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WG 3: Environmental challenges

Final report

Bateman Keith, Botnen Helle Augdal, Cameirao Ana, Cianella Roberto, Cinelli Claudia, Covarrubias Villegas Elfride, Dominiczak Aleksander, Fietzek Peer, Georgiev Valentin, Giustiniani Michela, Haeckel Matthias, Lichtschlag Anna, Melinte-Dobrinescu Mihaela C., Niemann Helge, Nunes de Carvalho Maria de Fátima, Obhodas Jamina, O'Neil Nick, Ostrovsky Ilia, Paris Jean-Daniel, Peuble Steve, Rochelle Christopher A., Ruffine Livio, Sedmach Manuela, Sedmach Manuela, Soares Sofia, Spagnoli Federico, Tang Anh Minh, Tinivella Umberta, Vasilev Atanas, Yang Jinhai and WG 3 community

1. INTRODUCTION

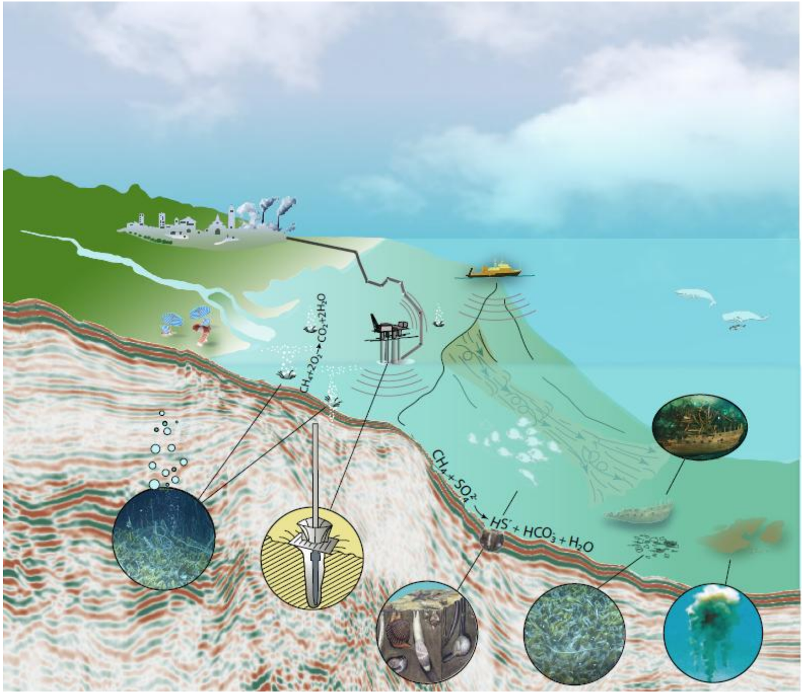
WG 3 has reviewed the environmental challenges associated with methane production from gas hydrates, collaborating with the WGs 1 and 2. Environmental risks are moderate compared to other deep-water operations since gas hydrates and the associated formation fluids do not contain toxic substances. Moreover, blow-out events are not a concern since gas hydrate deposits have low in-situ pressures and are maintained at or below hydrostatic pressure during the entire production process. However, gas hydrates can constitute environmental risks by affecting seafloor stability and triggering methane release (and associated gases) into the water column. In fact, methane is an important greenhouse gas and any large and long-term release of methane to the atmosphere would have an impact on climate change. The lifetime of methane in the atmosphere is much shorter than of CO_2, but CH_4 is more efficient at trapping radiation than CO_2. On a 100-year time scale, the comparative impact of CH_4 on climate change is approx. 28 times greater than CO_2 (IPCC, 2013). Sediments deposited at continental slopes are in some cases stabilized by gas hydrates cementing the grain fabric. Gas production from these deposits may induce slope failure causing severe damage to seabed installations and benthic ecosystems, and undesired methane gas emissions into the marine environment. Leakage of methane gas may also occur during the production process since the overburden sealing layer of the gas hydrate deposits from the marine environment has a limited thickness. It is important to recall that, on continental margins, methane-hydrate accumulations are often associated with gas seeps (Berndt et al., 2014; Marin-Moreno et al., 2013; Phrampus et al., 2014; Roemer et al., 2012a; Roemer et al., 2012b; Roemer et al., 2014; Sahling et al., 2014; Smith et al., 2014; Torres et al., 2002; Westbrook et al., 2009). These seeps may influence the development of oceanic ecosystems on the seafloor. When considering gas production from methane-hydrate accumulations, the question regarding the fate of potential methane release consistently arises as leaks may occur. Such release may have impacts on the ecosystem associated with methane-hydrate settings. In fact, the areas surrounding hydrate deposits, particularly those where gas hydrate are out-cropping on or located close to the sea-bed, often support a large microbial/benthic community – based on direct interaction with the hydrate itself or from gas release. These communities are delicate and could be seriously affected by changes in gas release rates, or exploitation of near seabed hydrates. Likewise, the exploitation of deeper hydrates that results in release of methane gas to the sea bed may result in dramatic changes to any indigenous microbial/benthic community – and whilst small gas releases may possibly stimulate the microbial community it is highly likely that large gas discharges will have a negative impact. Finally, methane may be present in the water column as free gas or dissolved gas. Gas may be released directly at the seafloor due to dissociation of hydrate or as a result of dissolution or dissociation of dislodged hydrate as it rises through the water column (methane hydrate is less dense than seawater). Methane will dissolve in the water column during its ascent, resulting in elevated methane concentrations (Zhang, 2003). Whilst it may be unlikely that methane will reach the atmosphere (except for catastrophic releases; de Garidel-Thoron et al., 2004) the spatial extent (and concentration) of methane in the water column will depend upon the depth and the local current. Elevated methane concentrations in the water column may have an impact on the microbial/benthic community (i.e., Boetius and Wenzhöfer, 2013; Steeb et al., 2015), or have implication in ocean acidification.

Therefore, in a production scheme, there is a need to better characterize the potential environmental challenges, and efficiently quantify the amount of methane discharged into the water column as well as its influence on the living communities in the surrounding area. From an environmental perspective, the Black Sea could serve as ideal test area for methane production exercises since the seabed is covered by anoxic waters inhibiting the development of benthic ecosystems.

WG 3 aimed to define an environmentally sound monitoring strategy and assess whether the legal framework regulating the exploitation of offshore oil and gas deposits needs to be adjusted to account for the specific environmental risks associated with the gas production from hydrates. To achieve the aims the WG 3 participants have:

- Assessed how slope stability may be compromised by gas production from hydrates under different geological boundary conditions;
- Identified suitable precursors/changes for slope failure to be targeted in a monitoring program;
- Developed a generic strategy for environmental baseline studies and the environmental monitoring of gas production from hydrates;
- Evaluated whether national legal frameworks regulating offshore oil & gas production are appropriate for gas production from hydrates using Romanian and Bulgaria systems as a case study.

In the following sketches, all topics related to WG3 are summarized.



The pictures related to methane panache and ecosystems are kindly provided by Dr. Karine Olu, Chief of the expedition of the WACS cruise (Ifremer Copyrigth).

