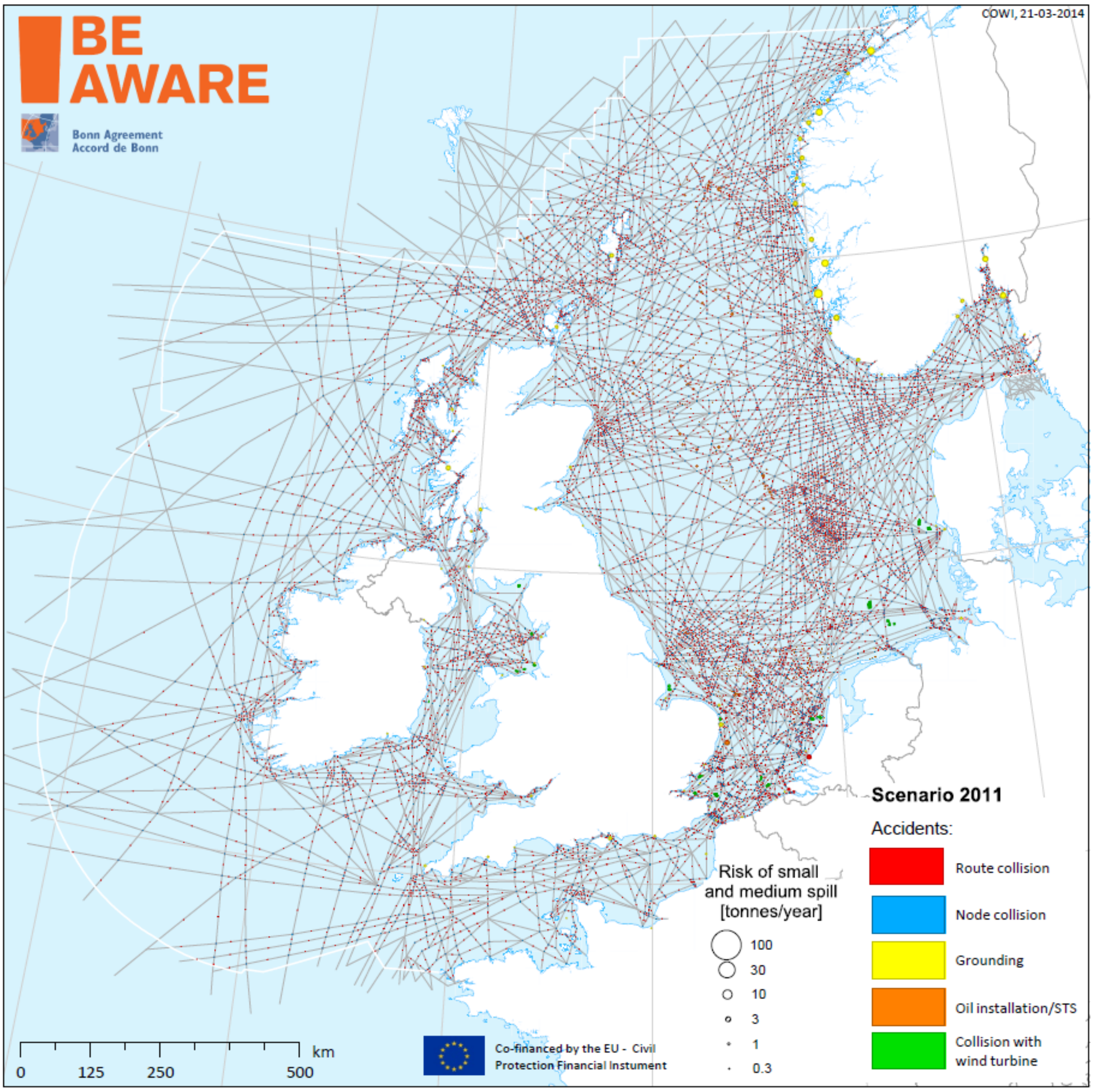


Figure 6-2 **Risk[4] of spills less than 300 tonnes for scenario 2011 in tonnes per year. A risk bubble of 10 tonnes/year could relate to a spill of 100 tonnes with a return period of once every ten years.**

The risk of spills of less than 300 tonnes of oil coming from ship-ship collisions are distributed over the entire route net although some areas locally have an increased risk. The risk of spills given grounding is most pronounced on the Norwegian coastline. The local risk contribution from groundings is among other factor dependent on the ground type of seabed and the type of vessels in the area. The risk of groundings around the Norwegian coast is therefore affected by the amount of oil carried in on the vessels there and the primarily rocky coastline that increases the probability of

[4] In calculating the frequency of accidents at the entrance to the Elbe in the German Bight the effect of pilotage was not included.The frequencies in this area have therefore been hatched to indicate this omission. These frequencies will be recalculated in the BE-AWARE II project.

having a spill. The overall risk contribution from oil installations is comparable to the risk from ship-ship collisions. The overall risk contribution from ship collisions with wind turbines is relatively small.

For the traffic scenario 2011 the resulting risks for large spills, in tonnes per year, is shown in Figure 6-3.

