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Hydrate occurrence in Europe: Risks, rewards, and legal frameworks

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A S B T R A C T

In January of this year (2020), a major scientific study (‘the Minshull report’) announced that gas hydrate reservoirs were found in many offshore areas across Europe. The European Commission is now considering a policy view to commercialize the development and extraction of methane gas from European offshore areas. Affirmation from the European Commission that offshore methane hydrates are too useful and too valuable to forego development could initiate a global response to adopt offshore methane hydrates as a new source of natural gas for heating, for electrical power supplies, and for potential new revenues.

The upside? The potential rewards from offshore methane hydrates are multi-fold. Coastal states are surrounded in methane hydrate resources that if responsibly developed could enable vast amounts of methane (natural gas) to be produced for decades or centuries beyond the timelines of conventional natural gas assets. There are also massive volumes of fresh water trapped in hydrates that could aid in fighting droughts and desertification.

The downside? There are novel foreseeable risks that might result from those commercial methane hydrate activities. The climate change risks and geo-physical hazards from offshore methane hydrates are quite distinct from both conventional and unconventional hydrocarbons. There are new challenges to achieving safety and sustainability.

In review, this paper both welcomes the discovery and confirmation of offshore methane hydrates in European waters and also raises concerns that more research is required on the optimal policy strategies for the known and foreseeable risks to best enable safe and sustainable policy choices.

1. Europe’s new natural gas – offshore methane hydrates

Apart from a few areas of development, Europe is not known as a large producer of hydrocarbons. Most people would assume that if there were hydrocarbons available in Europe, that they would surely have been detected many years or decades ago. And of course, if you do not have many hydrocarbons to produce in Europe, then the problems that might be caused by production or extraction accidents might be seen as less pressing than other risks. And even if the European Union (EU) did have such hydrocarbons in its waters, the EU has already enacted directives respondent to extraction risks and activities further downstream, such as the Offshore Safety Directive, 1 so one could take some comfort in the EU’s preparations.

In January of 2020, Timothy A [1], and 30 other scientists published a report evidencing the discovery and determination of large volumes of methane hydrates in European waters and oceans in the journal Marine and Petroleum Geology (hereafter, ‘the Minshull report’). 2 (see Fig. 1) The Minshull report had been funded by the European Commission under its project ‘Marine Gas Hydrate – an Indigenous Source of Natural Gas for Europe (MIGRATE)’, among other sources of European research funding, reflecting the European Commission’s policy view to commercialize the development and extraction of methane gas from European offshore areas. 3 This discovery and evidence of offshore methane hydrates in European waters requires a broad discussion on the potential environmental risks and hazards from offshore methane hydrates; first, to identify the risks and rewards, 4 and second to enquire ‘are the commercial opportunities and environmental risks adequately provided for by existing laws and conventions or will new substantive legal rules need to be developed?’

The concept of methane hydrates is novel for many; that natural gas can become combined with fresh water in such a manner as to produce what could be described as a snowy frozen matrix but at ‘room

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1 Directive [3]/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 [4]/35/EC.

2 Minshull et al., 2020.
3 Minshull et al., 2020, 736–737 and 759.
4 For a survey of those issues, see sec 4, infra. See also Partain [5]; 294–299.
temperatures.\textsuperscript{5} Historically, carbonaceous fuels have been listed as a trio of coal, crude oil, and natural gas; to this list methane hydrates must be added.\textsuperscript{6} And if emerging reports from Europe and beyond are accurate, the global volumes of methane hydrate may match or exceed the volumes available from the other three sources.\textsuperscript{7} It is because of the sheer potential volume of a new source of methane that so much attention is properly due to the study of methane hydrates.\textsuperscript{8}

Indeed, one might ask, ‘are these risks and rewards limited to Europe,’ and the answer would be no. The rewards from potentially abundant, ubiquitous supplies of natural gas would be the same for all producers: energy supplies, revenue creation, industrial stimulation. And many of the risks would be the same: massive carbon emissions, offshore landslides, and potentially lethal anthropogenic tsunami. But our focus here remains on Europe for two reasons. First, the Minshull report documents large volumes of offshore methane hydrates in European waters. And second, the EU might be able to develop new rules to protect its peoples and its resources that also enable sustainable development; rule sets that might become a standard for other countries and regions considering the development of their own offshore methane hydrate reservoir systems.

While recognizing the accomplishments of the MIGRATE project and their implications for transforming EU energy policies, this present paper raises additional policy questions and broadens the scope of policy assessment. It also hopes to serve as a call to research, to increase the number of researchers and to broaden the legal methods and perspectives engaged. Ultimately, this paper endeavors to demonstrate that the risks and hazards from the development and commercialization of offshore methane hydrates are substantially different from previous conventional and unconventional hydrocarbons and those differences require several novel considerations if those commercial activities are to be undertaken in a sustainable and responsible manner.

2. A hydrocarbon unlike all others

This section is divided in three parts. The first part provides a primer to the unique scientific characteristics of this resource, how those characteristics could be very attractive for policy makers, and how those events could lead to novel risks and hazards demanding new legal concepts and solutions, and thus, demanding of more legal research.

