The use of GIS mapping techniques and resources to validate resource assessments in UK Shale Gas Exploration

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Disclaimer

'I certify that this Dissertation is my own unaided work and that all sources of references have been acknowledged'.

Signed:

Eamonn Dolan
at Sheffield, UK on 3rd September 2012

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Abstract

Whilst renewable energy projects have been established to provide future sustainable energy solutions, unconventional hydrocarbon resources such as shale gas have also been targeted as world energy demand increases. Though shale gas plays in the USA have been successfully developed, surface constraints to the development of similar resources in space limited countries such as the UK require to be taken into further consideration when energy companies estimate resources. An evaluation using Geographical Information Systems (GIS) specifically utilising constraint mapping techniques, was developed to evaluate drill-site location suitability; calculate potential shale gas acreage and subsequently estimate resource potential.

The study area focused on the Bowland Basin in West Lancashire (Petroleum and Exploration Development License - PEDL 165). The estimates were primarily based on surface restrictions for drilling. ArcGIS 10.0 software was utilized to create a series of constraint maps: geological, man-made, landscape and environmental, which when overlaid produced a composite map identifying regions of drilling suitability. This area was then calculated and using typical shale gas production yields an assessment of resources was made.

46.2 % of the licensed area was deemed suitable for drilling locations. 22.1% of this area was considered most promising to develop. An overall range of 0.8 – 3.9 Trillion Cubic Feet (TCF) recoverable resources was estimated, equating to a maximum 2.0 % of the original Gas-in-Place (GIP) estimate for the licensed area. This structured, pre-development GIS approach has applications for similar areas where onshore drilling is proposed. The framework could be utilized by energy companies to validate and fine-tune resource estimates based on land accessibility, whilst also assisting the planning process by identifying areas of potential conflict.

1. Introduction

Understanding, evaluating, exploring and developing finite natural resources such as mineral aggregates and hydrocarbon deposits of oil and gas have traditionally belonged to the realms of geoscientists and engineers. Field work, including surface, subsurface and aerial analytical techniques have for many years been employed to determine and assess potential zones of geological riches and evaluate their possible commercial viability. Once subsurface hydrocarbons have been located and mapped, either through test well analysis, inference, or both, further exploration wells can provide affirmation of the resource and delineate potential acreage leading to estimates of resource yield. In offshore exploration, a hydrocarbon play's development is mostly constrained by its geographical extent, geological complexity and the technological difficulty required in extracting it.

Onshore exploration by comparison generally provides a less exacting challenge, however, other factors (besides geological), come into play which provide a bearing as to potential yields. In the UK, energy companies drilling in the North and Irish Seas are predominantly constrained by the geographical limitations of their licensed blocks. When exploration and development 'comes to town', the industry rules and regulations must provide for the further protection of the onshore environment, most specifically, the immediate communities and habitats most likely affected.

Focusing on the pre-development estimation of onshore shale gas resources in West Lancashire, this study takes a predominantly quantitative approach using GIS mapping techniques to identify surface barriers to drilling operations. By compiling a series of GIS feature layers, a series of constraint attributes were built up to create a restrictive map to hydrocarbon development. By calculating the available area and using typical gas production figures, a baseline estimate of shale gas resources was made. Geological factors other than the source rock extent and zones of faulting would not be taken into consideration.

Conventional hydrocarbons are typically found in clastic sandstone or carbonate limestone where the rocks' porosity and permeability are key factors in oil and gas storage and movability. Naturally interconnected micropores, fractures and fissures are vital for fluid and gas migration and ultimately effective production. Unconventional hydrocarbon resources which include shale gas are those deposits which require unorthodox extraction techniques generally due to low permeability. With shale gas, these techniques are a combination of commonly used conventional methods: Horizontal drilling and hydraulic fracturing (or fracking) (Durham University).

Although shale gas development began slowly in the US in the 1980s, it now accounts for its largest supply of natural gas (Figure 1), with its importance expected to increase and as conventional resources continue to dwindle, greater attention has now focused on similar hydrocarbon bearing shales in the UK and further afield.

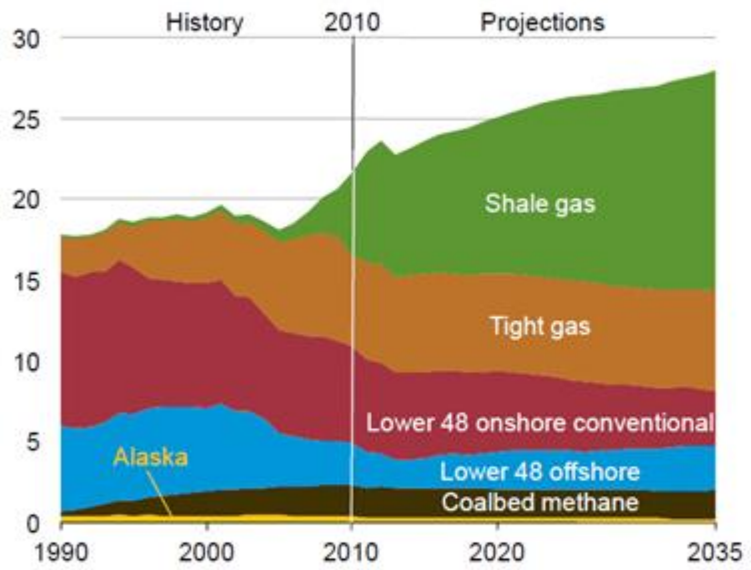

Figure 1 US Natural Gas Production (Trillion Cubic Feet) (Source: EIA)

In the UK, environmental concerns regarding extraction techniques, headline-grabbing estimates of potential resources and ‘gold rush’ type knock-on effects for the communities involved have been commonplace. This study focuses on resources in the Petroleum & Exploration Development License Block (PEDL) 165, located in the West Lancashire Basin. It is currently operated by ‘Cuadrilla Resources Limited; the first company to start exploratory fracking for shale gas in the UK’ (FT 2012). Estimates of up to 200 Trillion Cubic Feet (TCF) of Gas-in-Place (GIP) (Cuadrilla Resources 2011) in the principle target formation, the Bowland Shale, were made by the company. However, the amount of developable or recoverable resources is expected to be much smaller. Analysis of shale gas volumes produced from US wells reveals that on average 1 well occupies 160 acres, 4 occupying 640 acres, (1 square mile) and that each well produces between 1 - 5 Billion Cubic Feet (BCF) of gas, that is, 4 - 20 BCF per square mile. Holding acreage of 436 square miles, 'Cuadrilla' would require to drill 1,744 wells (using the same US data), to produce a maximum of 8.7 TCF of gas (less than 5 % of the estimated GIP).

Although 'Cuadrilla' point out that only a fraction of their GIP estimates may be extracted, this study focuses on mapping the non-geological surface constraints to drilling which may reduce estimated yields. It is not known whether 'Cuadrilla' have taken these constraints into consideration. However, prior to any development, it is suggested that this type of analysis is of beneficial value.

In the fossil fuel / renewable energy debate where long term policy commitments may be made in favour of sustainable, greener power sources such as wind, wave and solar energies, it is important to understand what contribution to power generation, these various resources will provide. Can we begin to reduce our dependency on hydrocarbons? Or shall we embrace new discoveries of fossil fuel resources (such as shale gas), along with associated technological advancements in extraction techniques, which will help feed global energy consumption levels which continue to increase. Using GIS as a tool to assist in determining more accurate estimates of such resources provides us with a clearer picture of potential reserves.

Especially in times of economic gloom, headlines which create positivism**,** news of jobs, wealth and growth are welcomed and well received. However, claims of 'boom-times' need to be tempered by energy companies and the media before full assessments and analysis have been made. Announcements of discoveries of large resources are one thing, knowing recoverable amounts however are another. Company share prices may be a factor, poor communication another and indeed the media like to 'big' a story also, but the public should not be misled regarding the true volumes of recoverable resources involved, or the many implications, necessary procedures and possible hurdles which may arise along any development path.

Though the tool of GIS in surface assessment is only one facet of resource evaluation, its importance is advantageous to many parties and may prove the difference between economic viability or otherwise.

Alongside concerns of affected communities regarding the environmental impacts of drilling, other questions regarding the well numbers required to extract such estimated quantities of hydrocarbons have also been raised. In West Lancashire where estimates of shale gas suggests hundreds of wells would be required, the local and regional authorities of the Fylde Borough Council and Lancashire County Council, alongside affected communities could be forgiven for directing their concerns more towards the visual and landscape impacts of development rather than its economic potential.

Truly accurate assessments of technically recoverable shale gas can only be made once a study of all the factors relating to its accessibility have been identified and analysed. This is where GIS mapping techniques and research methods and the multiple public and proprietary GIS resources can be used to validate developable areas, claims of energy companies and better inform the public of wider, related issues.

Although this study's target is to assess resource estimates, the constraint maps produced also provide a revealing picture of areas best suited for drilling operations. This provides additional value, incorporating themes useful to a variety of interested parties. The technique and overlay maps produced would be informative and transferable, allowing other potentially affected communities and authorities, (particularly relevant, should shale gas development expand in the UK), to better visualise issues of development. As hydrocarbon exploration is a global pursuit, using GIS to preliminarily map and assess onshore prospects in this way, the author suggests that an early-doors analysis should be made common practice throughout the industry.

As a Petroleum Geologist of many years, incorporating the fields of GIS, planning and environmental issues into this project, provides added interest to the author as it affords an alternative perspective on exploration and development. Having previous experience in such diverse environments as the North Sea and the Middle East, the recent GIS skills acquired have enabled me to assess proposed development from a different standpoint and produce an independent, unbiased, balanced report. With involvement in tight gas projects in the Middle East, it is believed that GIS constraint mapping analysis was unnecessary because of locational remoteness. However, the potential shale gas developments closer to home currently provide many more questions than answers, namely: What are the spatial implications of any development? And also whether GIS as a tool can assist in refining resource estimates? The fusion of geological and geographical information to provide a realistic assessment of resources together with the social and environmental aspects of such a development gives the topic a multi-dimensional appeal.

As energy demands increase, the development of smaller hydrocarbon basins, unconventional plays and tertiary extraction methods have become more commonplace. Wind farms on our door-steps have sprung-up, quarries in our 'back yards' have been extended; encroachment on urban and rural populations will become more frequent. The North Sea and Middle East hydrocarbon sources have largely been out of sight / out of mind. Exploiting resources on our home turf requires much more consideration and understanding of our future energy needs, striking the correct balance between fossil fuel and renewable energy. Appropriate planning safeguards ensuring minimal damage to the environment should be high on the agenda.

Shale formations typically exhibit poor permeability and induced fractures created to extract the gas can only drain relatively small areas. More wells are required to be drilled to commercially exploit the resource. Whilst geological data can determine how much resource lies subsurface, the high number of wells required to viably exploit the gas may mean that greater access to land is required. This presents a serious problem in densely populated areas such as England, having a population density of 383 per km^2 as opposed to 27 km^2 in the United States (Stevens 2010).

Traditionally, onshore exploration licenses in Western Europe have been granted over relatively small areas, each with their own specific work programme as part of the contract. 'This would require the granting of many small areas to make plays economically viable' (Stevens 2010).

GIS, however, can be beneficial in the exploration industry, as Knox-Robinson & Wyborn assert ‘by being built to be used as a project management system’, storing such relevant information ‘as lease boundaries, land tenure applications’ and previous exploration outcomes. The incorporation of non-geological project-related datasets, for example, ‘rare faunal habitat locations and important heritage sites’ can be readily achieved. ‘The ability to readily’ access the locations of such sites ‘relevant to a planned exploration program will help ensure that a drilling pad is not placed on a site of recognized value’ (Knox-Robinson & Wyborn, 1997).

This project provides an independent evaluation of shale gas resource estimates, which is not only fascinating from the geological perspective with quantitative results but also from the geographical, socio-economic and environmental aspects of constraint mapping. The topic is important as GIS pre-development mapping can provide more accurate, tighter estimates of potential resources for energy companies whilst also furnishing a more sceptical public with accessible, easily visualised information. As Jacobs (2012) states ‘greater industry openness, focusing on developing a set of global regulatory and operational best practices for shale gas exploration is required in order to counter the growing public fears over, for example, such concerns as hydraulic fracturing (fracking) techniques’.

Although energy companies may use GIS constraint mapping in-house, information and studies regarding their planning, development or company acreage assets are understandably scant in the academic and public domains. However, as the increasing demand for energy becomes more focused, evidenced by the implementation of wind-power technology closer to our shores and homes, pre-development reports and analyses including GIS oriented studies will undoubtedly become more accessible, meaningful and beneficial, especially if projects such as UK shale gas prove economically viable.

In the United States, an inventory directed by Congress to assess restrictions to oil and gas exploration onshore was managed by the Bureau of Land Management (BLM). This GIS based report was the first ‘national assessment of restrictions and impediments to oil and gas exploration and development’ (Watson 2009). The mapping of federal land providing information on accessibility, constraints due to numerous restrictions and mitigations to protect the environment, was regarded beneficial to the petroleum industry and environmental interest groups alike.

Research Questions & Aims

Many recent GIS studies utilizing constraint mapping techniques have primarily focused on site location for renewable energy wind farms, landfill sites or nuclear power plants. Though a generalized map of the potential shale gas drilling areas is created in this study, (as detailed subsurface geology was not the focus), none the less, a similar GIS-assisted approach to develop criteria for onshore shale gas drilling in Lancashire is made.

