European Commission

# European Unconventional Oil and Gas Assessment (EUOGA)

## Resource estimation of shale gas and shale oil in Europe

*Deliverable T7b*

# Table of Contents

This report is prepared by Mart Zijp, Susanne Nelskamp and the TNO EUOGA Team in July – February 2017 as part of the EUOGA study into EU Unconventional Oil and Gas Assessment commissioned by the Joint Research Centre (JRC). This report is based on agreements between the National Geological Surveys (NGS), the project team (TNO), the project coordinator (GEUS) and JRC on the applied methodology as described in Report T2b, the criteria and selected basins as well as the input dataset for the assessment as delivered by the NGS and compiled by GEUS (described in Report T6b). The calculations in this report were, in accordance with the contract, executed on regional (basin) scale and are not representative for evaluating site-specific occurrences or local variations within the basins. The availability and quality of the input data, and the extent to which this data is representative for the proper assessment of the potential resources on basin scale varies per basin and stratigraphic interval. These variations are included in the determination of uncertainty ranges and in the initial selection of the formations included in this evaluation. This report represents a draft version and should be treated as such; the final report will be finalized in March 2017.



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# Abstract

The resource assessment of shale gas and shale oil is performed within Task 7 of the EUOGA Project. The gathered data, insight and knowledge achieved from all previous tasks of EUOGA project were used to assess how much shale hydrocarbons resource Europe holds in 82 appraised formations found within 38 basins of 21 countries. From these formations, 49 have undergone stochastic volumetric probability assessment. The total resource potential found for all EUOGA formations is 89.2 tcm of gas initially in place (GIIP, P50) and 31.4 billion barrels of oil initially in place (OIIP, P50). The resource is distributed between 15 formations holding both oil and gas, 26 gas bearing formations and 8 oil bearing formations. The main uncertainty for GIIP resources calculation is coming from the following parameters: saturation, porosity and Langmuir's parameters controlling the amount of adsorbed gas. The main uncertainty for OIIP resource calculation is in uncertain estimates of saturation. The main recommendation to National Geological Surveys to decrease uncertainty is to re-examine currently available data in order to get better constraints on depth, thickness, TOC, porosity, maturity and reservoir temperature and pressure of shale formations. Prior to the EUOGA project, these parameters have not been thoroughly surveyed while controlling the resource assessment. Significant improvement in resource estimates can be expected if vintage data on shale formations is released on defaults by individual Member States (or non EU countries participating in EUOGA project). Vintage well data from areas located in shale basins and from wells drilled through shale formations is of particular value.

# Executive Summary

This report summarizes the results of Task 7 of the geological resource analyses of shale gas and shale oil in Europe, dealing with the resource estimate. The EUGOA study incorporates data for a total of 82 hydrocarbon-bearing shale formations within 38 geological basins covering 21 countries of Europe (Figure 1, Report T4b and T6b). Based on the criteria described in T6b and agreed methodology described in T2b, 49 out of the total 82 formations within 19 countries were selected for a stochastic volumetric assessment of prospective hydrocarbon resources (Table 1). 15 shale formations are considered to hold both shale oil and shale gas, while 26 formations are considered to hold only gas and 8 formations only oil. The total estimated resource potential for all assessed countries within the EU is 89.2 tcm of gas (P50) and 31.4 billion barrels of oil in place (P50).

**Table 1: Overview of total GIIP and OIIP for all 49 EUOGA assessed formations.**

| | **Total gas in place estimates (bcm)** | | | **Total oil in place estimates (billion bbl)** | | |
|---|---|---|---|---|---|---|
| | P90 | **P50** | P10 | P90 | **P50** | P10 |
| Austria* | 898 | **2237** | 4863 | 0.06 | **0.35** | 1.97 |
| Belgium | 368 | **852** | 1842 | | | |
| Bulgaria | 2646 | **7177** | 16786 | 1.01 | **6.54** | 39.38 |
| Croatia** | 1 | **2** | 5 | | | |
| Czech Republic* | 169 | **514** | 1269 | 0.03 | **0.18** | 1.04 |
| Denmark | 1317 | **2533** | 4488 | | | |
| France | | | | 0.44 | **2.61** | 14.68 |
| Hungary | 287 | **813** | 1885 | 0.22 | **1.28** | 7.09 |
| Italy | | | | 0.26 | **1.46** | 8.46 |
| Lithuania | 187 | **256** | 391 | 0.90 | **2.03** | 3.88 |
| Netherlands | 1254 | **2710** | 5872 | 0.25 | **1.38** | 7.36 |
| Poland | 6221 | **13243** | 26206 | 2.93 | **6.64** | 12.24 |
| Portugal | 412 | **1079** | 2480 | 0.32 | **1.77** | 9.94 |
| Romania** | 3324 | **9714** | 26972 | | | |
| Slovenia | 83 | **195** | 411 | 0.04 | **0.21** | 1.13 |
| Spain | 798 | **2049** | 4700 | | | |
| Sweden | 257 | **482** | 823 | 0.02 | **0.06** | 0.16 |
| UK | 11844 | **35432** | 84984 | 0.67 | **4.16** | 24.44 |
| Ukraine | 3846 | **9949** | 23080 | 0.41 | **2.78** | 17.17 |
| | | | | | | |
| **Total EU EUOGA** | | **89235** bcm | | | **31.4** billion bbl | |

* Resource estimations calculated for formations between 5 and 7 km depth.
** Resource estimations which are partly or fully of biogenic origin

The volumetric assessment presented in this report is based on the following input and preparatory steps:

1) Characterization of each shale formation by 20 geological assessment parameters, as provided by the National Geological Surveys and processed by GEUS (Report T6b). In case no value for a parameter could be provided for a certain assessment unit, an average value has been used based on the combination of available parameters for all shale formations included in EUOGA.
2) Determination of the probability and uncertainties regarding the presence of gas and oil in each shale formation (report T4b, results summarized in Appendix A).
3) Subdivision of each shale formation into regional assessment units using GIS data, parameter values and common agreed cut-off values.
4) Implementation of a ranking system based on TOC, depth, thickness and maturity of the shale formation leading to three uncertainty classes that are represented in the final numbers.

Based on the outcomes of these preparatory steps and input data the GIIP/OIIP values per formation and basin were estimated by applying a stochastic probability (Monte Carlo) method as outlined in report T2b. For gas-bearing shale formations the amount of free gas as well as the amount of adsorbed gas has been estimated. For oil-bearing shale formations the amount of free oil has been estimated. Note that if a formation is classified as either gas or oil only this type of hydrocarbon is calculated although in reality it is very likely that both are present. No recoverable volumes are calculated due to the lack of successful shale operations in the EU which inhibits realistic estimates of recovery factors.

Sensitivity analysis of the results shows that the largest uncertainties are associated with estimates of gas saturation and porosity for the amount of free gas. For the adsorbed gas the Langmuir volume and formation thickness are the biggest uncertainties. Saturation has largest uncertainty for estimates of the amount of oil in place. For each formation, however, the exact contribution of these parameters to uncertainties is different, mainly determined by the quality and quantity of the available data and the assumptions underpinning data constraints. In some cases the formation thickness has a higher than average influence on the uncertainty, for example when little is known about the spatial distribution of the formation or when the thickness of the prolific layers within a thick general formation is not well constrained. In some cases little to nothing is known about the porosity of the formation, and only rough estimates could be made. Additional geological studies executed by the National Geological Surveys on available conventional exploration data can aid in reducing the uncertainty of these parameters. Uncertainty with respect to saturation and Langmuir factors are very difficult to reduce. These parameters can vary significantly over small distances, and average values representative for a regional scale are difficult to determine.

The main results of this study are the collection and standardisation of geological data for potential shale gas/oil formations from the participating European countries as well as the identification of gaps in this dataset. During this study it became evident, that a lot of relevant data is missing from the current inventory (for various reasons). Accordingly, this study should be regarded as a basis for future extensions and improvements of the database. The unified method that is adopted for data gathering and resource estimates makes it easier to implement new or modified data into the present calculations.

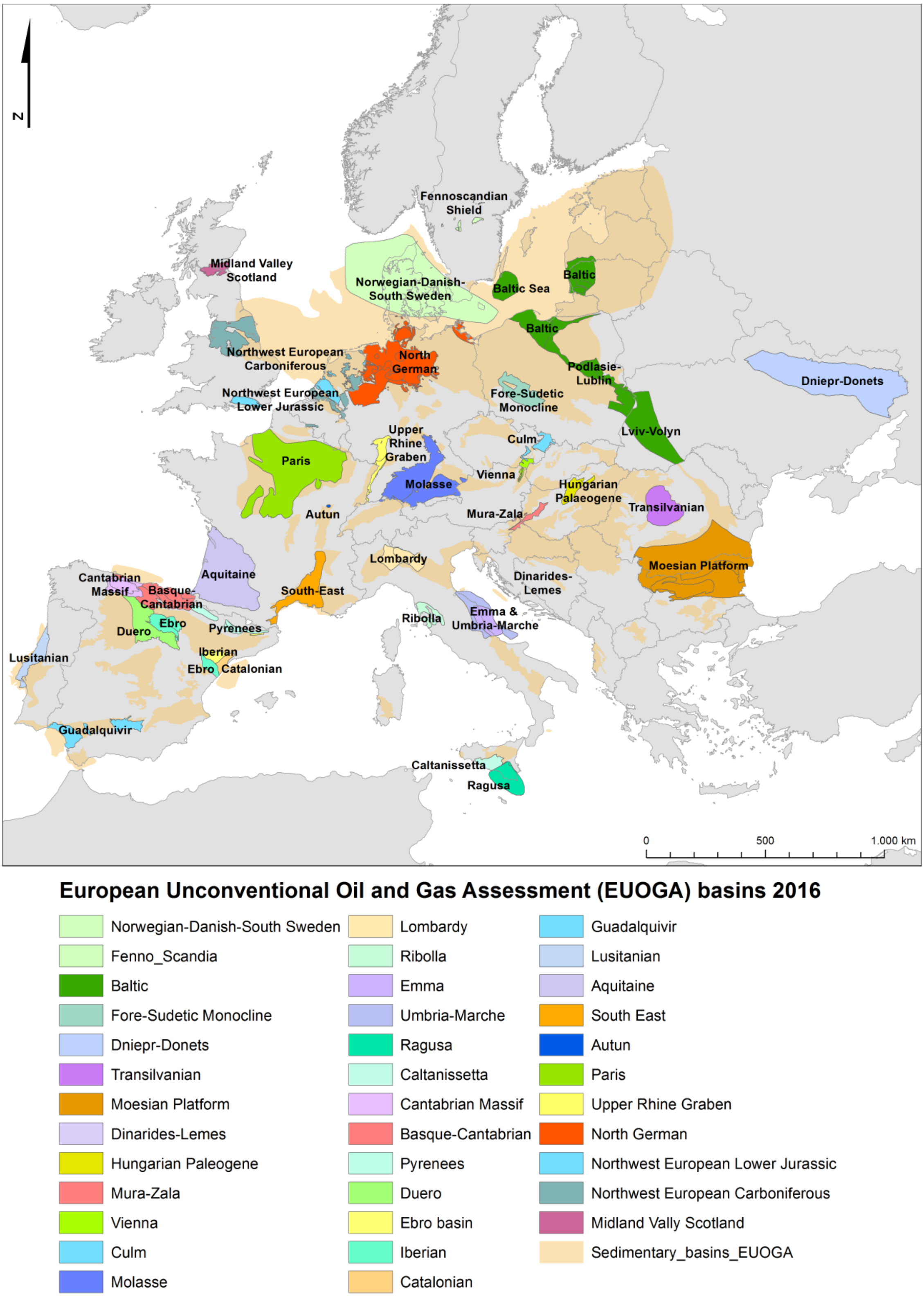


**Figure 1: Overview of the 38 identified shale basins within the 21 countries contributing to the EUOGA study.**

# Introduction

This report is part of the European Unconventional Oil and Gas Assessment project (EUOGA), commissioned by JRC-IET. It presents the results of Task 7 "Resource estimation of shale gas and shale oil in Europe".

