THE DANISH SOLUTION: A BLUEPRINT FOR CLEAN SOIL

An introduction to the Danish soil remediation solution
In Denmark, we have developed solutions to soil contamination issues for more than three decades; and the results show that the solutions work. Denmark is better equipped than ever to manage soil contamination towards a sustainable future. This publication will give you the key to our approach.

The early 1970's were central to how we manage environmental challenges in Denmark, as visible signs of the effects of industrialization became a wake-up call for the entire country. Denmark faced serious environmental problems. Fish lay dead in inland seas and rivers, and the groundwater was seriously polluted. The latter is particularly problematic, in a country, where drinking water is supplied almost entirely from our groundwater resources.

For soil contamination, we needed to provide a framework for identifying and prioritizing soil-contamination sites, while at the same time developing green technological solutions to remedy them.

Mapping as a first step to clean soil
But where to begin? In the early 1980s, we had no overall experience with soil remediation. We were literally entering uncharted territory and as a consequence, we initially began by mapping contaminated sites.

Today, we have identified more than 35,000 Danish properties and sites that have been classified as either contaminated or potentially contaminated.

Action based on four priorities
Subsequently we have developed methods to assess, which sites need urgent attention, and which can wait.

The regional authorities prioritize their remediation efforts towards:

- Contaminated sites threatening our groundwater resource.
- Contamination where evaporation from the soil is causing a health risk.
- Sites where there is a risk of human contact with the contaminated soil.
- Contaminated sites posing a risk to nature protection areas and our lakes, fjords, streams and rivers.

Developing innovative solutions
In the Danish approach, it has been important to ensure that public and private actors have the best possible conditions to adopt new green technologies and find new solutions to soil contamination challenges.

With the tasks and priorities identified, the public authorities in Denmark have been able to support and fund new innovative projects in collaboration with the private sector and universities. This has enabled us to develop unique solutions to different soil contamination challenges.

The public involvement has also ensured a high level of data transparency, as all innovations have been made publicly available, along with the data from the site mapping and investigation processes.

Who foots the bill?
To ensure continued clean-up of contaminated soil, we have had to address the issue of responsibility and financing. With potentially thousands of contaminated sites across Denmark, the public coffers would quickly run dry if the authorities alone were to finance remediation efforts on all property.

Therefore, the company or contractor responsible for damage to the environment is also responsible for remediating it. However, in cases where it is not possible to impose an environmental responsibility, the public authorities finance the remediation project.

The Danish recipe for soil remediation
We still have contaminated sites in Denmark, and we will for many years to come, but we are well underway in dealing with the task. We have found a framework for identifying and prioritizing soil-contamination sites, and we are continuously developing green technological solutions to remedy the sites.

The goal is a sustainable future without soil contamination - this publication contains our recipe to reach it.

I trust you will find plenty of inspiration.

Kirsten Brosbøll  
Minister for the Environment  
December 2014
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GETTING SMART ABOUT CLEANING OUR SOIL

Denmark is a small country in which groundwater is the primary source of drinking water. With contaminated sites in their thousands, it has been paramount to develop smart ways to identify and prioritize which sites to remediate. Here are the key components of Denmark’s unique soil remediation system.

In the autumn of 2014, the second phase of one of Denmark’s biggest soil remediation projects began in the wind-swept dunes on the country’s North Sea coast. The soil contamination in the Kærgård Plantation took place between 1956 and 1973, when the Grindstedværket chemical plant released up to 340 tonnes of chlorinated solvents into Grindsted stream and the neighbouring plantation.

Now, 40 years later, the regional authorities of Southern Denmark are in charge of the massive operation, where so far two pits of contaminated soil have been excavated and a further two will be remediated during phase two. When phase two is completed, the final two pits will remain for remediation.

Although on a large scale, this is a good example of how all Danish soil remediation works.

A five-step approach to clean soil
The first thing to notice is that the regional authorities are in charge of soil remediation. In serious contamination cases, like the one in Kærgård Plantation, the national authorities have sometimes stepped in to assist the remediation efforts, but the rule is that the regional authorities are free to prioritize remediation efforts.