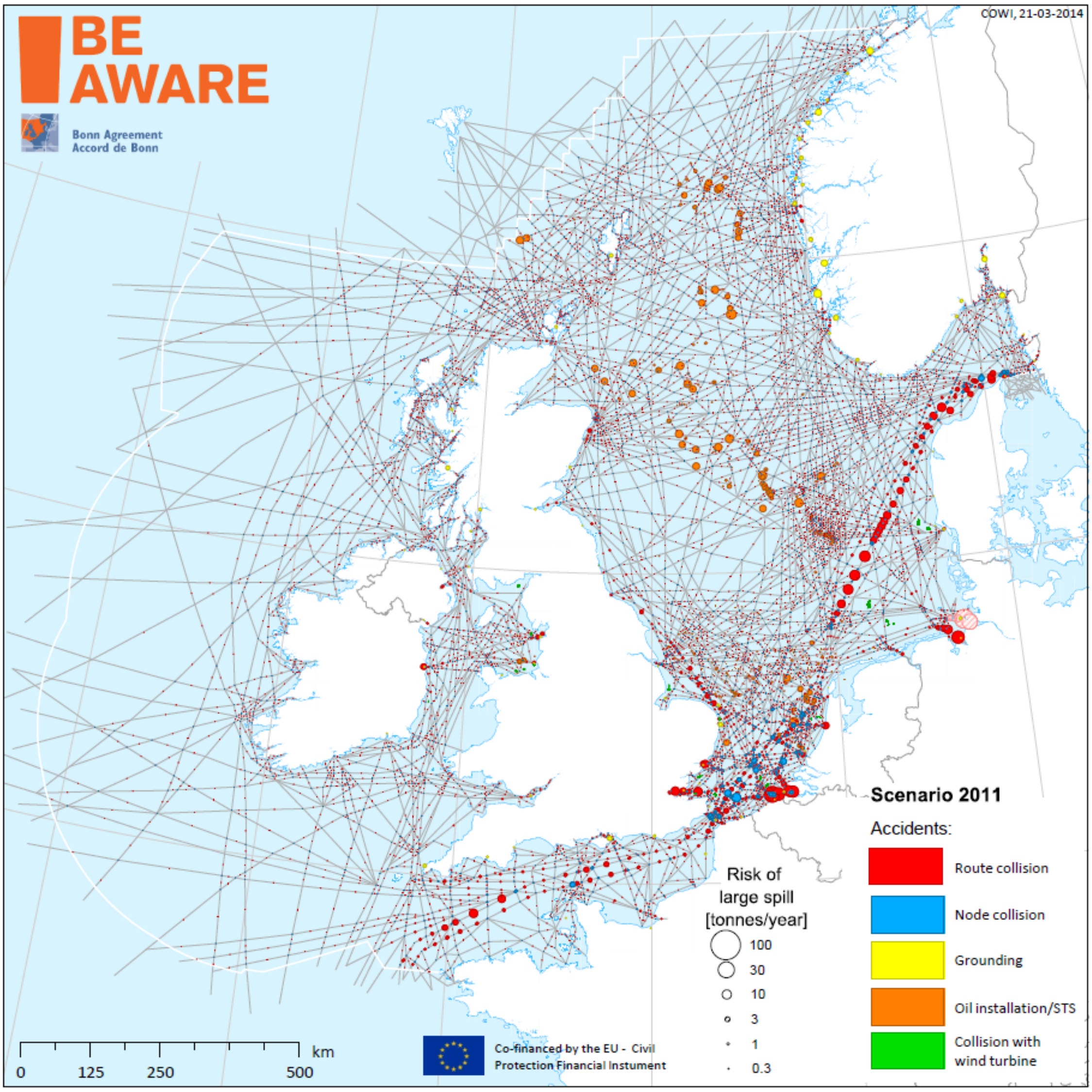


Figure 6-3 **Risk[5] of spills between 300 and 5000 tonnes for scenario 2011 in tonnes per year. A risk bubble of 30 tonnes/year could relate to a spill of 3000 tonnes with a return period of once every hundred years.**

The risk of large spills of between 300 and 5000 tonnes of oil coming from ship-ship collisions is clearly seen to be following the main traffic routes. There are however significant increases in narrow traffic lanes with high intensity traffic e.g. in the Thames, Rotterdam and the German Bight. Most surprising is the risk contribution along the diagonal route in the middle of the North Sea. The vessels are taking the shortest route possible and this gives a narrower sailing pattern than one might expect

[5] In calculating the frequency of accidents at the entrance to the Elbe in the German Bight the effect of pilotage was not included.The frequencies in this area have therefore been hatched to indicate this omission. These frequencies will be recalculated in the BE-AWARE II project.

at this location far from the coast and with no other obstacles in its path and therefore adds to the overall risk picture.

Groundings also add to the risk in this spill class and as for the smaller spills the contribution along the Norwegian coastline is most pronounced. The risk contribution from oil installations is for this spill size smaller than the risk from ship-ship collisions but also confined to a smaller area. The overall risk contribution from ship collisions with wind turbines is relatively small.

For the traffic scenario 2011 the resulting risks for very large and extreme spills in tonnes per year is shown in Figure 6-4.