The main objective of Task 7 is to provide a volumetric estimate of unconventional hydrocarbon resources (GIIP and OIIP, respectively gas and oil initially in place) for a selection of prospective shale formations and shale basins across Europe. The methodology is approved by JRC and described in Report T2b.

The selection of shale formations to be included in the resource estimation is based on a subdivision into more homogeneous and coherent assessment units(see report T2). The formations in the study are subjected to a pre-screening based on the availability of a minimum set of critical parameters needed for estimation; average TOC more than 1.5%, average depth below 7 km, average thickness at least 20 m and this is performed on distinguishable GIS objects leading to the different assessment units.

The estimation methodology itself produces a stochastic distribution of GIIP and OIIP volumes obtained by a Monte Carlo simulation taking into account the uncertainty ranges for the used parameters. The values and uncertainty ranges for each parameter are derived from the approved data and information of shale formations, delivered by Task 4, Task 5 and Task 6 (Reports T4b and T6b) originating from the National Geological Surveys (NGS's).

The resource estimations are performed on a per-formation basis. The outcomes are aggregated and reported per basin as well as per country.

# Used method and assumptions

The following paragraphs describe the application, assumptions and results of step two (subdivision into assessment units), three (screening and ranking of shale formations) and four (estimations of GIIP and OIIP) of the assessment method (Report T2b). The assessment results of step one (….) of the assessment are detailed elsewhere (report T4b), and summarized here in the description of the assessment results per formation.

## Subdivision into assessment units (2nd assessment step)

The subdivision into assessment units is based on the geological description of the shales (step 1, see report T2b, chapter 4.1 and T4b), the basin and the delivered GIS maps. Important parameters for this subdivision are:

- Depth
  - For this assessment a maximum average depth of 7000 m and a minimum depth of 1000 m were used. Regions shallower than 1000 m were included in the assessment as possible biogenic plays or as very shallow thermogenic if the maturity suggests that they were located at higher depths in the past. Areas between 5000 and 7000 m are included in the assessment, but assigned a lower success factor. Areas with an average depth of more than 7000 m were not considered any further.
- Thickness
  - An average thickness of 20 m has been set as the lower boundary for the assessment in this study. Shale layers with an average thickness less than 20 m are not taken into account in the final calculation of the GIIP/OIIP. Also information on the thickness distribution is necessary for the calculation of the total shale volume, formations without thickness information were not included in the assessment.
- Maturity (Immature/oil/gas transition)
  - Immature shale layers were only included for the calculation of biogenic gas when the layer is shallower than 1000 m. The other formations were subdivided into oil shales for the calculation of the OIIP and gas shales for the calculation of the GIIP or both. This subdivision is based on the average measured vitrinite (or equivalent) reflectance or other forms of maturity data. It is important to know that once a formation has been rated as either an oil shale or a gas shale only this form of hydrocarbons has been calculated. Note that if a formation is classified as either gas or oil (by its maturity) only this type of hydrocarbon is calculated although in reality it is very likely that both are present. If it's characterized as being in the oil window only oil is considered.
- Biogenic versus Thermogenic gas systems
  - Shallow immature layers were included in the study as possible biogenic shale gas formations.
- Onshore/Offshore
  - Offshore areas were excluded from the calculation of the GIIP/OIIP
- Mineralogy, Porosity and Permeability
  - Subdivision not possible with current dataset
- Source rock quality (OM type and TOC content)
  - Subdivision not possible with current dataset

The subdivision into individual assessment units will be shown in the GIS environment. If needed analogues are selected for each individual unit. This step reduces the overall uncertainty of the assessment as it reduces the variability of these parameters within one assessment unit. Because of this it is possible to exclude those parts of a shale formation that do not meet assessment criteria as well as subdivision between GIIP, OIIP or both.

## Ranking of shales per country (3rd assessment step)

The ranking/pre-screening of the shales is performed per individual assessment unit with the objective to:

1) discard units that either do not comply to the minimum prospectivity threshold or lack critical parameters
2) increase the range of uncertainty parameters if values are inconsistent with analogue plays

Figure 2 provides an overview of the pre-screening and ranking process and the parameters involved. The criteria and cut-off values are defined and approved in Report T2b. The data and information is provided by the results of Task 4, 5 and 6. This ranking/pre-screening is supposed to identify the most interesting shale formations per country/basin with enough data available for a full assessment and limit the total number of formations a full assessment is performed on.

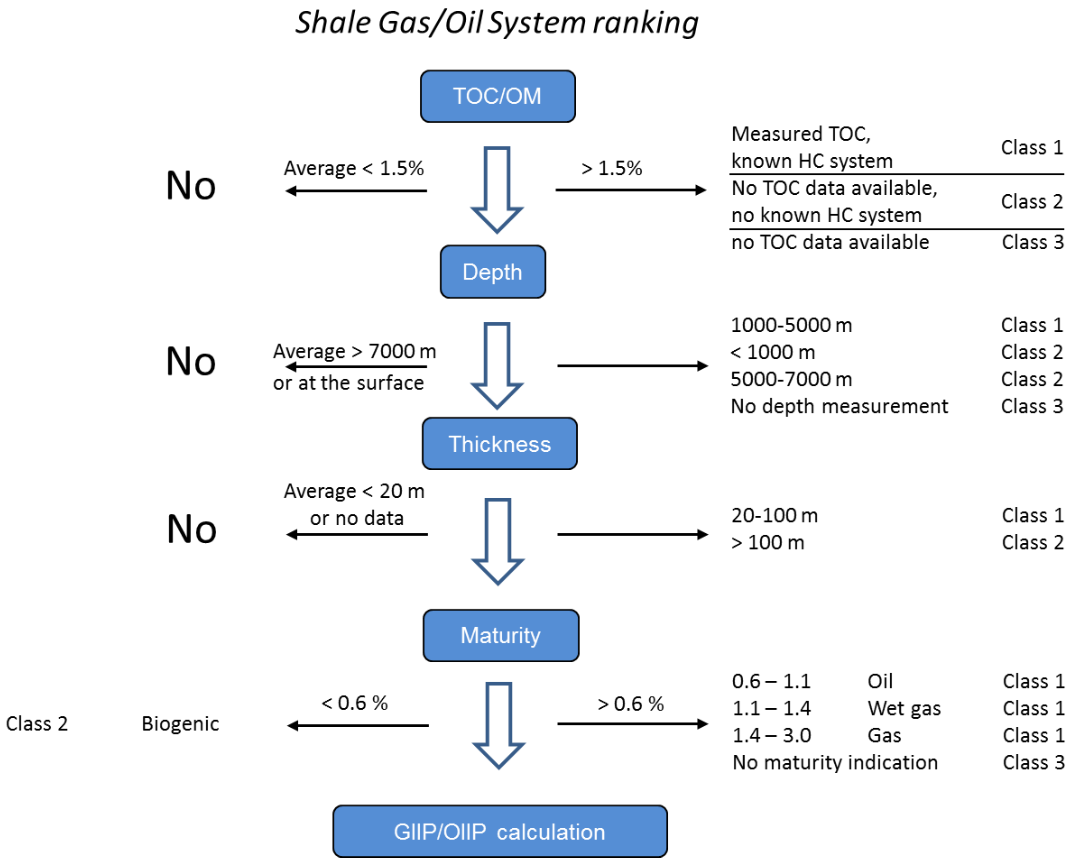


**Figure 2: Shale ranking/pre-screening criteria used in step 3.**

The ranking/pre-screening uses the most important and basic criteria and information necessary for a GIIP/OIIP calculation. The classes were defined to identify how close to a "normal" successful US type shale gas/oil system the formation is while the 'No class' refers to formations that fall out of the assessment criteria or have insufficient data and are therefore not taken into account in the GIIP/OIIP calculation (Figure 2).

- Class 1 – Main screening parameters consistent with typical shale gas/oil play as known from plays in the US

    - GIIP/OIIP calculation
- Class 2 – Depth, TOC and thickness data is available but are not consistent with typical shale gas/oil plays
    - GIIP/OIIP calculation with wider range for parameters and overall higher uncertainty
- Class 3 – Some parameters are unknown
    - GIIP/OIIP calculation only if critical parameters are available. Possible zero value in uncertainty estimation
- No – A parameter falls out of the range of shale gas/oil plays
    - no GIIP/OIIP calculation

## GIIP/OIIP estimation (4th step)

After the shale formation has been ranked, the stochastic volumetric approach has been chosen as the resource estimation method: see report T2b for further discussion. By using this method the GIIP/OIIP is calculated using the following function:

$$GIIP = G_f + G_a$$

where

$G_f$ = free gas in the macro pores of the rock
$G_a$ = adsorbed gas in the micro pores

The free gas in the macro pores is be calculated by means of:

$$G_f = V \times \phi \times S_{gas/oil} \times B_g$$

$V$ = Volume (m$^{3}$)
$\phi$ = bulk porosity in %
$S_{gas/oil}$ = gas saturation in %
$B_g$ = Expansion factor (gas formation volume factor) (Rm$^3$/Sm$^3$)

The adsorbed gas is be calculated by:

$$G_a = V \times \rho \times G$$

$V$ = Volume (m$^{3}$)
$\rho$ = Rock density (g/cm$^{3}$)

In this formula G is the Langmuir factor, which is calculated through:

$$G = \frac{P \times L_V}{P + L_P}$$

G = gas content ($m^3$/ton)
P = Reservoir pressure (Pa)
$L_V$ = Langmuir volume ($m^3$/ton rock)
$L_P$ = Langmuir pressure (Pa)

The Langmuir factors and isotherms is developed to describe adsorbed gas, methane sorbed to the surface of kerogen, which is in equilibrium with methane present in the gas phase.
For the stochastic calculation for each parameter the mean, minimum and maximum values which describe the probability density function for that parameter which describes the distribution of the values in the assessment unit. These values are then combined by random sampling (Monte Carlo simulation) and give a probability distribution for the GIIP along with an indication which values have the biggest influence on the uncertainty of the calculated value.