Unlike previous site location projects whereby criteria-weighting had been used to construct suitability maps and develop lesser or greater zones of acceptability, criteria are un-weighted in this project. The focus is purely to eliminate areas of non-drilling suitability, then, based on underlying source rock layer information, provide an estimate of recoverable shale gas. Although many problematic issues arising from potential shale gas development have been highlighted in the media and voiced by a concerned public, particularly regarding environmental aspects such as potential groundwater contamination and drill-site visibility, the scope of this analysis is only to examine accessible acreage & calculate the resource within the license block PEDL 165.

The key questions asked in this study are:

- Will using GIS constraint mapping techniques assist in providing a clearer picture of drill-site suitability in West Lancashire prior to any shale gas development?
- Will a GIS-assisted site location area map help clarify, validate, improve and fine-tune estimates of initial shale gas resources from the licensed area?

- Could early initiatives such as the production and release of constraint maps help to better inform other interested parties, stakeholders, and potentially affected communities regarding such developments?
- Could the criteria used to produce the GIS constraints map for onshore drilling be improved, and also be used as a template for similar developments?

The following section outlines the legislative framework which exploration companies must follow.

Regulatory Framework

Government policy states that it is in the national interest to 'ensure the recovery of all economic hydrocarbon resources' – a requirement for licensees with PEDL's and although the Crown owns all UK mineral rights, regardless of land ownership, special provisions may be necessary 'to protect environmentally sensitive areas, areas of high conservation value or areas of commercial or recreational value' (Radke *et al.* 1997). Similarly, Rahm & Riha (2012) point to 'whether the economic and energy benefits associated with shale gas are worth the potential environmental impacts'.

Developing a resource such as shale gas is not so straightforward. Foley *et al.* (2005) point out in their report of the *Global Consequences of Land Use,* 'we face the challenge of managing trade-offs'. Land accessibility for drilling can be another issue. Regarding shale gas development, Energy minister Charles Hendry MP stated, 'Getting permission from property owners and landowners will be challenging (Probert 2011). Environmental concerns regarding fracturing fluids and groundwater contamination have also been expressed.

Before an energy company is allowed to begin exploratory and developmental operations, a strict regulatory framework must be adhered to. It is suggested here that GIS constraint mapping analysis should be initiated at an early stage of planning but certainly prior to any field development. The analysis would help clarify recoverable estimates, which would then be based on both sub-surface geology and surface geographical restrictions. As well as a Petroleum Act License, granted by the

Department of Energy & Climate Change (DECC), health and safety and environmental regulations also need to be complied with (Figure 2).

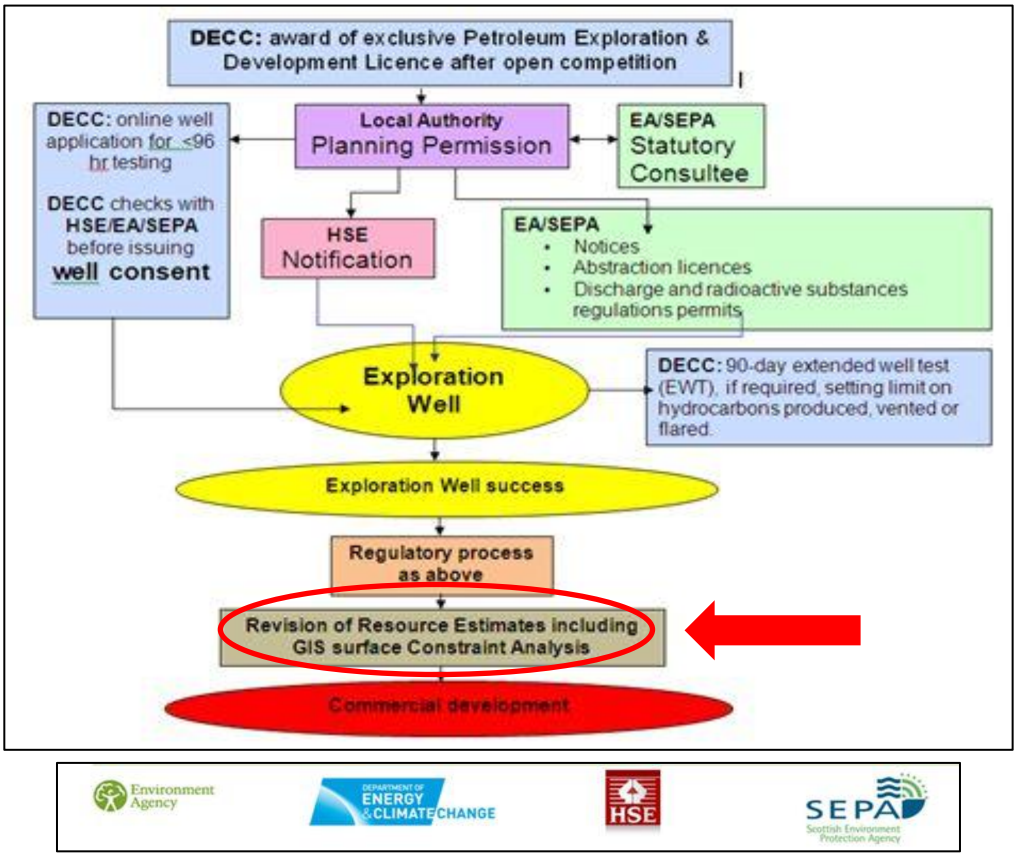

Figure 2 Steps through the regulatory process - Exploration & Development
Source: DECC 2012 (modified by Dolan)

In 'Cuadrillas' case, 'local planning permission is required by Lancashire County Council (LCC), and with this comes project specific requirements including ecological studies, transportation, noise and lighting surveys etc**.** The Environmental Agency also scrutinizes proposals to ensure environmental risks have been minimized.' (Cuadrilla Resources 2011). Up to now the local planning authority has concluded that 'Cuadrilla's activities do not fall within the criteria for Environmental Impact Assessment (EIA), and none has been performed (The Guardian 2011). However, this is a site specific decision and assessments would be made for each new well location. HSE fundamentally focuses on well operations and well design.

Regarding UK shale gas development, 'Planning and Environmental considerations are likely to limit the number of surface locations from which wells can be drilled' (DECC

2011). In the initial stages of exploration, small scale sites may provide minimal impact, but with development on a larger scale, the environmental implications may become more crystallized. It is essential therefore that a thorough Environmental Impact Assessment has been conducted prior to development.

To facilitate this, a Strategic Environmental Assessment (SEA) is conducted by DECC. This is a system of incorporating environmental considerations into plans, programmes and strategies. The main considerations in West Lancashire are the effects of development on 'geological features; biota and features of archaeological interest from drilling rig construction' (DECC 2010). This West Lancashire case study lies within the SEA Area 2, (Figure 3). The Environmental receptors which affect the mapping of constraints in the license block include:

- Biodiversity, habitats, flora and fauna
- Water environment (Aquifers, groundwater, surface water)
- Landscape
- Population
- Cultural heritage, including architectural and archaeological heritage

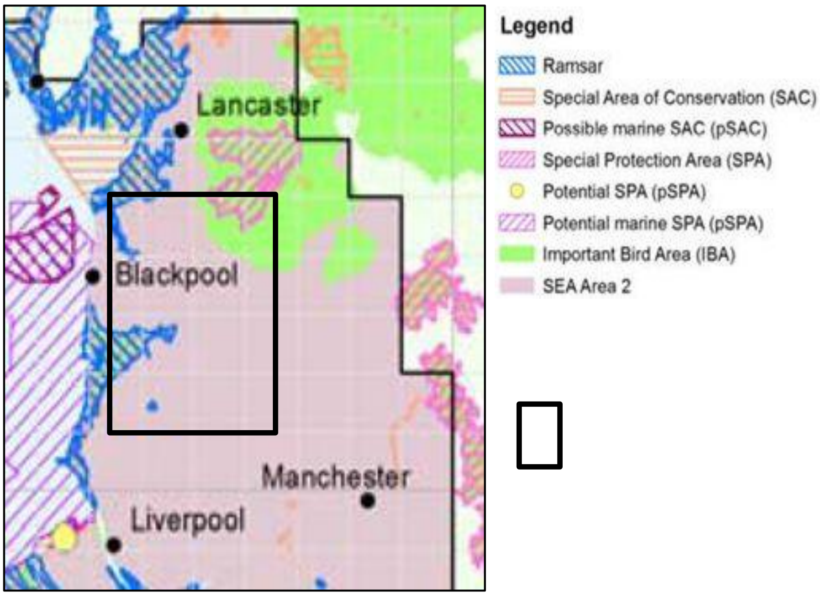

Figure 3 Conservation Sites of International Importance in part of SEA Area 2
(Source DECC 2010)

Figure 3, taken from the *SEA for a 14th & subsequent Onshore Oil & Gas Licensing Rounds Environmental Report*, illustrates how sites of international importance, located in the study area may have constraining implications on hydrocarbon development.

Regarding planning applications for drilling, the *Lancashire Minerals & Waste Plan 2006* sets out detailed policies for mineral working and development. Several policies provide insights which assist in this study, these include:

Policy 3: Buffer Zones. Indicates that these 'will be determined on a site-by-site basis', the scale, development, nature, landscape, topography, proximity to communities being factors.

Policy 7: Open Countryside and Landscape. Acknowledges Lancashire's fine countryside, specifically two Areas of Outstanding Natural Beauty and that 'these areas are afforded protection'.

Regarding *Trees & Woodland in Policy 8*, it is noted that Lancashire's landscapes are an 'important visual, ecological and historical resource which should be retained and protected wherever possible'. This is specifically true of Ancient Woodland whereby 'considering proposals which affect them, their conservation will be given added weight'. In *Policy 10*, concerning *Areas of Outstanding Natural Beauty*, the primary objective 'is one of conserving and enhancing their beauty'. The Forest of Bowland and Arnside/Silverdale are no exception. Lancashire also has a number of internationally recognized habitats designated as Special Protection Areas (SPAs) (see Figure 3). *Policy 32* also recognizes potential unacceptable adverse impacts of development on more local recreational facilities such as managed access areas, parks, and water-based facilities stating that such activity would in these circumstances not be permitted.

As a final caveat, however, many policies also note that developments may occur where demonstrated that there is an overriding need, exceptional circumstances or in the Public interest. With regards to Buffer Zones in the Governments *Planning Policy Statement 22 Renewable Energy,* it is stated that*:* 'Regional Planning bodies and local planning authorities should not create 'buffer zones' around internationally or nationally designated areas and apply policies to these zones that prevent the development of renewable energy projects'(ODPM 2004).

Developments can and do take place in so-called protected areas. A recent communiqué from the Woodland Trust stated, 'We have many cases where ancient woodland has been protected from development and permission has not been granted, but we also have cases, some involving drilling where permission has been granted for the planning application' (Rist 2012). With regards to Ancient Woodland, Natural England suggest a minimum buffering of 15 m, however, depending upon the type of application the Woodland Trust usually recommend a minimum of 50 m to stop any adverse edge effects to the woodland.

A recently accepted planning application submitted by 'Cuadrilla' to carry out exploratory drilling at Hale Hall Farm, Wharles included statements that apart from principle geological issues, the site was chosen for a variety of other reasons including: 'distance from residential properties regarding noise and visual intrusion and most importantly the site does not affect sites of special interest, special conservation area or known archaeology' (Cuadrilla Resources 2012).

At two 'Cuadrilla' sites in PEDL 165, Hale Hall & Balcombe, the nearest properties to the wells were 300 and 400 m respectively, however at a site in Albury, Surrey the closest residential property was 157 m. It is interesting to note that in an environmental section of the application, the proposed site was characterised as farmland, growing a crop of grass for winter fodder and general grazing. In the Agricultural Land Classification, this is classed as Grade 3 (good to moderate). Had it been Grade 1, (excellent quality agricultural land), would the planning application have been accepted? This may have been so considering that the drilling rig would be removed from the site after a matter of only a few weeks and the full restoration of the site can normally take place.

The company also shows consideration for the environment; though the site is adjacent to Pointers Wood, a 10 m buffer zone was instigated for protection.

Concerns have been voiced, however with the current regulatory system. How the Environment Agency and other regulatory bodies would cope with a potential shale gas drilling expansion is another question being raised as well as the adequacy of systems in light of potentially hundreds of wells.

The following section provides an overview of the methods and techniques used for spatial planning and the requirements of GIS for drill-site suitability analysis.

2. Literature Review

Suitability analysis and constraint mapping techniques utilizing GIS for site location, specific developments have been commonly employed in projects such as landfill siting, and renewable energy schemes such as wind-farm placements. However, these mapping techniques have also been applied in a variety of other arenas such as: landscape suitability for nearby recreation (Kienast *et al*. 2012); investigating health care needs and access to services, planning service locations (McLafferty 2003); soil landscape constraints to various land uses (Yang *et al.* 2007) and mapping marine geohazards to assist in hazard mitigation for offshore construction sites (Leon & Somoza, 2011).

In the vast openness of offshore exploration, compared to the restrictions that onshore projects pose, relatively few environmental and seabed constraints affect a given well location. A key question to be asked may be: Is the location of the proposed well within environmental protection and other surface and/or seabed constrained areas? The surface and seabed constraints may include: shipping lanes; offshore wind farms; cables and pipelines and oil platforms. Environmental Constraints may include: UNESCO protected sites; Natura 2000 sites, accidental risk areas, together with geohazard areas, for instance, close to other platforms (Exprodat 2011).

Although the constraints involved in onshore drilling exploration are more numerous for example, due to population density and a variety of environmental habitats, no specific regulations exist for such projects, let alone unconventional gas exploration.