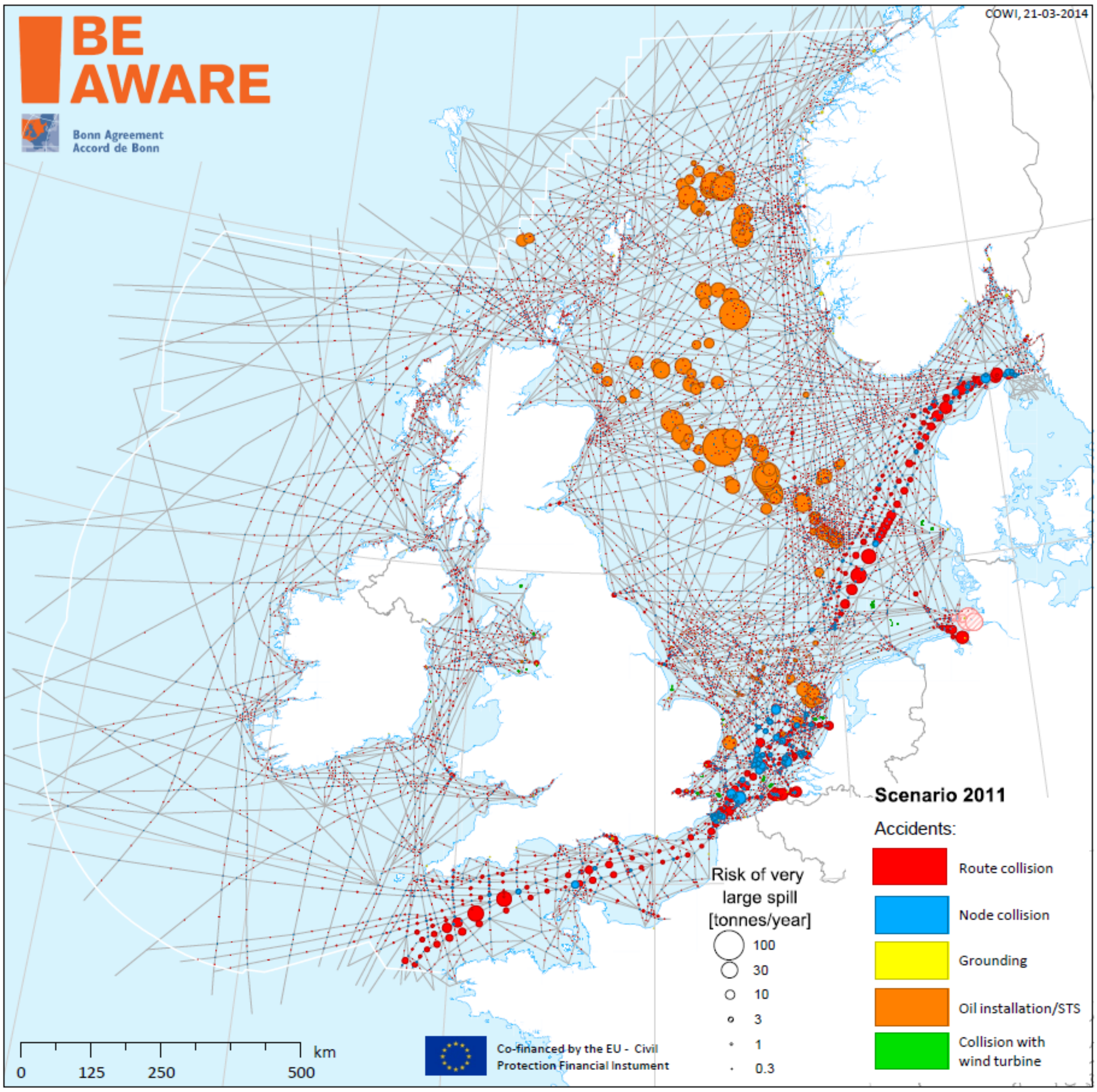


Figure 6-4 **Risk[6] of spills larger than 5000 tonnes for scenario 2011 in tonnes per year. A risk bubble of 100 tonnes/year could relate to a spill of 50000 tonnes with a return period of once every five hundred years.**

6 In calculating the frequency of accidents at the entrance to the Elbe in the German Bight the effect of pilotage was not included.The frequencies in this area have therefore been hatched to indicate this omission. These frequencies will be recalculated in the BE-AWARE II project.

For the very large and extreme spills the risk contribution from possible accidents related to offshore oil installations are predominant. These installations are primarily located quite far from the coastline in the North Sea, however with some exceptions especially near the Dutch coast. Ship-ship collision risks related to very large and extreme spills are primarily located on the largest shipping routes as these also are used by the largest tankers. Groundings have a relatively low contribution to risk coming from the large and extreme spills compared to the previous accident types discussed. Collisions with wind turbines contribute to the risk from large and extreme spill events however less so for the traffic scenario 2011 when there was a relatively small number of wind turbines.

Looking at all sizes of spill over the BE-AWARE area divided into the sub regions the regional differences becomes clearer. This is seen in Figure 6-5.

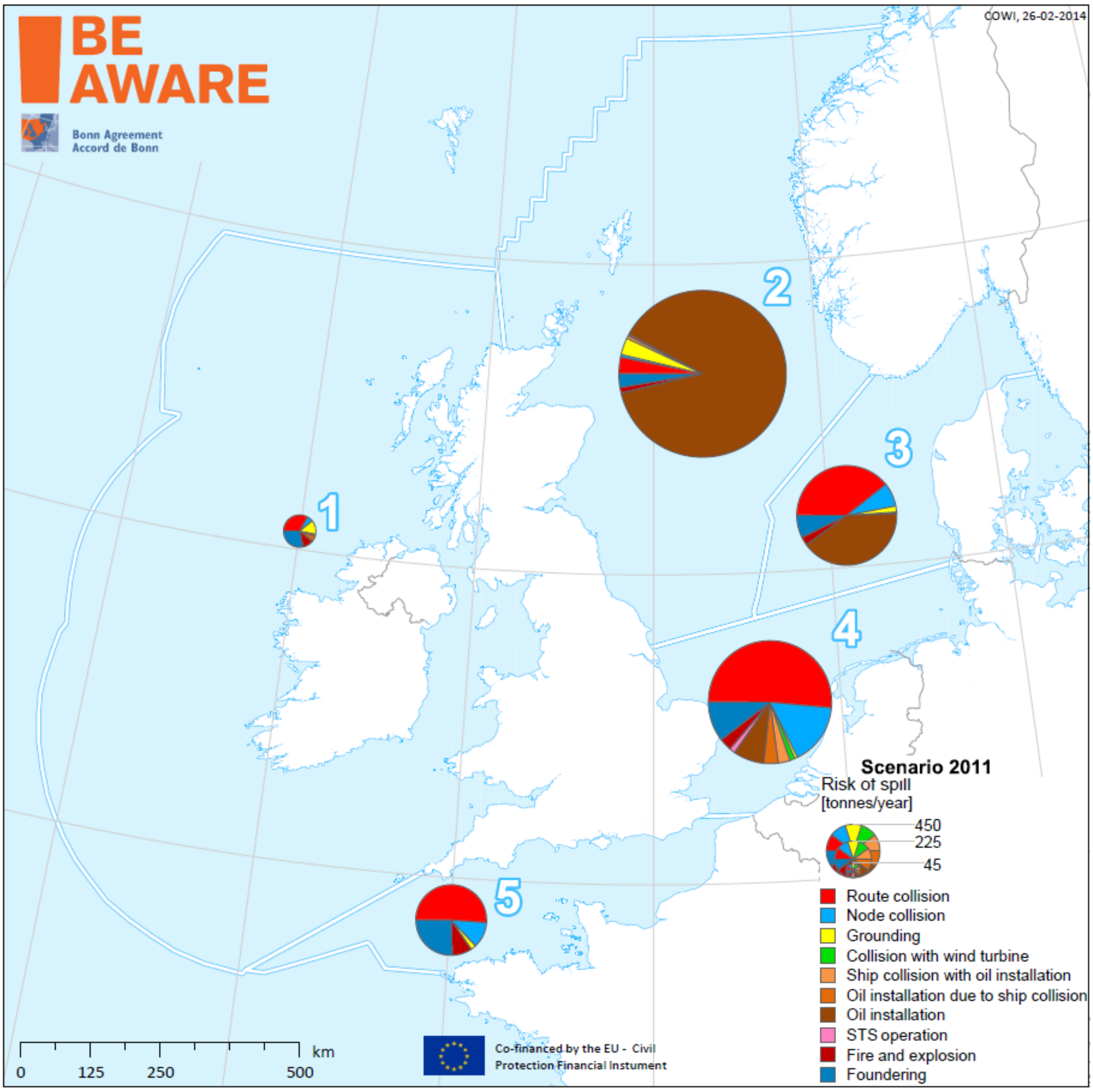


Figure 6-5 Risk of all sizes of spills divided into the defined regions for scenario 2011 in tonnes per year

It is clearly seen in Figure 6-5 that large regional differences are present in the Bonn Agreement area in relation to the risk of oil spills. In general ship-ship collisions are the main contributor except in area 2 where accidents with oil installations dominate the risk. The intensity of the traffic does influence the relative size of ship-ship collisions compared to e.g. grounding and foundering. In a highly complex area such as region 4 the ship-ship collisions constitute almost ¾ of the risk contribution for the area. Accidents such as foundering and fire and explosions are dependent on the sailed distance in the area and not on the distribution of the traffic. Therefore the relative size of these are larger in region 1 compared to the other regions. The regional differences can clearly be seen in Figure 6-6 where the relative distributions of the risk contributions for the regions are given.