2. HAZARDS

The hazards related to gas hydrate production has been identified, discussed and classified in three categories as followed:

- seabed deformation hazard;
- gas release hazard;
- production related hazard.

2.1 Seabed deformation hazard

The current understanding of phenomena involved in gas hydrate formation and the physical properties of hydrate-bearing sediments are still unclear, as described in the review paper of White et al. (2009). Formation phenomena include pore-scale habit, solubility, spatial variability and host sediment aggregate properties. Physical properties include thermal properties, permeability, electrical conductivity and permittivity, small-strain elastic P and S wave velocities, shear strength and volume changes resulting from hydrate dissociation. The magnitudes and inter-dependencies of these properties are critically important for predicting and quantifying macroscale responses of hydrate-bearing sediments to changes in mechanical, thermal, or chemical boundary conditions. These predictions are vital for mitigating borehole, local, and regional slope stability hazards, because the gas hydrate production can have small (*e.g.* hydrate dissociation) and large (*e.g.* sliding, induced seismicity) impacts on the seabed deformation.

Sediment strength and the extent to which sediment deforms under a load are critical inputs for the analysis of potential failures around wells (Masui et al., 2008; Rutqvist and Moridis, 2007) and for evaluating seafloor stability over larger length scales (Nixon and Grozic, 2007; Sultan et al., 2004a). The presence of methane hydrate increases stiffness, enhances pre-failure dilation, and leads to higher strength. White et al. (2009) described shear resistance and dilation mechanisms occurring at different levels of hydrate saturation in the pore space. Moreover, effective stress strength parameters can depend strongly on the hydrate formation history (White et al., 2009). This suggests that a deep knowledge about the geological setting, and its temporal evolution are required.

In addition to sedimentological, physical and geotechnical studies, sea floor morphology should be considered because of its influences on the seafloor stability. Accurate multi-beam swath bathymetry, high-resolution side-scan sonar data and high-resolution seismic records can be indispensable to model the seafloor stability. Yamamoto et al. (2014) suggested that it is important to monitor the seafloor subsidence and instability by using a seafloor deformation monitoring devices, particularly important if the gas hydrate is present in the shallower sediments.

Regarding the influence of temperature change on hydrate stability, it is worth underlining that the time scale of potential hydrate exploitation and natural changes are different. In fact, recent modelling of the impact of warmimg on West Svalbard of hydrate deposit by Thatcher et al. (2013) suggested that the delay between the onset of warming and the incipient of gas emission can amount to about 30 years.

In conclusion about the seabed deformation hazard, emphasis must be placed on further developing comprehensive *in situ* sediment characterization through borehole logging tools that incorporate the simultaneous measurements of multiple properties from the minimally disturbed material surrounding the probe (White et al., 2009). In addition, continuous monitoring of important indicators on the seafloor such as subsidence should be considered within baseline studies as well as during production processes.

2.2 Gas release hazard

In the following paragraphs, we discuss in details the impact of methane leakage on ecosystem and sea water chemistry. This is currently studied only at natural gas leakage sites.

2.2.1 Impact of gas release on the ecosystem and likelihood to reach the atmosphere

The production of methane from hydrate accumulations involves a perturbation in their stability field to release free methane, the valuable product. Yet, there is no literature dealing with the quantification of methane leaks during production tests and its fate, nor on its impact on the associated ecosystems. However, several studies have been devoted to the consequence of methane release from hydrate destabilization during past climate change (Dickens et al., 1997; Kennett et al., 2003; Norris and Röhl, 1999). They argued that hydrate destabilization contributed to an increased amount of methane in the atmosphere that accelerated climate change. This involves that methane bypassed the water column to reach the atmosphere. However, the assessment of the injection of ocean methane into the atmosphere remains controversial, as such transfer depends on water depth, water biochemical and physical states and other site-specific parameters (Hu et al., 2012; Kessler et al., 2011; Ryerson et al., 2011; Ryerson et al., 2012; Yvon-Lewis et al., 2011; Zhang et al., 2014). Thus, if one really wants to evaluate hydrate-production methane contribution to the global atmospheric budget, it is necessary to have a sound knowledge of the methane fluxes from seeps and to carry out investigation on the processes, which degrade this molecule in the sediments and the water column.

Such investigations are also essential due to their link with fluid migration within the sedimentary column, and the development of living communities which populate those structures (Andersen et al., 2004; Olu-Le Roy et al., 2007; Ondreas et al., 2005; Sibuet and Vangriesheim, 2009).

During its migration in the anoxic part of the sediment, and before being released in the water column, part of the methane is oxidized via a microbial-mediated reaction called Anaerobic Oxidation of Methane (AOM) (Boetius et al., 2000; Borowski et al., 1996, 1999; Joye et al., 2004; Kastner et al., 2008; Niewohner et al., 1998; Reeburgh, 1976; Regnier et al., 2011; Snyder et al., 2007; Yang et al., 2010). This reaction takes place at a specific sedimentary horizon. It allows the mitigation of methane release to the seafloor, and therefore naturally prevents its transfer into the water column. It is coupled with the reduction of sulfate to sulfide, and the resulting redox reaction sustains rich chemosynthetic communities at the seafloor. The latter is divided in three major groups, the Vesicomyid bivalves, Mytilidae and Siboglinid polychaetes (Andersen et al., 2004; Duperron et al., 2005; Olu-Le Roy et al., 2007; Ondreas et al., 2005). Most of them live in symbiosis with bacteria capable of performing specific redox transformations, including those involve in methane mitigation (Cavanaugh, 1983; Nadalig et al., 2002). In addition, the seafloor is inhabitated by large mats of sulfide-oxidizing bacteria that consume the sulfide resulting from the Anaerobic Oxidation of Methane (AOM). These mats are often used as indicators for methane presence/consumption near the seabed. It has been demonstrated that the intensity of the methane flux and its duration over time strongly influence the development of specific chemosynthetic communities (DeBeer 2006, Lichtschlag 2010, Felden 2013). The microbial AOM community serves as an efficient filter consuming a major portion of the ascending methane (Boetius and Wenzhoefer 2013). This microbial filter may also mitigate methane emissions during gas hydrate production.

2.2.2 Methane concentration in the water column as a function of temperature and mixing

Methane from natural gas hydrates can be released either as free gas or as dissolved gas (Gentz et al, 2014), depending on the destabilization process. During their ascent through the water column, part of the methane bubbles is dissolved in the ambient seawater and subsequently can be oxidized by aerobic microorganisms using dissolved oxygen as terminal electron acceptor. This explains the rapid disappearance of CH_4 after the Gulf of Mexico oil spill (Atlas and Hazen, 2011).

Experiments showed that strong vertical density gradients in the water column developing during the warm season may limit the ascent of methane gas to the surface and its release into the atmosphere. During winter, the vertical mixing in the water column is enhanced and consequently methane is released into the atmosphere (Gentz 2014).