For the calculation the mean, minimum and maximum values provided by the NGS on their critical parameter sheets are used (see report T6b). If a parameter necessary for the calculation is not available for an assessment unit, an available value from an analogue was used. The chosen analogues were discussed with the respective NGS representatives and can be either from the same country or from a neighbouring assessment unit. If these options were not available, the average distribution of that parameter from all reported and assessed European shale layers (see report T6b) was used as an analogue.

For several assessment units the reported range of maturity spanned the oil as well as the gas window. In this case a calculation for both GIIP and OIIP was performed and the reported area of the assessment unit was subdivided according to the assumed distribution of the gas mature and oil mature areas. This subdivision was done in accordance with the respective NGS.

Some parameters have less than ten reported values, which makes the calculated EU average less trustworthy. When this occurs, which is the case for the oil saturation, the Langmuir Pressure and the Langmuir Volume, the reported values are complemented with published values from U.S. analogues. For the oil saturation only seven EU values were reported, one of which was very high (more than ten times the maximum of the other values). The EU analogue oil saturation value consists therefore of the reported EU average plus data from the U.S. shales. This gives an average saturation of 4.44% in a log normal distribution with a standard deviation of 0.083 at a location of 0. This is used for the OIIP calculation for EU formations that do not have a reported value.

Very few values were reported also for the Langmuir Pressure and Volume. Literature values (Gasparik 2013, Wei Yu 2015, Yu and Sepehrnoori 2013, Charoensuppanimit 2016) of measurements on both European and American shales are added to get a better average value. This resulted in a lognormal distribution for the Langmuir volume with a mean of 69 scf/ton rock, a standard deviation of 34 at location 5. For the Langmuir pressure this resulted in a lognormal distribution with a mean of 1230 psia with a standard deviation of 450 and a location of -300.

A detailed description of all individual parameters is given in EUOGA report T2b.

### Calculation of the expansion factor

The expansion factor of each formation holding gas is calculated using an approach based on the ideal gas equation together with the given temperature and pressure gradients of the formation. For the three depths (min, mean, max) the density of methane gas is calculated and compared to the density of gas at surface conditions. The website of NIST Chemistry Webbook (http://webbook.nist.gov/chemistry/) aids in determining Thermo Physical Properties of Fluid Systems, using 100% methane gas. In cases where the local pressure gradient of the formation was not given a hydrostatic pressure increase was used. When the temperature gradient of the formation was not given the NGS was contacted to aid in this, or values were acquired from literature. For surface conditions 25 degrees Celsius and 1 bar pressure are used.

### Probability density function (PDF)

For each parameter a probability density function needs to be defined. The shape of the function is determined by the assumed distribution of values in the assessment unit and the mean, minimum and maximum value.

*Uniform distribution*

A uniform distribution is selected when the parameter values are equally probable , i.e. a high value for a parameter is equally likely to occur as a medium or a low value.

*Normal distribution*

A normal distribution is the standard distribution used in most cases. The distribution follows the standard bell shaped curve, the medium values are the most probable, the minimum and maximum values determine unlikely endmembers of the distribution.

Other types of distribution like a triangular or log normal distribution are be chosen when necessary.

### Definition of the area uncertainty classification

The area parameter for the calculation is derived from the polygons as delivered by the geological surveys. It is the calculated area based on the geographic projection of the GIS project (ETRS_1989_LCC, further information can be found in the report to work package T5). In the case that no polygon for the area was available or the area of the polygon was significantly different to the reported values, the area value delivered by the NGS in the critical parameter sheets (see report T6b) was used.

For the application of the probabilistic calculation of possible GIIP/OIIP value ranges an area uncertainty was introduced according to Table 2 and Table 3. Following this Figure 3 shows the overview of the (combined) formations classes per basin.

**Table 2: Area uncertainty classification for areas with discrete mapping of distribution**

| *Type of data* | *Class A* | *Shale distribution continuous* | *Shale distribution patchy* | *Class B* |
|---|---|---|---|---|
| 3D seismic; >1 well/100 km2 | 1a | PDF=Normal<br>M=Area<br>SD=2.5%*Area | PDF=Normal<br>M=Area<br>SD=5%*Area | 1b |
| 3D seismic; <1 well/100 km2 | 2a | PDF=Normal<br>M=Area<br>SD=5%*Area | PDF=Normal<br>M=Area<br>SD=10%*Area | 2b |
| 2D seismic; >1 well/100 km2 | 3a | PDF=Normal<br>M=Area<br>SD=7.5%*Area | PDF=Normal<br>M=Area<br>SD=15%*Area | 3b |
| 2D seismic; <1 well/100 km2 | 4a | PDF=Normal<br>M=Area<br>SD=10%*Area | PDF=Normal<br>M=Area<br>SD=20%*Area | 4b |
| Wells only | 5a | PDF=Normal<br>M=Area<br>SD=25%*Area | PDF=Normal<br>M=Area<br>SD=50%*Area | 5b |

**Table 3: Area uncertainty classification for areas with global mapping of the maximum shale extent or basin area**

| *Type of data* | *Class A* | *Shale distribution continuous* | *Shale distribution patchy* | *Class B* |
|---|---|---|---|---|
| Abundant/good data | 6a | PDF=Uniform<br>Min=Area*90%* shale%<br>Max=Area + 5% | PDF=Uniform<br>Min=Area*80%* shale%<br>Max=Area | 6b |
| Little/poor data | 7a | PDF=Uniform<br>Min=Area*75%* shale%<br>Max=Area + 10% | PDF=Uniform<br>Min=Area*50%* shale%<br>Max=Area | 7b |

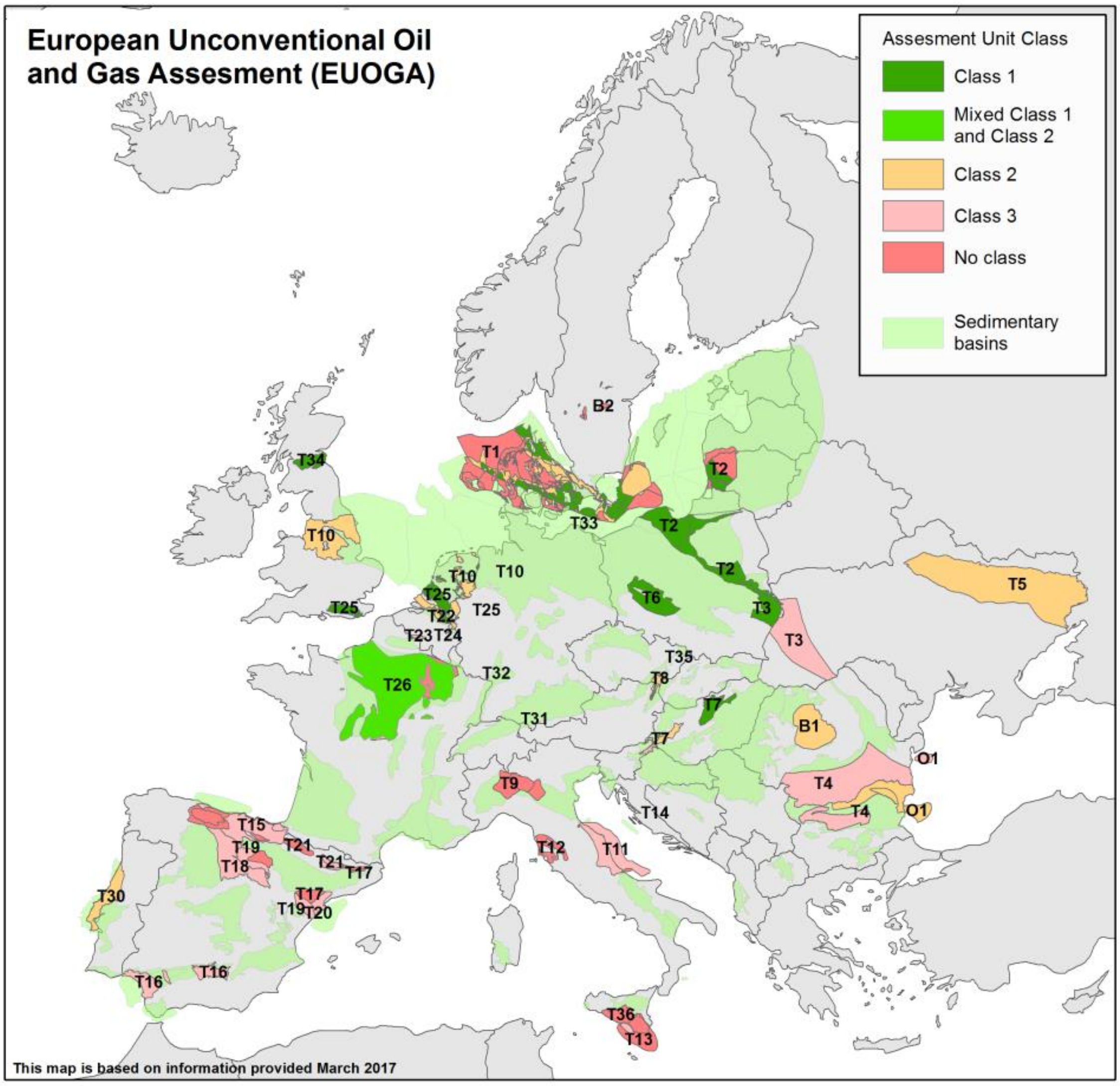


**Figure 3: Basin classification according the shale ranking/pre-screening data, following the criteria set in Figure 2.**

# Results

The pre-screening results from step 3 identified 30 assessment units as Type 1 (S, DK, B, HU, PL, LT, NL, UK, F), 30 assessment units as Type 2 for being too deep or having an average thickness of more than 100 m (HR, S, A, DK, UA, B, HU, BG, CZ, NL, UK, P), 5 assessment units as Type 2 for bearing biogenic gas (S, RO, BG), 25 assessment units as Type 3 because of unknown maturity or TOC (RO, I, E, B, BG, UA, SLO) and excluded 60 assessment units from the calculation (I, LV, HR, S, DK, E, RO, BG, LT, SLO, F, UK).

In total 38 basins (Figure 4) holding 82 formations are reviewed for this study. 49 formations from 19 countries met the requirement to undergo resource estimations. This chapter describes the general results of each of those, per country. A detailed overview of the calculation parameters and sensitivities per formation and basin can be found in Appendix A.