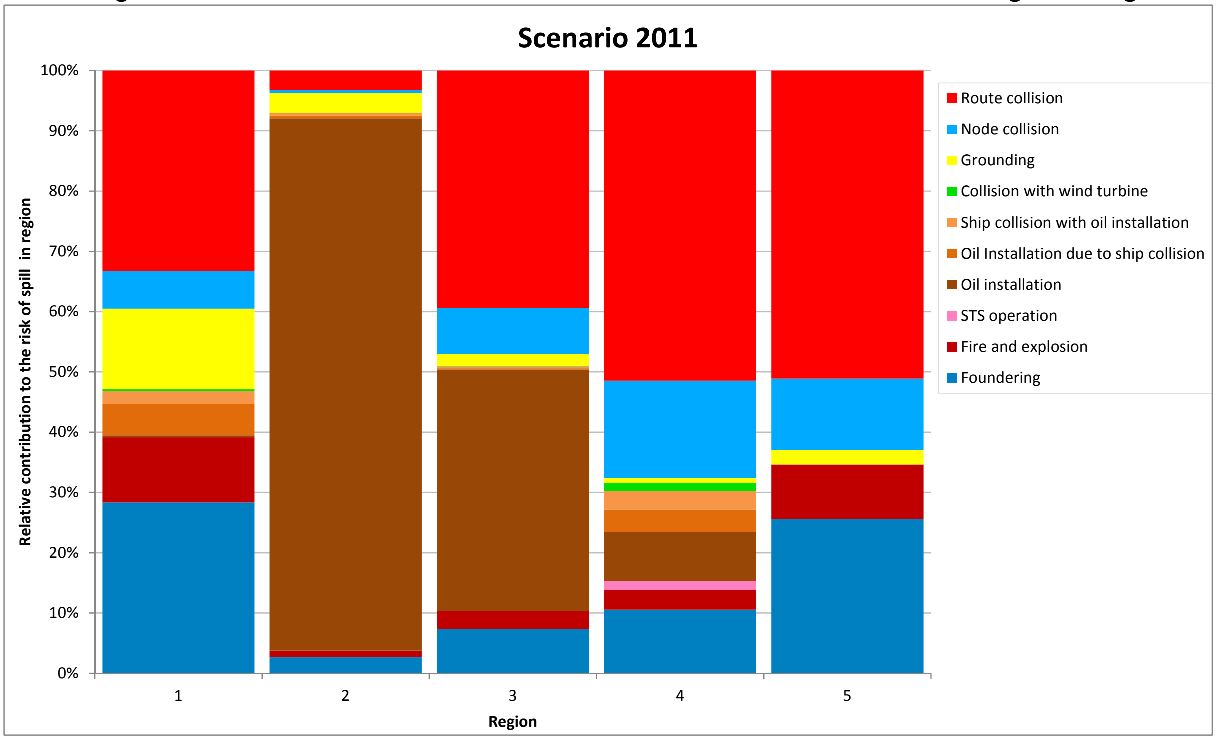


Figure 6-6 Overview of the relative distribution of the risk from various accident types for the regions in the Bonn Agreement area for scenario 2011

An overview of the risk of all sizes of spills in the analysis can be seen in Figure 6-7

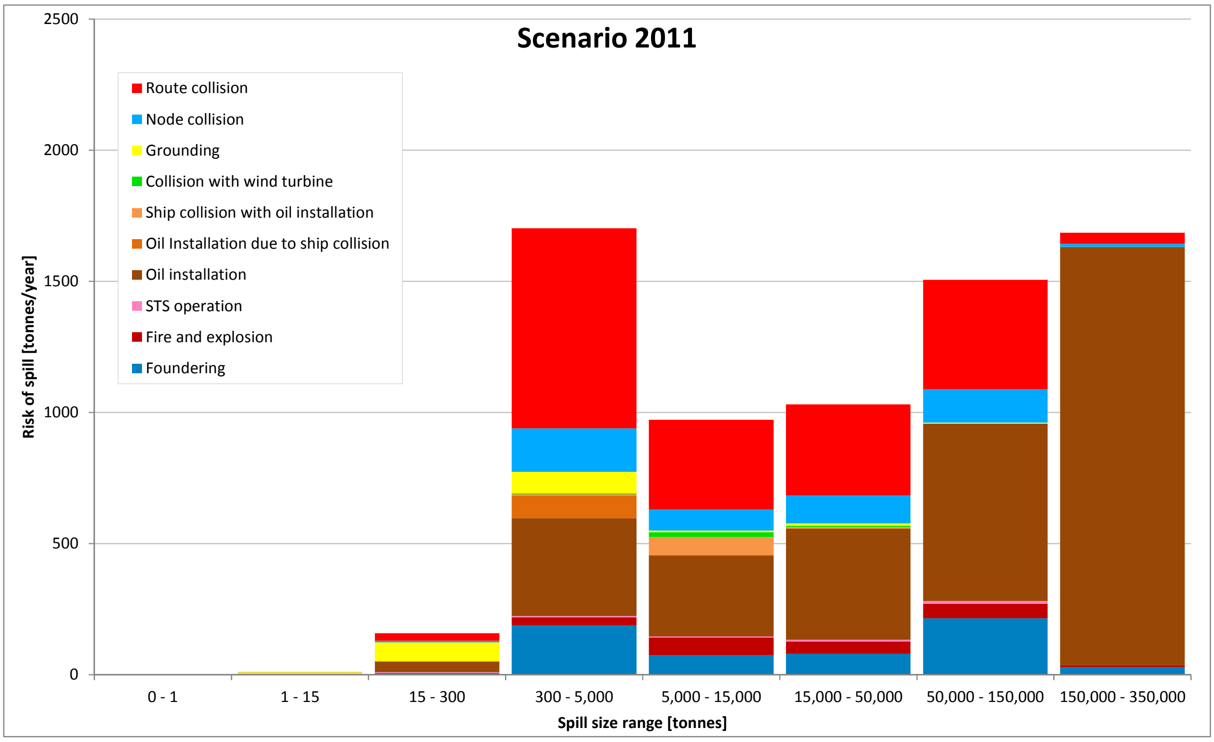


Figure 6-7 Overview of the risk of various spill sizes divided into various accidents for scenario 2011

6.2 Scenario 2020

The 2020 scenario includes the construction of new wind turbines and redistribution of traffic on this basis, implementation of new risk reducing measures including new TSS and the general development in ship traffic and ship sizes. For the traffic scenario 2020 the resulting risks for small/medium spills in tonnes per year is shown in Figure 6-8.