Modeling of gas bubble ascent can predict the evolution of bubble sizes and the fractions of methane reaching the surface and the atmosphere under idealized conditions. However, the internal dynamics of large-scale bubble plumes and the interactions with ambient bottom currents and density stratification adds further complexity that is not yet fully resolved by numerical models (von Deimling et al. 2015, Leifer 2015, Wiggins 2015). Hence, hydro-acoustic measurements and further field data are required to monitor and forecast the fate of methane gas released at the seabed and to improve the existing models (Chong et al. 2016).

2.2.3 Sea water chemical and physical properties change (salinity and pH of water)

Dissociation of dislodged hydrate into the water column will result in local changes of the fluid chemistry due to the release of fresh water. However, the extent will dependent on the volume of hydrate dissociation and may have only limited spatial effect on pH and water chemistry including salinity due to subsequent mixing with the seawater. Note that the decreased chlorinity is used as indicator for gas hydrate dissolution in marine sediments. Moreover, in the oxic ocean water column methane can be oxidized by Aerobic Oxidation of Methane, according the reaction (Reeburgh, 2007):

$$CH_4 + 2O_2 \longrightarrow CO_2 + 2H_2O$$

Open ocean water column methane oxidation rates are generally viewed as being quite low, but fractional turnover rates of days and months have been observed in maxima with methane concentrations of ≈ 20 nM which results in an increase in acidity, favoring carbonate dissolution (i.e., Magalhães et al., 2012). Methane release followed by aerobic oxidation may decrease the pH and oxygen content of bottom waters. This may affect pelagic and benthic ecosystems if very large amounts of methane are emitted over an extended period of time (Biastoch et al., 2011).

The AOM occurs below the sediment surface, where sulfate-reducing microbes play an important role. The infiltration of sulfate within the sediment from the seawater (29 mM) leads to profound differences in methane geochemistry in marine systems compared to fresh water system (Reeburgh, 2007). In fact, release of methane below the seabed surface, stimulates the microbial community, and changes the pore-water chemistry as follow:

$$CH_4 + SO_4^{2-} \longrightarrow HS^- + HCO_3^- + H_2O$$

The extent of any impact this oxidation would have, depends on the concentration (*i.e.* the flux of methane released; Gruca-Rokosz et al., 2011).

Numerical models simulating the AOM in marine sediments (Luff and Wallmann, 2003) and the aerobic methane oxidation in the water column (Steinle et al., 2015) should be further enhanced and employed to better understand the environmental impacts of methane leakage induced by gas hydrate production.

2.3 Production related hazard

Exploitation of methane hydrate and production of methane gas from methane hydrate via depressurization, thermal stimulation (Sakamoto, 2008), inhibiter injection (Kawamura, 2006) and gas swapping/exchange have been proposed. With all methods, fluid (gas and water) permeability in the methane hydrate sediments are important factors for estimating the efficiency of methane gas production (see also WG 2 report).

For depressurization, the gas production rate increases with increasing pressure drawdown. However, high-pressure drawdown causes a cooling of the sediment because of the endothermic property of methane hydrate dissociation. Such temperature decrease promotes hydrate formation or hinder its dissociation. The gas production rate then decreases as the sediment temperature decreases (Kamata et al., 2005).

For hot water thermal stimulation, the pressure near the methane hydrate-decomposed region increases (Minagawa et al., 2015).

For gas swapping/exchange, the principle relies on the difference between the hydrate stability fields of the two hydrate formers methane and carbon dioxide in the low-pressure range. One of the main advantages of this method consists on avoiding the geomechanical destabilization of the sedimentary layer as it may happen for the other methods (*e.g*. depressurisation or thermal stimulation). On May 2012, COP oil company (ConocoPhillips) in partnership with US DOE and the Japanese JOCMC completed the first methane-hydrate production test coupled with sequestration of CO_2 on a pilot site in Alaska. The primary objective was to demonstrate the feasibility of a CO_2/N_2 injection into methane hydrate-bearing sediments and to assess the CO_2-CH_4 exchange, together with the storage integrity.

The German gas hydrate initiative SUGAR – Submarine Gas Hydrate Reservoirs was a collaborative R&D project with 20 partners from SMEs, industry and research institutions (information on phase 1 and 2 of the project: http://www.geomar.de/en/research/fb2/fb2-mg/projects/sugar-2-phase/). Results from this project can act as good starting points for the investigation and the assessment of production related hazards.

In the SUGAR II sub-project B2 *e.g.* methods for the production of CH_4 from gas hydrates were investigated in laboratory experiments. These focused on the conversion of the methane hydrate to CO_2 hydrate in the reservoir. Note that the replacement by CO_2 and the subsequent formation of CO_2-hydrate could mitigate the release of fresh water, reducing the impact on the microbial/benthic community. In fact, if large amounts of hydrate are destabilized *in-situ, i.e.* during exploitation of the hydrate then the addition of large volumes fresh water could have a significant effect on the local water chemistry, particularly salinity through dilution of seawater/pore-water.

In general, gas swapping in hydrates is a slow reaction/process. A promising approach to accelerate the exchange reaction and to achieve higher CH_4 production rates is the injection of hot supercritical CO_2 or the combination of this approach with depressurization via separate injection and production wells.

Submarine venting of natural liquid CO_2 and presence of CO_2 hydrates have been recently observed at the Japanese offshore site called Yonaguni Knoll IV hydrothermal field. The two investigated seep sites, Abyss Vent and Swallow Chimney, are located in the Okinawa Trough (1380–1382 m water depths) and are characterized by a few holes in the seafloor emitting hot fluids (Inagaki et al., 2006). The hydrothermal system is part of a sedimentary basin covered by volcanic rocks. A bacterial community has been characterized at different depths in the marine sediments: the bacterial density is high in sediments lying above the CO_2 hydrates (more than 10^9 cells per cm^3) but much lower at the interface between CO_2 hydrates and liquid CO_2 (10^7 cells per cm^3) at a temperature of 4°C.

The two main bacterial groups present in those sediments are:

1. Archae oxidizing methane (ANME) and bacteria reducing sulphates (SRB);
2. Bacteria oxidizing sulfur or/and hydrogen (e.g. *Sulfurovum*, *Beggiatoa*, *Hydrogenovibrio*, *Thiomicrospira)*

The most active bacterial community in the vicinity of CO_2 hydrates-bearing sediments of this site contains anaerobic methanotrophic archaea (ANME) and sulphate reducing bacteria (SRB). At this site, recent observations suggested that CO_2-saturated seawater (between 1 and 1.7 mol/L) inhibit sulfate reduction and anaerobic methane oxidation in the deep-sea sediments (de Beer et al., 2013). While most microbes need to maintain a near neutral cytoplasmic pH and do so even under the most extreme external pH levels, the extremely high levels of CO_2 will pass the membranes, dissipate the ΔpH across the cell membrane, and thus disrupt the cellular pH homeostasis. Moreover, AOM, with its very low energy yield, will not be possible due to end-product inhibition.

