Introduction

The Dutch offshore is generally considered a mature area for hydrocarbon exploration. Nevertheless, significant yet-to-find volumes are still expected to be present in locally underexplored areas such as the A & B quadrants in the northern Dutch offshore with limited well density and sparser 3D coverage. High level identification and maturation of those yet-to-find volumes would strongly benefit from regional play maps capturing risk and reward for each of the several (sub)play intervals present in the Netherlands. Several critical key elements contribute to the play success and in large parts of the Dutch offshore the most critical elements are formed by (1) source rock presence and efficiency, and (2) charge and migration of expelled hydrocarbons.

As the Dutch State Oil & Gas company, it is EBN’s mission to create value from the subsurface and actively stimulate and support exploration activities in the Dutch offshore whilst seeking to reduce exploration uncertainties. In order to achieve this better, EBN has endeavoured into a project with the aim to publicly deliver regional Common Risk Segment (CRS) maps capturing geological chance of success for each of the play elements for a series of ranked play and sub-play levels. Ultimately, these individual CRS maps for each of the play elements (Reservoir, Source rock, Seal and Charge and Migration) may stack to a combined Composite Common Risk Segment map (CCRS) and identification of the weakest and most critical play elements. To enable this, EBN identified the need to deliver an assessment of the source rock distribution and efficiency of the most important source rock intervals present across the entire Dutch offshore area.

Petroleum System Analysis

Accordingly to above, EBN commissioned a Petroleum System Analysis (PSA) study to IGI Ltd., including an integrated geochemistry analysis of rock sample analyses available, 1D basin modelling of key wells covering all structural elements and a grid-based 3-D model calibrated to temperature and maturity data for the entire Dutch offshore. The above are all based on publicly available data. This project was delivered by IGI in 2019 well within time and budget.

![Figure 1 Tornado plot illustrating the source rock potential for the stratigraphic intervals in terms of kerogen type (Hydrogen Index) and organic richness (Total Organic Carbon and Rock-Eval S2).](image-url)
A geochemical database, containing over 10,000 samples of pyrolysis data (mainly Rock Eval and Vitrinite Reflectance) from over 370 wells, has been constructed. By analysing the organic richness (average TOC and S2), the kerogen type (HI value) and maturity (Vitrinite Reflectance) for each stratigraphic group, the source rock potential of each interval is identified. Figure 1 provides an overview of the geochemical characteristics for each stratigraphic interval and their corresponding source rock potential. The Westphalian Limburg Group and the Posidonia Shale are confirmed here to represent the most important source rock interval for the Dutch offshore.

The Westphalian Limburg Group (Late Carboniferous) shales and coals are thick, regionally extensive and dominated by gas prone, terrestrial material typical of Type III kerogen and proven source rock to many gas accumulations in the Dutch on- and offshore. The Jurassic Posidonia Formation (Middle Jurassic) on the other hand is rather thin and only locally present, but the predominantly marine environment Type II source rock is oil prone and highly organic rich and proven source rock to several oil accumulations in the Dutch offshore. Although the Posidonia shales and Westphalian coals represent the best source rock in the Dutch offshore, other and more local source rock potential is present in other units. For future study, EBN has identified the need to further investigate the source rock potential of other intervals such as, for example, Lower Carboniferous coals and organic rich shales in the Northern offshore.

Following the geochemical analysis, a grid based 3D model has been constructed that is thermally calibrated by 1D models of key wells covering all structural elements. As the Posidonia shale and Westphalian coal are considered as the main source rocks in this study, maturity maps (VR and Transformation Ratio) and expulsion maps have only been created for these intervals. Due to the extensive thickness of the Westphalian, the Top and the Base of the formation are modelled separately. Results demonstrate that the minimum maturity (Top Westphalian) is predicted to be mid-oil mature at present day and the predicted maturity of the Base Westphalian is mid-late gas mature in the offshore region (figure 2a and b). The predicted gas maturity shows good agreement with the location of proven gas accumulations.

\[ \text{Figure 2 Maturity of a) the Top Westphalian and b) Base Westphalian. Note: the thickness of the Westphalian is either very thin, absent or unproven in the north, so the predicted maturity is presented here only as a guide.} \]
Common Risk Segment maps – Charge & Migration