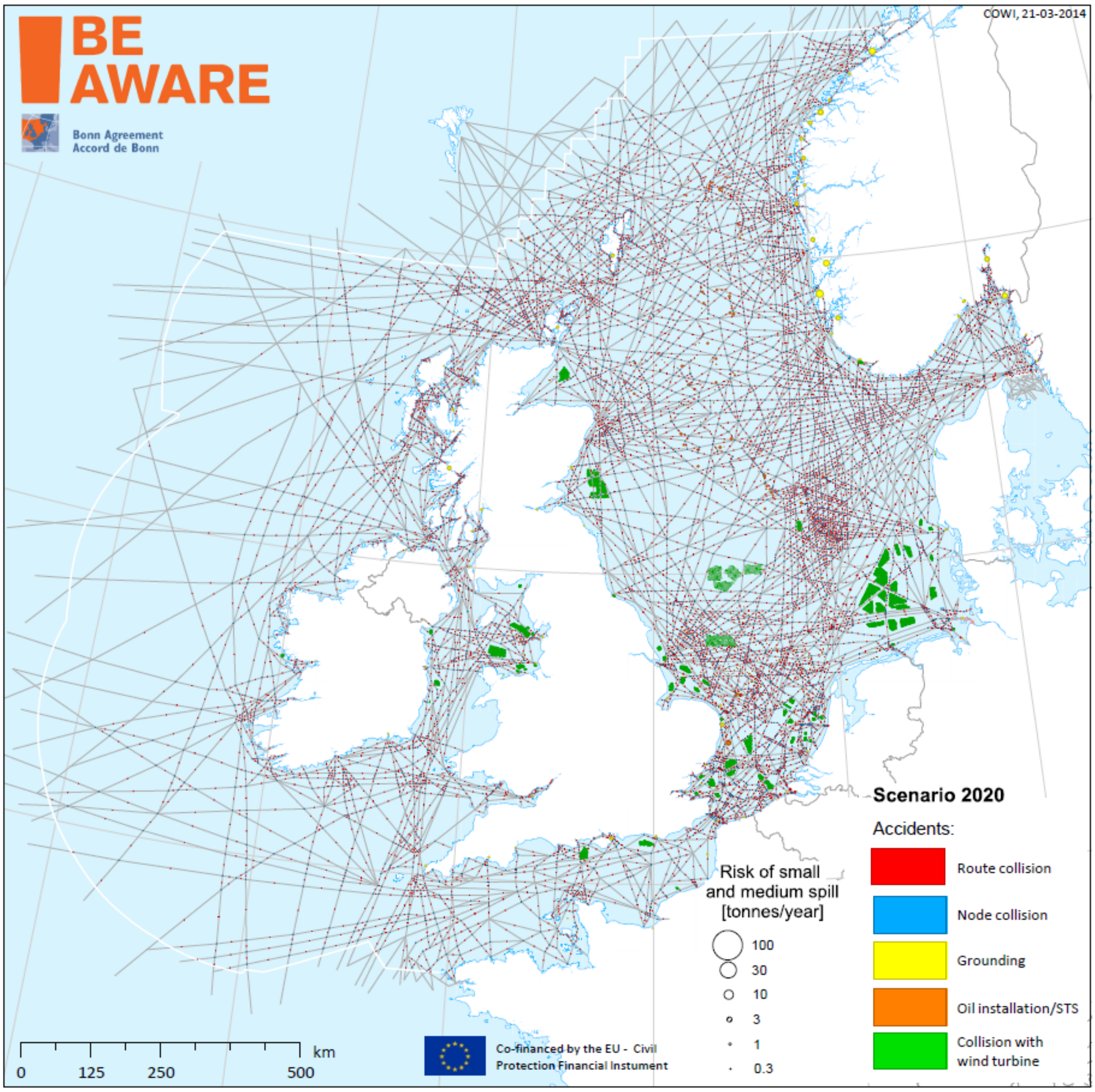


Figure 6-8 **Risk[7] of spills less than 300 tonnes for scenario 2020 in tonnes per year. A risk bubble of 10 tonnes/year could relate to a spill of 100 tonnes with a return period of once every ten years.**

Compared to the 2011 scenario the construction of wind turbines gives an additional risk for the 2020 scenario. This additional risk contribution comes from both the possible ship collisions with the turbines but also from the vessels that after completion of the turbines will need to sail around the park and therefore closer to other vessels.

For the traffic scenario 2020 the resulting risks for large spills in tonnes per year is shown in Figure 6-9.

[7] In calculating the frequency of accidents at the entrance to the Elbe in the German Bight the effect of pilotage was not included.The frequencies in this area have therefore been hatched to indicate this omission. These frequencies will be recalculated in the BE-AWARE II project.