The CO_2 hydrate formation which may hinder or trap the movement of CO2 in both the deep and shallow sub-surface may actually provide a long-term storage unit if the original caprock is to fail (Tohidi et al., 2010). A more complete understanding of the effectiveness of the precipitation of CO_2 hydrate to inhibit CO_2 migration in the overburden would be of great value also to the CCS community (Rochelle et al., 2009).

Environmental risks associated with methane hydrate production can strike:

- Rich ecosystems flourishing around outcropping methane hydrate deposits at the deep-sea floor. The associated risk can be: Destruction of these ecosystems (by CH_4 or/and CO_2); c.f. *2. Gas release hazard*.
- Continental slope sediment failures that are often cemented and mechanically stabilized by methane hydrates. The associated risk can be: Destabilization of continental slopes; c.f. *1. Seabed deformation hazard*.

The following measures were proposed by the SUGAR project to account for these potential hazards:

- Outcropping hydrate deposits should not be exploited. Only those deposits that are covered by extensive layers of impermeable fine-grained sediments should be developed. These deposits are not colonized and used by benthic fauna. The impermeable sedimentary apron will also inhibit the release of methane into the environment during hydrate mining.

- Hydrates deposited in steep slope areas should not be developed. Hydrates will only be exploited in even terrain and extensive geotechnical surveys will be performed prior to hydrate production to avoid slope failure.

3. GENERIC STRATEGY FOR ENVIRONMENTAL BASELINE STUDIES

Baseline studies are essential to assess the environmental conditions and, for this reason, they should include the following investigations:

1. Geological characterization, including detailed bathymetry, geochemical, mineralogical and petro-physical characteristics of the sediment and geological structures;

2. Biological community of the seafloor and near seafloor sediments (biocenosis);

3. Biogeochemistry at the sediment-seawater interface;

4. Physicochemical characteristics of the water column especially in relation to oxygenation and acidification, *i.e.* dissolved gasses such as O_2, CO_2, and CH_4 as well as pH, DIC, alkalinity; and nutrients, dissolved species and total Hardness);

5. Cultural heritage, in order to evaluate the possible acceptance of the society, and mapping of human infrastructures.

Note that required information to plan the hydrate production could be provided by literature, while other information could only be obtained through dedicated site surveys or monitoring installations (see also WGs 1 and 2 reports).

The baseline studies could be carried out by autonomous underwater vehicles (AUVs) and/or monitoring vessels, equipped with suitable instruments (echo sounders, hydrophones, chemical sensors, still camera, piston corers, landers, benthic chambers *etc.*) and/or water column monitoring stations (c.f. Fietzek, et al. 2016). This approach would permit to have full areal coverage.

The geological characterization is necessary to evaluate the possible seafloor deformation hazard. The analysis should be:

- 2D and 3D seismic, OBSs or OBC (maybe already available from site survey);
- high-resolution bathymetry/backscatter mapping of the seabed;
- hydro-acoustic imaging of shallow gas accumulations in the seabed;
- geological/petro-physical/geotechnical characterization of the shallow sediments, including paleo-geological history.

To evaluate the impact of gas release on the environment, the following studies are recommended:

- gas bubbles imaging ascending into the water column;
- sampling and analysis, including isotopes, of any ascending gases.
- video/photo imaging of biota at the seabed;
- geochemical characterization of the shallow sediments;
- chemical/physical/biological characterization of the seawater;
- biological integrity;
- oceanography measurements to model the transport of sediments;
- chemical detection of dissolved gas and related parameters in ambient bottom waters;
- chemical and isotopic composition of pore water and dissolved gases (fractionating in order to determine the gas origin and processes in which they have been involved);

- dissolved benthic flux measurements (molecular and isotopic composition of dissolved gases, release or absorption of chemical species on clay) by benthic chamber deployments;
- habitat mapping.

To evaluate the impact of the exploitation on population and human infrastructures, it is necessary to realize the following studies:

- human infrastructures mapping;
- stakeholder engagement plan (SEP).

To optimize the monitoring step, a site with similar characteristics and same geological context of the selected one should be identified and studied in order to have a reference undisturbed site with respect to the site where the activities should be realized.

The results of baseline study will be used as input of models (geotechnical, geochemical reactions and fluid-flow, *etc.*) and allow us to predict the evolution of reservoirs during and after the exploitation. In addition, the modeling can be used as tool to plan the monitoring regime and to define the area that may be influenced both temporarily and spatially by the exploitation. The modeling can help to understand if an additional dataset is necessary to complete the baseline study. Commercial software is available for partially modelling site evolution. Thus, we suggest evaluating the possibility to develop new software to enable complete modelling of site evolution.

4. GENERIC STRATEGY FOR ENVIRONMENTAL MONITORING OF GAS PRODUCTION FROM HYDRATES

Once the comprehensive characterization of the site (baseline study) is completed and the production activity starts, monitoring is necessary in order to identify any anomalies with respect the pre-production state. The first step is to generate a detailed project description based on the baseline study and modeling, in order to identify the main risks for the environment, and assess the potential impacts. From the environmental impact assessment, a recommendation of mitigation measures and a plan for environmental management and monitoring should be established. The next step is to plan the management and monitoring strategy based on the risk and impact assessment (see also WG 2 report).

Surveys carried out during the baseline study should be repeated. It could include autonomous underwater vehicles (AUVs), monitoring vessels, water column moorings and benthic chamber deployments, as used for the baseline study. The deployed tools can be equipped with suitable instruments (echo sounders, hydrophones, chemical sensors, still camera, etc.) to conduct multiple surveys with full area coverage. However, each surveys should be conducted at a specific height above the seabed, along with permanent monitoring of the seabed by fixed installations such as observation wells and seafloor observatory, to achieve optimal results (c.f. Fietzek, et al. 2016). Additional targeted studies will have to be conducted if active formation water seeps, gas seeps, and pockmarks with deep roots reaching into the storage formation are observed at the seabed.

The production sites must be revisited on a regular basis to asses the emission rates of fluids and determine if any seepage is strengthened and/or pockmark formations are re-activated. If new seeps develop during the operational phase, they must be investigated and sampled in detail to determine the origin and chemical composition of the seeping fluids and their emission rates. These studies could be conducted with remotely operated vehicles (ROVs) deployed from suitable monitoring vessels, and by monitoring data from permanent installations on the seabed (observation wells and seafloor abservatory on and above the seafloor). Samples should be taken for chemical analyses and instruments deployed at the seabed to measure fluxes and emission rates.

5. INTERNATIONAL REGULATORY FRAMEWORK

WG3 discussed extensively about the existing regulations and legal procedures for gas hydrate exploitation at international and national level. This is important also to properly address the environmental impact assessment and risk analysis. Taking into account the specific characteristics of the matter, and of the “precautionary approach”, we evaluated existing regulations for offshore oil and gas production and the emerging legal framework for the mining of deep-sea resources.