Source rock based CRS maps typically cover not only presence and maturity, but also consider charge and migration. As part of the current PSA study hydrocarbon generation maps at key time intervals in geological history (figure 3) were generated. To understand the basin in a regional context it is necessary to understand the presence of the source rocks in the basin and their capability and capacity to hydrocarbon generation and expulsion. In order to achieve successful trapping and retention of hydrocarbons, the timing of hydrocarbon generation should post-date the timing of reservoir deposition and trap formation. The predicted Limburg Group (Westphalian) gas expulsion during the Cenozoic underlies most known gas fields, suggesting relatively recent charge (figure 3).

These maturity and hydrocarbon expulsion maps are then translated into CRS maps for the entire Dutch offshore, by which the following questions are addressed: Firstly, ‘is there a source rock present, and if so, is the source rock mature and able to generate hydrocarbons?’ Secondly, ‘what is the timing of the hydrocarbon generation and expulsion of the source rock?’.

CRS maps of the Westphalian Limburg Group

Subsequently EBN used these maturity maps as well as the expulsion maps to compile CRS maps. The workflow included the following steps:

1) Areas with a proven mature source rock present and hydrocarbon expulsion are defined by combining the maturity and expulsion maps. Typically, proven gas fields are found in these areas and the overall play chance of success for these areas is 100%.

2) The locations of proven gas accumulations are cross-checked against the outline of the hydrocarbons expulsion area. The location of the proven gas accumulations is then used as a guideline to create several buffer zones of 5 resp. 10 km to take lateral migration into account.

3) The defined areas are risked based on their distance from the proven expulsion area, i.e. the larger the migration distance, the higher the overall play risk.

A set of regional CRS maps for Charge and Migration play element thus have been created for the Westphalian coals and Posidonia shale formation, which may feed into individual play and sub-play evaluations and their stacked CCRS maps.

The Permian Rotliegend is the most prolific gas play in the Netherlands, with the Westphalian coals as principal source rock and Zechstein salt as its seal. A different setting exists in the Triassic play, the second most important gas play, where Westphalian gas has to migrate vertically through the Zechstein salt formation to reach Triassic reservoir. In some areas the Zechstein thickness in excess of hundreds of meters of salt significantly hampers or prevents vertical migration. In the latter scenario, chance of success for vertical migration needs to be included by defining additional risk areas from a regional Zechstein thickness map. This vertical migration CRS map is then stacked with the Westphalian gas expulsion CRS map to create the overall charge and migration CRS map for ‘post-Zechstein gas plays’.

Figure 3 Predicted Westphalian gas expulsion through time. Colour scale shows the amount of gas expulsion ranging from light to dark blue in billion cubic feet (bcf).
In addition, timing of hydrocarbon expulsion is incorporated by making use of the expulsion maps through time. For example, a total gas expulsion from the Westphalian coals and a ‘present-day’ charge map (i.e. during the Cenozoic) is created for both the ‘post' and 'pre'-Zechstein gas plays.

Figure 4 shows an example of the overall CRS maps for the 'pre-Zechstein gas plays' and 'post-Zechstein gas plays'. Both maps show a high correlation between proven gas fields and areas with a low play risk (certain – very likely). A similar method is used for risking the oil charge and migration from the Posidonia shale formation, which is among others used in the assessment of the Chalk play in the Dutch Northern offshore.

Conclusions

To reduce exploration uncertainty it is necessary to gain good regional understanding of the petroleum system in the basin. EBN performed a Petroleum System Analysis (PSA) study with the aim of providing regional maturity- and expulsion maps for the main source rocks in the Dutch offshore. A set of Common Risk Segment (CRS) maps has been created from the PSA results for the Westphalian coals and Posidonia shale. The CRS maps are an essential element of the Play Based Exploration (PBE) approach and, in combination with reservoir and seal CRS maps, help in the process of identifying and screening areas of interest. It is the aim of EBN to publish regional play maps for the main plays in the Netherlands. The results of the PSA study are publicly available at www.ebn.nl.

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References