The second part discusses the potential rewards and why policy makers may be considering the commercial development of these resources. It is submitted that the potential rewards from offshore methane hydrates are multi-fold. Europe is surrounded in methane hydrate resources that if responsibly developed could enable vast amounts of methane (‘natural gas’) to be produced for decades or centuries beyond the timelines of conventional natural gas assets.\textsuperscript{9} Beyond that, the

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\textsuperscript{5} Partain [5]; 23.
\textsuperscript{6} Partain [5]; 16 and 32.
\textsuperscript{7} Gerald Traufetter, [6]; available at: https://www.spiegel.de/international/world/warning-signs-on-the-ocean-floor-china-and-india-exploit-icy-energy-reserves-a-523178.html. Especially note the graphic, “Energy from Ice”.
\textsuperscript{8} Mark Zacharias, [7], 279.
\textsuperscript{9} Partain [5]; 26–28.
Methane hydrates are naturally occurring forms of natural gas; they are a combination of methane and fresh water. Visually, methane hydrates resemble ice, snow, or an ice slushy, depending on how they lay in the earth. And while they are commonly referred as ‘ice’, they are usually found at temperatures well above 0°C or above 32°F. Chemically, methane hydrates are a molecular combination of acid-free methane and fresh water. The water and methane remain somewhat separate; the water ‘freezes’ into cage-like structures that surround a tiny space where a single methane or carbon dioxide molecule could be contained. Once extracted, methane hydrates readily dissociate into fresh water and combustible methane.

Methane hydrates do come in several variant structures (sI, sII, sH), with some of those structures able to hold larger ‘guest’ molecules within the water cages of the hydrate structures. Thus, the type of hydrate reservoir could impact the types of hydrocarbons recovered from the reservoirs, or, could affect what types of chemicals could be injected and stored within the hydrates.

Offshore methane hydrates are usually located between the mud layers and the rocky surfaces below them in benthic ocean locations. They can be found in other locations, such as above the mudline, or floating at the surface. In onshore settings, methane hydrates tend to be found in areas of cold climates, so they are extensive across Siberia, Alaska, and Northern Canada. They can also be found in mountainous ranges, such as in Tibet. Where offshore methane hydrates are not usually found are the deep earth reservoir systems where conventional crude oil and natural gas are found trapped. While hydrates can be found in both onshore and offshore settings, approximately 99% of all hydrates are primarily found in the offshore.

While the existence of methane hydrates has been known for two centuries, it is only in the last decade or so that they have become a feasible energy resource. Methane hydrates were first discovered by Humphrey Davy in 1810 and their basic chemistry by Michael Faraday in 1823. In 1934, Hammerschmidt identified that methane could condense in gas pipelines to form hydrates. The transition from chemistry to energy took a little while.

Methane hydrates were first recognized as an energy resource at the Messoyakha, in Siberia, in 1964. Then in 1970, the first public survey of offshore methane hydrates was undertaken, and the first recovery of offshore methane hydrates occurred in 1981. While conventional crude oil was in well-based production as early as 1859, and natural gas soon thereafter, methane hydrates remain unproduced in a commercial manner. Just recently in 2013, Japan achieved success with the first continuous production of methane from offshore methane hydrates in the Nankai Trough. The People’s Republic of China achieved their own success in 2017, producing methane from hydrates in the South China Sea. Other countries have achieved success with non-continuous extraction from offshore deposits, notably, the United States of America (US), South Korea, and India. Japan has long announced that their goals for commercial feasibility in the mid-2020s with China offering similar guidance.

2.1. An introduction to methane hydrates

Methane hydrates are easily formed and often trigger instability. The transition from gas to ice is a relatively rapid process, and can sometimes cause instability. The basic chemistry to energy took a little while.

2.2. Global locations

One of the most potentially transformational aspects of methane hydrates is the fact that early surveying and modelling strongly suggests that almost every coastal state in the world contains methane hydrate reservoirs beneath their offshore waters.

Those offshore reservoirs can be found in these areas:

- The western shelf of Europe, extending towards Eire and Iceland.
- The Mediterranean Sea is expected to contain methane hydrates, including certain parts of the Adriatic, Tyrrhenian, Aegean Seas and the Sea of Marmara.
- The west coast of the Americas, from Alaska down to Chile.
- The eastern coast of North America, including almost all of the Caribbean islands.
- The coasts of Argentina, Uruguay and southeastern Brazil.
- The whole coast of Africa in all direction, including the Red Sea and off of Madagascar.
- Everywhere near the South Asian peninsula, including large zones of the Arabian Sea and the Sea of Bengal.
- Areas offshore of South Korea, Japan, and the Russian islands north of Japan including offshore Kamchatka.
- Almost all of the ASEAN waters, ocean, and seas.
- Australia’s and New Zealand’s offshore areas.

10 Partain [5]: 50–51. The fundamental mechanism here is that the molecular structure of the hydrate is indifferent to whether natural gas/methane (CH4) or carbon dioxide (CO2) is the molecule trapped in the molecular cage. One known method to extract the methane from the hydrates would be to inject pressurized carbon dioxide into the hydrate formation, washing out the methane while trapping the carbon dioxide in the same molecular locations. Japanese researchers have explored the idea of lifting the methane from the hydrates, combusting it offshore to produce electricity (which is much easier and safer to transport via wires), and then re-injecting the captured carbon to complete the cycle by lifting more methane. Germany pioneered the technology to use unsaturated methane hydrate reservoirs as a method of carbon capture and storage (CCS) storage system in its gas hydrate initiative “SUGAR – Submarine Gas Hydrate Reservoirs,” which was run by the Helmholtz Centre for Ocean Research Kiel (GEOMAR); a website archive is available at: https://www.sugar-projekt.de.