For this topic, in the setting of the international law of the sea, (UNCLOS was signed by 157 and ratified by 167 Countries), the International Seabed Authority (ISA) was established as an Institutional body responsible for managing the mining sector and for the protection of the marine environment from any harmful effects which may arise during mining activities, including exploration. ISA has already prepared a document, entitled "Environmental baseline in the Clarion Clipperton Zone" (focused on polymetallic nodules, sulphides and ferromanganese crusts), in which some criteria for definition of environmental baseline are already set up:

- Chemical Oceanography: chemistry of water column
- Bioturbation: mixing of sediments by organism
- Monitoring system: establish at least one station within each habitat type or region
- Assess benthic communities: structure genetics of organism associated with the nodules and surrounding habitats
- Physical Oceanography: carbon flux in deep water, temperature and turbidity, current velocity
- Sediment properties: chemical streams, sorting, and grain size
- Assess pelagic communities: recording of the species and levels of trace metals in the dominant species

It needs to be evaluated whether the term "seabed resources" as employed by UNCLOS and ISA also refers to gas hydrates.

In this sense, WG3 discussed on the general approach and criteria set by ISA that may be applied to gas hydrates. This is also important to create a procedure in according to UNCLOS principles PART XI, XII, XIII that several Member States have to transpose in their regulation.

In addition, it is important to consider the safety of operators during production and the legal regulation that can be applied to gas hydrate production, considering that the gas hydrate reservoirs are shallower than conventional reservoirs. The regulation about conventional gas should be considered as starting point.

5.1 Regulation related to safety of offshore operations

Directive 2013/30 is the EU reference of the EU Member States for preventing major accidents in offshore hydrocarbon exploration and exploitation and limiting the consequences of such accidents. Although the term “methane hydrates” is never mentioned in the Directive, Article 1 clearly states that the Directive covers all offshore activities associated with a fixed or mobile installation relating to exploration and production of oil or gas. The Directive specifies the keywords, the involved entities and the tools concerning procedures to ensure safety in the "upstream" operations offshore. Among the definitions of the Directive, we could focus on the following ones:

- “offshore” means situated in the territorial sea, the Exclusive Economic Zone or the continental shelf of the State (Member State for the Directive) within the meaning of the United Nations Convention on the Law of the Sea;
- ‘offshore oil and gas operations’ means all activities associated with an installation or connected infrastructure, including design, planning, construction, operation and decommissioning thereof, relating to exploration and production of oil or gas, but excluding conveyance of oil and gas from one coast to another;
- “major accidents”: an accident is defined as “major”, if it involves release of liquid or gaseous hydrocarbons or dangerous substances, explosion, fire, loss of well control or structural damage which are related to actual or potential personal injuries. A major accident is also any other incident which implies fatalities or serious injury to five or more persons or a major environmental accident (Strada et al., 2015);
- “installation” means a fixed or mobile facility, used for offshore oil and gas operations.; “Production installation” means a fixed or floating installation that is necessary for the offshore extraction of oil and gas from the underground strata of the licensed area including offshore processing of oil and gas and its transportation through connected infrastructure; “non-production installation” means an installation other than a production installation (such as a mobile drilling units).

- “well operation” means any operation concerning a well that could result in the accidental release of materials and consequently in a major accident, including the drilling of a well, its repair or modification;
- safety and environmental critical elements (SECE) are the parts of an installation (including computer softwares) which are necessary to prevent or limit the consequences of a major accident, or the failure of which could cause a major accident.

The Directive also defines the following parties involved in the procedures to ensure safety of operations:

- Competent authority is the public authority, responsible for safety of offshore o&g operations;
- licensee is the holder (or joint holders) of a license;
- operator is the person who conducts offshore oil and gas operations, including planning and executing a well operation or managing a production installation;
- owner is the duty holder for a non-production installation and is the entity legally entitled to control the operation of a non-production installation;
- contractor means any entity contracted by the operator or owner to perform specific tasks on behalf of the operator or owner.

The operator and the duty-holder (owner) of a non-production facility must submit a report on major hazards- respectively for production and non-production installations - to the Competent Authority. The report on major hazards (RoMH) is one of the key documents for the safety management of offshore oil and gas operations. The RoMH contains a large variety of information and details, such as the policies for major accident prevention, safety and environmental management system and the demonstration that all the major hazards have been identified, their likelihood and consequences assessed, including any environmental, meteorological and seabed limitations on safe operations, and that their control measures including associated safety and environmental critical elements are suitable so as to reduce the risk of a major accident to an acceptable level.

Notification of well is another key document that contains information on the well work program, the risk assessment (incorporating a description of subsurface hazards and the particular hazards associated with the well operation - including any environmental, meteorological and seabed limitations on safe operation) and a description of the well configuration at the end of the operations.

Concerning the legal situation of unconventional hydrocarbon production, some EU Member States rely mainly on the general mining, hydrocarbons and environmental legislation and its related permitting procedure transposing the EU legislation to regulate such activities (as for conventional gas extraction) and very few have adopted specific requirements. Operators may be obliged to request several permits under different acts (e.g. water law, mining waste law). In order to address the specificities of unconventional gas exploration and exploitation, several EU Member States have adopted or are reviewing their legislation or develop guidance focused on unconventional gas developments. A few useful examples of regulatory provisions applied specifically to unconventional gas activities were identified in some EU Member States (*e.g* management of induced seismicity). For example, the Norwegian Petroleum Department (NPD) acknowledges the presence of unconventional oil and gas on the Norwegian Continental Shelf, including gas hydrates. However, in the NPDs view these resources are not especially suitable for production due to the size and physics of the hydrate reservoir. Since none of the unconventional oil and gas resources in Norway are viewed as very suitable to production by the NPD, there are no laws or regulations directly aimed for these resources. Thus, in Norway the law applying to these resources would be the general law on petroleum activity.

Nevertheless, none of the assessed countries have set in place measures to control and monitor the effects of hydraulic fracturing in the ground with the exception of induced seismicity in the UK.

Gas hydrate are considered as an unconventional fossil reserve in the EU even if the official document (*http://eur-lex.europa.eu/resource.html?uri=cellar:a46647dd-843b-11e3-9b7d-01aa75ed71a1.0001.01/DOC_1&format=PDF*) mentions that methane hydrate production and underground coal gasification technology are in the early stages of development and there are no examples worldwide of commercial production. Regulating methane hydrate is a new challenge of the law of the sea and its implementation at European and national level. Like conventional oil and gas activities, it is probable that any actions dealing with the production of natural gas from methane hydrate would utilize a risk assessment approach, primarily based in scientific sources. However perceived risks do not fully correspond to the scientific certainty related to causal link of action (exploration and/or exploitation) to effect (*i.e.* environmental damage). There are circumstances, as the exploration and exploitation of methane hydrates, where science is not able to provide full certainty yet– that is when the precautionary principle comes into play. This scientific uncertainty may form the premise for a precautionary approach to methane hydrate exploration and exploitation. Such an approach can be a useful tool for enhancing the protection of marine environment. It would be valuable because current law of the sea provisions, including at European and national level, are very general and their applicability is frequently challenged.