The first step towards remediation of contaminated soil is to map potentially contaminated sites. Authorities investigate this by studying data on the historical use of specific sites. This means surveying for specific company types like gas stations, gasworks, chemical companies, metal goods producers, wood preservation manufacturers, pesticide producers and users, or dry cleaners. Sites can also be included in the mapping effort due to reports from companies or property owners who detect contamination on their property. This mapping effort has been ongoing since the early 1980s and has so far resulted in more than 35,000 sites categorized as “contaminated” or “potentially contaminated”.

From suspicion to certainty
At stage one, the initial mapping is of course based on a suspicion of possible soil contamination. Therefore, each site mapped at stage one is subsequently subject to a preliminary investigation. The public authorities finance these preliminary investigations, and the investigations themselves are often carried out by private consultancies.

All data gathered from the investigations are collected in a national database, and the site is classified as a “stage two knowledge site”.

The preliminary investigation is designed to determine whether the site may pose a risk to human health, water bodies, natural habitats or the groundwater. If this appears to be the case, an in-depth investigation is launched.

Testing soil thoroughly before remediation
If the suspicions are not allayed by the preliminary investigation, and the pollution might pose a threat to the environment or human health, a more thorough, indepth investigation of the soil is carried out.

These investigations are carried out by qualified professionals, who follow guidelines from the Danish Environmental Protection Agency to prevent inadequate sampling and minimize the risk of deliberate cheating.

The investigation aims to map the extent of the contamination, quantify the risk to human health and the environment as well as suggest a remediation measure. When the investigators are done with this investigation, the regional authority decides whether remediation is necessary or not.

If remediation is deemed necessary, the work will then commence.

Depending on the type and extent of contamination, the remediation can take place at the contaminated site (in-situ) or by transporting the contaminated soil to a facility for treatment (ex-situ).

The remediation can be financed by the public authorities or as a voluntary remediation by private building developers. In the latter case, the preferred measure will often be to transport the soil for ex-situ treatment. The public authorities traditionally sets high standards for remediation measures, in order to stimulate eco-innovation that benefits the public health as well as the environment.

New uses for purified soil
Once the remediation measures have been completed, the purified soil will be put to good use. For example as coastal protection, landscape modelling or as noise barriers along roads with heavy traffic.

Danish legislation also has a provision that requires building developers to report movements of soil from classified areas in a national register.

Soil quality criteria guide efforts
When is society satisfied with a remediation effort of a contaminated site? Denmark has guideline criteria for soil, groundwater, water bodies and evaporation to help guide soil remediation efforts. These four forms of criteria are used to help evaluate the severity and extent of a site contamination. The soil quality criteria set limits for a number of substances to ensure that the soil can be used freely and without fear of exposure, for example on farmland, in private gardens, at daycare centres and on playgrounds.
The groundwater quality criteria are applied for contaminations that pose a risk to the groundwater resource. Because of a relative shortage of surface water, Denmark has always relied heavily on groundwater for its water supply. Groundwater is less exposed to pollution than surface water, the water is of higher quality, and it requires less treatment.

**The Danish approach to soil remediation owes its success to three key components: knowledge, regulation and technology.**

Each has been crucial in pushing forward innovation and remediation efforts towards a future with clean soil.

We will elaborate on these three components in the following sections.
Water sample. Protection of the groundwater resource is crucial in Denmark, as the country relies on it for drinking water.

Photo by The Information Centre on Contaminated Sites
Research into the effects of soil contamination, and new methods to remedy these effects, have been pivotal in the Danish solution. Knowledge institutions routinely contribute to remediation projects, and data about contaminated sites is collected and made available to professionals and the public in a national database.

When prospective buyers of a house in Denmark want to know whether their new home sits on contaminated soil, they can access the “Area Information” database on the Environmental Portal. They can then download a soil contamination certificate on the property free of charge.

The Danish Environmental Portal is an online database, created by a partnership consisting of the Danish municipalities, the five regional authorities and the Ministry of the Environment. It aims to aid the authorities in performing their regulatory functions.

The service for private citizens is just one visible example of how the data gathered on soil contamination is benefitting continued efforts for cleaner soil.

The data in the database has been collected over decades and it is a powerful tool for public authorities and soil professionals alike.

The Regional Information Center on Contaminated Sites
Along with the database, authorities and soil professionals have a powerful tool in the Regional Information Center on Contaminated Sites (RICCS). The Center is run by the five Danish regional authorities and it collects, analyses and disseminates knowledge on soil and groundwater contamination.