The government relies on existing procedures and Acts developed for the offshore industry. Hence, the majority of case studies and methodologies drawn on in utilizing GIS and multi-criteria evaluation in this site location / evaluation analysis, stems primarily from a variety of suitability mapping projects as described previously and not from the oil and gas industry.

Although some general comparisons can be drawn from these studies in methodological terms, site suitability is obviously very specific to the industry concerned. The indisputable relationship for shale gas development when compared to renewable energy schemes are that location suitability centres on the area where an energy source is most abundant, whether wind, wave, solar energy or fossil fuel. Apart from physical and geological barriers, other key constraints to offshore development are technological and logistical challenges.

Defne *et al.* asserts that 'Resource mapping is a fundamental step in development' and implemented the application of GIS as a multi-criteria assessment tool to assess tidal stream power potential and select the most suitable locations in Georgia, USA. Although location assessment depended on 'a number of criteria: available power, site characteristics, environmental, economic and social impacts', the physical constraints of the analysis were the easiest to assess quantitatively. (Defne *et al.* 2011)

Analogous to the Bowland Shale source rock of the study area, the tidal stream power map, (physical layer) contained the most critical 'data for the site selection' project. In Lancashire, the underlying energy source layer is considered virtually ubiquitous in PEDL 165, covering an estimated 1,035 km^2 of the licensed block. Man-made structures, landscape and environmental constraints are the key obstacles to surface development. However, as Krewitt and Nitsch (2003) demonstrated regarding wind energy potential in Germany by 'taking into account site specific information on nature conservation aspects,' wind energy potential was reduced by 75 %. 'In areas of medium to high visual sensitivity', a further 20 % reduction was required. Constraints can be seen to affect energy valuations.

Although this report centres on GIS pre-development surface mapping to assess resource evaluation, areas of potential conflict can also be highlighted by the study. Concerns about environmental encroachment because of rig number expansions in the area, should not be ignored. However, although hundreds of wells may be required, multi-well drilling from fewer sites is the most likely development scenario over longer a passage of time.

As Baban & Parry (2001) point out in a GIS-assisted approach to locating wind farms, 'planning and environmental restrictions and conflicts would inevitably accompany this growth'. Their study showed how 'GIS has the capability to handle and simulate the necessary physical, economic and environmental constraints. Consequently, the GIS can play a significant role as a decision support tool regarding optimum locations'. This shale gas analysis incorporates comparable constraining factors to their study, most notably Physical (Topographical); Planning (Population and Environmental); Ecological, Historical and Cultural factors.

In the UK, assessments for suitability of drill-sites are made on a case-by-case basis. Like wind-farm planning legislation, current regulations for the industry appear in need of updating. No specific guidelines for example, exist regarding the buffer zone creation around developments. For onshore exploration, the existing *Petroleum Act 1998* still applies. A more recent application of GIS to identify and quantify the 'spatial and climatic factors affecting the availability of renewable energy potential' in India, was made by (Ramachandra & Shruthi 2005). As a spatial and temporal analysis tool to create maps, quantifying the effects of local constraints, GIS aided as a Decision Support System.

A further study combining methods of Multiple-Criteria Decision-Making (MCDM) and Spatial Decision Support Systems (SDSSs) to identify least contentious locations, was employed by Brody *et al.* (2006) in conflict identification associated with oil and gas development offshore Texas. In many ways the Texan study is most closely aligned with this shale gas analysis. Brody states 'it is not meant to replace existing site selection processes but facilitate in the strategic decision making operation'. The model can be used 'as a supplemental technique that cannot outweigh the importance of the location of energy reserves' (Brody *et al.* 2006). It can be used as a first-look analysis to determine the extent of potential conflict with other stakeholders in onshore hydrocarbon licensed blocks.

As onshore energy development may take on a more significant role in the future, particularly in the UK shale gas arena, it is likely that greater involvement, communication, discussion, and understanding between diverse interested parties and stakeholders, would better facilitate such planning processes.

The basic methodology used in this project focuses on mapping suitable / non-suitable areas for drilling. Because the licensed area is already selected on the potential of gas resources, the attention for this analysis lies on evaluation of 'other spatially represented land values not traditionally incorporated in the site selection process' (Brody *et al.* 2006). This assessment builds on the Texan study by incorporating secondary data, for example, utilising the governments *Strategic Environmental Assessment for Onshore Oil & Gas Licensing*. Decision makers could be aided in site-suitability issues by the integration of information from multiple perspectives and disciplines (MacEachren 2000). In MacEachren's study, stakeholder conflict mapping was employed proactively to guide planners and help mitigate potential controversy.

Similarly, with shale gas development in the UK, the energy source factor is pre-eminent and the location of energy resources cannot be outweighed. However, the approach adopted should serve as a supplemental technique in conflict identification management where conflict maps can assist in guiding the planning process.

As well as identifying and mapping a definitive shale gas drilling area based on surface constraints, this study attempts to validate initial resource estimates made by the operating company, Cuadrilla Resources. In a similar vein**,** Prest *et al.* (2007) evaluated the 'impact of exclusion zones' using GIS and Multi Criteria Decision Analysis on the connection costs of wave energy to the electricity grid in South Australia. Although this association is not directly related, it does show that exclusion zones can reduce energy potential through the limiting of suitable locations.

The study by Prest *et al.* utilised *Least Cost Path Analysis* and was performed using the Path Distance tool in ArcMap which calculates the cost for each cell in the study area. This took into account the cable/connection route and barriers to transmission routes, such as National Parks, conservation areas and cliffs. Although roads and surface water body features are categorized as physical constraining factors to site location in Lancashire, conversely, their close proximity would also be a positive factor in further large scale development, by reducing transportation and water requirement costs. Though exploratory locations in Lancashire would be predominantly determined by geological factors, the Cost model developed by Prest *et al.* would be more applicable to downstream shale gas operations during the development phase, that is, gas pipeline routing. Similarly in a study of optimal pipeline routing Luettinger & Clarke (2005) also accounted for exclusion zones in assessing project costs.

It is interesting to note that wave energy has been focused on in light of increasing 'planning and environmental restrictions associated with wind energy, particularly in space-limited countries such as the UK' (Baban & Parry, 2001). If shale gas development proceeds, tighter regulations may also follow. The role of policy makers is also important; especially to ensure that resource figures are viable when energy targets have been set. It is crucial that resource estimates are as accurate as possible.

A study conducted by Faber Maunsell (2006) regarding Scottish marine energy capacity noted the locational suitability of such a resource, but that the economic feasibility was brought into question if transmission routes were required to transverse around a Marine Protected Area (MPA). Although a similar case of cost-effectiveness could be implemented for future shale gas pipeline networks, this study focuses on pre-development constraints where determining accessible acreage for drilling is a key economic assessment in its own right, required, long before any gas may flow from production wells.

Where differing groups may have conflicting interests on a project for example, economic and environmentalist groups, a GIS based decision support system can assist in deriving a consensual selection of locations. A study by Ramirez-Rosado *et al.* (2008) promoting new wind farms in La Rioja (Spain) by creating criteria maps for each group, then tolerance maps, provided 'an adequate framework to conduct a complex negotiation process'. In such a project, it may be argued that more 'tolerance' and compromise would be required between conflicting groups especially in light of the permanency of wind-farm structures. Conversely, once the exploration phase of drilling a gas well is completed, (averaging three months), the rig is removed and is replaced by a much less visible production tree.

Constraint maps therefore rather than tolerance maps are best-suited to supplement pre-development assessments for drilling location and resource evaluation. Although individual themed maps created from physical, urban and environmental constraints are developed, the composite output map is definitive, providing no gradational leeway for the site location (no tolerance involved). In the Spanish study, criteria used by the environmentalist group included visual impact and noise buffers around inhabited areas, restrictions around environmentally protected areas, sensitive areas, vegetation and ecological zones. Similar constraints are also used in this project.

In an analysis of wind turbine placement using GIS in Northern California, Rodman & Meentemeyer (2006), point to land use restrictions as one of the prime obstacles to development. Although negative visual impact and noise are the leading oppositional factors in many wind farm developments, it is the potential subsurface damaging environmental impacts such as groundwater pollution and seismic events which have caused most opposition to shale gas development in the UK. However, it is through better communication, more diligent assessment and targeting of the most suitable locations (as demonstrated by the Northern Californian study), that controversy can be minimized and the public perception of such energy projects be improved.

In the Californian model to target suitable wind power sites, maps of variables analysed in a GIS, targeted 'Physical, Environmental and Human impact factors'. Combining the maps gave a comprehensive consideration of most suitable wind turbine placement. In the West Lancashire licensed area for shale gas exploration, apart from the geological source map highlighting the Bowland Shale gas formation, an environmental constraints layer and a layer combining physical restrictions, including populated areas is utilized. Similarly to the Californian model, 'physical factors would provide a measure of the maximum land availability that could be considered' as a potential (shale gas) resource whilst the human and environmental impact factors would reduce this availability (Rodman & Meentemeyer, 2006)

In an evaluation applicable to all renewable energy sources in Crete but focusing on wind energy, Voivontas *et al.* (1998) developed a GIS Decision Support System with a methodology based on 'energy potential and the determination of the restrictions applicable'. With broadly similar aims to this study, the issues of identification and estimation of Renewable Energy Sources (RES) was tackled.

'In the first step, *theoretical potential* was defined as the maximum energy output in the region', (this could equate to initial GIP estimates for the source rock layer in Lancashire). 'The *Available potential* was defined as the theoretical potential, (harvested easily)', minus environmental impacts. Exclusion criteria would eliminate some areas of potential wind energy resource and which included: areas near towns; archaeological sites and protected areas (forests and National Parks). This would equate to an environmental constraint layer in Lancashire. *Technological potential* was defined as 'the energy that could be harvested by existing technology (or the characteristics of commercially available wind turbines)' (Voivontas *et al.* 1998).

The technological analogy with shale gas extraction is that due to horizontal drilling applications performed on this unconventional resource type, increased know-how, machinery and skills can now help achieve higher gas extraction volumes. Utilising simple overlap and buffering techniques incorporating user defined threshold values, the mapped areas of unsuitability are excluded. The study by Voivontas *et al.* concludes that 'GIS is a useful tool for identifying and quantifying the effects of local constraints on the renewable energy potential, providing flexibility and enrichment of the database which decisions are based on, with spatial data providing additional RES availability restrictions' (Voivontas *et al.* 1998).

In a further study utilising 'an Environmental Decision Support System (EDSS) for selecting optimal site selection for photovoltaic power plants' in Andalusia, Carrion *et al.* (2008) combined 'Multi-Criteria Evaluation (MCE) and Analytic Hierarchy Process

(AHP) with GIS' to provide a structured technique for organizing and analysing complex decisions. Pairwise comparisons are made from several competing criteria, namely: Environment, Orography, Location and Climate whereby resulting weighted matrix is produced based on criteria factors. In their study, it was deemed that the orientation factor in the orography criteria held a higher weighting than for example: distance to substation in the location criteria. Based on matrix criteria weights, suitable priorities can be derived with respect to the goal.

In this shale gas project however, the AHP approach would appear over-elaborate as the target geological structure is the overriding key determining factor for location. However, should the geological target be large enough, specific well-site location could be fixed according to competing sub-criteria, for example, basing the site according to its locational merits on its proximity to water resources or its locational beneficial nearness to roads.

In this West Lancashire assessment, geology and geophysics are the predetermining key factors for site suitability, the focus of study is locating accessible areas to resource by way of mapping constraints. Though GIS is a useful aid in this process, specific rig-site / well location can only be fundamentally determined by further subsurface exploration, testing, geological and geophysical analysis.

Though most renewable energy resource initiatives are welcomed, environmental and visual impacts are often barriers to such projects. The prospect of scores of drilling derricks on the landscape, (like wind turbines) is not an appealing vista for many, however, drilling rigs are a transient part of hydrocarbon exploration unlike the more permanent wind turbine structures. Social factors may also play a part in site suitability, though likely more so in wind turbine and landfill siting than well-site positioning. Chang *et al.* (2008), points to the 'protracted, tedious and complex process involving social, environmental, technical and financial factors involved in landfill siting'.

Although onshore oil and gas exploration has been established in the UK for many decades, the advent of a potential boom in the shale gas sector of the industry may require more planning, negotiation, consent, diplomacy and regulation than was ever required before. Offshore development has largely proceeded in the background since mid-1960s, but shale gas is now a topic in the forefront of the energy debate and striking the correct balance of efficiently extracting and utilising this natural resource whilst managing the landward environmental and social implications of potential development will be a challenge.

Unlike many studies which have applied GIS techniques to determine site suitability from a 'blank canvas', where criteria is analysed and focused to fundamentally pinpoint maximum energy source locations, the shale gas energy bedrock layer in Lancashire has mostly been pre-determined. The complex geology, however in such a fault-prone setting, means highly technical deviated drilling skills are likely to be required to hit the targets. Although more accurate resource estimates would be achieved with additional data from test wells, the mapping of surface constraints can reveal further information, supplementing the geological canvas, to provide more accurate assessments.

The removal of areas from the shale gas picture, such as those pockets of land or features where development could not physically take place, such as on urban settlements, road, rail and water bodies, may not reduce baseline resource estimates significantly. However, the combination of several other themed layers including more subjective elements such as conservation areas and sites of special scientific interest may provide a different perspective to decision-makers, leading to revision of acreage availability, and ultimately recoverable gas volumes.