5.2 Brief Overview of International Legislation

This overview briefly reviewed and characterized the key legal framework relevant to the marine gas hydrate exploration and production in the EEZ of Romania with some amendments to the Bulgarian legal framework.

5.2.1 Conventions

The following conventions are of key importance for all offshore research, exploration and production activities in the Black Sea and ratified by Romania and Bulgaria:

- **MARPOL 73/78 (Annexes I, IV and V)** – this international convention and its annexes is valid and subject of obligatory consideration for any human activities in the World Ocean and therefore is well known to all users of the marine environment and don't need to be commented;
- ***1982 United Nations Convention on the Law of the Sea*** *(ratified by Romania and Bulgaria in 1996).*
- **1991 Espoo Convention on Environmental Impact Assessment in a Transboundary Context** *(ratified by Romania and Bulgaria in 2001);*

- **1998 Aarhus Convention on access to Information, Public Participation in Decision-Making and Access to Justice in Environmental Matters** *(ratified by Romania in 2000, in force since October 2011; ratified by Bulgaria in October 2004, in force since 16th March 2004);*

- **1996 Protocol to the Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter of 29 December 1972:**

  - The 1996 Protocol is more restrictive than the Convention 1972 and *"prohibits the dumping of any wastes or other matter with the exception of those listed in Annex 1"* (Art. 4 (4.1)), among which are the "*inert, inorganic geological materials*". This means that the disposal of the drill cuttings, as well other materials related to offshore exploration/drilling activities on the seabed within the boundaries of the shelf (territorial waters) and exclusive economic territories of the relevant country is under the control of 1996 Protocol.

  - The dumping of the wastes requires a permit (Art. 4 (4.2)), which is necessary to be issued by the Ministry of Environment and Water (MOEW); Regional Inspection of Environment and Water (RIEW – Varna or RIEW-Burgas). For the issuing of the permit an application form is necessary to be submitted to the competent authority (MoEW; RIEW – Varna / RIEW-Burgas). The application shall also be in compliance with the provisions of Annex 2 of the above quoted Protocol.

- **1994 Convention of the Protection of the Black Sea against Pollution (Bucharest Convention).** The Bucharest Convention is the basic framework of agreement and it has three specific Protocols, summarized as follows: 1) Protocol for the control of land-based sources of pollution; 2) Protocol for prevention, reduction and control of the pollution by dumping of waste and 3) Protocol for joint action in case of accidents (such as oil spills):

  - Art. 10 of the Bucharest Convention states that: *"The Contracting Parties shall take all appropriate measures and cooperate in preventing, reducing and controlling pollution caused by dumping in accordance with the Protocol on the Protection of the Black Sea Marine Environment Against Pollution by Dumping which shall form an integral part of this Convention"*.

- The **Protocol on the Protection of the Black Sea Marine Environment Against Pollution by Dumping (PPBSMEAPD)** states that:

1. Dumping of wastes or other matter containing substances listed in Annex 1 to this Protocol in the Black Sea is prohibited (Art. 2);
2. Dumping of wastes or other matter containing **noxious substances listed in Annex II** to this Protocol in the Black Sea requires, in each case, a prior special permit from the competent national authorities (Art 3);
3. Dumping of all other wastes or matter in the Black Sea requires a prior **general permit** from the competent national authorities. (Art. 4) and
4. The permits, which refer to the requirements of articles 3 and 4, mentioned above, shall be issued after a careful consideration of all factors, set forth in Annex III to this Protocol, by the competent national authorities of the relevant coastal State. The Commission shall receive records of such permits (Art 5).

5.2.2 Relevant EU Directives

The following EU Directives are of key importance for the offshore oil and gas exploration and production activities. It is important to mention that these Directives are transposed in the legal framework of Romania and Bulgaria, the two countries that are interested to gas hydrate in the Black sea, the most promising area as indicated by WGs 1 and 2.

- Directive 2013/30/EU of the European Parliament and of the Council of 12 June 2013 on safety of offshore oil and gas operations and amending Directive 2004/35/EC.
- Directive 2004/35/CE of the European Parliament and of the Council of 21 April 2004 on environmental liability with regard to the prevention and remedying of environmental damage (Environmental Liability Directive or ELD).
- Directive 2008/98/EC of the European Parliament and of the Council of 19 November 2008 on waste and repealing certain Directives (*Waste Framework Directive*).
- Directive 2012/18/EU of the European Parliament and of the Council of 4 July 2012 on the control of major-accident hazards involving dangerous substances,

amending and subsequently repealing Council Directive 96/82/EC *(Seveso III Directive).*

- Directive 94/22/EC of the European Parliament and the Council of 30 May 1994 on the conditions for granting and using authorizations for the prospection, exploration and production of hydrocarbons (*Hydrocarbons Directive*).
- Directive 2008/56/EC of the European Parliament and of the Council of 17 June 2008 establishing a framework for community action in the field of marine environmental policy (*Marine Strategy Framework Directive*).

In the following, the main Directives related to the protection of the biodiversity are summarized:

- Directive 2011/92/EU on the assessment of the effects of certain public and private projects on the environment (*Environmental Impact Assessment Directive* or *EIA Directive*).

  This Directive applies to the assessment of the environmental effects of those public and private projects which are likely to have significant effects on the environment. Member States have to adopt all measures necessary to ensure that, before consent is given. Projects likely to have significant effects on the environment by virtue, inter alia, of their nature, size or location are made subject to a requirement for development consent and an assessment with regard to their effects.

- Council Directive 92/43/EEC of 21 May 1992 on the conservation of natural habitats and of wild fauna and flora *(Habitats Directive).*

  The Habitats Directive ensures the conservation of a wide range of rare, threatened or endemic animal and plant species. Some 200 rare and characteristic habitat types are also targeted for conservation. The Directive stipulates the establishment, protection and management of a coherent European ecological network of special areas of conservation in the geographical sea and land (Natura 2000). This network aims to maintain or, where appropriate, restore the favorable conservation status of the targeted natural habitat types (listed in Annex I) and habitats of the species (listed in Annex II).

- Directive 2009/147/EC on the conservation of wild birds *(Birds Directive). Europe is home to more than 500 wild bird species. At least 32 % of the EU's bird species are currently not in a good conservation status. The Birds Directive aims to protect all of the 500 wild bird species naturally occurring in the European Union. It stipulates the establishment, protection and management of a coherent European ecological network of special protection areas for the conservation of wild birds in the geographical sea and land (Natura 2000).*

The main part of these directives is already adopted by the Bulgarian national legislation In the process of its harmonization with the EU legislation. The remaining part (in particular the Directive 2013/30/EU on safety of offshore oil and gas operations and amending) are still in process of harmonization.

5.3 Bulgarian National Legislation

Due to the lack of specific legal acts for regulation of offshore oil & gas exploration and production activities the Bulgarian authorities are using, for the administrative procedures for granting exploration licenses (exploration permits) and concessions for production of oil in gas in the offshore blocks located in the Bulgarian territorial waters and EEZ, some basic rules and requirements formulated in international good practice documents (codes, regulations, manuals, *etc*.). As a typical example can be mentioned the MODU CODE (Code for the Construction and Equipment of Mobile Offshore Drilling Units), issued by the International Maritime Organization (IMO), London, 2001. For some specific aspects are also used the basic principles and rules of the offshore oil and gas legal framework of UK and Norway.