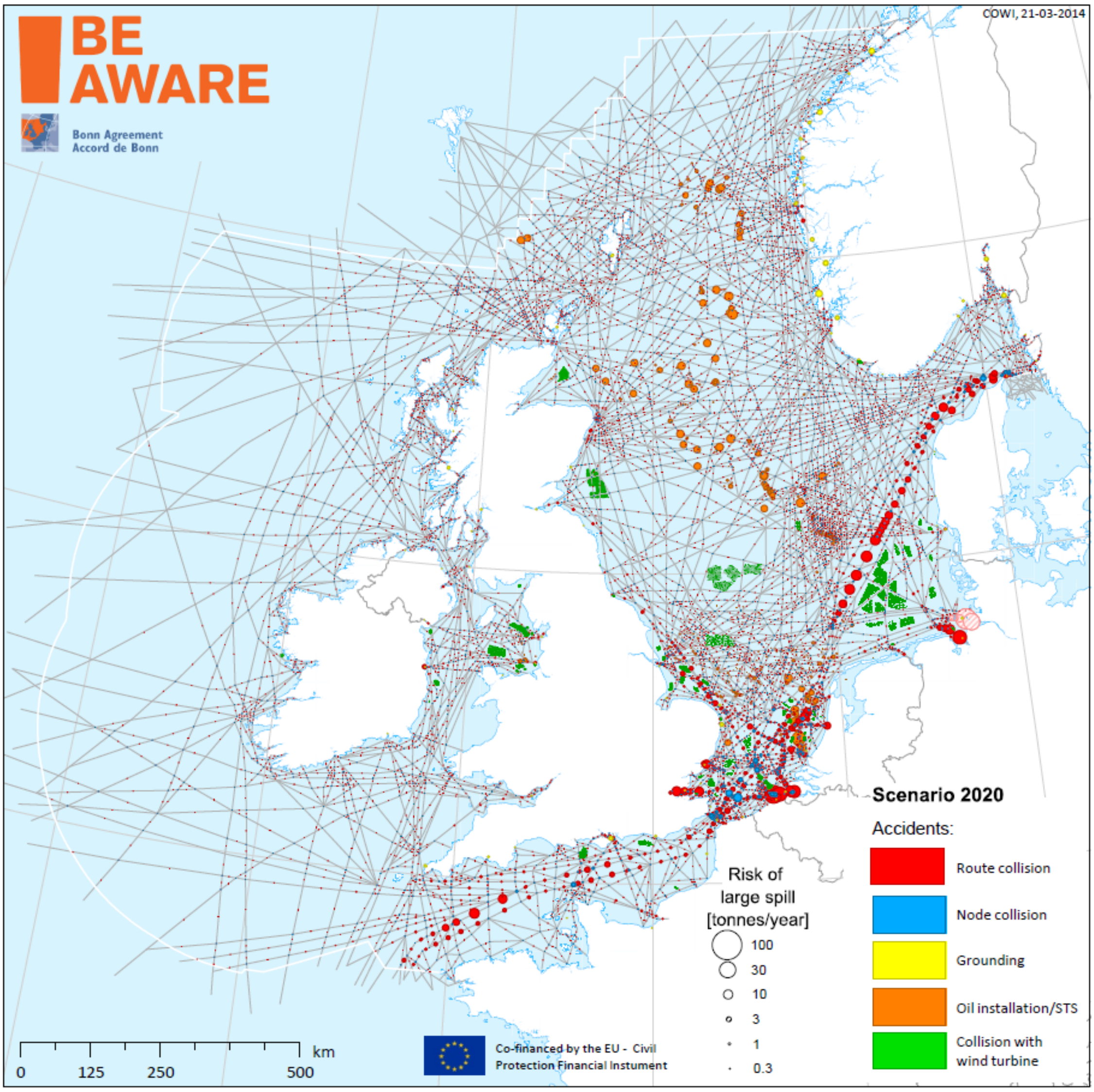


Figure 6-9 **Risk[8] of spills between 300 and 5000 tonnes for scenario 2020 in tonnes per year. A risk bubble of 30 tonnes/year could relate to a spill of 3000 tonnes with a return period of once every hundred years.**

It is clear that the additional wind turbines will increase the risk for 2020 compared to the 2011 scenario. The overall distributions of the risks have not changed significantly. Variations of the ship-ship collision risks as a result of the changed traffic are however seen more locally.

For the traffic scenario 2020 the resulting risks for very large and extreme spills in tonnes per year is shown in Figure 6-10.

8 In calculating the frequency of accidents at the entrance to the Elbe in the German Bight the effect of pilotage was not included.The frequencies in this area have therefore been hatched to indicate this omission. These frequencies will be recalculated in the BE-AWARE II project.

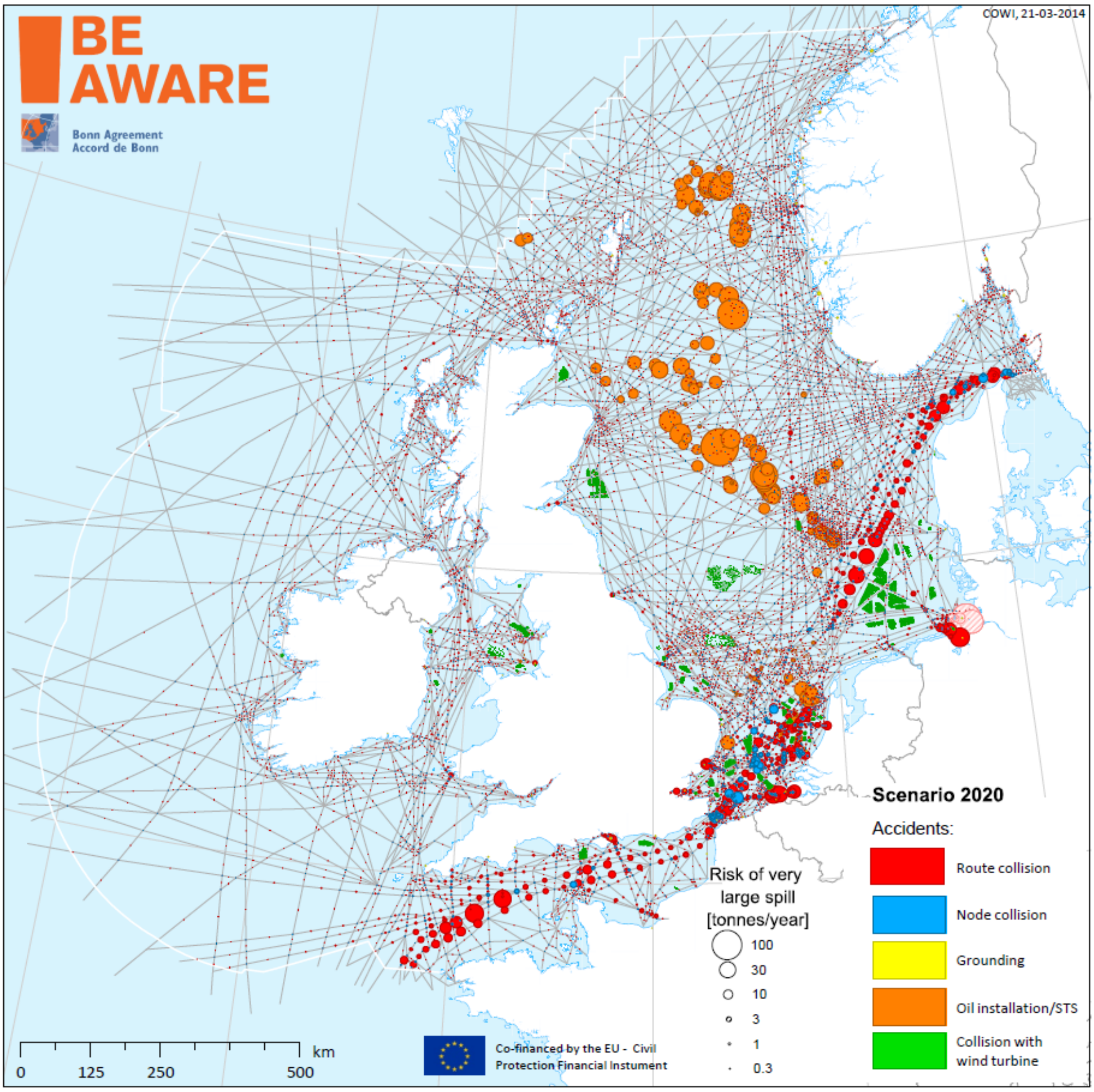


Figure 6-10 **Risk[9] of spills larger than 5000 tonnes for scenario 2020 in tonnes per year. A risk bubble of 100 tonnes/year could relate to a spill of 50000 tonnes with a return period of once every five hundred years.**

Looking at all sizes of spills over the BE-AWARE area divided into the sub regions the regional differences becomes clearer. This is seen in Figure 6-11.