The methodology used by Nas *et al.* (2010) in selecting a 'landfill site for Konya, Turkey using GIS and multi-criteria evaluation' are not dissimilar to the techniques employed in this shale gas mapping analysis, (though one study involves inserting materials, the other extraction!). To identify appropriate areas, 'eight input map layers, including water well proximity, irrigation canals, transport routes, rail, distance from archaeological sites, distance from urban areas, land use and land slope were used in constraint mapping' (Nas *et al.* 2010).

As (Malczewski 1996) states, GIS is used to 'manage large volumes of spatial data and MCE to support decision makers in assimilating large amounts of complex information'. Though GIS can provide complex manipulation and presentation of data based on various criteria, unlike the Konya project, the ranking of criteria in this study is not used. Using a similar method to Vatalis & Manoliadis' (2002) project, in finding 'suitable landfill sites in Western Macedonia', digital map overlay techniques were employed.

Although the methodology Nas *et al*. involved weighted criteria according to the 'relative significance resulting in ranking on a suitability scale'; this shale gas mapping more plainly categorizes an area as suitable or non-suitable. Though singular buffer zones are created for roads, rivers and urban areas, no scaling is performed and equal importance is given to each of the criteria being combined.

This more disjunctive though effective technique of map overlay, following the McHargian approach to site suitability analysis is adopted. Lober asserts that 'an exclusionary approach begins by identifying areas that are inappropriate for use because of a particular land feature such as endangered species; layers are then overlaid so that the final map shows all excluded areas as well as the remaining potential sites' (Lober 1995)

The technique of 'weighting-and-rating' applying differing emphasis to the layers before they are compiled is inappropriate for well-site locating at an early exploratory stage. However, as with the Konya landfill criteria study; analogous comparisons can be made with respect to larger scale shale gas development. Factors to 'weigh-up' may be: aesthetic considerations; distance away from heavy traffic routes; (though also taking into account expensive transport costs); the problem of locating close to surface water bodies, (with the potential for contamination), yet also realising the need for water during fracking operations. The more powerful, discretionary technique of locational suitability using criteria rating could be adopted for specific siting once the overall suitability picture was established.

In light of the various methodologies outlined, the following chapter characterises the research process and the construction of the shale gas suitability map. Using GIS ArcMap overlay and buffer analysis functions, a variety of themed maps with constraining factors are combined to create a simplistic composite locational map. As the energy source was already predetermined, unlike many renewable energy studies described, an elementary constraints / opportunities map is created. From this, area and resource assessments are quantified.

3. Methodology

The research methodology adopted for this study can be summarised in the following steps:

1. Problem Identification
2. Research Objective
3. Decide on Area of Study
4. Determine Constraint Criteria
5. Data Acquisition
6. Create GIS Layers from selected criteria
7. Execute Spatial Operations
8. Analyse Results
9. Identify suitable Drilling sites
10. Calculate areas of suitability
11. Calculate Resource potential

The research was initiated by identifying a query, namely: Have estimates for the shale gas resource in the study area taken into account surface restraining factors to development? The objectives were thereby established, to map restrictions and calculate acreage, further to calculating the resource. The study area identified is the first to be drilled for shale gas in the UK and is chosen as resource estimates have been made. Constraint data was decided upon by initially viewing maps of the study area and identifying physical obstacles to potential development. More subjective barriers, such as environmental considerations were also included. As this was a desk study, information and data was acquired through research papers and electronic data was acquired online. A constraint mapping technique developed in a GIS was applied to identify potential sites for shale gas drilling in the licensed area. A process of map overlay was followed, originally developed by architect Ian McHarg in the 1960s to better visualise and consider environmental factors in the planning stage.

ArcGIS 10.0 software was used to create digital maps from the various criteria. Most of the data used was in vector format apart from the creation of a raster Digital Terrain Model (DTM). The *Clip*, *Merge*, *Buffer* & *Spatial Join* tools from ArcMap were predominantly used to perform spatial operations. Calculations of areas for suitable well siting were made and resource estimates were created based on anticipated well numbers and typical shale gas production figures from related US shale gas plays.

The creation of an initial base-map energy source layer was fundamental to the process. As the subsurface source rock layer of potential energy in the licensed area has been considered to be essentially ubiquitous - underlying the region, the main non-geological restrictions to accessing potential shale gas arise from surface barriers to drilling locations.

Along with a Geological source layer three conceptual layers were categorized: the Landscape constraints layer; the Man-made constraints layer and the Environmental constraints layer. These themed layers incorporated exclusionary features which would eliminate zones of potential development. The geospatial data used for the creation of the geological and restrictive layers, (gathered from a variety of sources and publicly available) is shown below in Table 1.

Table 1 List of layers, sources and themes used in Constraint Maps

Layer	Source	Designation Type	Theme
Geology (Source)	BGS*		Source Rock Formation
			Fault Lines
			2D Seismic Data
	DECC*		PEDL 165 /Wells
Man-made Constraints	Ordnance Survey		Urban Areas
			Parks & Gardens
			Railway
			Motorway
			Primary, Minor Roads
			A Roads, B Road
Landscape Constraints	Ordnance Survey		Rivers, Lakes & Reservoirs, Elevation And DTM data
	English Nature	National Protected Areas	Ancient Woodland
Environmental Constraints	RSPB	Internationally & Locally Protected Areas	RSPB Reserves
	Local Authority (LCC)*	Locally Important Areas	Local Nature
			Local Conservation Areas
	English Nature	National Protected Areas	National Nature Reserves
			Sites of Special Scientific Interest
	English Heritage	Major Archaeological Sites	Scheduled Monuments
	English Nature	International Protected Areas	Special Protection Areas
			Special Areas of Conservation
	Countryside Agency	National Landscape Areas	Areas of Outstanding National Beauty

BGS* British Geological Survey / DECC* Department of Energy & Climate Change
LCC* Lancashire County Council

Unlike many other projects such as those schemes involving renewable energy where suitability or tolerance mapping initially establishes key energy areas based on criteria, the energy source in PEDL 165 is pre-determined and assumed constant. However, two differing regions of shale source rock were delineated based on geological maps). In reality, more exploration is required to firm-up this assumption. There is also no doubt that due to regionalized faulting, technological challenges would deem some zones to be economically unviable. However, the source layer created with reference to BGS *Pre-Permian Geology of the United Kingdom South* map and the *Regional structural setting of the Bowland basin* map included in de Pater & Baisch's (2011) geomechanical study, provided the most up-to-date publically available assessment of shale source subcrop over the area.

The geological maps were digitized using ArcGIS 10.0 software and a shapefile of the relevant sections were created for PEDL 165. Further shapefiles were added to the layer to provide corroborative detail, namely Bowland Shale outcrop data, faulting, current wells, onshore license blocks and seismic data. Two block areas lying centrally within PEDL 165, namely, Exploration License 269 (EXL 269) were excluded from this analysis as they did form part of the study area. All area and resource calculations were performed omitting these blocks.

The Man-made exclusion zone layer was created in ArcMap to show surface physical barriers such as urban areas, motorway, road, railway and parks where drilling sites could not be physically placed. This thematic map layer was constructed primarily from Ordnance survey data. After all shapefile features were added, a map showing drilling exclusion zones was obtained together with polygon area statistics revealing the total restrictive area in km^2 for the layer. Buffer zones of 20 m were created for roads, railways and parks whilst 100 m and 200 m buffer zones were created for motorways and urban areas respectively.

From a planning perspective, regarding wind farm placement, Baban & Parry note 'the social implications arising by such a development, that is, noise / light pollution, safety and aesthetics, which therefore dictates the need for wind farms to be located outside urban areas' (Baban & Parry, 2001). A similar case could be brought for drill-site locations also.

As no specific or national guidelines exist regarding buffer zone areas around developments such as wind-farms or drilling sites, and planning assessments by local authorities are made on a case-by-case basis, buffer areas created in this report should be regarded as a minimum and arise from a variety of planning reports observed. Calculations were also acquired by plotting all ten previously drilled wells in the study area and recording distances to nearest the constraint features.

The Landscape constraints layer represented restrictions to drilling sites associated with physical geographic barriers in the region. DTM data was utilized for the area to show potential topographical restrictions, whilst shapefiles added for rivers, lakes, reservoirs and ancient woodland would also restrict areas of drilling. 10 m buffer zones were used for water bodies, (the author has experienced such minimum buffer zone distances personally in UK onshore drilling), whilst a 15 m minimum distance for ancient woodland is recognized by the Woodland Trust. Once the features were added to ArcMap, the total area of exclusion to drilling was calculated.

The Environmental constraints layer was a thematic layer composed of habitats and zones within the study area that were regarded 'special' set aside for conservation or protection. These included areas such as the Bowland Fells, the Ribble Estuary and Martin Mere. Shapefiles for environmentally protected regions were added to ArcMap producing a composite overlay indicating regions where in an environmentally 'best-case' scenario, no drilling sites could be placed.

Adopting the approach outlined in the Governments *Planning Policy Statement 22 for Renewable Energies*, no buffer zones were created around these areas. Ramsar sites which corresponded spatially with other themes such as Special Protection Areas were not incorporated in the map, but can be seen in (Figure 3). Equal importance was given to each of the themes and each of the constraint layers being combined providing an overall output map showing the presence or absence of constraints determining the location to be either satisfactory or not for drilling. However, although it could be argued that the inclusion of areas of environmental constraints is more subjective and debatable, as opposed to true physical barriers to development; a best-case scenario has been adopted. This approach takes into account Lancashire County Council's recognition of its 'fine countryside', Cuadrilla Resources' previous planning applications, (steering clear of 'special areas') and public concerns regarding shale gas environmental issues which the energy company and industry as a whole, is acutely aware of.

Initial calculations of potential resources from West Lancashire have been treated with scepticism. This primarily quantitative study of shale gas potential attempts to inform and highlight the benefits of utilizing GIS mapping capabilities to provide a balanced assessment, defining regions of possible energy resource whilst introducing restrictive elements. Every attempt has been made to minimise the effects of erroneous data and considering that GIS maps are often unique, allowing the user to design maps by combining data from multiple sources, every effort has been made to include appropriate feature layers for analysis. This desk-based study utilized spatial data to create the maps which were derived from secondary sources, all publicly available. The datasets were easily acquired and minimal geoprocessing in ArcMap was required to clip the data to the study area.

In many renewable energy studies, determining the key energy source using multi-criteria evaluation is fundamental. Shale gas exploration in the UK is in its infancy and the geological extent of this energy source in West Lancashire is not fully realized. Although many wells have been drilled in the region and seismic data has provided a good picture of source rock coverage, further wells and geophysical information will give greater clarity – the accuracy of the geological data source layer therefore could not be 100 % guaranteed, but with reference to geological assessments and BGS maps, this dataset is the most up to date publicly available.

The absence of definitive regulations regarding buffer zone requirements around features near prospective developments meant that the distances used were based on examples from individual case studies, planning applications for wells submitted by Cuadrilla Resources and spatial calculations made in ArcMap using UK wells.

Objectives

The main objectives of this study are:

- To assess spatially the location of land available to shale gas drilling in PEDL 165
- To calculate shale gas resources, based on available land using typical shale gas yields.

Study Area

The study area was 30 km by 40 km, and was enclosed by the UK National Grid Coordinates SD31,0000, SD34,0000, SD51,0000 and SD54,0000. This area is found wholly within England within the county of Lancashire (Figure 4). Primary settlements within the region include Blackpool on the west coast, Southport to the south and Preston in the central eastern part of the area. The region was chosen as Cuadrilla Resources are the first company to have begun drilling for shale gas in the UK and hold the Petroleum Exploration and Development License for this area (PEDL 165).

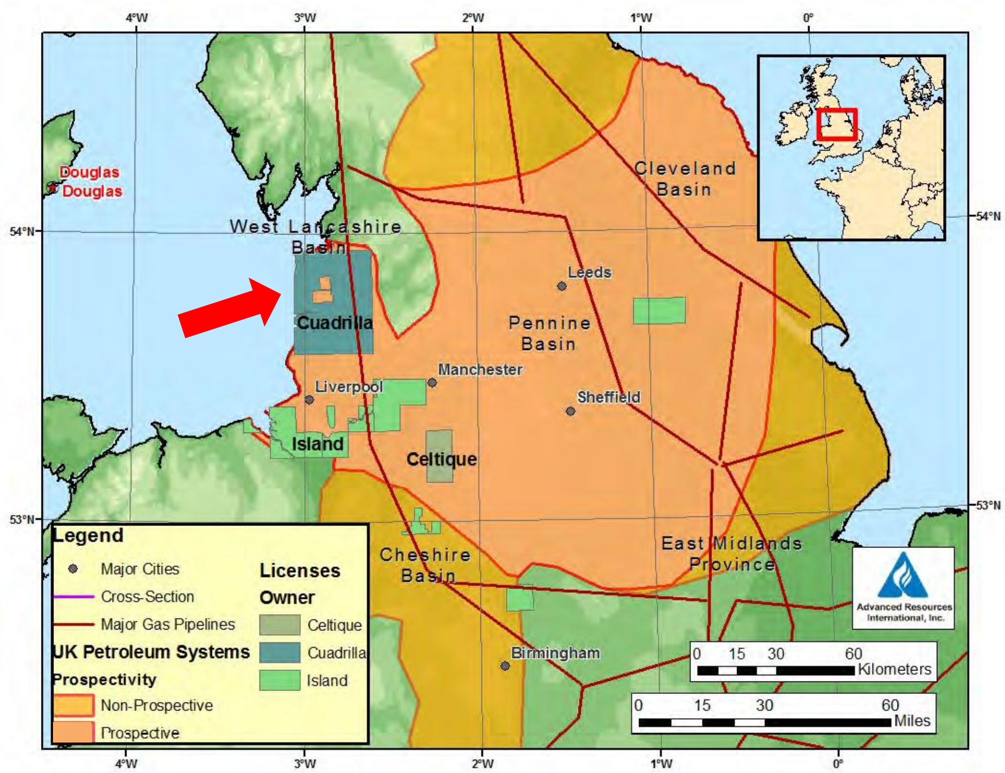

Figure 4 Area of Study - West Lancashire - PEDL 165
Source: US Energy Information Administration (EIA)

The exploration licensed area covers approximately 1,130 km^2, (436 sq. miles). The area of potential development has been chosen by 'Cuadrilla' from a geological perspective as shale gas prospects appear high, associated with the underlying proven Namurian Bowland Shale source rock. Exploration Seismic data from the region, acquired by British Gas in the 1990s has also provided 'Cuadrilla' with further subsurface information.