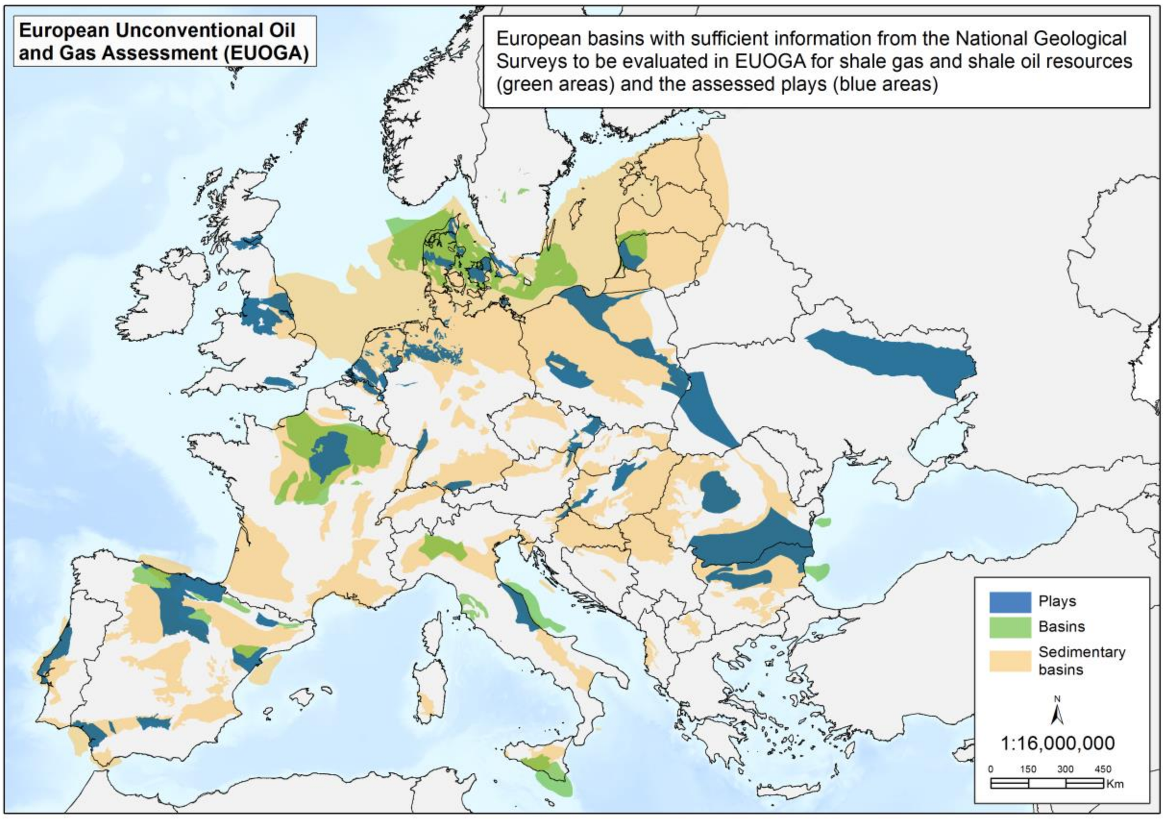


**Figure 4: Overview of all 38 EU basins identified within the EUOGA project. Of the 82 formations studied 49 were considered for of shale hydrocarbons.**

Final results of the GIIP and OIIP calculations are shown in Figure 5-9 and Table 4 and Table 5. Total resource estimation is a P50 of 89.2 tcm of shale gas and 31.4 billion barrels of shale oil. Countries with the biggest expected amount of shale gas are the United Kingdom, Poland, Romania and Ukraine in the order of 9-13 tcm for the last three and over 30 tcm for the United Kingdom (75% of the total shale gas in the EU, Figure 5). The other 16 assessed countries estimates show relatively little shale gas or only shale oil present (Figure 5 and Figure 6).

For the amounts of shale oil (Figure 5 and Figure 7) there are two main players, which are Bulgaria and Poland with each over 6 billion bbl per country. Next to this France, Portugal, UK and Ukraine are also expected to hold high amounts of shale oil around

2-4 billion barrels of oil. Remaining European countries have little to a few 100 million bbl. Of the smaller countries the Netherlands and Lithuania show interesting results as although they are rather small countries the best estimates for shale oil are still over 1 billion barrels of oil.
Take in mind that these are GIIP and OIIP with unsure recovery factors, thus comparing this to conventional resources should be done with caution as it is unclear how much eventually can be produced.

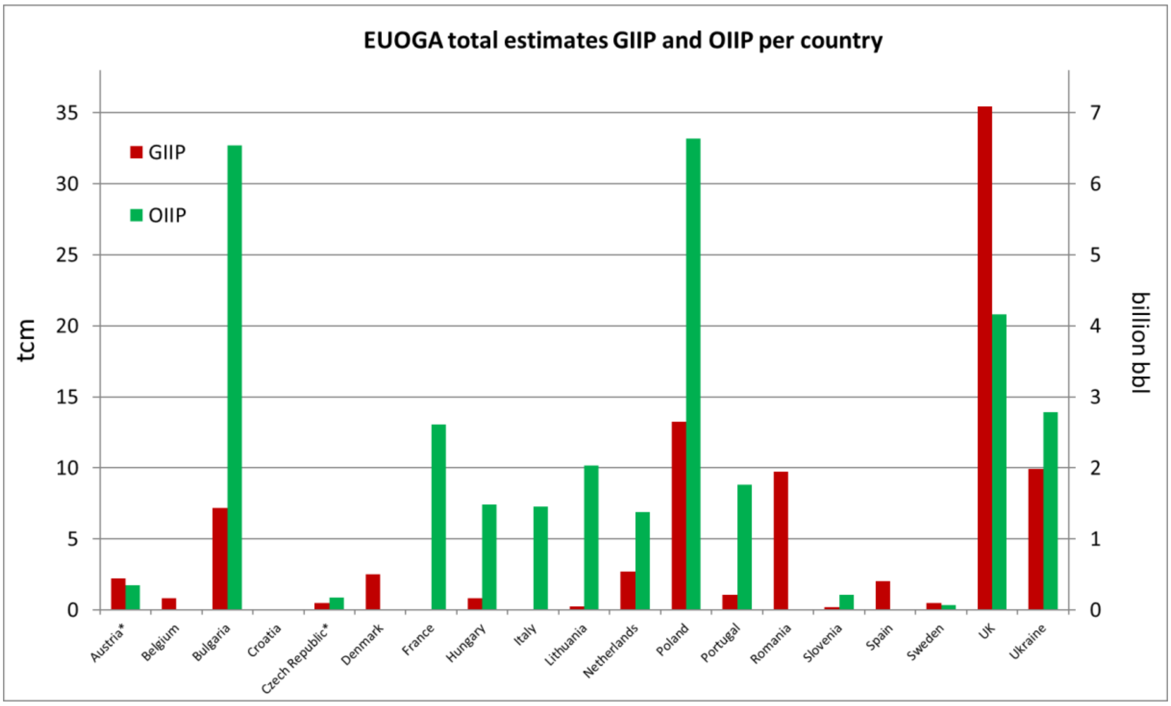


**Figure 5: Total estimated gas initially in place (red) and oil initially in place (green) for all 49 formations used in this study, per country. *The GIIP values for these two countries were calculated for formations between 5 and 7km depth.**

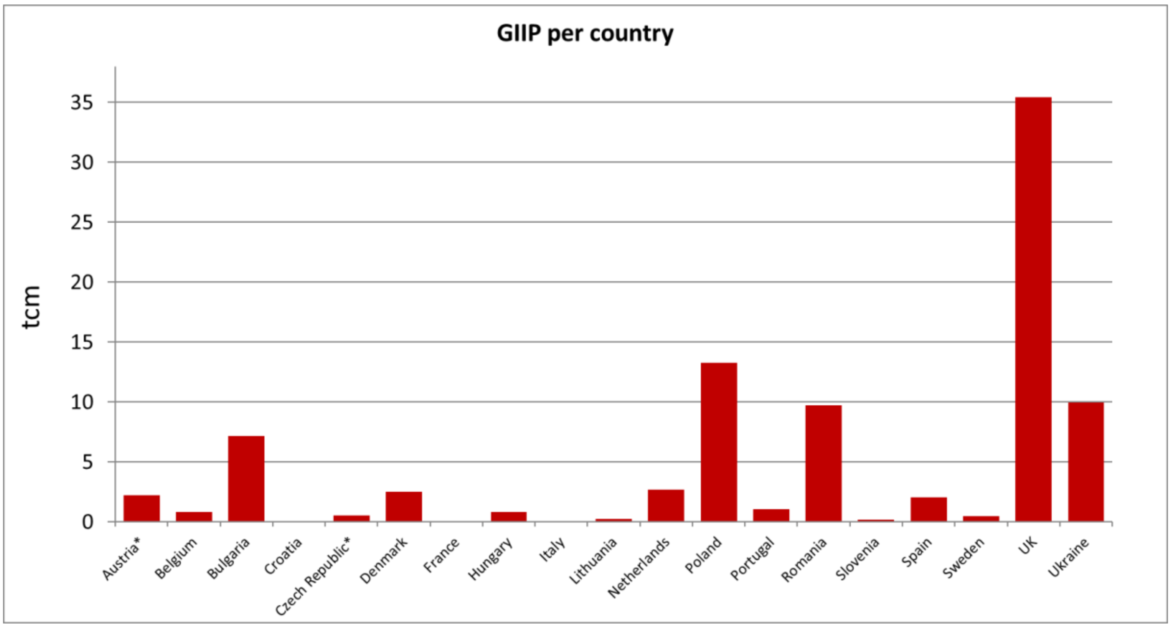


**Figure 6: Total gas initially in place for all European shale formations, totals per country.**

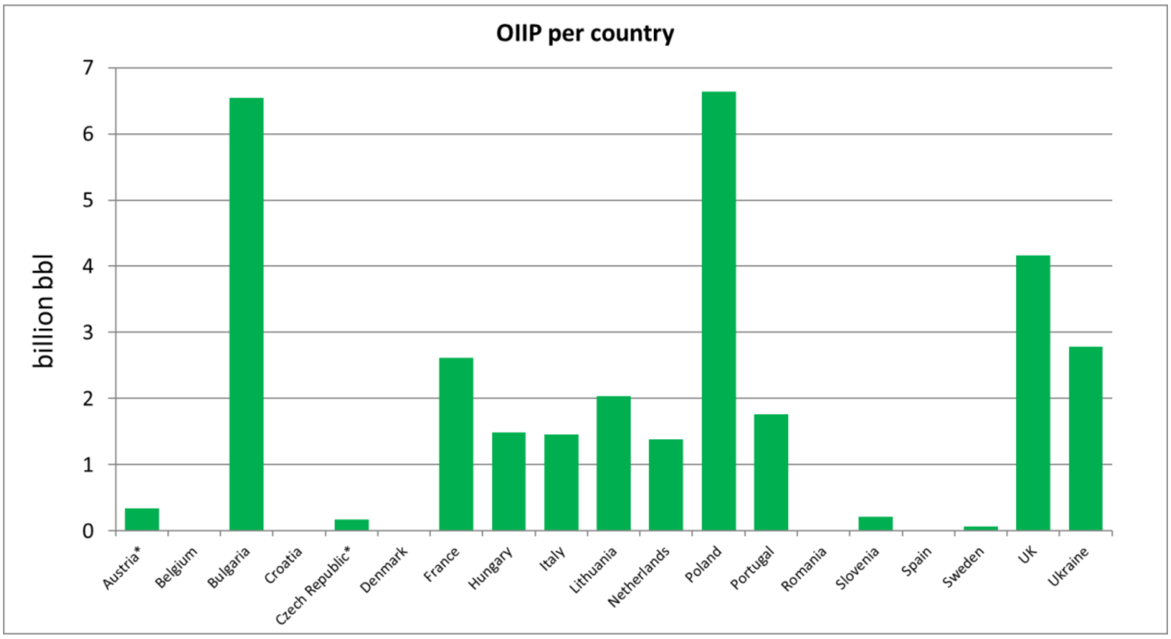


**Figure 7: Total oil initially in place for all contributing European shale formations, per country. *The OIIP values for these two countries were calculated for formations between 5 and 7km depth.**