The following legal acts are in force and applicable for the offshore oil & gas exploration and production activities:

- **Mineral Resources Act** and the **Ordinance for Specific Requirements for Mining Waste Management**. *These legal acts regulate all onshore kinds of prospecting and exploration activities for mineral resources and fossil fuels, production activities, as well as regulates the administrative procedures for granting exploration licenses (exploration permits) and concessions for production of mineral resources and fossil fuels; also specifies the management* *of the mining wastes, generated from the exploration, extraction and primary processing of mineral resources (Art 1 § 3), including onshore extraction of oil and gas (Art 2 § 3). They do not include and consider the wastes, generated as a result of the same operations, conducted offshore (Art 22a § 3). It should be underlined that in these documents are absent any special provisions regulating offshore prospecting, exploration and production activities for oil and gas (including for marine gas hydrates).*

- **Maritime Spaces, Inland Waterways and Ports of the Republic of Bulgaria Act** (2002). *The Act transposes the recommendations of MARPOL 73/78 and European Directive 2000/59/EO in BG legislation and regulates all maritime activities in the inland waterways, ports, territorial water and EEZ of Bulgaria (including scientific research, exploration and production of mineral resources, oil and gas, etc.) ;*

- **Mineral Resources Act** and the **Ordinance for Specific Requirements for Mining Waste Management** (1999, last amendments 2011). *These legal act regulates all onshore kinds of prospecting and exploration activities (onshore and offshore) for mineral resources and fossil fuels, as well production activities, as well regulates the administrative procedures for granting exploration licenses (exploration permits) and concessions for production of mineral resources and fossil fuels; also specifies the management of the mining wastes, generated from the exploration, extraction and primary processing of mineral resources (Art 1 § 3), including also onshore extraction of oil and gas (Art 2 § 3). They don't include and consider the wastes, generated as a result of the same operations, conducted offshore (Art 22a § 3);*

- **Ordinance for the requirements for prevention of accidents at prospecting and exploration or exploration, or production of underground resources – oil and natural gas, in the territorial sea, continental shelf and exclusive economic zone of Republic of Bulgaria in the Black Sea** (Adopted with Decree #266 /21.12.2016 of the Council of Ministers, published in State Gazette v. 103/27.12.2016, in force since 27.12.2016. *This ordinance transposes the provisions of the DIRECTIVE 2013/30/EU OF THE EUROPEAN*

PARLIAMENT AND OF THE COUNCIL of 12 June 2013 on safety of offshore oil and gas operations and amending Directive 2004/35/EC.

With respect to the substances, listed in Annex I of PPBSMEAPD, the following national legal documents should be considered for the marine physical environment protection:

- **Ordinance H-4 on the Characterization of Surface Water** (State Gazette/SG 22/2013, last amended 2014). Potential organic and inorganic pollutants and their maximum permitted values, including PCB's, organophosphorus compounds, oils and heavy metals, except barium are included in the Annexes of the Ordinance. The specific issue here is that this ordinance refers to the littoral but not offshore water quality.
- **Ordinance № 3/2014 on the Requirements of the Order and Manner of Inventory of Equipment Containing Polychlorinated Biphenyls, Marking and Cleaning, as well as Treatment and Transportation of Wastes Containing Polychlorinated Biphenyls** (SG 21/2014**)**. PCB's contaminated wastes have to be disposed for incineration and their transportation has to be carried out in accordance with the Ordinance for transportation of hazardous wastes.
- **Act on Protection against Harmful Impact of Substances and Mixtures** (SG 63/2010). This Act states the rights and obligations of individuals and firms that manufacture, market, use, keep and export chemical substances on their own or in mixtures in order to protect human health and the environment. It does not relate to the protection of surface waters by chemical pollution, including disposal of chemical substances in the sea.

The following key general legal documents developed in general for onshore human activities are applicable as well for offshore activities:

- **Environmental Protection Act** (2002, last amendments 2008). *This legal act is fully harmonized with the EU EPA Directive.*
- **Ordinance for the Conditions and Order for Implementing EIA** (2003, last amendments 2011). *This legal act is fully harmonized with the EU legislation*.

Regarding the marine biodiversity protection, the following acts are considered:

- **Environmental Protection Act (EPA) (2002, last amendments 2016)**

  This act regulates the public relations associated with protection of the environment for the present and future generations and the protection of human health; conservation of biodiversity in accordance with natural bio-geographical characteristics of the country; conservation and use of components of the environment; control and management of the factors that damage the environment; control of the state of the environment and sources of pollution; preventing and reducing pollution; establishment and functioning of the National System for Environmental Monitoring; strategies, programs and plans for environmental protection; collection and access to environmental information;. economic organization of activities on environmental protection; rights and obligations of the state, municipalities, companies and individuals in environmental protection. This legal act is fully harmonized with the EU EPA Directive.

- **Ordinance on conditions and procedures for execution of Environmental Impact Assessment *(2003, last amendments 2016)***

  This ordinance stipulates the procedures for execution of Environmental Impact Assessment of the investment proposals, as per art. 81, paragraph 1 pt. 2 of EPA.

- **Biological Diversity Act (BDA) (2002, last amendments 2016)**

  This Biodiversity Act regulates the relations between the state, municipalities, companies and individuals in the conservation and sustainable use of biological diversity (i.e. the variety of all living organisms in all forms of their natural organization, their communities and habitats, ecosystems and processes) in Bulgaria. The Biodiversity Act stipulates the establishment, management and protection of the Natura 2000 network in Bulgaria, as part of the European Ecological Network. This legal act is fully harmonized with the EU legislation.

- **Ordinance for the terms and conditions for assessment of the compatibility of plans, programs, projects and investment proposals with the object and purpose of conservation of protected areas (2007, last amendments 2012)**

  The ordinance regulates the terms and procedures for the execution of Appropriate Assessment (as per art. 31 of BDA) for the compatibility of plans, programs, projects and investment proposals with the conservation objectives and purposes of Natura 2000 sites.

Regarding the marine cultural heritage protection, the related Law (2009, last amendments 2012) is fully harmonized with the EU Directives and regulates also all aspects of the underwater cultural heritage.