A previously established conventional hydrocarbon field (Elswick) also exists. As of August 2012, two test wells had been drilled (Preese Hall at Weeton & Grange Hill at Singleton), both proved thicknesses of over 1,000 ft. shale source rock. The well at Preese Hall was fractured and tested to provide estimates of recoverable gas. Further exploration wells are planned to confirm the estimated Gas-in-Place and likely portion recoverable. A decision to proceed with commercial development of the rest of the Bowland Basin will then be made based on findings.

4. Results & Analysis

Geological Assessment

Before defining surface constraint layers; assessing how restrictions may hinder potential development and recognizing suitable drilling areas to validate gas estimates from PEDL 165, a geological source base layer was created in ArcMap 10.0 (Figure 5).

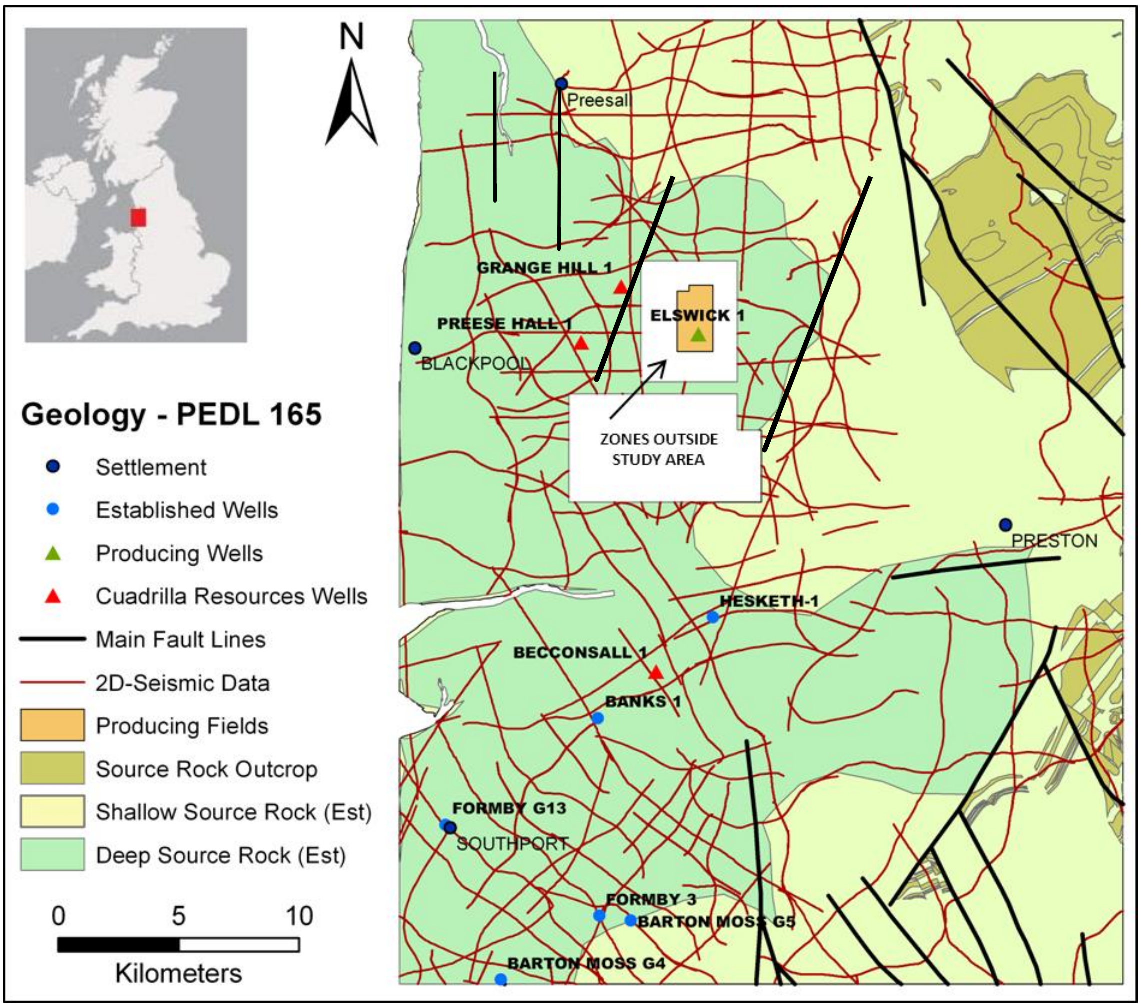

Figure 5 Geological features of the study area in West Lancashire

Although numerous wells have been drilled and several geological maps and studies have been made in Northern England and around the study area, determining precisely where the richest resources occur and how thick they are, is still being investigated. Test drilling and seismic surveying is on-going. Though it is generally considered that shale gas source rocks (including the key Bowland Shale) are likely present throughout the whole licensed area, it is the further analysis of their thickness, uniformity, geochemical and geophysical properties which will most determine the extent and recoverability of any gas.

Although similarities have been made between the Bowland Shale and the gas producing Barnett Shale in Texas, there are also many other differences, not least that geologically the Bowland Shale is located in a much more fractured / faulted environment. However, averaging an estimated 2,400 ft. thick compared to a maximum of 984 ft. thick for the Barnett Shale, many of the source rocks of the Bowland Basin, make up for vertically what they lack aerially, with the Texan shale covering 13,000 km^2, compared to 1,200 km^2, in the West Lancashire region. However, it is also relevant that the productivity zone for these shales may be limited to several hundred feet.

Bearing in mind the geological uncertainty and current lack of available data, (prior to adjusting for constraint feature restrictions), the maximum potential available acreage of shale gas source rock in PEDL 165 was determined to be 1,035 $km^{2.}$ This calculation took into account the excluded blocks of EXL 269 from the original 1,200 km^2 area to leave 1,131 km^2, then by subtracting the outcrop (exposed) layer of source rock from the rest of the licensed area, the shale gas source aerial coverage was calculated. A further calculation however was made by considering only the deeper, (maturer) portion of the acreage which is more likely to be developed. This region covered an area of 553 km^2 (prior to constraint mapping).

Commenting on the Bowland Prospect at a Shale Gas Environmental Summit in 2011, the British Geological Survey (BGS) stated ‘We worked out our old resource figure for the Bowland shale, somewhat crudely, by comparing the recovery rate for Barnett shale in Texas, which is the same geological age, and multiplying it by the land area of Bowland’ (millicentmedia 2011).

Adopting a not too dissimilar strategy and highlighting the fact that more data on the area is required to prove estimates, the Geological Source layer developed in this analysis, serves as a backdrop to the main surface constraint study, by mostly including corroborative features to set the scene, with the outcrop layer providing the only restrictive surface factor to drilling.

Nine shapefiles predominantly obtained from the BGS and DECC websites were added to ArcMap and clipped to the study area. The Carboniferous Namurian and Dinantian age source rock outcrops would restrict drilling in the eastern side of the block, where the target formations would likely be too exposed or shallow to produce gas. However, the rest of the block is likely to be underlain by gas-generating organic shales.

Using BGS map data, however, included in the *Geomechanical Study of the Bowland Shale Report* by de Pater & Baisch (2011), a further deeper, basinal shapefile was created based on the structural sub-division of the Preston-Leyland Ridge and the Formby Sub-basin. This zone appearing as green in (Figure 5) represents the most promising areas to target as source rock maturity is likely better.

Incorporating a shapefile of the main fault lines in the block provides further evidence of the structural discordance in the region highlighting the deeper basinal, graben features predominantly located in the western and northern central areas. However, numerous minor faults would also be present in the bedrock layers posing subsurface restrictions to prospective zones.

A 2D seismic data shapefile was included to indicate that hydrocarbon prospecting has previously taken place. This seismic data was shot in the early nineties and further surveys are on-going to reveal far more geophysical information. The spatial distribution of the data most notably concentrated in the northerly and south-westerly regions, indicates the areas which were regarded most promising and / or easily accessible.

The essence of McHarg's early overlay technique is clearly demonstrated in this map construction, as direct associations of the individual, varying criteria, emerge once the separate overlay features are combined. The juxtaposition of data reveals new patterns and a clearer understanding of the relationships between previously isolated criteria. A shapefile containing previously drilled wells was also added to the map, their locations corroborating further, the westerly-side exploratory focus.

Apart from the nearby oil producing Lennox Field offshore to the West, a much smaller structure, (the Formby Oil Field) located in the South West of the block provides added evidence of potential hydrocarbon gains in the area. This field produced oil from 1939—1965 to aid in Britain's war effort. The only producing onshore gas well in the block is from Elswick-1 which was brought on-stream in 1993 by *Independent Energy.* Located in the previously licensed blocks (Exploration License EXL 269) and therefore outside the study area, the gas is not produced from organic shale, but from permeable sandstone.

Cuadrilla Resources has currently drilled three wells and has acquired consent for three more. On the basis of the early wells drilled which revealed shale thicknesses of up to 3,000 ft. plus and results from stimulation tests conducted at the Preese Hall site, 'Cuadrilla's Gas-in-Place estimated resource for the block was calculated to be 200 TCF although acknowledging that only a fraction of this may be recoverable. It is not known whether Cuadrilla Resource' estimates were based on geological factors solely or whether surface constraining factors to drilling were utilized in their resource estimation model.

The following GIS constructed maps and analysis take into account these considerations, provide an estimation of the areas unavailable to drill-sites for each constraining category, then, a composite picture of land suitability for well-site placement is produced. Finally, based on this area and typical shale gas well production figures, a recoverable resource estimate is made.

The following constraint layers were developed using ArcGIS, ArcMap 10.0 software:

- Man-made Constraints
- Landscape Constraints
- Environmental Constraints

Man-made Constraints

This Exclusion zone layer (Figure 6), represented physical obstacles to the siting of drilling pads in PEDL 165 and included shapefiles of Urban Settlements, Parks & Gardens, Rail and Road features.

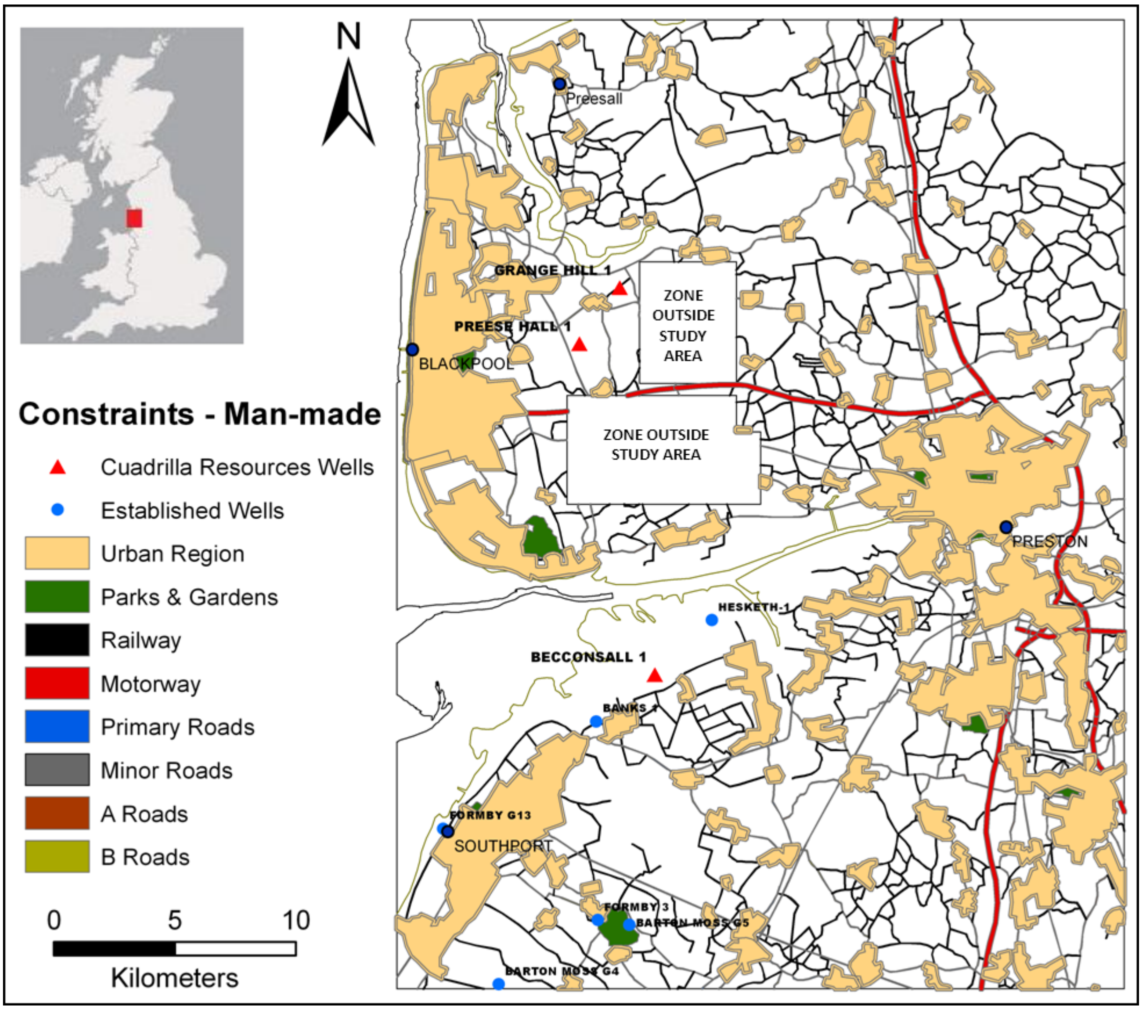

Figure 6 Man-made restrictions to drilling sites in the study area

As Baban & Parry (2001) noted in their Lancashire wind farm study, 'increasing planning restrictions would inevitably follow development, particularly in space-limited countries such as the UK'.