[9] In calculating the frequency of accidents at the entrance to the Elbe in the German Bight the effect of pilotage was not included.The frequencies in this area have therefore been hatched to indicate this omission. These frequencies will be recalculated in the BE-AWARE II project.

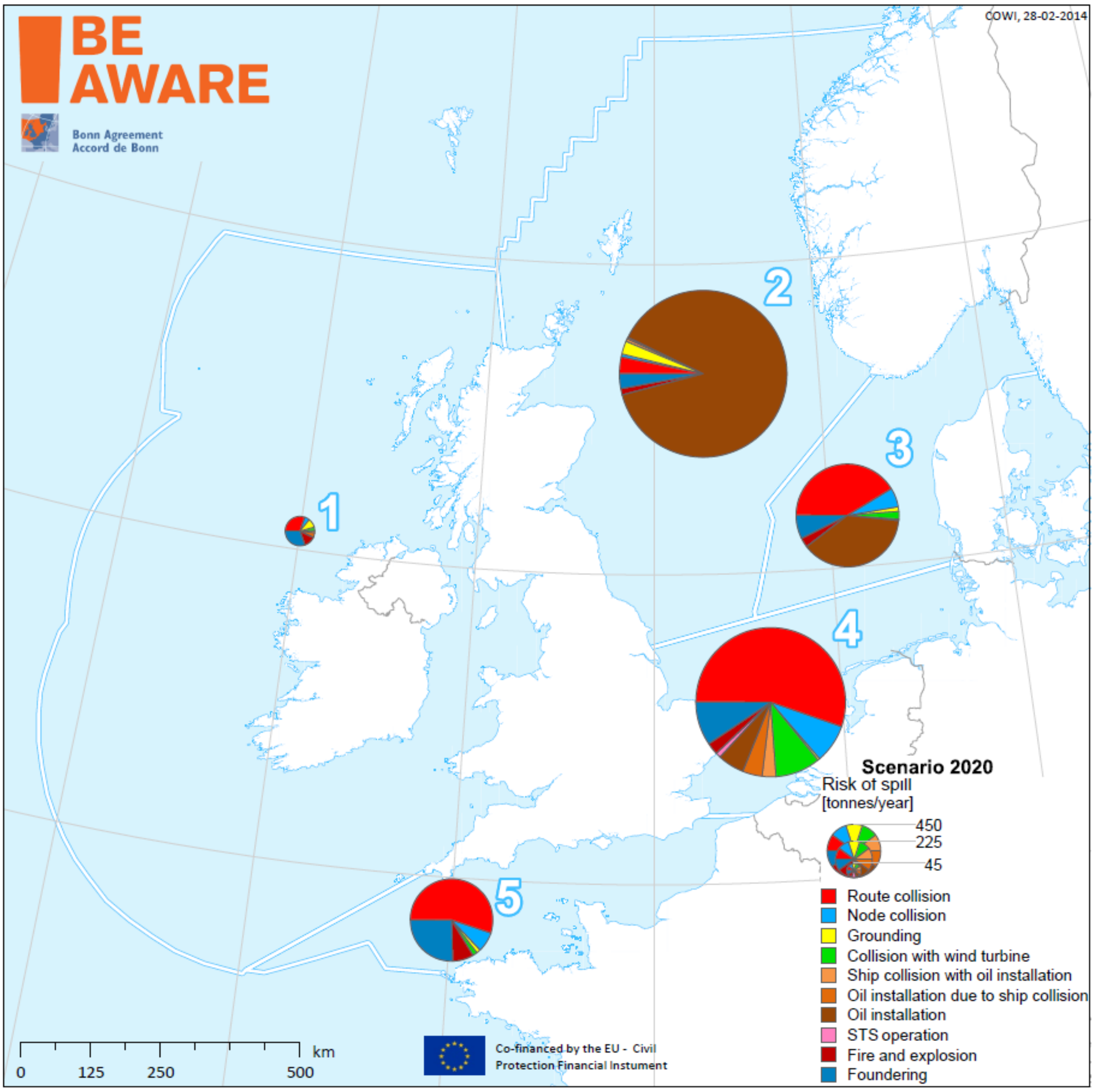


Figure 6-11 Risk of all sizes of spills divided into the defined regions for scenario 2020 in tonnes per year

The largest increase in the risk from scenario 2011 to scenario 2020 is seen in area 4. This is partly caused by the increase in traffic and the high intensity of the traffic in the area. Risk reducing measures such as new TSS has however limited this increase. The development within wind energy in the area also has a significant impact for scenario 2020. The development of wind turbines is not limited to area 4 and the additional contribution to the risk from an impact with these can also clearly be seen in areas 1, 3 and 5.