11 Partain [5]: 51–52.
12 Partain [5]: 57.
13 Partain [5]: 13, with reference to Koh 2002, 157.
14 Partain [5]: 13, with reference to Makogon, Holditch and Makogon, 2007, 16.
15 Partain [5]: 14, with reference to Makogon, Holditch and Makogon, 2007, 16.
16 Partain [5]: 14.
17 The reference here is to Drake’s oil well, the first commercially operated drilled oil well.
18 Yiaylourides and Partain [8]: xi, with reference to Ai Oyama and Stephen M Masutani, [9].
19 Matthew Brown [10]: “China, Japan extract combustible ice from seafloor,” Phys.Org, May 19, 2017; available at: https://phys.org/news/2017-05-china-japan-combustible-ice-seafloor.html?utm_source=TrendMD&utm_medium=cpc&utm_campaign=Phys.Org_TrendMD.1.
20 Partain [5]: 14.
21 J. B. Klauda and S. I. Sandler [11]; See also Minshull et al., 2020. See also the discussion, infra, at sec 2.2.2.
When contrasted against the more limited locations of crude oil and traditional natural gas fields, the resource owners of methane hydrates form a much larger proportion of the global community. This means that most countries will now have natural gas off of their coasts and will not need to import from faraway lands. Presently, only a small list of countries produces and markets hydrocarbons, but this new ‘seabed energy geography’ will transform most coastal countries into producers of hydrocarbons. This combination alone, that most coastal states will be able to become energy producers and if so that they will not need to pay for imported fuels, will transform the energy markets that were based on few exporters to global markets. In an offshore methane hydrates future, not only would consumers ‘eat locally’, they might also ‘fuel locally’.

The expansion in the list of producing nations mean that more areas will come in contact with the risks of natural gas production and of the special risks presented by offshore methane hydrates, as discussed below. Because of these structural transformation in hydrocarbon markets, the development of future energy and environmental policies as offshore methane hydrates come into production or commercialization will become quite different from the policy issues we dealt with in the previous era.

2.3. European locations

There are very few coastal areas offshore Europe that are not expected to contain some offshore methane hydrates assets. It still remains too early to know for certain where all the reservoirs are and to have fully characterized the quality of the deposits, but the prospect for finding offshore methane hydrates in European waters is quite high. The Minshull report locates offshore methane hydrates offshore of Greenland, onshore and offshore Norway and Norwegian islands, offshore of Ireland, offshore of Portugal and Spain, offshore of North-west Africa, across the eastern Mediterranean Sea, the Sea of Marmara, and the Black Sea. An earlier study, by Reichel and Husebø, included the aforementioned locations and also suggested that offshore methane hydrates would be found off the southern coasts of France reaching across to Corsica and Sardinia, in the waters between Scotland and Iceland, and broadly stated in most of the waters between Greenland and Norway.

In a nutshell, in an era seeking green energy alternatives, Europe just found many massive new reservoir systems of natural gas in its offshore areas. This new resource wealth extends to many locations around Europe and it remains too early to tell who might be the first offshore methane hydrate producers; but the question, “does Europe have more natural gas” has just been answered very strongly and affirmatively.

3. The rewards from commercializing methane hydrates

Offshore methane hydrates offer governments and communities novel opportunities that go far beyond those of conventional oil and gas and their unconventional alternatives. What hydrocarbon provides its own carbon sinks (see section 3.4 below) while also providing fresh natural gas alongside the dozen forecasts for in-place offshore methane hydrates. These are located in Table 1.

3.1. Abundant reservoirs of methane

Policy makers are likely to be attracted to the reserves of natural gas for the traditional reasons of revenues, power supplies, and opportunities for economic development. But what makes offshore methane hydrates truly unique is the scale of the resource. To illustrate the potential scale of the methane hydrates resources, we collated various forecasts of global resource in place. We include two forecasts on natural gas alongside the dozen forecasts for in-place offshore methane hydrates. These are located in Table 1.

What is perhaps most stunning is that the volume of forecasted offshore methane hydrates is magnitudes larger than the forecasts for conventional natural gas volumes. This is a revolution in energy supply policy and strategy. Given this scale of resource, it becomes obvious that the supply problems of peak oil are no longer reliable incentive structures to drive consumers to carbon-free green energy solutions, as offshore methane hydrates are foreseeably going to extend the viability of hydrocarbon production deep into the next century, perhaps further. And that is a cause for policy preview, to avoid Epimethean consequences, ‘planning for the onset of commercial development of offshore methane hydrate resources should be done prior to that development, not as a consequence of accidents following that development’.

As stated earlier, survey and detection of hydrate occurrence of offshore methane hydrates fields across Europe and elsewhere across the globe means that for many states, methane hydrate resources will be their first domestic seabed energy resource to be developed. Thus, for many states, an attractive element of offshore methane hydrates will be the simple fact that they now possess offshore methane hydrates when they did not previously have any domestic seabed energy resources. This is surely a motivating factor in Japan’s research into offshore methane hydrate.

### Table 1

Comparative estimates for global methane hydrates.

| Scientist(s) | Tcm | Energy Source |
|--------------|-----|---------------|
| BP Statistics | 187 | Natural Gas |
| Englezos and Lee | 370 | Natural Gas |
| Walsh - Low | 2,800 | Methane Hydrates |
| Chatt – Low | 3,100 | Methane Hydrates |
| Demirbas | 7,104 | Methane Hydrates |
| Collett | 9,000 | Methane Hydrates |
| Englezos and Lee - Low | 10,000 | Methane Hydrates |
| Englezos and Lee | 20,500 | Methane Hydrates |
| Kvenholden and MacDonald | 21,000 | Methane Hydrates |
| U.S. Methane Hydrate R&D Act | 24,000 | Methane Hydrates |
| Englezos and Lee - High | 40,000 | Methane Hydrates |
| Klauda and Sandler | 120,000 | Methane Hydrates |
| Walsh - High | 2,800,000 | Methane Hydrates |
| Chatt - High | 7,600,000 | Methane Hydrates |

- Estimate was stated as 6.4 Trillion tons of methane. Demirbas 2010, at 1551.
- Marcille-De Silva and Dawe 2011, at 221.
- Referred to as the standard estimate, partially due to their age. MacDonald’s numbers date from 1990, Marcille-De Silva and Dawe 2011, at 219.
- This number is actually a statutory statement regarding the U.S.’s internal estimate of its own domestic supplies, which it estimates at a quarter of the world’s supplies of methane hydrates. It provides an estimate of the domestic volumes at 200,000 Tcf. 800,000 Tcf converts to 24,000 Tcm. Public Law 106–193, §1, as added by Public Law 109–58, title IX, §986(a), Aug. 8, 2005, 119 Stat. 894; also available at 30 United States Code 2001, “Methane Hydrate Research and Development Act of 2000.”
- Refereed to as the most up-to-date model and likely the most accurate. Marcille-De Silva and Dawe 2011, at 219.