The Center is a platform on which regional authorities develop and exchange knowledge on best administrative practices and new technology.

The Center also conducts a number of development projects and the results are made public as reports or tools for soil contamination professionals.

The Center also has an educational responsibility in that it holds specialized courses for regional soil professionals. It also monitors all sources of literature on soil contamination in Danish, and these are added to a database (called LIX).

Finally the Center issues a magazine four times a year, solely dedicated to new knowledge on soil contamination.

No commercial interests help knowledge sharing
Because the regional and national authorities have no commercial interest in the knowledge obtained from the large number of projects they are responsible for, they function as a knowledge provider for private companies.

This ensures that companies are always well-informed about the newest technologies and developments within the field.

It has also ensured a vibrant Danish private sector within soil contamination and it is estimated that private companies in the sector employ around 1,000 people.

Ongoing research at national level
How do you detect gas from contaminated soil intruding into the indoor air? Environmental Project number 1590 examines the possible methods to do just this.

The Danish Environmental Protection Agency regularly funds such research projects within the field of soil contamination. A condition for this funding is often that the results of the projects are made available to the public.

The projects provide valuable new information that supplements the knowledge and research conducted by Danish knowledge institutions. Regional development benefits as well.

Universities are crucial
Soil contamination, investigations and remediation measures often demand technology that has not yet been developed. Therefore, Danish knowledge institutions play a key role in developing and testing new technology.

Integrating the Danish universities and knowledge institutions into the soil contamination value chain ensures the highest level of professional expertise.

DKJORD – the database on Denmark’s soil
The regional authorities collect huge amounts of data. Data from the ongoing mapping of contaminated and potentially contaminated sites in Denmark as well as the many site investigations, test and pilot projects, and actual remediation projects.

This data is uploaded and stored in a central, database called ‘DKJord’ (‘DK Soil’). In addition, data about groundwater, geological soil composition, and historical land use is also collected and used by the public authorities as well as the private sector. This helps the authorities to make the optimal decisions regarding new remediation projects.

Moreover, the regional authorities have developed a number of IT tools and assessment tools which help them prioritize their efforts.

The data in the database has been collected over decades and it is a powerful tool for public authorities and soil professionals alike.

12: the number of new research papers on soil and groundwater contamination published by the Danish Environmental Protection Agency in 2014.
THE RIGHT FRAMEWORK FOR TACKLING SOIL CONTAMINATION

The Danish Act on Contaminated Soil from 2000 is one of the most comprehensive pieces of legislation on soil remediation in the world. It is the result of years of development for the right legal framework on soil contamination.

Before 1974, and the entry into force of the Danish Environmental Protection Act, it was not unusual for companies to dispose of waste chemicals by dumping barrels into landfills. Little was known about the associated long-term health and environmental risks, but the Act on Chemical Waste Deposits in 1984 changed that. The Act also heralded a massive three-decade effort to remEDIATE soil contaminations.

The Act on Chemical Waste Deposits was the first legislative Bill to be passed which solely addressed soil contamination. The Act charged the regional authorities in collaboration with the municipalities to mapping the existing chemical waste deposits and landfills, and the results showed a total of 500 contaminated sites.

It was estimated that remediation efforts would take 10 years, with a price tag of EUR 50 million.

Introducing the five-step principle for remediation

By 1993, the national mapping effort of contaminated sites showed that the total number of contaminated sites might actually be as high as 10,000, and the estimated costs of remediating the contaminations had skyrocketed to EUR 3 billion.

One very pressing issue was to develop tools to process these sites in a uniform manner so that efforts could be focussed where they were most needed. Therefore, in 1998 the Danish Environmental Protection Agency published a guidance document on how to remEDIATE contaminated sites. The guidance document introduced the five-step approach to tackling soil contamination.

The process is as follows:

- **Mapping:** based on data on historical use of the site (stage-one knowledge level).
- **Preliminary investigation** (stage-two knowledge level): investigation to identify underground storage tanks etc. from historical archives. Soil and groundwater samples are taken to decide whether or not the site is polluted.
- **Further investigations** to find the extent of the pollution and perform a risk assessment.
- **Suggestions** for possible remediation measures if the pollution poses a risk.
- **Remediation.**
- **Operation and control** (if it is a longterm remediation scheme).