When looking at the amount of shale gas and shale oil initially in place per basin (Figure 8, see basins in Figure 3) there biggest differences occur because of different size and different amount of formations within one basin. By far the largest amount of shale gas in present in the Northwestern European Carboniferous basin, which is also one of the biggest basin complexes in Europe and includes the UK and the Netherlands. Next to that the Baltic basin (including Lithuania and Poland) and the Moesian Platform show substantial amounts of shale oil in place.

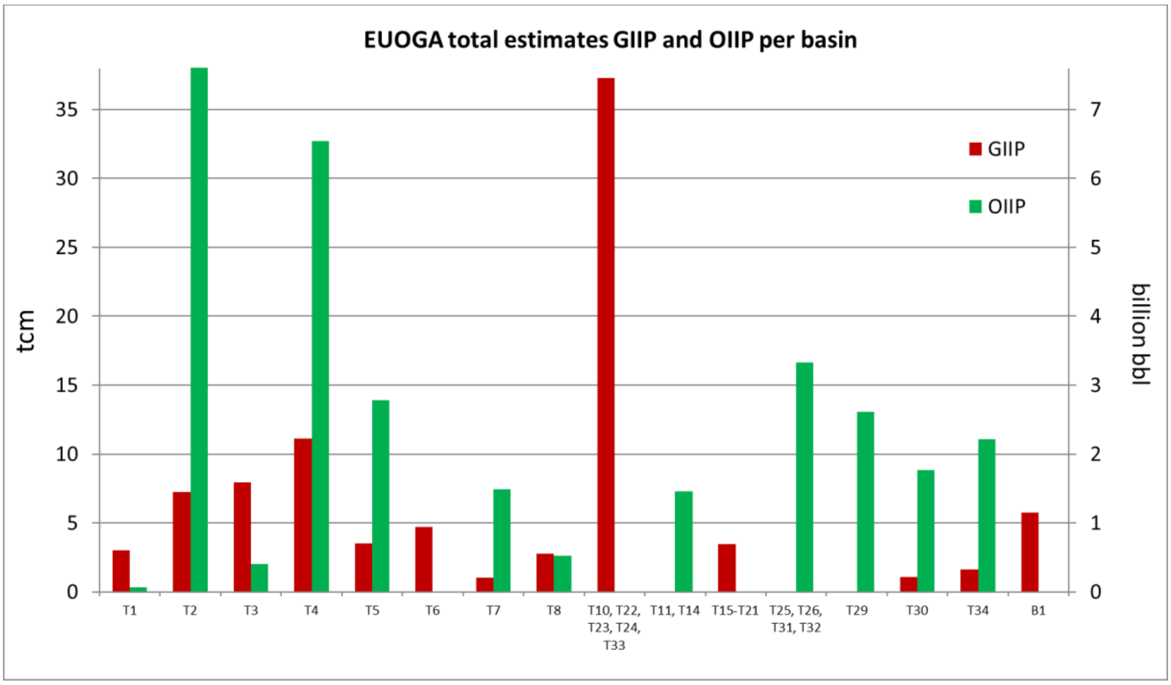


**Figure 8: Total estimates for all estimated formations in gas in place (red) and oil in place (green), per basin where the Spanish basins (T10, T22, T23, T24, T33) are grouped together. For basin and formation names see Appendix A.**

**Table 4: Overview of total resources of the 49 calculated formations, summarized per country.**

| | Total gas in place estimates (bcm) | | | Total oil in place estimates (billion bbl) | | |
|---|---|---|---|---|---|---|
| | P90 | **P50** | P10 | P90 | **P50** | P10 |
| Austria* | 898 | **2237** | 4863 | 0.06 | **0.35** | 1.97 |
| Belgium | 368 | **852** | 1842 | | | |
| Bulgaria | 2646 | **7177** | 16786 | 1.01 | **6.54** | 39.38 |
| Croatia** | 1 | **2** | 5 | | | |
| Czech Republic* | 169 | **514** | 1269 | 0.03 | **0.18** | 1.04 |
| Denmark | 1317 | **2533** | 4488 | | | |
| France | | | | 0.44 | **2.61** | 14.68 |
| Hungary | 287 | **813** | 1885 | 0.22 | **1.28** | 7.09 |
| Italy | | | | 0.26 | **1.46** | 8.46 |
| Lithuania | 187 | **256** | 391 | 0.90 | **2.03** | 3.88 |
| Netherlands | 1254 | **2710** | 5872 | 0.25 | **1.38** | 7.36 |
| Poland | 6221 | **13243** | 26206 | 2.93 | **6.64** | 12.24 |
| Portugal | 412 | **1079** | 2480 | 0.32 | **1.77** | 9.94 |
| Romania** | 3324 | **9714** | 26972 | | | |
| Slovenia | 83 | **195** | 411 | 0.04 | **0.21** | 1.13 |
| Spain | 798 | **2049** | 4700 | | | |
| Sweden | 257 | **482** | 823 | 0.02 | **0.06** | 0.16 |
| UK | 11844 | **35432** | 84984 | 0.67 | **4.16** | 24.44 |
| Ukraine | 3846 | **9949** | 23080 | 0.41 | **2.78** | 17.17 |
| | | | | | | |
| **Total EU EUOGA** | | **89235** bcm | | | **31.4** billion bbl | |

*The GIIP and OIIP values for these two countries were calculated for formations between 5 and 7km depth.
** Resource estimations which are partly or fully of biogenic origin.

For three countries shale gas resources were calculated for formations deeper than 5km, Austria, Czech Republic and Denmark. In the case of Austria and the Czech Republic these reserves are the only shale gas occurrences included in this study and therefore included in the above overview. Denmark has additional reserves located at depth < 5km, the calculation results for the deeper formations are not included in the general overview and only reported in the detailed calculation overview (Appendix A) and in Table 5 and Figure 9.

**Table 5: Overview of the total amount of GIIP of the deep (5-7km) occurrences of shale hydrocarbons within the EUOGA study.**

| | Total gas in place estimates > 5km depth (bcm) | | |
|---|---|---|---|
| | | P50 | |
| Austria | 898 | 2237 | 4863 |
| Czech Republic | 169 | 514 | 1269 |
| Denmark | 1333 | 2576 | 4512 |
| | | | |
| **Total deep occurences EUOGA** | | **5326** bcm | |
| | | | |

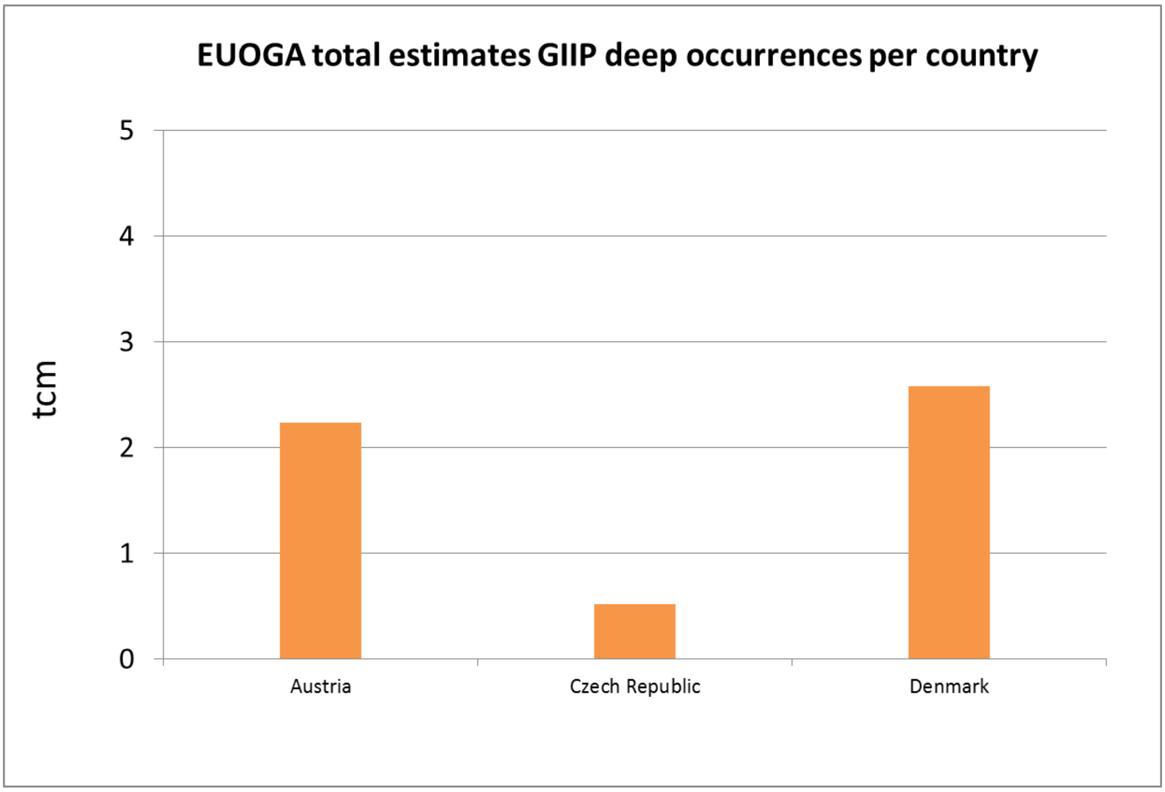


**Figure 9: Overview of total estimates of deep occurrences of shale gas for EU formations deeper than 5 km.**

In Figure 10 and Figure 11 estimated resources are shown subdivided into the three different quality classes. This is done to get a better grip on the quality of the calculated resources. From the GIIP subdivision the figure shows that here are only a few countries which have substantial Class 1 resources, namely Denmark, Poland and the UK. The rest of the countries do not have such a high standard of data quality leading to the most reliant estimates. Most of the resources are of Class 2 with 60 tcm out of 92 tcm in total. Class 3 follows with 13.4 tcm in total, coming from mainly eastern European countries.