Unlike the US which has a population density of 27 km^2, England's population density is 383 km^2. However, though this figure is much less in rural areas such as West Lancashire, the conurbations of Blackpool, Preston and Southport in the case study area, comprise 641,000 residents alone. An urban region shapefile clipped to the licensed area provided an overall restrictive zone to drilling of 313 km^2. This included a buffer zone of 200 m created in ArcMap, which was considered realistic in light of previous onshore site studies. With the coastline and conurbations of Blackpool and Southport restricting drilling in the West and Preston restricting drilling to the East, it is the central and northern regions (where 'Cuadrilla' has completed three wells already) that land areas are least restrictive to drilling.

A Parks & Gardens feature was added to the layer and a buffer zone of 20 m was created. Although the combined area accounted for only 9 km^2 and the buffer used would appear narrow, it does at least provide a restrictive curtain. When oil was crucially needed during the Second World War, exclusionary zones would have been unheard of as indicated by the position of wells in the Formby Oil Field, (Figure 7). Located in and around residential and parkland areas, archives suggest the area was full of 'nodding-donkeys' producing oil. Road and rail shapefiles were added to the map which would also provide further restrictive elements to drillsite locations. Although this infrastructure could not be drilled upon and would add to the exclusionary features, the close proximity to a good road network, would benefit & reduce overall operational costs. During both drilling and testing phases of the well, vast volumes of water are required to be transported to the site to be used in downhole hydrofracking of the shale. In a renewable energy constraint mapping report, locating wind farms in Mid Devon, *Dulas Resolutions Ltd* (2005), highlighted the restrictions to potential resource, as the unsuitable road arteries severely inhibited the size of the turbine that could be transported. Nas *et al.* (2010) also refer to the aesthetic considerations required in good planning, by locating landfill sites 200 m from major highways. However, the expensive costs of placing them too far away is also pointed out.

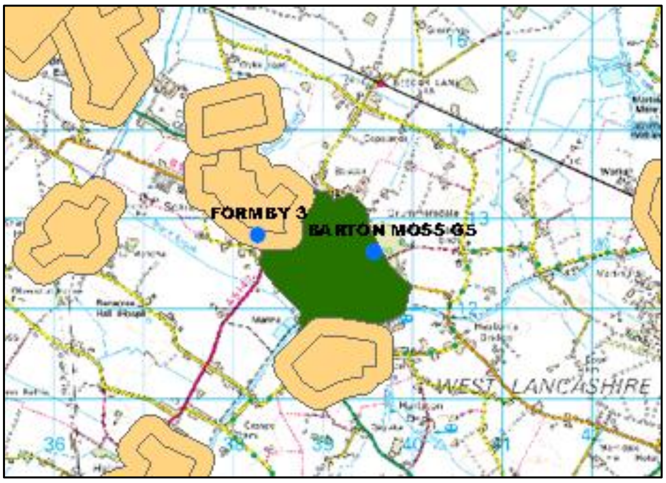

Figure 7 Formby Oil Field wells at Scarisbrick Hall

Although the M6 and M55 motorways running N-S and E-W respectively accounted for 17 km^2 of restrictions in the study area, the overall road and rail network exclusionary area (adding primary, minor, A and B roads) accounted for 85 km^2. This calculation included buffer zones of 100 m for motorways and 20 m for all other features and was based on technical transport assessment reports commissioned by Cuadrilla Resources and further GIS spatial analysis.

Utilising the Spatial Join tool in the Analysis Toolbox of ArcMap, a shapefile of all onshore wells was clipped to a UK shapefile which included the road network. The join feature (*closest*) determined the average distance from wellpoint to road polyline and also the minimum distance for all the wells. The minimum distance was found to be 20 m and was therefore used as the buffer. Using the *Clip, Buffer* and *Merge* geoprocessing tools in ArcMap which allowed for removal of overlapping segments of these features, an overall restrictive area to drilling sites for the Man-made constraints layer was calculated to be 372 km^2.

Although the 'Cuadrilla' Grange Hill well in the North of the map, (Figure 6) appears to overlap road features, the wellhead was in fact, 46 meters from the nearest road. All wells previously drilled in PEDL 165, (apart from the Formby wells) were located away from residential areas and highways.

Landscape Constraints

This layer (Figure 8, below), represented the physical geographic aspects of the landscape which would exclude development on or near such features. Shapefiles of Rivers, Lakes and Reservoirs and Ancient Woodland were added to the map. Elevation data was also provided to add corroborative detail to the licensed area. The River Ribble which drains to the Ribble Estuary from higher elevations in the southern Pennines flows to the Irish Sea from the North and the North East of the area. Several secondary rivers including the Darwen, Douglas, Yarrow, Brock, Calder and Wyre and many minor rivers amounted to 229 waterways overall. A 10 m buffer zone was added around all the waterways.

Using the Spatial Join feature as previously used to calculate road buffers, 10 m was discovered to be the minimum distance found when analysing the proximity of all UK onshore wells and river courses. The overall restrictive area was calculated to be 11.2 km^2 with the central and northern areas of the block providing the least constrictions.

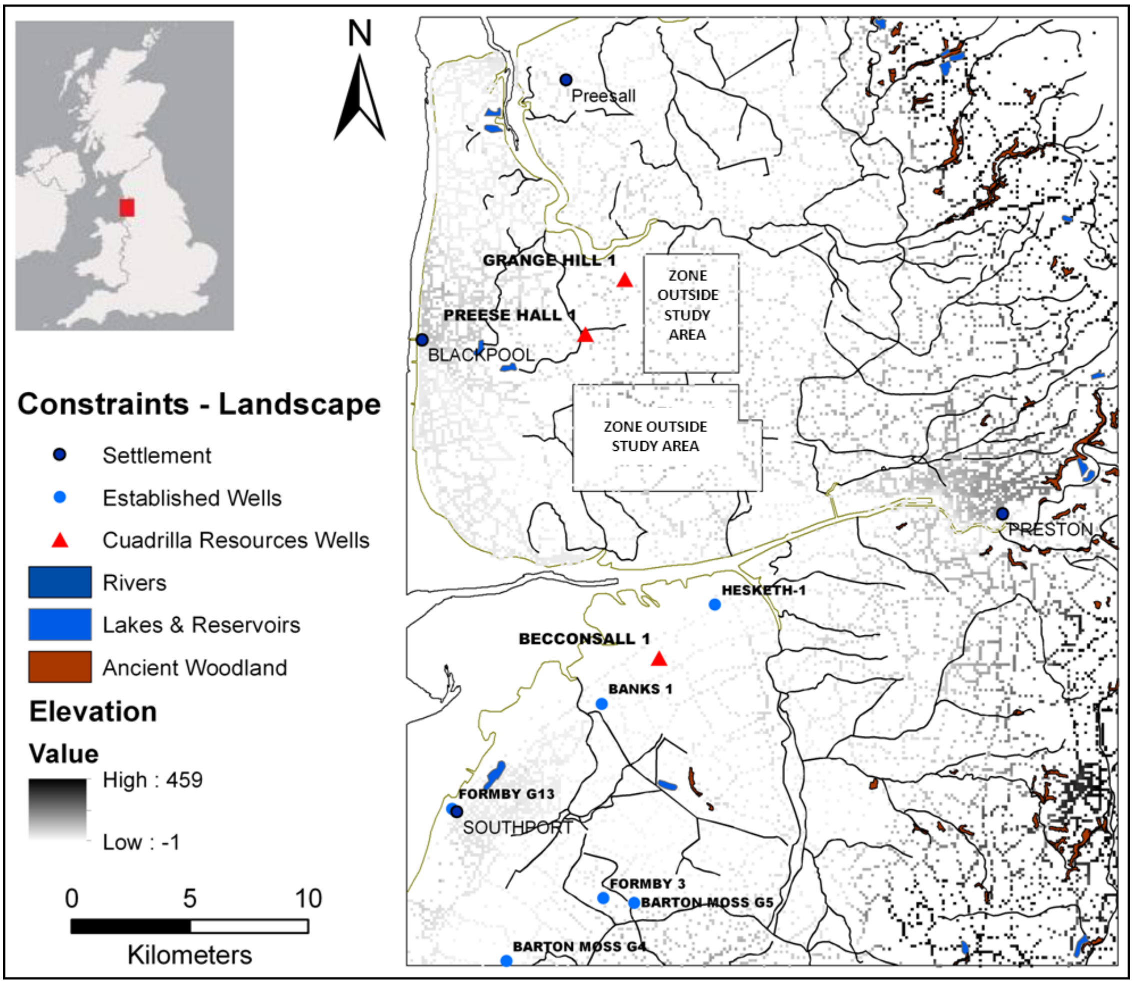

Figure 8 Landscape restrictions to drilling sites in the study area

Although potential contamination of water supplies by fracking operations at shale gas drill-sites has been highlighted, this refers to possible subsurface aquifer contamination by fluids and chemicals used in fracturing the shale at depth. This is highly unlikely though, due to steel casing which is set to isolate drilled zones.

A recent report by Davies *et al.* (2012) also recommends that fracking should be restricted to 600 m from water supplies, (aquifers). This follows a study examining fracture propagation where the chance of fractures extending more than 600 m upwards was deemed to be exceptionally low. Unlike the landfill siting study conducted by Nas *et al.* (2010), where 'proximity of landfill to surface streams, lakes, rivers, wells or wetlands were critical because of potential leachate and gas leakage' (and therefore a much wider 300 m buffer zone was employed), a narrower surface buffer zone chosen for drill-sites in this study was deemed more appropriate. This also takes into account that drill-sites are temporary features compared to landfill sites. Shapefiles for reservoirs and lakes were also added to the map, 15 water bodies accounting for 2.6 km^2 was calculated. This area also included a 10 m buffer zone. Although this areal restriction is minimal compared to other constraining factors, close proximity to surface or groundwater sources would benefit 'Cuadrilla' economically considering the large volumes of water required in fracking operations, estimated to be 8,400 m^3 per well (Broderick *et al.* 2011).

Apart from the transportation costs, possible noise and traffic issues in trucking water to the sites, the alternative method of direct water abstraction also presents issues particularly as 'water resources in the UK are already under a great deal of pressure making additional abstraction difficult' (Broderick *et al*. 2011). Using 'Cuadrilla's own data, the estimated total water consumption over a 20-year period of development would be 25-33 million cubic meters. The removal from the site of injected, contaminated water is also a factor. Although the spatial mapping of lakes and reservoirs shows higher densities in the North and East of the area, the current 'Cuadrilla' well-sites have had good proximity to water resources especially east of Blackpool.

Although there is undoubtedly greater acreage of woodland areas in the licensed block than has been mapped in this analysis, it is believed that the progress and benefits of any shale gas development would likely outweigh the need to retain such features, though obviously consideration would be made on a case-by-case basis. However, Ancient Woodland which has formed part of the landscape historically, one expects would require more consideration. An Ancient & Semi-Natural Woodland dataset was mapped to the study area, which showed the highest densities along the eastern side of the block. Comprising 90 individual wooded areas, the total acreage accounted for 8.5 km^2. This calculation included a buffer distance of 15 m which has been advised as a minimum buffer by the Woodland Trust. Although such areas are unprotected, previous planning application documents submitted by 'Cuadrilla' have indicated their consideration in such matters, allowing for a buffer zone of 10 m at Pointers Wood (non-Ancient woodland) around their Wharles site (yet to be drilled).

Figure 9 shows a Digital Terrain Model (DTM) created in ArcMap, and was provided to show elevation contrasts over the licensed area.