The polluter pays principle

For many of the contaminated sites, the question of liability has proved more than difficult. Contamination often occurred years or even decades ago, meaning the perpetrating companies could be bankrupt or closed. Even if the companies are still operating, it is often difficult to establish clear liability for the contamination.

Therefore, it has been paramount to establishment of a clear “polluter pays principle”. The Danish Act on Contaminated Soil from 2000 did just that.

The Act is the most comprehensive piece of legislation on soil contamination to date and it sets out clear criteria for who has to pay for remediation efforts.

For soil contamination committed in the past, the public authorities step in when remediation is not covered by insurance or it has been impossible to reach a settlement on voluntary remediation.

For any new soil contamination, the polluter pays for investigation and remediation.

Soil classification

In urban areas, the soil will often contain traces of diffuse contamination from industrial emissions or traffic. For example lead, cadmium or PAHs.

Cleaning up gasoline retail sites

One such voluntary and very successful arrangement was agreed with the Danish oil industry in 1992.

Nine oil companies operating petrol stations in Denmark jointly established a fund by charging DKK 0.01 for each litre of petrol sold to consumers.

This fund was subsequently used to finance remediation of about 9,800 sites previously used for petrol stations.

The massive task was completed in 2011, when the last contaminated soil excavation was completed.

The arrangement was approved in 1994 by the Danish competition authorities as well as the EU.

On the other hand, the health risks associated with this kind of contamination are negligible compared to other risk factors. However, until 2007 this soil technically had to undergo the same scrutiny as the more classically contaminated sites.

To better focus soil remediation efforts on the truly pressing sites, in 2007 the Danish authorities introduced an amendment to the Act on Contaminated Soil, exempting lightly contaminated soil from diffuse sources within city limits from the mapping requirement. At the entry into force of the legislation, it was estimated that at least 90,000 sites could be exempted from the mapping requirement. The Danish authorities followed this move with an extensive information effort aimed at citizens and municipalities. The aim was to provide advice on how to minimize risks from lightly polluted sites - e.g. washing hands, using clean soil for cultivation and cleaning vegetables.
**Monitoring the movement of contaminated soil**

Though the mapping requirements have been relaxed for certain types of soil, it is still vital to have up-to-date data on the whereabouts of contaminated soil.

Therefore, the legislation on soil movement introduced an obligation to notify the municipal authorities when soil from urban areas (area classification sites) is moved – for example by contractors. This obligation to report movement of soil already applies to mapped sites and soil from road areas, as this soil has often turned out to be contaminated.

**Screening for threats to recipients**

While soil remediation initially focused on protecting human health and groundwater, in recent years Denmark has also made moves to strengthen the protection of water bodies (coasts, streams, rivers, fjords and lakes).

Currently, the regional authorities are working to screen contaminated sites that may pose a risk to nearby water bodies. This means investigating whether contamination from, for example, metalproducts factories, dry cleaners or old landfills can pollute streams, rivers, lakes or fjords.

The authorities first establish the concentration level of the contamination in question. Afterwards, the distance to nearby bodies of water is established. Thirdly, the screening calculates the dilution of the contamination once it enters the body of water. Lastly, the screening calculates the overall risk of the particular contamination for the body of water.

The screening is expected to be completed by 2019.

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**90,000:**

The number of sites in urban areas exempt from the mapping requirement.
DEVELOPING THE TOOLS FOR THE JOB

New problems call for new solutions. Denmark has developed a framework in which public demand for soil remediation technologies drives innovation. The resulting technologies have been made publicly available to further stimulate innovation and to keep costs low.

How do you remove chlorinated solvents from contaminated clayey soil? This problem has caused headaches for soil remediation experts as remediation technologies that can remove solvents in sand and gravel often fail at sites with clayey soil types.

However, the company NIRAS A/S, in collaboration with the specialist American company Geosyntec Consultants and the Capital Region of Denmark, have developed a solution: removing chlorinated solvents by electrokinesis.

The award-winning technology is a good example of the Danish approach to developing soil remediation technologies.

Innovation with public backing

Authorities in Denmark realised early on that the private sector needed a public driver to stimulate innovation of soil remediation technologies.

Therefore, the government set up a public programme in 1996 to develop clean-up and remediation technologies relating to soil contamination.