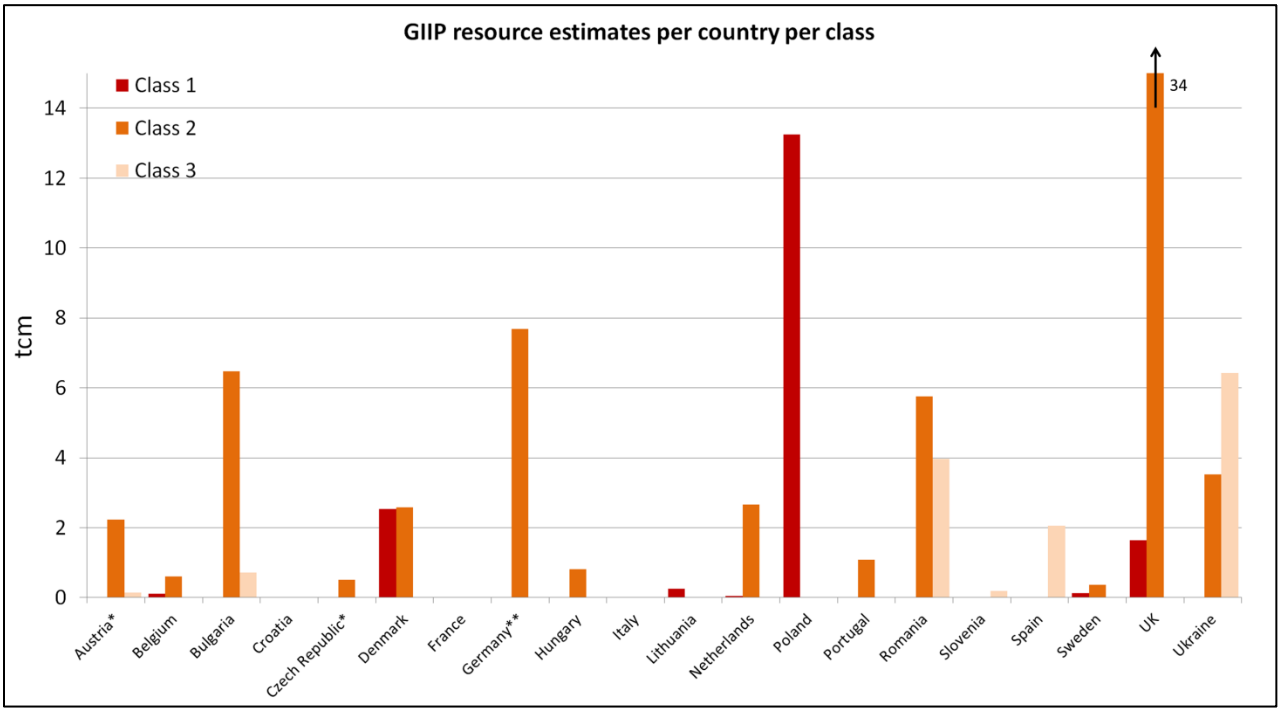


**Figure 10: Overview of calculated GIIP per country subdivided per class. For the class ranking system see earlier in this report. *The resource estimates for these two countries were calculated for formations between 5 and 7km depth. **Values taken from country specific report.**

For the OIP subdivision into the three classes it is visible that there are considerable more countries with high quality data and shale formations leading to Class 1 OIIP resources. In total 13 billion bbl resources are ranked Class 1 out of 31 billion bbl of the entire EUOGA OIIP estimate. When looking at total numbers Poland and Bulgaria have the two biggest OIIP estimates with more than 6 billion barrels each, but following Figure 11 it is visible that the estimates of Poland actually are expected to be more precise following the quality of the data the NGS send in.

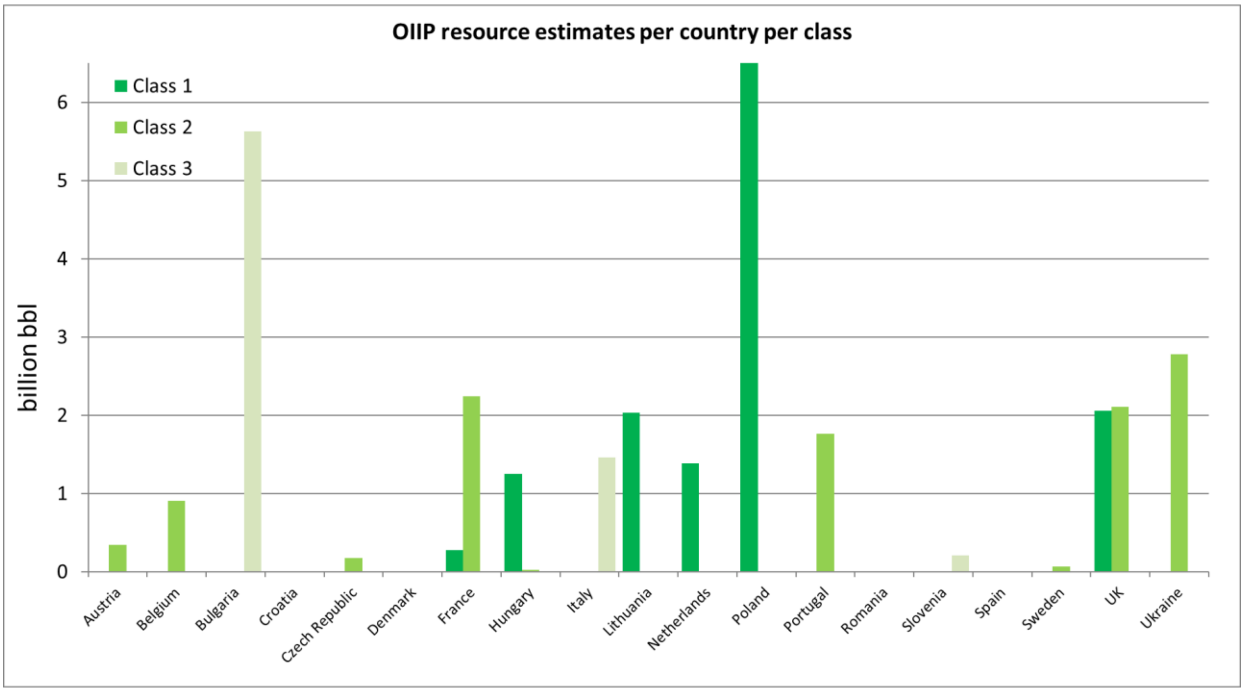


**Figure 11: Overview of estimated OIIP per country divided per class. The shale ranking system is explained earlier in this report.**

# Comparison with existing European Resource assessments

Large scale resource assessments were published for Europe in general by the EIA (2011 and 2013) and USGS (2010) as well as for individual countries (e.g., UK, Andrews et al. 2013 and 2014, and Poland, PGI, 2012; see report T3 for a complete list). In this section the results of this report are compared with the already published reports for the individual countries.

In order to compare the results in general, it is important to compare similar reserves. The main result of this study is the GIIP/OIIP and no systematic upscaling to TRR was attempted. It is therefore not possible to compare these results to the study of the USGS, as they calculated only TRR. For completeness the calculated TRR of Poland are included in the overview.

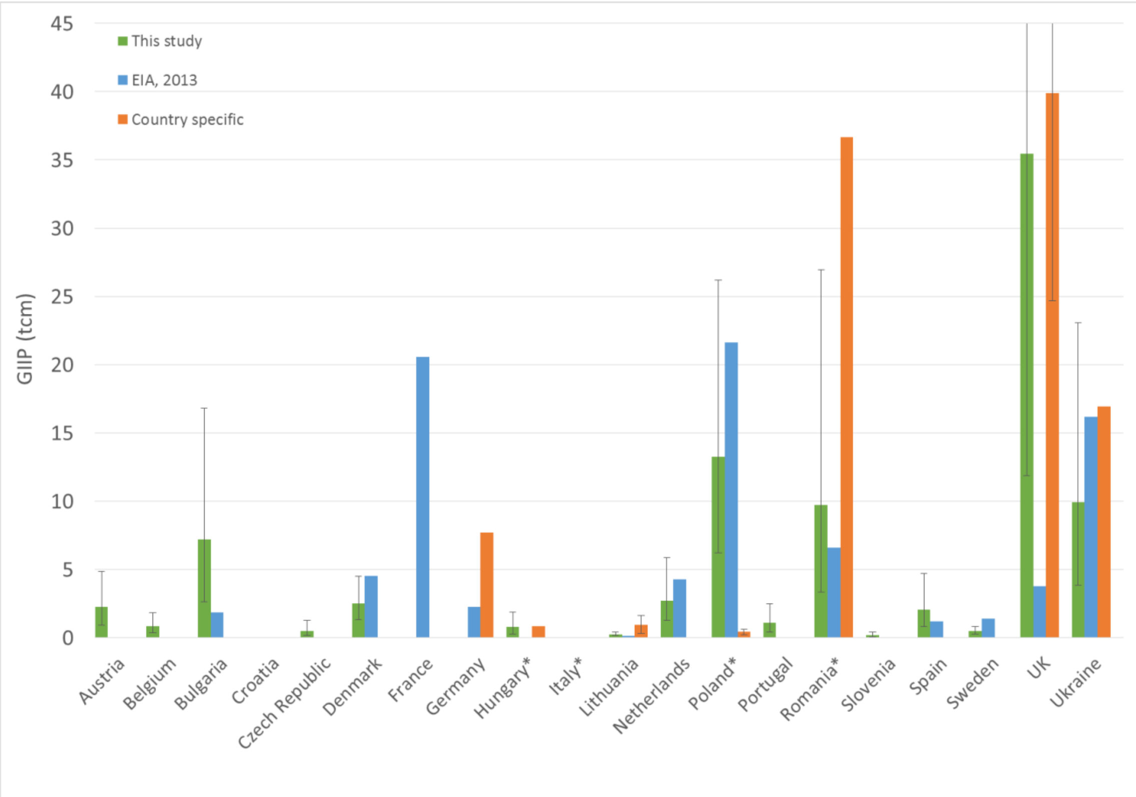


**Figure 12: Comparison of the assessment results of total gas initially in place (GIIP) of this study to earlier published results from the EIA, 2013 assessment and assessment results reported by the National Geological Surveys (see report T3). *Hungary; reported values for the Kössen Marl only, Italy; the Ribolla Basin was not calculated in this study, Poland; total recoverable resources for the EIA values, Romania; only the Silurian of the Moesian Platform are calculated.**

The study of the EIA (2013) gives an overview of the European countries with the biggest expected shale gas and oil potential. They did not use a stochastic method for the calculation of their values; the given value lacks therefore an uncertainty range. When comparing their results with the results of this study, their GIIP values are either higher or lower, but most of the time within the calculated possible range given in this study (Figure 12). A significant exception is the UK, where the EIA identified significantly less potential GIIP. The same observation can be made for the calculated

OIIP with in this case the exception of France, the Netherlands and Poland, where the EIA reports significantly higher volumes of OIIP (Figure 13). It is worth noting that the EIA reports substantial amount of GIIP for France, where this study only shows an OIIP. This study uses GIS data on the maturity of the French formations where everthing lower than 450 Tmax is classified as oil mature. As the maturity data originates directly from the NGS we have reason to believe this has led to an accurate estimation. In general the EIA estimates are within the EUOGA ranges, but overestimate a few countries.