22 Minshull et al., 2020, throughout the article, but in summary at 738–739 and at 757–758.
23 Reichel and Husebø [12]; see also Klauda and Sandler [11] who include some potential offshore methane hydrates offshore the west coast of France and north of Spain.

24 Roy A. Partain [13].
hydrates, as they need to import a very high percentage of their energy supplies.²⁵ But this will be equally true for many European countries who lack their own offshore methane extraction technologies, for they will have new policy options for economic development with their own domestic energy supplies. That so many countries will enjoy access to domestic hydrocarbon supplies will both be attractive to their national development plans, but it will also mean that offshore methane hydrates will be their first experience regulating energy production activities and environmental laws in the offshore environment. Early stages of development could especially pose problems for those states, as they build their institutional capacity for offshore hydrate governance.

3.2. Abundant sources of freshwater

Methane hydrates are a mix of water and methane, but mostly water. For example, 1 m³ of methane hydrate could dissolve into approximately 160–170 m³ of methane gas and 0.8 m³ of water – although the exact amount varies depending on conditions of temperature and pressure of measuring environment.²⁶ Scaled differently, if you know the total cubic meters of offshore methane hydrates, then the volume of fresh water produced is 85% of that volume. Thus, if you find methane hydrates, you have both fresh water and pure natural gas with no salt and no contaminants. So, given the comments earlier on the phenomenal potential scale of globally available offshore methane hydrates, that is almost the same statement that there is a phenomenal potential scale of fresh water trapped in offshore methane hydrate reservoirs.

Given the legal duties and obligations incumbent upon parties to the United Nation’s Convention to Combat Desertification and Desertification (UNCCD), which the European Community ratified on October 14, 1994,²⁷ the existence of technologies to extract freshwater from ubiquitous global locations, and the presence of hydrates offshore areas of need, parties in possession of methane hydrate extraction capacities may find themselves obligated to support the production of offshore methane hydrates to support the UNCCD.²⁸ There also appears to be some asymmetry in the UNCCD rules in that the duties to share technology and to offer financial support fall on developed economies; so European countries would find themselves with duties that other countries with the technology would not bear, like China.

3.3. Large carbon sinks to reduce climate change risks

While the terminology employed in the Minshull report and in legal literature generally dwells on the methane potential of gas hydrates, those molecular cages found in the hydrates are equally capable of holding carbon dioxide. Indeed, one of the tested methods for extracting methane from the hydrates is to flush out the methane with injected carbon dioxide. Thus, the hydrates can function as very stable sequestration or storage sinks for carbon dioxide.

Given the legal developments under the United Nations Framework Convention on Climate Change (UNFCC) and the London Protocol,²⁹ there is some legal support for offshore carbon, capture, and storage (CCS), but that legal option is not fully clear when injecting carbon dioxide into hydrate reservoirs, as they do not lay at the same depth as more conventional deep-earth storage designs. Furthermore, most coastal countries have not had the need to develop regulations for offshore CCS activities, so there are regulatory voids to address.

3.4. Potential for carbon-neutral electrical power

Countries such as China have expressed their interest in methane hydrates as part of developing a pathway of energy strategies to move from coal and crude oil to a less carboniferous energy supply, presented by offshore methane hydrates.³⁰ Beyond that, when the potential to generate electricity offshore from combusting methane is combined with hydrate-based carbon storage options, one can envision a vessel that lifts methane from the hydrates, runs the methane through a turbine that drives a generator, and then that exhausted carbon dioxide can be injected and stored into the hydrates. That would further simplify the transport problem by replacing pipelines of natural gas with wires running electricity. Thus, if the carbon storage technology was involved, several advantageous policy issues would likely benefit from additional clarity in the relevant legal frameworks.

3.5. When? Why not already?

Offshore methane hydrates are not yet in commercial production anywhere in the world; but they soon will be in East Asia and maybe in South Asia. Part of the answer is because methane hydrate reservoirs are so different from conventional oil and natural gas reservoirs, that new technology needed to be developed to produce the methane from methane hydrate reservoir systems. Japan was the first to achieve a functional capacity for ‘continuous flow’ production from offshore methane hydrate reservoirs in 2013.³¹ China was the second, in 2017.³² And so far, that is the whole club; the technology and related intellectual property has remained in limited hands.

The second part of the answer is economics. The actual costs of lifting from methane hydrates remains slightly higher than lifting from conventional offshore natural gas fields.³³ But that price difference remains under the price paid for natural gas when shipped by LNG in certain seasons. And, for some energy-resource-poor states like China and Japan, there may yet be strategic reasons to enable ‘back-up’ capacity to produce some volumes from methane hydrates to relieve overall market pressures. The cost problem exists but may not hold back early extraction efforts in East Asia.