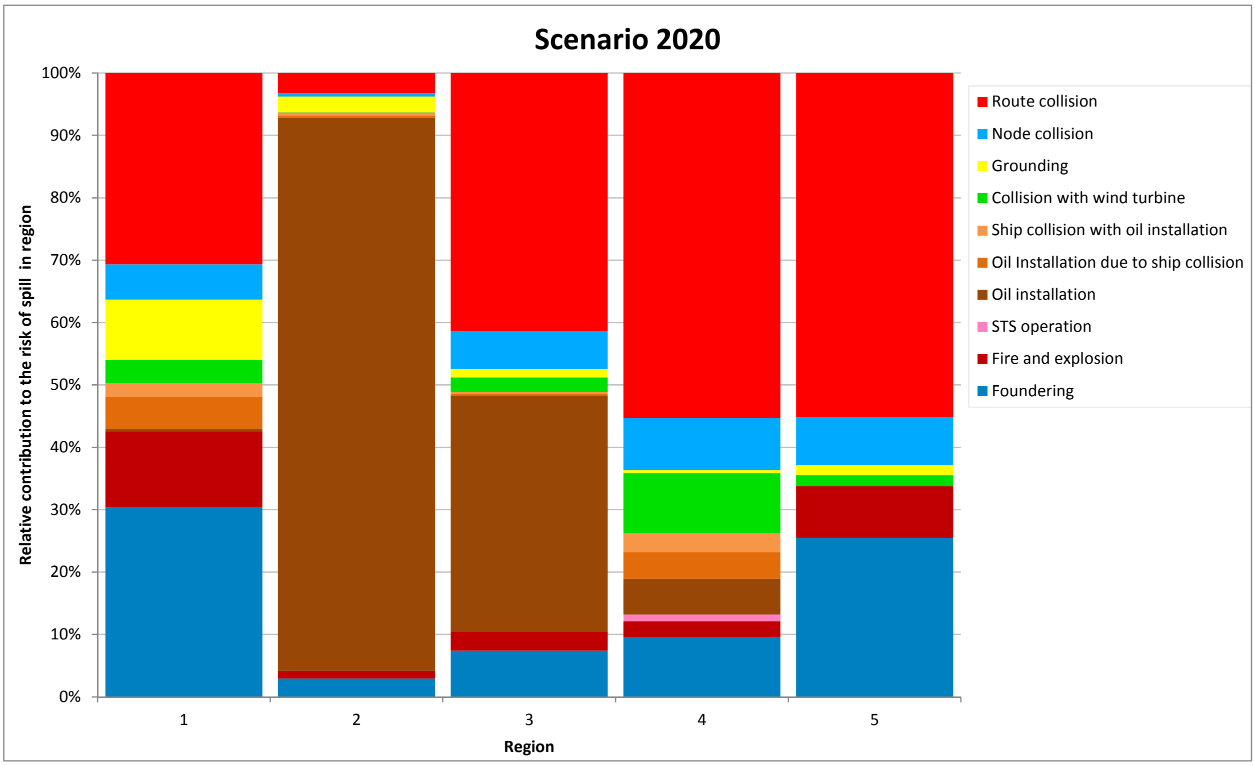


Figure 6-12 **Overview of the relative distribution of the risk from various accident types for the regions in the Bonn Agreement area for scenario 2020**

An overview of all risks for all sizes of spills in the analysis can be seen in Figure 6-13.

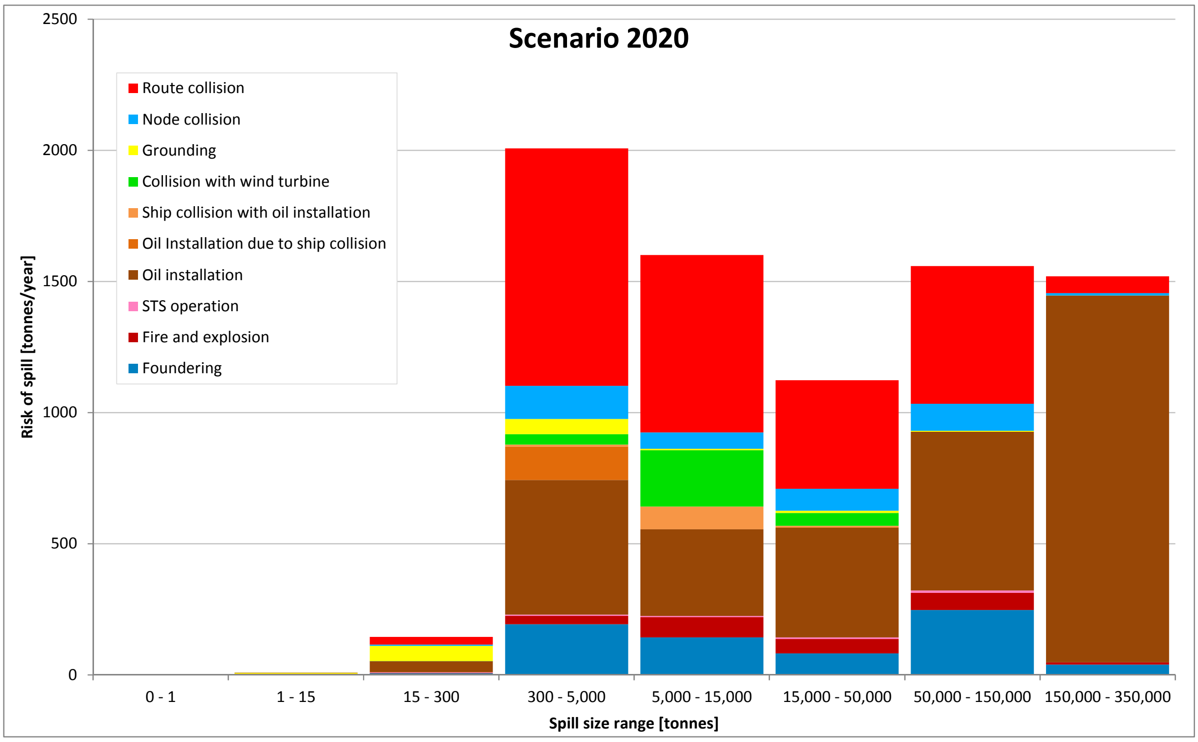


Figure 6-13 **Overview of the risk of various spill sizes divided into various accidents for scenario 2020**

7. Discussion

In the results significant regional differences are seen. Accidents caused by collisions are predicted to be most pronounced in areas with high intensity traffic in combination with narrow stretches or areas with crossing traffic or complex traffic patterns.

Grounding accidents are based on the grounding statistics in the period 2002-2011. There are significant local differences in the statistical background data and this is also apparent when looking at the results of the grounding accidents.

In the Bonn Agreement area the extremely large spills are dominated by rare events such as blow-outs from offshore installations. Even though the return period of such an event is high the size of an eventual spill does make these results very visible when looking at risks in terms of average annual spill.

Large spills can also come from offshore installations, but overall the largest contributor is the outflow of cargo as a result of collisions with large tankers although the probability of this event is low.

Minor and medium size spills are typically from accidents where the vessels have only sustained minor damage or from a leakage. Groundings mainly contribute to the overall risk with minor and medium size spills.

The frequency of collision accidents are mainly spread along the areas of the North Sea with the highest amount of traffic. Groundings are more dependent on local weather phenomena and bathymetry and the grounding model is based on representative points prone to these accidents. Foundering and accidents with fire and explosions are assumed to be distributed evenly in the area based on the distance sailed, thus it is only dependent on the development in the traffic.

There are significant differences both overall and on a regional level between the two scenarios 2011 and 2020. This is caused both by the changes in ship traffic, the development in the ship sizes and also the development in Risk Reducing Measures. The amount of traffic is primarily increased and congestion of vessels adds to the risk. The development of offshore wind farms also increases the risk of a collision with individual turbines significantly in the 2020 scenario compared to the 2011 scenario.

8. Abbreviations

8.1 Table of Abbreviations

AIS	Automatic Identification System
EEZ	Exclusive economic zone
IMO	International Maritime Organisation
LR	Lloyd's Register
RRM	Risk-reducing measure
STS	Ship-to-ship transfer

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