The assessments of the individual countries as reported by the NGS show a similar trend (Figure 12). The results are in most cases similar to the results of this study or at least in the same range. Here the assessment of Romania shows the most significant difference. They report more than 3 times as much potential gas for the Silurian of the Moesian Platform only. Not many NGS have reported OIIP assessments. The assessments of Hungary and the UK are in the same range as this study while the assessment of Lithuania is significantly higher (Figure 13).

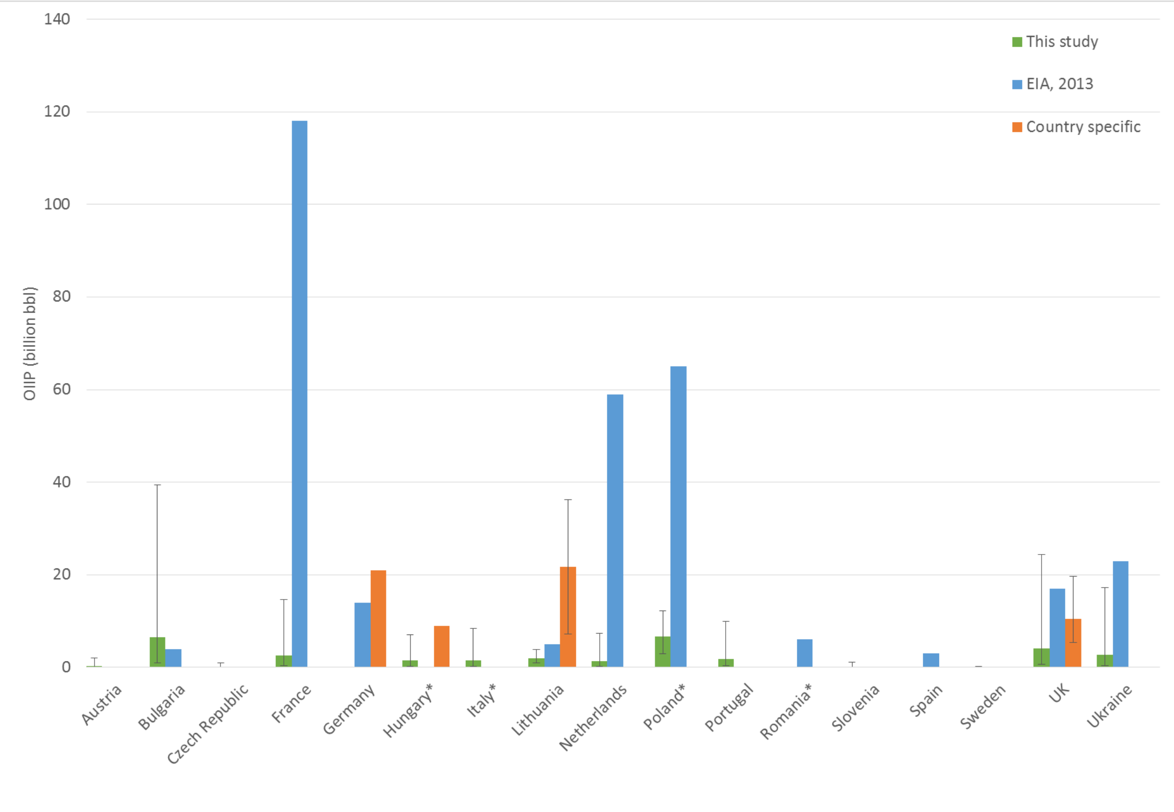


**Figure 13: Comparison of the assessment results of total oil initially in place (OIIP) of this study to earlier published results from the EIA, 2013 assessment and assessment results reported by the National Geological Surveys (see report T3). *Hungary; reported values for the Kössen Marl only, Italy; the Ribolla Basin was not calculated in this study, Poland; total recoverable resources for the EIA values, Romania; only the Silurian of the Moesian Platform are calculated.**

# Discussion

This report presents the results of a large scale regional assessment study, focusing on the general distribution of parameters on a regional scale. The level of detail for each of the used parameters and assumptions cannot be compared to local studies that are focusing on single formations or regions only. All results are based on an agreed upon a standard methodology as described in report T2b, an agreed upon set of selection parameters (see this report) and the data as received from the respective National Geological Surveys (see report T6b). Also this study acknowledges uncertainties in the estimates, as opposed to know studies which do not. This has an added value as the outcome of the resource estimation can be better evaluated.

## Sensitivity Analyses

With the stochastic volumetric resource assessment of the 49 formations a sensitivity analysis is performed to see which parameters have the most influence on the range of GIIP/OIIP values. Here we discuss the general trends, Appendix A shows the sensitivities per formation.

### Sensitivity analyses of the Free Gas in Place calculations

Sensitivity analyses for the calculation of Free Gas (Figure 14) showed that on average the gas saturation (36%) and the porosity (26%) have the biggest influence on the calculated range of values. The amount of gas per volume rock is linearly proportional to both parameters, and uncertainty in these parameters mainly controls uncertainty in resource estimates. So far not many formations in Europe have information on the gas saturation, this study therefore used an average value from all 20 reported values from Europe and 10 published values from US shales to get a good range of possible gas saturations. The porosity is in general much better known/measured (35% of formations with reported values from the European formations) and is expected to give a reasonable range at this point.

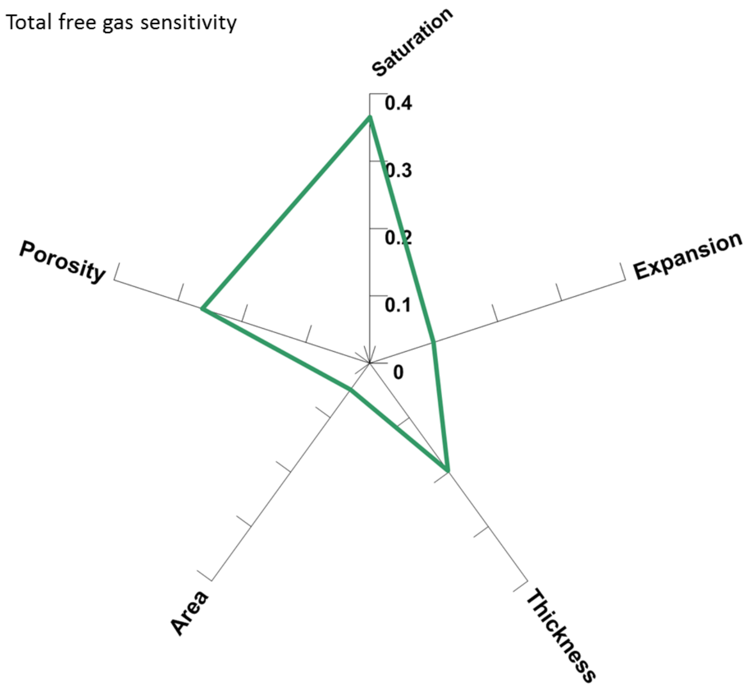


**Figure 14: Overall average of free gas sensitivities of the 41 calculated formations which are assumed to hold gas.**

### Sensitivity analyses of the Adsorbed Gas calculations

Sensitivity analyses for the calculation of adsorbed gas (Figure 15) show that there are two main parameters controlling uncertainty. These parameters are the Langmuir Volume with 54% and the formation thickness with 30%. This means that of the entire range of resource estimates for one formation is for 54% caused by the range in the Langmuir Volume and the range of formation thickness is for 30% responsible for the spread in calculation outcome. The Langmuir volume has a large influence on the final calculated amount of adsorbed mainly because it is the parameter with the biggest range of reported values in the adsorbed gas calculation. Gasparik (2013) reports measured values of 16.7 - 265 scf/ton for European samples. Wei Yu (2015) and Yu and Sephehrnoori (2013) did measurements on U.S. shale where they obtain ranges of 50.7 – 203 scf/ton for the Langmuir Volume. These measurements were the reason to choose a log normal distribution for this parameter with a mean of 69 scf/ton and a standard deviation of 34, according to the EU mean (report T6b). Another important source of uncertainty in the calculation of the adsorbed gas is the thickness of the formation. As in the case of the free gas calculation, calculated amount of gas are linearly proportional to thickness.

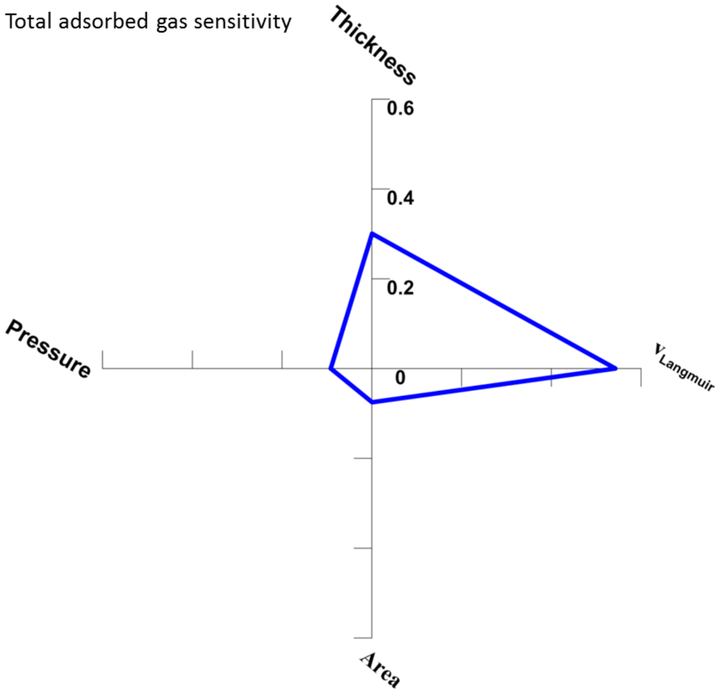


**Figure 15: Sensitivity analysis of the adsorbed gas content based on Monte Carlo simulation of 41 formations.**

### Sensitivity analyses of the Oil Initial In Place calculations

The overall results of the Sensitivity analysis for the calculation of OIIP (Figure 16) show that the most important parameter controlling the range of outcomes in the resource estimates is the saturation (78%) with small influence of the porosity and thickness values. As with the calculation of free gas this is because the total amount of oil is linearly related to saturation and saturation is largely unknown thus leading to a high uncertainty. With even less reported values (7 from European formations and 10 from U.S. analogues) the actual possible range of influential parameter is not very well studied. However, oil saturation values reported from the US analogues show a much smaller range than the gas saturation.