Last but not least, had energy prices remained high, as they were just a few years ago, methane hydrates would likely be in the front of the queue for development and commercialization. But the collapse of oil prices, brought on initially by increasing levels of production from shale oil and some recovery in Iran’s output capacity, and now accelerated by the post-coronavirus economic slowdown, will likely keep energy prices sufficiently low to challenge the ‘break-even’ economics of all energy projects, including novel ones like offshore methane hydrates. Nevertheless, history does teach that once a technology is feasible, it is only a matter of time before the market will find a way to use it. While offshore methane hydrates are not yet in commercial production, very little

²⁵ See Yiallourides and Partain [8] examining the potential prospects and benefits stemming from the commercial development of offshore methane hydrates in Japan.
²⁶ Partain [5]; 16 to 18.
²⁷ Declaration made by the European Community in accordance with Article 34(2) and (3) of the United Nations Convention to combat desertification in countries seriously affected by drought and/or desertification, particularly in Africa (OJ L 83, 19.3.1998, pp. 3–35).
²⁸ Roy A. Partain, [14].
²⁹ UN General Assembly, United Nations Framework Convention on Climate Change [15]; A/RES/48/189; see also 1996 Protocol [16].
³⁰ Yen-Chiang Chang, [17].
³¹ Yiallourides & Partain [5] 2.
³² Yiallourides & Partain [8] 11.
³³ Partain [5]; 34: “Optimistic estimates suggest that the cost of developing off-shore methane hydrate projects should be 15% to 20% more costly than comparably situated conventional natural gas projects. Another forecast stated, based on technologies and costs prior to 2008, the incremental costs of producing from an offshore Class 3 methane hydrate reservoir were USD 3/Mcf more expensive than production volumes from a conventional offshore natural gas well.”.
actually stands in the way to prevent the onset of new commercialization activities. It will probably be in production by 2030, forecasts the USGS.34

4. The risks and dangers from commercializing methane hydrates

It is perhaps here that the divide between offshore methane hydrates and the conventional and unconventional hydrocarbons is most stark. The hazards of offshore crude oil are well-researched and publicly known and occasionally the plot of Hollywood movies or well-publicized documentaries. There are the risks of leaks from ripped vessel hulls, the risks from accidents on offshore production rigs, and long-term risks associated with general industrial activity in sensitive ecological marine areas and estuaries.

However, the risks and hazards of methane gas in oceanic settings are much less publicly known or discussed. Especially so for deep sea emissions of methane into benthic water columns.35 Here lies perhaps the most critical difference between the conventional offshore wells and those for offshore methane hydrates: the possibility for much more serious geohazards, some of which may trigger ‘cataclysmic’ events, discussed subsequently in this paper.

4.1. Non-cataclysmic events

The issues for offshore methane hydrates in extraction and commercialization activities are the movement of methane from subsea hydrate structures into the open water columns and to the sea surface where it could reach the atmosphere.36 This could occur via a variety of pathways. All of them involve lesser injuries to the covering seabed, as could occur in exploration (e.g., seismic activity), development (e.g., well drilling, installation of gathering lines), and production activities (e.g., well workovers).37 Any substantial vibration, heat, or other forms of energy in the area could cause these injuries to the covering layers. If the covering layer of mud were to become disturbed with cracks, cleavages, or become removed or relocated in a manner that exposed the hydrates to the open water, then methane volumes could seep or vent out into the water columns. This could occur at a variety of transmission rates, from slow and bubbly to so fast that a persistent ‘chimney’ could occur enabling the methane to directly reach the atmosphere without transmission via the water column.38

When in the water, the methane is likely to metabolize into carbon dioxide, acidifying the adjacent water volumes. Simultaneously, the effect of both methane and carbon dioxide is to displace oxygen and thereby creating asphyxiating conditions for marine life. That could have knock-on effects for local human communities.39 Were the hydrates to dislodge and arise to the surface as chunks, they will buoyant float and sublimate at the ocean surface. It’s foreseeable that a large enough chunk could sublimate sufficiently quickly that the methane might combust. The general worry would be that the methane reaching the atmosphere would contribute to atmospheric greenhouse conditions and worsen the risks of climate change.

4.2. Cataclysmic events

Cataclysmic risks will be primarily derived from serious injury to the covering mud layers. A dramatic disruption to the covering mud layers could result in subsea landslide events, further uncovering additional areas of the hydrates.39 As the seabed has a variety of topologies and a variety of potential land-slide runs, some offshore methane hydrate reservoirs will be set in more risky locations than other offshore methane hydrates reservoirs. Thus, a very substantial consideration for all future offshore methane hydrates activities should be to prioritize the identification of high-risk profile hydrate reservoirs and to reduce activity at those sites.

Should a major landslide occur, it would not be unforeseeable that the mass of falling land and rubble could result in substantial water displacement and potentially a tsunami or other onshore damages. If that tsunami were to hit a populated coast line, the cost in human lives could be very tragic. Many coastal cities located near expected offshore methane hydrate deposits do have populations in the millions. Thus, legal policies to address prevention of anthropogenic tsunami should be encouraged.

Geologically, it has been found that various natural modes of stimulation have enabled hydrate reservoirs to collapse and result in subsea landslides. While there is no known case of anthropogenic causation, these types of events have occurred, and we can make further observations based on those ancient events. Such landslides can be massive, the size of a small state or nation in territorial dispersion. With landslides this large, transboundary intrusions cannot be excluded, for instance, where a human-induced landslide crosses from one coastal state into another neighboring coastal state or where the landslide triggers a transboundary tsunami.

4.3. Climate change concerns

When one is speaking of a gigantic novel source of methane gas, a form that could be erupted, vented, or seeped into oceanic waters and the air above them, then one has to address the risk poised to climate change.