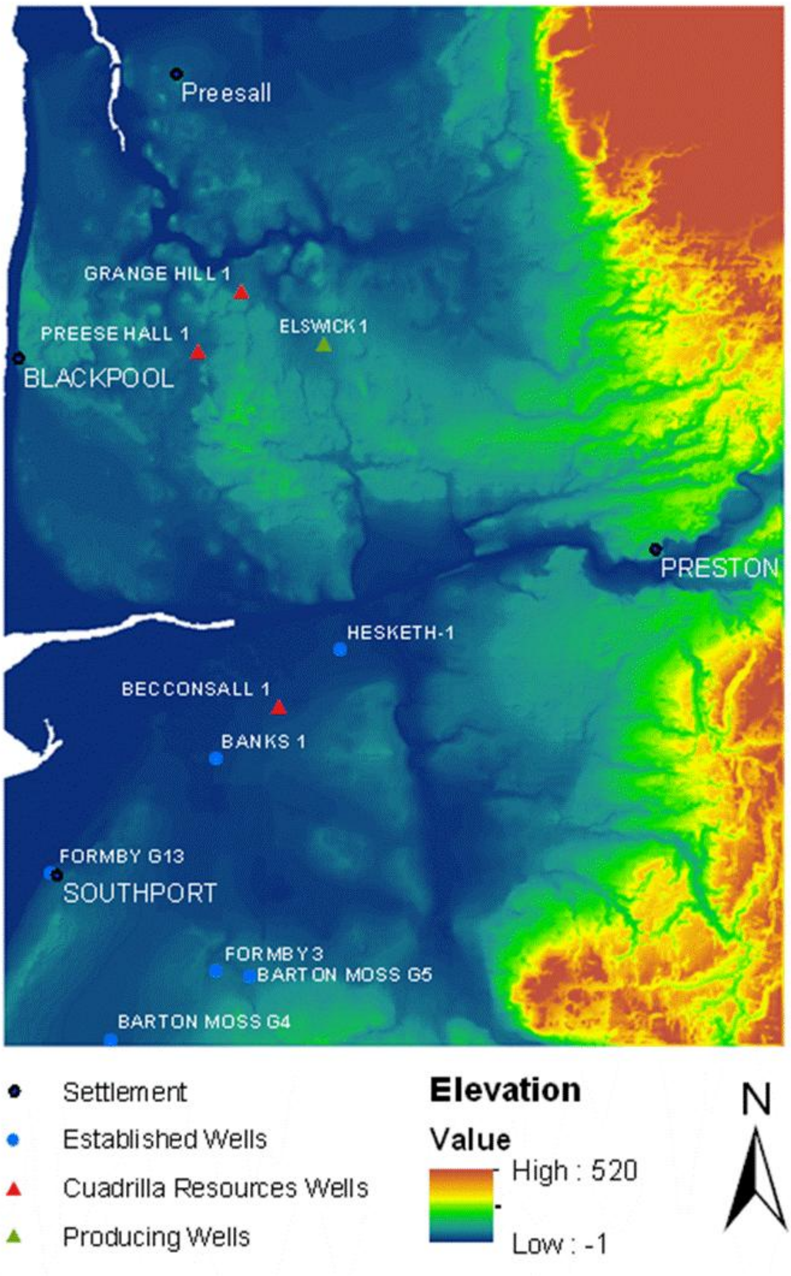

Figure 9 Digital Terrain Model of PEDL 165

Although North-Eastern parts of the region reach in excess of 500 m, the majority of the licensed area rarely rises above 30 m above sea level. All wells drilled so far, have been at elevations below 20 m. However, it is not so much the landscape elevation, but the nature of the terrain which may cause restrictions in development. With onshore wells being drilled at heights above 800 m, particularly in Scotland, but also at high levels, for example, at Nooks Farm, 96 km South East of Blackpool in Staffordshire, restrictions to drilling incurred by such elevated levels is thought not to be as problematic as one may expect.

However, because of the importance of the fells in this region with their associated environmentally sensitive areas, restrictive portions of the terrain were mapped. Where the landscape changed markedly such as in the NE towards the Forest of Bowland, together with more dispersed regions south of Preston, this change occurred at approximately the 100 m contour level.

In the Landscape Constraints layer, (Figure 8), elevation points were provided by downloading contour data at the 50 m spatial interval. The DTM raster map was developed from 10 m elevation points which allowed the further creation of a shapefile based on the restrictive 100 m contour level. This shapefile was included in the final suitability map.

The total restrictive area to drilling for ground height accounted for 68 km^2. The elevation shapefile was merged with the other features in the Landscape constraints layer. The total constraining area to drilling by physical geographic landscape features was calculated to be 87 $km^{2.}$

Environmental Constraints

The environmental constraint layer (Figure 10), was constructed in ArcMap and was comprised of nine separate feature shapefiles. Although unlike previous constraints, whereby the physical nature of the themed data would limit the siting of drill-pads, environmentally restrictive areas are more subjective, brought about by the belief to preserve, conserve, protect and recognize areas of diverse habitats and rarity. Local, national and international sites were recognized and included. Some sites, however, including Ramsar were omitted from the map due to their overlying nature with other areas, such as Special Protection Areas (SPA's), Special Areas of Conservation (SAC's) and National Nature Reserves.

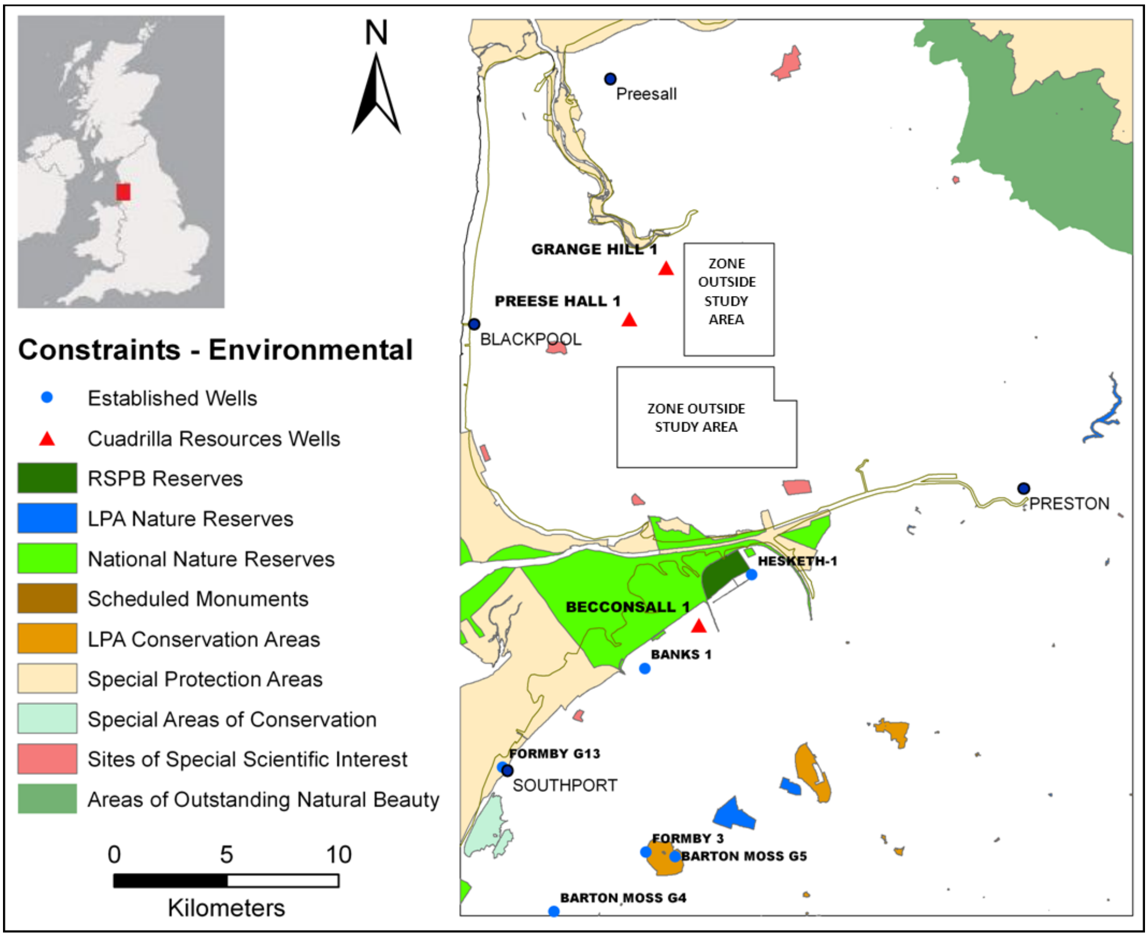

Figure 10 Environmental restrictions to drill-sites in West Lancashire

Although the full suite of environmentally sensitive areas could not be fully graphically represented, the map's objective, to show the full areal extent of land potentially lost to drill-site positioning was realised.

In a recent communiqué from *The BirdLife International Partnership,* Fishpool (2012), stated 'Although regulations and Directives can class regions as Protected or special, this may or may not preclude development and only requires that they are managed sympathetically for the bird populations or habitats for which they have been identified'. Fisher (2012) of the RSPB, also states that 'Organisations such as RSPB, have the power to control any development that takes place on land which they own and, as many of these reserves are also under statutory protection (for example, SPA's, or SSSI's) they also have to abide by the rules and regulations associated with them. There are also local government regulations which come into play'. In the licensed area, key sites such as Martin Mere, the Ribble & Alt Estuaries, Bowland Fells & Morecambe Bay are all 'Special Protection Areas, strictly protected sites classified in accordance with Article 4 of the EC Birds Directive' (JNCC).

With strict controls in place and in light of many environmental objections to shale gas development in the region, specifically potential noise, pollution and visual intrusion, Cuadrilla Resources are fully aware of their environmental responsibilities and state in their own policy a 'commitment to conducting operations in an environmentally responsible manner' (Cuadrilla Resources Ltd 2012). Furthermore, planning applications submitted by the company also indicate their intentions to be seen as responsible operators. With this in mind, the environmental constraints layer was developed as a best-case scenario, with the hope from an environmentalist viewpoint that the areas mapped could not be developed.

Local reserves, local conservation areas and scheduled monuments accounted for minor acreage in the block; 48 sites covering a total of 7.7 $km^{2.}$ National Nature Reserves and RSPB Reserves totalling eight sites, predominantly along the Ribble Estuary accounted for 40.4 km^2. Special Protection Areas which is a designation under European Union Directive on the Conservation of Wild Birds, accounted for the largest environmentally protected area in the study region, calculated at 127 km^2, the majority lying along the Ribble and Alt Estuaries. Special Areas of Conservation and Sites of Special Scientific Interest accounted for 11 areas totalling 5.6 km^2

·Although Areas of Outstanding Natural Beauty (AONB's) have similar status to National Parks when it comes to planning consent, they do not have their own authorities or special legal powers to prevent unsympathetic development. In PEDL 165, this region corresponded with The Forest of Bowland covering an area of 68 km^2.

Though there is some overlapping of protected regions, the overall exclusionary area to drilling was calculated to be 192 km^2 for the layer. As can be seen, the vast majority of environmentally sensitive zones are located along the Ribble, Alt estuaries and coastline. Apart from the Formby wells, more recent exploration has not encroached upon protected areas and although high grade agricultural land has sometimes been acquired during exploration phases in the region, the effects are often short lived and full restoration takes place.

In a recent planning application by 'Cuadrilla' for their Wharles site, a restoration paragraph refers to 'the topsoil being cultivated to bring it back to a suitable seed growing texture'. Figure 11 shows a Land Classification map created for the study area with land classified into five grades; Grade one is best quality and grade five, poorest quality (MAGIC). Although this is not a constraining factor in itself to potential development, the classification provides a further example of the ways in which the

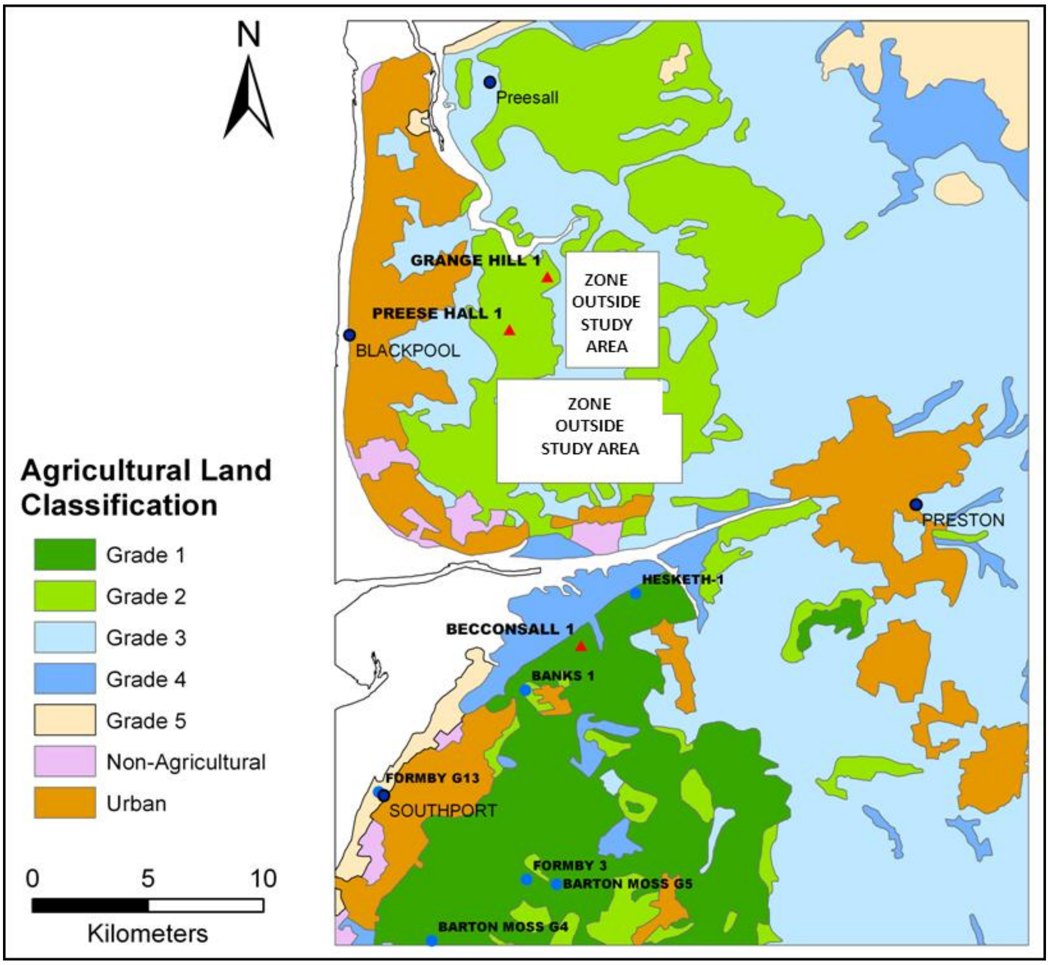

Figure 11 Agricultural Land Classification in the PEDL 165 area

the licensed area can be represented and may have differing values to different interested parties.