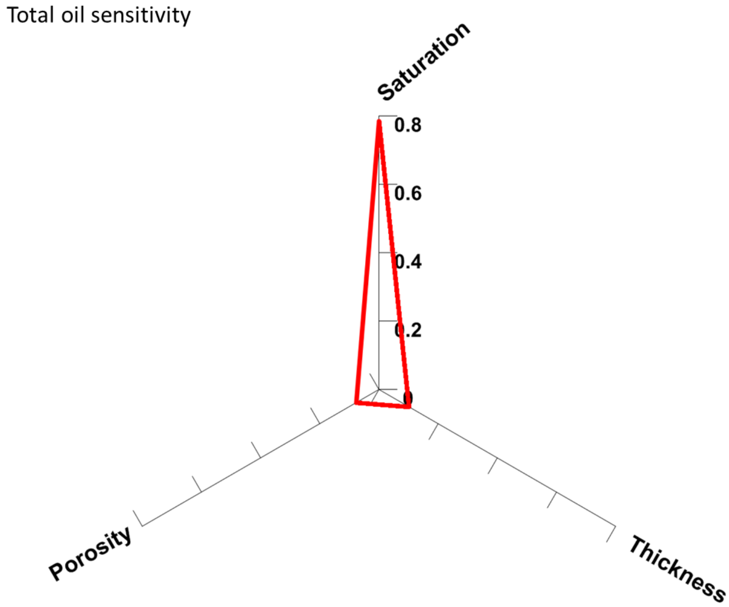


**Figure 16: Overall average sensitivity for oil calculations of all 24 shale formations which are expected to hold shale oil.**

## Parameters and assumptions

Area: At this stage in the assessment, the area is defined as the mapped outline of the shale formation or in some cases the outline of the basin. It does not necessarily represent the outline of the actual prospective areas of the shale formation and area is therefore most probably overestimated in the calculations. This was addressed in this methodology by introducing uncertainties to the areal distribution. More detailed mapping and identification of the prospective areas will reduce this uncertainty.

Depth: For several formations, especially in Spain and Italy, only rough estimates were available with respect to the depth of the formation. More detailed mapping of these formations will increase their chance of success significantly and reduce the uncertainty with respect to the amount of shale gas or oil that could be present.

Thickness and TOC: The variation in reported thickness is extremely high. In several cases formations with less than 5m in thickness but very high TOC were reported, in other cases the thickness of the formations was more than 2km with a low average TOC. A better assessment of the type of shale and the distribution of TOC in the formation could lead to a better identification of the "interesting" intervals in these thick formations while thin intervals intercalated in thick organic lean shale formations might be considered to be producible despite the thin character of the organic rich formation. In the current study these very thin intervals were not included in the calculation of the GIIP/OIIP while the thick formations were assessed using net to gross factors as agreed upon with the NGS on how large this should be. In other words if a N/G of a certain formation can be stated at 10% in agreement with, for instance, reported well log measurements as known with the NGS.

Maturity: The maturity of the organic material is an important factor when identifying whether the formation is oil, condensate or gas bearing. In most cases general minimum, maximum and average values were reported for most formations spanning from early oil mature to gas mature. For these formations the reported area was subdivided into two, one for the calculation of the OIIP and one for GIIP. The subdivision was discussed with the respective NGS. In other cases only surface measurements of the maturity were reported in the critical parameter sheet, which could lead to identifying a formation as immature when at depth it could be mature. Additional information from thermal modelling or basin modelling studies can aid in better identifying the area of the formation that is oil mature and gas mature for a more exact subdivision.

Porosity: In most formations the porosity had the second largest influence on the range of calculated free GIIP values and is also a source for the range of OIIP values. Accordingly, a proper assessment of the actual porosity distribution of a formation is of vital importance. However, only about one third of all reported formations had available measured porosity values and in most cases it is unclear whether these measurements are representative of the total porosity available for hydrocarbon storage. The burial history of the formation has the largest influence on porosity. Calibrating modelled compaction curves to locally measured porosity values can give a more detailed view on the porosity distribution of a formation and can therefore reduce the uncertainty related to this parameter significantly.

Expansion factor (Reservoir pressure and temperature and gas density): The expansion factor in the present study is calculated using an ideal gas equation approach and, when available, the average reservoir pressure and temperature. It is generally measured during production testing in conventional oil and gas exploration and production. A better understanding of the distribution of the reservoir pressure and temperature as well as the composition and density of the gas, or ideally, actual measurements on the gas produced from the shale would decrease the uncertainty of this parameter significantly.

All of the above mentioned parameters can be considered to be controlled by larger scale processes that can be defined on a basin scale. They can be refined using general regional geological studies for the individual formations based on available data (regional mapping, measurements on available surface and well samples, etc.). In addition to this, additional regional studies can also lead to a better identification of potential analogues (see for instance Zijp et al. 2015). In the current study the overall EU averages were used for parameters that were missing when no direct analogue (data from the same formation from neighbouring country) was available. More regional data and sample measurements could be used to update average parameter values, and better link formations to analogues for different types of shale formation.

The parameters mentioned below are controlled by small scale processes that can vary significantly over small distances. They have the largest impact on the uncertainty of the calculated GIIP/OIIP. Refinement of these parameters needs detailed local studies for individual plays and exploratory drilling.

Saturation: The gas or oil saturation has the largest impact on the uncertainty of the calculated free GIIP/OIIP numbers. However, as previously mentioned, this parameter cannot be estimated on a basin scale, as it is dependent on a multitude of small scale processes and can vary significantly even within one basin. Reducing the uncertainty of this parameter is therefore not possible in the context of a large scale regional study, but could be done by exploratory drilling.

Langmuir pressure and volume: The Langmuir volume has the biggest impact on the uncertainty of the adsorbed GIIP calculation. Recent measurements (e.g., Gasparik et al. 2013, Ter Heege pers. com.) show that this parameters depends on a wide variety of factors such as minerology or type and maturity of the organic matter. There are therefore a large number of factors and processes that influence this parameter on a very small scale. This parameter is so far one of least reported for the European shale plays.

Fraccability/Producibility (e.g., mineralogy, fracturing tests): The fraccability or producibility is not a measurable parameter but rather a combination of factors such as the brittleness of the shale and its permeability. In this study it was only qualitatively addressed by looking at the reported average mineralogical composition or in rare cases the results of fracturing tests. It does not influence the calculation of the GIIP/OIIP but is important for the calculation of the TRR.

### Cross-correlation of Monte Carlo parameters

Several of the parameters used for the calculation of the GIIP/OIIP values are linked to each other, such as depth and porosity or pressure and expansion factor. Including these dependencies in the calculations would reduce the range of resulting values. However, dependencies were not taken into account. For many of these relationships basin or even play specific relationships need to be defined as they can vary significantly even within one formation. For this regional assessment it was therefore decided not to include the dependencies of parameters. Future studies with a more local focus can explore dependencies and assess their effect on narrowing the range of GIIP/OIIP values.

## Recommendations

### Reduction of uncertainties on a regional scale

Several shale gas formations are still underexplored with respect to several important parameters such as depth, thickness, nett to gross, TOC reservoir temperature. Most of these parameters can be determined using standard conventional oil and gas exploration or production information or other types of vintage or surface data. This type of information gathering helps to increase the general chance of success of a play but also to narrow the uncertainty ranges of the calculation. Additional geological data can also aid in a more detailed subdivision into assessment units and the better definition of analogues. All newly gathered information can easily be run through the described methodology, making frequent updates of the presented GIIP/OIIP values possible.

### Local variations of the parameters

The most influential parameters during the calculation of the GIIP/OIIP are the gas or oil saturation and the Langmuir volume. Experience from conventional oil and gas production as well as from shale gas/oil production in the US shows that both of these parameters are difficult to estimate on a basin scale and can vary significantly on a small (cm-m) scale. These parameters are usually determined in later stages of exploration and production activities and are only meaningful on a local scale. Activities related to the gathering of additional information on saturation and Langmuir parameters should be focussed on areas with actual ongoing exploration activities (e.g. Poland and the UK).

### Potential technical recovery based on the notional development description

As described in report T2, upscaling to TRR using a notional development plan is extremely dependent on the local surface and geological situation of the respective area. It is not feasible to attach a general parameter for the upscaling. It is therefore recommended to focus this type of research on areas with actual ongoing exploration activities to get a realistic appraisal of the TRR.

# Conclusions

There is more than abundant evidence for large volumes of shale resources present in the European subsurface. Out of a total of 81 shale formations from 21 countries 49 formations have been assessed. 15 formations suggest to contain both shale oil and gas, 26 are expected to contain only shale gas and 8 are expected to contain only shale oil all on the basis of the current screening parameters. Total volumes reach 89.2 trillion cubic meter of shale gas (P50 estimation) and 31.4 billion barrel of shale oil (P50 estimation).

Countries with the biggest expected amount of shale gas are the United Kingdom, Poland, Romania and Ukraine in the order of 9-13 trillion cubic meters for the last three and over 30 tcm for the United Kingdom (75% of the total expected shale gas resources in the EU).

The other assessed countries are expected to have very little shale gas present (e.g., Croatia, Czech Republic, Italy, Slovenia) or in the order of a few tcm (e.g., Bulgaria, Denmark, Netherlands and Spain).

Highest resources in terms of shale oil initially in place are Poland, Bulgaria, the United Kingdom, Ukraine and France in the order of 2-6.5 billion barrels of oil. Besides these countries the other European contributing members have no to a few 100 million bbl.

According to the sensitivity analysis performed during the Monte Carlo simulation for this study the parameters that have the highest influence on the calculation are the saturation and the porosity for the amount of free gas, the Langmuir's Volume and formation thickness for the amount of adsorbed gas and the saturation for the oil in place.

When comparing to the EIA 2013 study we see that the those estimates fall within the calculated EUOGA ranges, where the EIA overestimates France, the Netherlands and Poland and underestimates the UK.

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