The sheer volumes of the methane trapped in hydrate structures could readily extend the commercial feasibility of the hydrocarbon era and thus continue the introduction of greenhouse gases of carbon dioxide and methane to the atmosphere. This is especially so if the methane extracted were to be combusted without a counterbalancing carbon capture and storage effort. On the flip side, if the methane was used to displace coal or crude oil, then the net impact might reduce carbon emissions; however, both Jevon’s paradox and the known price elasticities for energy demand generally suggests that the introduction of additional energy from novel methane resources is not, ceteris paribus, likely to cause a one-to-one reduction in reliance on other in-place energy supplies.41

The transmission of greenhouse gases could be slow and mostly

34 See graph in Yiallourides & Partain [8] 14; with reference to by Carolyn Ruppel, ’US Geological Survey (2019)’.
35 Marine geohazards are ‘disasters induced by natural processes or human activity’; they include ‘any feature or process that could harm, endanger, or affect seafloor facilities’ and have the ‘potential to develop into seafloor failure events, which cause losses of life or damage to health, environment or field installations’, see João Camargo et al [18], ‘Marine Geohazards: A Bibliometric-Based Review’ (2010) 9(2) Geosciences 1, 23–24 1; See also Jian-liang Ye [19]; Itsuka Yabe and Hideo Kobayashi [20]; Joo Yong Lee and others [21]; ‘The Seaﬂoat Deformation and Well Bore Stability Monitoring During Gas Production in Unconsolidated Reservoirs’ (World Congress on Advances in Structural Engineering and Mechanics, South Korea, 8–12 September 2013) 703–707; Zhenyuan Yin and Praveen Linga [22] Chinese Journal of Chemical Engineering 1, 16.
36 For a full account, see Roy Andrew Partain [23] 791–927.
37 For a full account, see Roy Andrew Partain [23] 795–978.
38 For a full account, see Roy Andrew Partain [23].
39 For a full account, see Roy Andrew Partain [23].
40 On the relationship between submarine landslides and methane hydrates, see Xuemin Wu et al [24] 11(12) Energies 3481–3499; M F Nixon and J L H Grozic [25]; ‘Submarine Slope Failure due to Gas Hydrate Dissociation: A Preliminary Quantification’ (2007) 44(3) Canadian Geotechnical Journal 314–325.
41 On Jevon’s paradox see here, Owen [26] ‘The Efficiency Dilemma’ (The New Yorker, 14 December 2014) <https://www.newyorker.com/magazine/2010/12/20/the-efficiency-dilemma>.
metabolized into carbon dioxide when released through non-cataclysmic means, as discussed earlier, and the gases react with ocean waters and above surface air currents. Should the release be sudden and severe enough, methane might vent directly to the atmosphere. Were a large enough area and volume of mud become removed and if the hydrates became uncovered, their buoyant nature would drive chunks of hydrates to the ocean surface. Similarly, if enough methane were able to escape fast enough from the hydrate reservoirs, then the momentum and volume of methane rushing to the surface could enable a chimney type event where the gas would not mix with the water column and enable methane to direct reach the atmosphere, thus contributing to anthropogenic climate change.

4.4. Militaristic concerns

While landslides and resulting tsunami could result from accidental events during development and operational activities, they could also be purposely triggered to obtain the results of that damage. In an article published in 2018, Rajaraman and Rao [2] explored the technical concepts of using offshore methane hydrates in a tactical or strategic manner during warfare. Their findings led them to advocate for the use of offshore methane hydrates as a desirable mode of warfare. Their research includes graphics of submarines attacking offshore methane hydrate deposits to create “firewalls”; “accelerated destabilization of Gas hydrates only need [sic] simple explosions through sediments and dropping bombs from air”. They set out an argument that the aftermath of these firewalls and tsunami would be preferable to those of atomic and nuclear weapons.

As reprehensible as the concept is to facilitate mass casualties on low lying coastal areas, where millions might be living, the reality is that without protection the hydrates might well serve as a dangerous resource that could be militarized. This is not unlike a water supply that needs protecting so that it is not poisoned nor unlike how cannons are sometimes used to trigger avalanches safely. To best prevent such atrocities, the waters near known hydrate reservoirs should come under additional monitoring and surveillance and likely be done in a reliable information sharing system to best facilitate transboundary awareness, coordination, and safety.

5. Offshore methane hydrates in european waters

The body of legal literature on offshore methane hydrates remains comparatively small, but it has established that in most areas, existing oil and gas regulations do not envision the chemistry, geology, geography, and engineering challenges that make the extraction and production of offshore methane hydrates extremely different from both conventional offshore crude oil and natural gas production and from the more recent unconventional hydrocarbons, such as shale oil and tight gas assets. That research has found that a wide array of existing legal frameworks remains inadequate or wholly non-responsive to the licensing, commercial, environmental, and safety and hazards issues raised by this very novel hydrocarbon resource. When one also considers the unique international and transboundary risks presented by offshore methane hydrates, there is next to no preparation for those unique risks, as discussed further below.

5.1. New and updated legal frameworks are necessary

If new legal frameworks are to be created and existing ones to be updated for offshore methane hydrates, the novel risks and hazards presented by methane hydrates must be fully understood. New and updated legal frameworks need to regulate a scientific context quite different from those of conventional and unconventional oil and gas rule sets. Offshore methane hydrates are not conventional nor unconventional oil and gas assets, in that their deposition in the earth is not at all like the previous categories. They do not lay miles deep in the earth, in rock or under salt domes, offshore methane hydrates lay under comparatively shallow layers of mud, usually measured in the hundreds of meters. Rules designed to anticipate a fluid or gas contained in such impermeable structures will not appropriately address the context of offshore methane hydrates. Safety rules, risk mitigating procedures and pollution response mechanisms are presently primarily designed for crude oil events, such as spills from transport vessels or crude oil leaks from offshore wells. The safety and environmental rules for producing natural gas from methane have been left regulatorily underdeveloped, as discussed below.

5.2. Private rights and access to rules of civil liability

In our reviews of existing legal frameworks, we have found that many jurisdictions likely to have offshore methane hydrate assets do not provide well defined private rights to environmental services that would be correlated with the ecological conditions that exist prior to the onset of offshore methane hydrate development and commercialization. Similarly, it might be useful to nudge certain default environmental rights to those most at risk to better enable them to defend themselves or to negotiate with those parties seeking to develop offshore methane hydrates. For example, assigning certain private rights to coastal communities affected by offshore methane hydrate operations in advance of the onset of licensing discussions and before the onset of public participation procedures would advance the wellbeing and quality of life, inclusive of livelihood, for the communities that might be placed at risk from offshore methane hydrate commercialization. Another set of potential rights could include ‘rights of non-development,’ to better enable communities to retain sufficient political independence and improve on their ability to remain engaged in volitional and non-coercive modes of negotiations.