Since the programme started, about 292 projects have been initiated, of which 120 have related to testing various remediation technologies.

The remaining 172 projects deal with developing innovative investigation and remediation methods and enhancing general knowledge about soil contamination.

In 2002 the technologies developed under the programme were evaluated and the results showed that the programme is making a considerable contribution to the development of technology in the area.

The benefits of the “Triple Helix”

Crucial in the development of new technologies has been the interplay between public authorities, the private sector and knowledge institutions (Triple Helix).

When public authorities are charged with remediation of a contaminated site, the contractor is often required to develop or use high-tech in situ solutions. Furthermore, private remediation companies are encouraged to form partnerships with research institutions.

National testing sites for technologies

To create optimal conditions for innovation of solutions, the regional authorities have jointly decided to form a common national network of test sites.

The Danish regions obviously have a natural interest in developing new and cost-effective methods to tackle the future remediation processes. Moreover, they are obligated to support business development in their catchment area.

The network consists of a number of different test sites in terms of geology, groundwater, and contamination. The sites are open to small-scale as well as large-scale testing of a wide variety of different types of remediation processes and technologies.

Millions of EUR to develop new technologies

At the same time, the regional authorities are co-funding a wide range of test and demonstration activities which involve stakeholders from the knowledge sector as well as private companies and international stakeholders from all parts of the world.

In 2012, the regional authorities invested a total of EUR 2.2 million on development projects, and a total of sixty development projects had been set up, many of which were being run through public-private partnerships.

The Danish Environmental Protection Agency also administers a pool for development of technology within the field of soil and groundwater contamination. The pool has been established to fund projects for EUR 0.8 million in 2015.

Examples of current development projects include:

- Jet injection into glacial clay till deposits
- Isotope fractionation
- Phytoremediation of heavy metals using tropical ferns
- Electrokinetic remediation of heavy-metals-contaminated soils
- Horizontal directional drilling
- New methods for indoor climate remediation

60: the number of development projects running in 2012 as a result of the regional authorities’ commitment to developing new soil remediation technology.
CHLORINATED SOLVENTS: THE SKULDELEV SITE

A major contamination with chlorinated solvents located beneath a city pond forced the regional authorities to get creative.

For ten years between 1958 and 1968 a metal manufacturer in the city of Skuldelev used chlorinated solvents to degrease metal. The wastewater was legally directed into the sewer.

Forty years later, authorities began investigating the site and uncovered a major contamination with chlorinated solvents beneath the city pond.

The main risk was from evaporation from the contaminated site, which posed a health risk to nearby residences. Furthermore, the authorities wanted to stop the contamination from polluting the groundwater resource.

Solution: electrokinesis and iron

The remediation effort began in 2008, and the regional authorities have employed a number of measures.

More than 1,000 litres of undiluted contamination with chlorinated solvents was pumped away from beneath the pond.

Subsequently the soil was cleaned using heat treatment, removing half a tonne of chlorinated solvents.

Here too the company Niras tested a new remediation technology using electrokinesis to clean the soil. This technology has since gone on to win awards.

Furthermore, the regional authorities used a technology where unique iron compounds were added to the contaminated soil to break down the contaminant compounds. The method involves adding a special kind of clay (bentonite) and iron particles.

Finally, the regional authorities took measures to secure several of the adjoining houses from vapours from the contamination. The solution consists of constructing new flooring that allows for ventilation beneath the houses.

Results: restoring the city pond

The last part of the remediation effort consisted of sealing leaks in the sewer to minimize the risk of evaporation from the contaminated soil.

After the remediation, the pond will be restored but the effort will continue in other affected parts of Skuldelev.

1,000 litres

The amount of undiluted contamination pumped from beneath the pond in Skuldelev.
Previously a major gasworks in Denmark’s capital, Copenhagen. Now the previously heavily contaminated site is hosting a cultural center and recreational area for Copenhageners.

For nearly a century the gasworks, Østre Gasværk (Eastern Gasworks) was in operation in Copenhagen. Built in 1878, the gasworks was expanded several times with new gas containers until it was decommissioned in 1969.

By the end of the 1980s the authorities decided that the site needed remediation, but investigations revealed such heavy contamination, that it was decided to seal the site and capture evaporating gasses.