5.3.1 Competent Bulgarian Authorities

The competent Bulgarian authorities are:

- ***Maritime Aspects, Scientific Research, Exploration & Production of Oil & Gas***
  - Council of Ministers *(issues permits for research and exploration of mineral and energy resources);*
  - Executive Agency Maritime Administration at the Ministry of Transport and Communications *(regulates and controls all maritime activities);*
  - Ministry of Education and Sciences;
  - Ministry of Exterior Affairs *(receipt of applications of foreign entities for conducting scientific/research cruises of research vessel in Bulgarian territorial waters and EEZ and proposes to the Council of Minister the applications to be approved and permits to be issues);*
  - Ministry of Interior Affairs / Border Police;
  - Ministry of Education and Science;
  - Ministry of Energy *(responsible for the administrative procedures for issuing/granting exploration licenses and production concessions for oil and gas in Bulgarian territorial waters and EEZ)*;

- Ministry of Economics;
- Ministry of Defense / Bulgarian Navy *(obligatory coordination of the plans for offshore research and exploration/production activities with these authorities).*

- ***Marine Environment and Marine Cultural Heritage Protection***
    - Ministry of Environment and Water (issues environmental permits);
    - Executive Environmental Agency (responsible for the national marine environment monitoring) ;
    - Black Sea Basin Directorate;
    - Regional Inspectorates of Environment and Water in Varna and Burgas;
    - Ministry of Culture / Centre for Underwater Archaeology (underwater cultural heritage protection).

5.4 Romanian National Legislation

Regarding the Offshore Oil & Gas Exploration and Production, the following laws should be considered:

- **Petroleum Law No. 238** (2004, last updated/amended in 2017). *The Romanian Petroleum Law regulates all activities for oil and gas exploration and production, as well the procedures for requesting and granting exploration licenses and concessions for oil & gas production, transport, etc. The key provisions of the Petroleum Law are related to the conventional oil & gas exploration and production onshore and offshore (only for the shelf area). No provisions for marine gas hydrates research, exploration and production are stipulated in this legal act.*

- **Law 165 on Safety of Offshore Petroleum Operations (2016).** *This legal act transposes into the Romanian legislation the provisions of DIRECTIVE 2013/30/EU OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 12 June 2013 on safety of offshore oil and gas operations.*

The marine biodiversity is protected by the following laws:

- ***Government Emergency Ordinance (GEO) 68/2007 on Environmental Liability with Regard to the Prevention and Remedying of Environmental Damage*** (approved by L 19 / 2008, amended and supplemented by GEO 15 / 2009, OUG 64/2011, L 249/2013). *This ordinance transposes into the Romanian legislation the DIRECTIVE 2004/35/CE OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 21 April 2004 on Environmental Liability with Regard to the Prevention and Remedying of Environmental Damage (Environmental Liability Directive or ELD).*

- **Government Decision (GD) 445/2009 on Environmental Impact Assessment of Certain public and Private Projects** (modified by GD 17/2012). *This decision transposes into the Romanian legislation the Directive 2011/92/EU on the Assessment of the Effects of Certain Public and Private Projects on the Environment (Environmental Impact Assessment Directive or EIA Directive).*

- **GEO 57/2007 Concerning the Regime of Natural Protected Areas, Conservation of Natural Habitats and Wild Flora and Fauna** (amended and supplemented by L 329/2009, L 49/2011, L 187/2012, GEO 31/2014, GO 20/2014, L 161/2014, OG 7/2016, L 73/2015, L 95/2016, L 194/2016). *This legal act transposes into the Romanian legislation the Council Directive 92/43/EEC of 21 May 1992 on the Conservation of Natural Habitats and of Wild Fauna and Flora (Habitats Directive).*

5.4.1 Competent Romanian Authorities

The key competent Romanian authorities for maritime aspects, marine scientific research and oil & gas exploration and production are:

- **Council of Ministers** - *issues permits for marine research cruises of research vessels under foreign flag and controls/coordinate the National Agency for Mineral Resources (NAMR);*

- Ministry of Exterior – *responsible for coordination of the above permitting procedure;*
- **National Agency for Mineral Resources (NAMR)** - *competent authority empowered to implement the provisions the Petroleum Law (granting of exploration licenses and concession for production of oil & gas) and the Law on Safety of Offshore Petroleum Operations, i.e. a specialized body of central public administration, with legal personality, subordinated to the Government and coordinated by the Prime Minister;*
- **Maritime Administration** - regulates and controls all maritime activities;
- **Ministry of Interior / Border Police;**
- **Ministry of Environment and Climatic Changes / National Environmental Protection Agency;**
- **Ministry of Culture and National Identity** (responsible for terrestrial and marine cultural heritage);
- **Ministry of Energy;**
- **Ministry of Economics;**
- **Ministry of National Defense / Romanian Navy;**
- **Ministry of Research & Innovation;**
- **Ministry of Transport / Romanian Naval Authority**

6. FINAL REMARKS

During the course of the COST Action MIGRATE, we concluded that a multidisciplinary group (geophysicists, geochemists, biologists, modelers) is indispensable to predict and describe the possible scenarios related to offshore human activities in order to evaluate the level of risks and to answer to important questions such as:

- How to differentiate between natural hydrate destabilization (e.g. climate change, continued re-equilibration after ice age) and induced through production activities?

- How to determine 'proof' for regulatory and/or liability purposes?

In order to properly adress to these important questions and to continue our studies, we decided to strengthen our collaboration by submitting a proposal to the call **H2020-MSCA-ITN-2019** (Marie Skłodowska-Curie Innovative Training Networks). The proposal was submitted in January 2019 and was entitled: ASSessment and mitigation of emissions indUced by offshore Resource Extractions – ASSURE. The project relies on the well-known consideration that the global ocean covers about 70% of the Earth surface and that it is one of humanities' main resources and core to the world's sustainability. Moreover, we considered that key issues in European marine resource management are the protection from contamination and the safeguarding of marine ecosystems from human activities to preserve biodiversity. As underlined in the section 5, while EU Directives recognize these issues, they extend beyond the boundaries of individual country legislation. Hydrocarbons, sand and fish are the main resources being extracted from EU seas. The extraction of aggregates, and other raw materials by deep-sea mining, is currently ongoing or planned. The most harmful events generated by human activities in the marine environment are oil spills, gas leaks and sediment clouds. Furthermore, the underground storage offshore of CO_2 may be accompanied by leaks via abandoned wells and through natural faults and fractures, causing damage to marine ecosystems. ASSURE will be an integrated program to study gaseous, liquid and solid particle emissions induced by anthropogenic offshore activities. It will combine several approaches including field work, numerical modelling, lab studies and legal framework. ASSURE will link these approaches to counter the adverse impacts of human activities offshore and investigate mitigation measures. Currently, the study of emissions from the hydrocarbon, fisheries and mineral resource sectors is carried out separately. However, there are common physical sciences and similarities in technology related to these emissions. What is missing is a cross-sectoral view that can only be achieved in a multi-disciplinary manner. ASSURE is a large-scale program with a broad scope that will provide unprecedented insight into the impact of offshore human activities. In summary, ASSURE will create a new generation of experts that will equip the EU to become a key world player competing at the top scientific and technological level in monitoring, evaluating, preventing and mitigating anthropogenic impacts on marine ecosystem services.

Finally, in order to disseminate the results obtained during our fruitful discussions, we decided to submit a paper in a scientific journal. This final and important step will be done at the end of MIGRATE project, enforcing once again the strong multidisciplinary and inter-sectoral network created by MIGRATE on gas hydrate topic.

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