To complement the existence of the private rights, there needs to be a proper design of the civil liability system. While there is not enough space to detail our previous studies; we have recommended a default preference for strict liability while retaining recognition that a negligence rule might be more robust under certain conditions. Additional decisions would need to be made on who might be held liable, time limits or financial limits to liability, and if defenses of contributory or comparative negligence or of ‘last chance to avoid’ rules would be in play.

42 Partain [5]; 77 and 78.
43 Janani Rajaraman and S. Narasimha Rao [2] 249–267.
44 [2] 254.
45 Partain [5]; 76.
46 Partain provides a complete listing of the known legal literature on methane hydrates and offshore methane hydrates up till 2017; Partain [5]; 11. For a more recent update on the literature, see Yiakourides & Partain [8].
47 Partain [5]; 282–284.
48 Partain [5]; 289.
49 see Moridis et al. (2009) 745, 748–52.
50 Roy A. Partain[23].
51 See also, [13,14,23], introducing the idea of ‘methane hydrate banking’, whereby ‘unsafe fields could defer development in exchange for revenues from safer fields in production. If those riskier fields become safe due to later improvements in legal institutions or technological advances, those fields could go into development and repay those field owners that shared revenues in the earlier time period.’ Roy A. Partain [13].
52 Partain [5] Ch. 12.
5.3. Provision of public regulations for offshore methane hydrates

Within the focus of offshore methane hydrates in ‘European’ waters, and specifically in EU jurisdictional waters, the new evidence of offshore methane hydrates being in those waters means that a host of existing directives, regulations and other modes of public law will need to be updated to better reflect the context of offshore methane hydrates. Currently, it is only by indirect reference and fortuitous drafting when commercialization.

To respond timely to the issues at hand, and to ensure that the unique characteristics of offshore methane hydrate risks and activities can properly governed, the existing and functioning legal frameworks should be updated. This might be best accomplished by the drafting of a new annexes to the existing Offshore Safety Directive, Environmental Liability Directive, Environmental Impact Assessment Directive (EIA), Seveso, CCS Directive, and the Marine Strategy Framework Directive. Then, the Member States could update their laws and regulations in accordance with the annexes.

Similarly, other climate change policies might need updating. The EU would likely want to ensure that greenhouse gases from offshore methane hydrates were both measured and reported, to coordinate with the Greenhouse Gas Mechanism. Additional efforts might be needed to observe and protect various fragile ecosystems and habitats in the vicinity of the methane hydrate operations. Depending on the extraction technologies involved, even the London Convention and Protocol might be engaged, as chemicals might be injected into the shallow reservoir systems from vessels operating over the well sites. There will be many new activities and new consequences that would benefit from additional review and research in anticipation of commercializing offshore methane hydrates, a more complete listing and set of recommendations exceeds the limits of this paper.

55 Yen-Chiang Chang [17] 374.
54 Partain [5] Ch. 10. The goal being to obtain responsive legal frameworks while reducing the overall transactions costs and risks of delay to updating these frameworks, in contrast to the complexity and time-consuming work of drafting a new directive to the same results.
53 Offshore Directive [3]/30/EU on the safety of offshore oil and gas operations.
56 Directive [4]/35/EC on Environmental Liability with Regard to the Prevention and Remedying of Environmental Damage; European Union, Directive 2001/42/EC of the European Parliament and of the Council of 27 June 2001 on the assessment of the effects of certain plans and programmes on the environment, OJ L 1997/30, 21 July 2001 [SEA Directive]. Note that the EU ratified the Protocol on Strategic Environmental Assessment to the Convention on Environmental Impact Assessment in a Transboundary Context 2685 UNTS 140 on 21 November 2008.
57 The EU EIA Directive [41]/52/EU (“EIA Directive”) of the European Parliament and of the Council of 16 April 2014 amending Directive 2011/92/EU on the assessment of the effects of certain public and private projects on the environment Text with EEA relevance Orkesterjournalen L 124, 25.4.2014, 1-18.
58 Seveso-II Directive [27]/18/EU on the Prevention of Major Accidents involving Dangerous Substances.
59 European Union, Directive [28] of the European Parliament and of the Council of 23 April 2009 on the geological storage of carbon dioxide (text with EEA relevance) (2009/31/EC), OJ L 140/114, 5 June 2009.
60 European Union, Directive [29] 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 (text with EEA relevance), OJ L 164/19, 25 June 2008.
61 Partain [5] Ch. 10.
62 See Partain [5] Ch. 12, for a more complete discussion on these issues.

5.4. Concerns for international and transboundary issues

The impacts on climate change risks, on subsea landslide risks, on tsunami risks, and on risks to the ecological communities near and surrounding offshore methane hydrate development projects can all readily engage international law. Looking, for example, at the recent discoveries of offshore methane hydrates in the eastern Mediterranean Sea, there are many and multifaceted disputes to resolve and the potential for transboundary environmental accidents is high given the very close adjacency of many coastal countries in that area. Furthermore, while the MIGRATE study was sponsored by the EU Commission, it clearly discovered hydrates in offshore areas outside of the EU legal jurisdiction. From waters off Norway to areas in the Black Sea and in the East and South Mediterranean, there are many areas lacking legal systems that are ready for domestic offshore methane hydrates and doubly so for the international aspects of the above discussed risks from the development of such resources.