Solution: Biological water treatment plant
Previously purification of contaminated groundwater from gasworks has proved more than difficult. The water typically contains a complex mixture of organic and inorganic compounds that are hard to extract.

Therefore, the authorities established a biological water treatment plant on the gasworks site in 2002.

The facility uses new method to purify contaminated groundwater by adding pure oxygen before leading the water through a sand filter.

Results: Restoring the city pond
And the methods has proved very efficient in removing tar compounds, like BTEX, napthenes, PHAs, phenols. The purification process gets rid of between 95 and 99 percent of these compounds at an estimated price of EUR 1-2.5 per cubic meter of contaminated water.

The technology is less efficient in removing ammonium compounds and cyanide from the contaminated water. The plant has managed to remove between 30 and 65 percent of the cyanide from the groundwater.

Soil sampling at contaminated site. Photo by Grontmij A/S.
PREPARING FOR EXTREME WEATHER

Sites that were previously considered not to be of any significant risk to the environment may pose a risk in the future due to climate change. The Danish authorities are working to tackle soil contamination in a future with increased precipitation. Moreover, other challenges need to be addressed as well.

Increased rain in the winter and less rain in the summer. It may seem like a negligible change, but changes in the weather have the potential to alter the risk posed by contaminated sites.

For instance, recent research suggests that more precipitation in the future will result in rising groundwater levels and increase leaching from closed landfills. This does not necessarily result in an increased risk to the environment, but further investigation is needed to evaluate this.

Planning under conditions of uncertainty
One very real challenge when addressing the impact of climate change on contaminated sites is the huge uncertainty in projections. What will the temperature increase be? How much more rain will fall? And when and how?

What seems to be certain is an increased level of precipitation, which means that the current amounts of evaporation, run-off to streams and lakes as well seepage to the groundwater will change.

There is currently a big push from both national and regional authorities to fill this knowledge gap with new research. However, in the meantime the authorities are forced to navigate on the basis of incomplete knowledge.

Near-coastal sites at risk
Current projections suggest that rising sea levels will result in increased flooding. This could result in more leaching from contaminated sites near the coast but the evidence is unclear as to whether this means an increased risk to human health or the environment.

Rising groundwater levels may also pose a risk.

A 2013 study of contaminated sites in the city of Horsens (a gasworks site and wood treatment plant) calculated that rising groundwater levels could result in 10 to 20 percent more leaching of contamination into the nearby fjord.

For this reason, regional authorities are currently being urged to include climate change in their risk assessments of contaminated sites.

New substances demand attention
Apart from the challenge of climate change, the Danish authorities are currently investigating a number of substances that were previously deemed of little concern in relation to soil contamination.

For instance, hazardous perfluorooctanoic acids like PFOA and PFOS have been found to accumulate in the soil in areas used for fire drills because the substances are used in fire-fighting foam.

Arsenic also poses challenges. The chemical has been used in production of sulphuric acid and is sometimes also naturally present in the soil, and can be released to the groundwater resource and, by extension, to the drinking water. Arsenic is hazardous to humans and is difficult to remove from the groundwater.

10 to 20%: the calculated increase in leaching from a contaminated site due to climate change
Oblique gravel sedimentation. Photo by The Information Centre on Contaminated Sites.
FOR A DETAILED MAPPING OF THE DANISH SOIL AND GROUNDWATER REMEDIATION SECTOR AND SPECIFIC CASE EXAMPLES DOWNLOAD THE WHITE PAPER “A COMMON GROUND FOR CLEAN SOIL” HERE

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ABOUT STATE OF GREEN

State of Green is a public-private partnership founded by the Danish Government, the Confederation of Danish Industry, the Danish Energy Association, the Danish Agriculture & Food Council and the Danish Wind Industry Association.


As the official green brand for Denmark, State of Green gathers all leading players in the fields of energy, climate, water and environment and fosters relations with international stakeholders interested in learning from the Danish experience.

Connect through: www.stateofgreen.com

ABOUT THE ENVIRONMENTAL PROTECTION AGENCY

The Environmental Protection Agency is part of the Ministry of the Environment. The Environmental Protection Agency is responsible for legislation and is the authority in charge of major national tasks as well as particularly complex tasks.

The Environmental Protection Agency prepares legislation and guidelines and grants authorisations in several areas. Further duties include the monitoring of chemicals and offshore platforms.

Connect through: www.mst.dk