We would expect more detailed support to enable the UN Convention on the Law of the Sea (UNCLOS) and associated institutions to support protection of the various continental shelves and the Area where impacted. Beyond UNCLOS, we would expect to see serious contemplation on the need for amending and extending relevant sections of the UNCTEIA, the UNFCCC, the Espoo (EIA) Convention, the Århus Convention on Information Access and Public Participation, as well as the various regional maritime conventions (e.g., OSPAR, Bonn, Barcelona, and Bucharest) and the international hydrocarbon accident conventions (e.g., MARPOL). Similarly, given the seabed interactions, likely the London Convention and its Protocol would need also contextual amendments if offshore methane hydrates are to be sustainably developed. None of this can be accomplished quickly, clearly careful work would take time, but the time to start is already upon us.

63 See Nicholas A. Ioannides [30]; ‘Rights and Obligations of States in Undelimited Maritime Areas: The Case of the Eastern Mediterranean Sea’ in Stephen Minas and Jordan Diamond (eds), Stress Testing the Law of the Sea Dispute Resolution, Disasters and Emerging Challenges (BRILL 2018) 311–337; Recent geological studies have suggested that the Levant seafloor in the Eastern Mediterranean Sea contains approximately 100 trillion cubic feet (Tcf) of gas hydrates, see Ziv Tayber et al. [31].
64 United Nations Convention on the Law of the Sea [32] 1833 United Nations Treaty Series.
65 Convention on the Transboundary Effects of Industrial Accidents (adopted 18 September 1992, entered into force 19 April 2000) United Nations Treaty Series Vol 2105 p 457.
66 United Nations Framework Convention on Climate Change [15] 1771 United Nations Treaty Series 107.
67 Convention on Environmental Impact Assessment in a Transboundary Context [33].
68 Convention on Access to Information, Public Participation in Decision-Making and Access to Justice in Environmental Matters [34].
69 OSPAR Convention [35].
70 Agreement for Cooperation in Dealing with Pollution of the North Sea by Oil and Other Harmful Substances [36].
71 The Convention for the Protection of the Marine Environment and the Coastal Region of the Mediterranean [37].
72 Convention on the Protection of the Black Sea Against Pollution [38] International Legal Materials 110.
73 International Convention for the Prevention of Pollution from Ships (MARPOL) (adopted 17 Feb 1978, entered into force 2 Oct 1983) United Nations Treaty Series 1340.
74 International Convention on Oil Pollution Preparedness, Response and Cooperation [39].
75 On the interplay between UNCLOS and the UNFCCC, see Alan Boyle [40]; ‘Litigating Climate Change under Part XII of the LOSC’ (2019) 34(3) International Journal of Marine and Coastal Law 458–481; see also Partain [5] Appendix I Appendix 1 ‘Offshore Methane Hydrates and Climate Change Hazards’.
Finally, one would hope that Europe can lead on development of templates for other parts of the world. The risks of offshore methane hydrates will not be limited to those in European waters but will be found in regional oceans and seas around the world. If the EU and its nearby allies could take lead to create strong models for other regions less experienced in regional pacts and conventions on marine ecology, on environmental protection, and on multi-state coordination for sustainable development, the future for sustainable development of offshore methane hydrates would be much brighter.

6. Review and conclusion

If the European Commission finds the results of the Minshull report promising, and if the European Commission decides to begin a pathway towards the commercialization of natural gas from offshore methane hydrate reservoirs, then there are exciting rewards and terrifying risks facing European citizens and policy makers. Beyond Europe, the signal to support large scale development of offshore methane hydrates could encourage many other countries to ponder, if it is good for Europe, are offshore methane hydrate also good policy for our country, too? Thus, affirmation from the European Commission that offshore methane hydrates are too useful and too valuable to forego could initiate a global response to adopt methane hydrates as an exciting new source of natural gas for heating, for electrical power supplies, potentially for fresh water supplies, and of course for potential new revenues.

But this could also lead to many new problems. First and foremost, the reliance on fossil fuels is at best challenged by finding ways to prevent or offset carbon emissions, worst, it will result in greater emissions of carbon dioxide and methane, both greenhouse gases. It is hard to see how the use of natural gas from methane hydrates can be coordinated with goals of carbon emission reductions. Yes, scientifically the hydrate reservoirs could store carbon dioxide, but many citizens would likely prefer the simpler ‘never-burned’ alternative.

Second, there are many non-climate-change environmental problems that could be unleashed by accidents in the handling of the methane hydrate reservoir systems. Even small cracks in the mud layers could result in methane leaking into the oceans, removing oxygen from already oxygen poor zones of the benthic oceans. Larger cracks or ruptures could enable persistent methane venting; even potentially continuous leakage reaching the atmosphere. Methane is a greenhouse gas, but it is also an explosive gas and a powerful asphyxiant and could bring great risk of life to those animals in the zone of the released gas, including humans.

Third, there are pragmatic risks from structural collapse of the mud layers protecting and securing the hydrates to the seabed. The ecology of the seabed is delicate and often fragile; subsea landslides and other acts of turbulent energy could cause waste to those environments. At sufficiently large scale, the landslides could disrupt human activities below the sea, such as communication and internet cables, and cause disruption to the lives of coastal communities. Subsea landslides are a known trigger for tsunami; thus, human development of methane hydrates could lead to human-induced tsunami. And everyone who remembers the tsunami of Sumatra, Indonesia, in 2004 and of Fukushima, Japan, in 2011 will recall the human tragedies created by such natural tsunami.

It is foreseeable that there should be strong voices on both sides, but so far, there is primarily discussion of the development and commercialization of these offshore hydrates. That should change. Both the risks and the rewards are worthy of discussion; that discussion is best done before the first drill sinks into the mud instead of after the first catastrophe from a subsea landslide or major eruption of methane into the atmosphere.

We hope this paper can enable many researchers to consider the multi-disciplinary issues raised by the potential commercial development of offshore methane hydrates before serious binding policy decisions are made by European and other international bodies and states. As is commonly said in environmental law, it is much easier to prevent harm before it occurs than to try to solve how to restore after the injury is done.

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