Baban & Parry (2001) state how ‘GIS has the capability to handle and simulate the necessary physical, economic and environmental constraints’ in their GIS approach to locating wind farms, it can also ‘play a significant role as a decision support tool’ regarding optimum well-site locations. Though quality of land may not be a constraining factor in the pursuit of shale gas, land ownership may impede its development. Unlike the UK, US landowners own the mineral rights beneath their land, this has meant a greater incentive to drill as the landowners have a stake in the asset and as Charles Hendry MP declared in 2011, regarding the UK’s fledgling shale gas industry, ‘It has a potential role to play, but it will be done within very strict environmental constraints’ (The House of Commons).

Another potential bottleneck in the scenario may arise from the number of UK landowners who would be required to give individual consent for their land to be worked. This is a necessary process as opposed to the US where the government may acquire the land. The number of individual landowners in a small part of Lancashire would likely be much more numerous compared to the equivalent ownership numbers for the same acreage in Texas.

Although the Environmental constraints outlined here refer predominantly to landscapes, habitats and regions requiring special consideration over the whole licensed area, as yet, only three wells have been drilled by the operator and on information submitted by them to the Lancashire County Council, the sites were not deemed Environmental Impact Assessment developments (EIA). Though the environmental focus has been magnified on a handful of well-site locations thus far, if shale gas development is realised, one hopes the environmental canvas will be re-assessed in light of anticipated high drilling activity.

Shale Gas Drilling Site Suitability

Following the creation of each constraint layer in ArcMap, a composite picture of overall restrictions was developed by overlaying the individual themed-layers of man-made, landscape, environmental and geological features. Using the *Merge* function tool, the layers were combined removing overlapping segments to produce a map (Figure 12) showing surface areas of exclusion to shale gas drilling in PEDL 165. As can be seen, the prominent areas of exclusion form most of the west coastal region (principally from environmental & urban restrictions) and eastern areas of the block (where settlement is high or geology and landscape restrictions dictate).

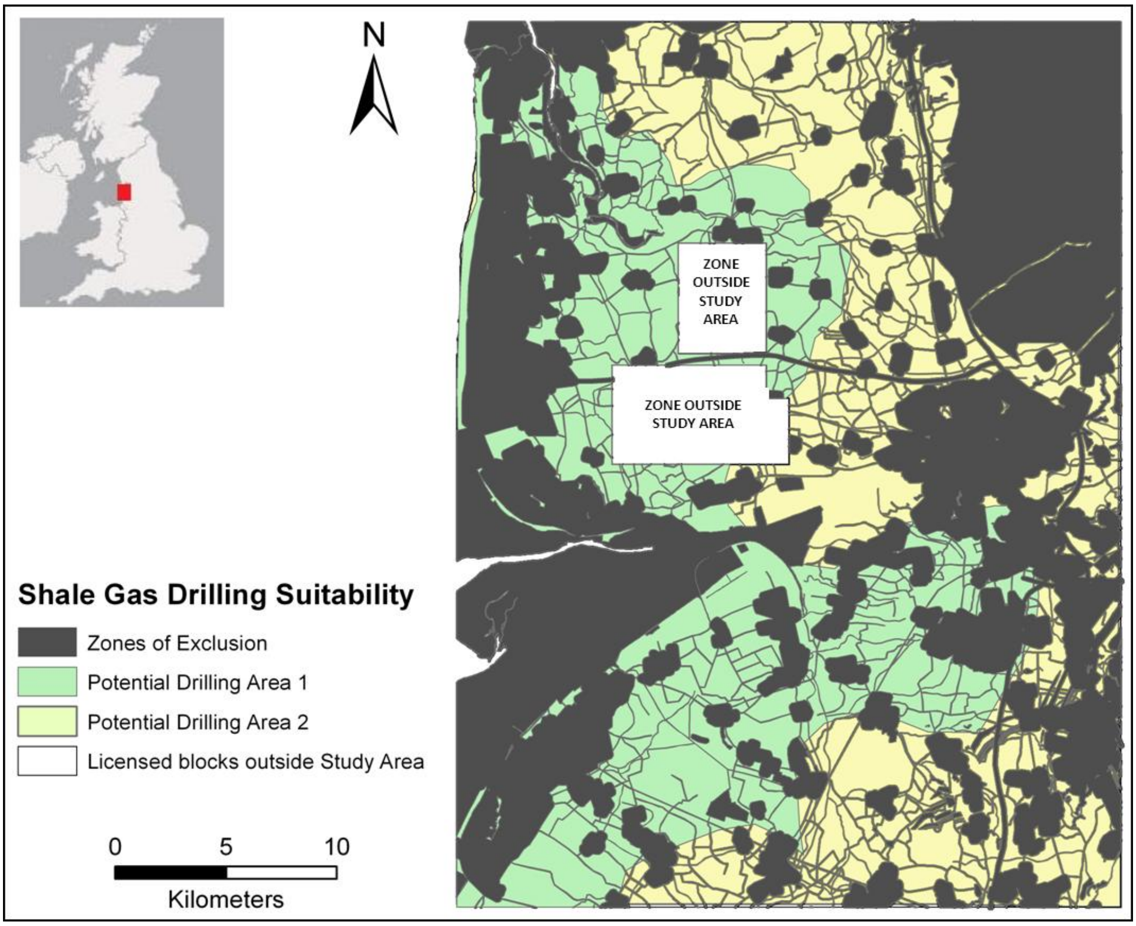

Figure 12 Shale Gas Drilling Location Suitability PEDL 165

The northern and southern areas of the block therefore provide the most suitable locations for the siting of well pads in the region. The potential drilling zone is divided into the deeper Area 1 (the most promising acreage) and Area 2, (shallower source rock). The calculations for the individual and overall restrictive layer areas to drilling are shown in Table 2 below. The results provided from merging the constraint layers, indicate that from the original 1,131 km^2 available to Cuadrilla Resources in PEDL 165, less than half this area is likely to be available to site drilling operations with man-made obstructions, (principally settlements), providing the largest barrier to development. Of the available 522 km^2 of land, it was calculated using the *Merge* function in ArcMap that 112 km^2 (21 %) of this would be Grade 1 agricultural.

Table 2 Area calculations from Constraint Mapping layers used in PEDL 165

Layer	Area	Restrictive Area	Restrictive Area %	Available Surface Area	Available Surface Area %
PEDL 165	1,131				
Geology (outcrop)		96 km^2	8.5 %		
Man-Made Constraints		372 km^2	32.9 %		
Landscape Constraints		87 km^2	7.7 %		
Environmental Constraints		192 km^2	16.9 %		
Total		747 km^2	66 %		
Total Merged Layers		609 km^2	53.8 %		
Total Surface Locational Area				522 km^2	46.2 %
Most Promising Drilling Area				250 km^2	22.1 %
Secondary Drilling Area				272 km	24.0 %

When assessing the deeper, most promising basinal shale region, the original area was calculated to be 553 km^2, however with the same constraints over this area alone, this target acreage would reduce to 250 km^2, less than a quarter of the licensed area. It is interesting to see that all the hydrocarbon wells drilled historically in this block fall into this band. However, most drilling was targeted at conventional deposits long before the notion of extracting gas from largely impermeable rocks was considered.

Resource Assessment

Since September 2011 when Cuadrilla Resources announced estimates of 200 Trillion Cubic feet of Gas-in-Place (GIP) in West Lancashire, many analysts (including the British Geological Society) have strived to determine not only if this figure is valid, but if so, what percentage of this gas could be recoverable?

‘Cuadrilla’ acknowledges that only a fraction of this amount could be extracted, however, the initial estimation still raised eyebrows considering that only two shale gas wells had been drilled at the time. Although ‘fracking’ (fracture stimulation) was performed at their Preese Hall site, no specific data has been released regarding flow rates or potential production of shale gas from these tests. It is also not known whether a GIS-based desktop study had been undertaken by the company prior to acquiring a production and exploration license which may have assisted them in determining land areas available to drill.

Based on the surface area constraints defined in this study and the available geological and drilling data, estimates of potential recoverable shale gas were calculated. The following considerations were taken into account:

- Maximum UK well spacing estimates of 1.5 well pads / $km^{2,}$
- Multi-well pad drilling to reduce well pad numbers (10 wells/pad)
- Cuadrilla Resources' own well construction estimates
- Well production flow rate range of 1 – 5 BCF
  (Taken from typical shale gas wells in the US).

As UK space is limited, the maximum well pad spacing has been estimated to be 1.5 well pads / km^2, (Broderick *et al*. 2011). With even well spacing in PEDL 165, this would equate to 1.5 pads x 522 km = 783 well pads.

As 'Cuadrilla' Resources will be implementing multi-well drilling of 10 wells / pad. This scenario in theory would equal 7830 wells, however, 'Cuadrilla's own high end estimates for wells to be drilled = 810. It is most likely therefore that the 783 wells estimated here (using constraint mapping acreage) will be drilled from approx. 78 well pad locations (783/10 = 78.3).

This would equate to 1 well pad every 6.6/km^2. However, as the high end well estimate would be drilled over a 16-year period at a maximum of 60 wells / year, it is most likely that only 6 drilling rigs will be operational at any one time.

Two Resource areas were defined. The more promising, deeper, Area 1 occupies a surface area of 250 km^2 (97 $miles^{2)}$. Tables 3 & 4 provide estimated recoverable shale gas for each area, whilst Table 5 provided an estimated total resource for PEDL 165.

Table 3 Shale Gas Estimation for Area 1 based on surface constraints

AREA 1			
Estimated Gas In Place for PEDL 165 = 200 Tcf (Trillion cubic feet)			
**A typical shale gas well in the US will deliver between 1 - 5 Bcf (Billion cubic feet)*			
* Source: U.S. Energy Information Administration *(July 2011)*			
***UK Max well pad spacing = 1.5 / km²*			
** Source: Broderick *et al. (2011)*			
250 km (97 miles)			
250 x 1.5 =	375 sites / 10	37.5 pads	375 wells
		375 x 1 Bcf =	375 Bcf
			0.375 Tcf
		375 x 5 Bcf =	1875 Bcf
			1.85 Tcf
Production @ 1 Bcf = equivalent of 0.19% of estimated Gas In Place (GIP) Production @ 5 Bcf = equivalent of 0.93% of estimated Gas In Place (GIP)			

Table 4 Shale Gas Estimation for Area 2 based on surface constraints

AREA 2			
272 km (105 miles)			
250 x 1.5 =	408 sites / 10	40.8 pads	408 wells
		408 x 1 Bcf =	408 Bcf
			0.408 Tcf
		408 x 5 Bcf =	2040 Bcf
			2.040 Tcf
Production @ 1 Bcf = equivalent of 0.20% of estimated Gas In Place (GIP) Production @ 5 Bcf = equivalent of 1.0% of estimated Gas In Place (GIP)			

Table 5 Estimated Total Recoverable Shale Gas in PEDL 165

TOTAL RECOVERABLE SHALE GAS PEDL 165
Area 1 = 0.38 – 1.85 Tcf
Area 2 = 0.41 – 2.0 Tcf
Total Estimated Recoverable Resources = 0.8 Tcf to 3.9 Tcf
Percentage of Original GIP estimate = 0.4% to 2.0%
Number of wells required to drill = 783 Well Pads = 783 / 10 = 78

5. Discussion

As traditional supplies of offshore oil and gas diminish and deposits of unconventional resources such as those finds in Lancashire are discovered, the prospect of developments closer to home loom larger. There are many facets of shale gas development, and many interested parties have voiced their opinions and concerns. However, whilst onshore UK drilling has been established for many decades, the scale of potential Bowland Basin development, coupled with environmental anxieties and some perceptions of a fossil-fuelled future, means that actively operating energy companies, governmental and planning authorities involved in this arena, will come under more scrutiny than ever before.

A study using constraint mapping within a GIS was made to determine site suitability for drilling in Cuadrilla Resources' licensed area in West Lancashire. The suitability factors came from Geological (mostly supporting placement), and non-Geological (urban; landscape & environmental) factors, restricting placement. Isolating each factor layer provided an indication of its individual impact. The final composite map provided identification of unrestricted areas for drilling. No weighting factors were assigned among layer groups. Although physical constraints would be a barrier to development, environmental constraints were more subjective.

Once further test well data and improved seismic data have been acquired, criteria-weighting could be introduced to fine-tune specific locations within the broader area of suitability. Higher weightings may also be given to prospects which are closer to water bodies (for fracking requirements) or (where prospects are similar), to those locations which least impact on communities. Geological considerations, however, will always be the principle determining factor. Unlike the US which has a much lower population density, UK space is much more contested. Current drilling activity has located in primarily agricultural areas but with possible development, more contentious urban and environmental encroachment may follow. However, even under 'Cuadrilla's high-end developmental scenario, there appears the prospect of fewer rigs operating in the landscape, because of multi-well drilling, a situation which would appease many observers.

6. Conclusions

There is no doubt that from the geological information gleaned from historic hydrocarbon finds, current well analysis, geochemical and geophysical reports that in the study area of the Bowland Basin, there is great potential for shale gas development. The extent, thickness and organic carbon content of the principle source rock, (the Bowland Shale) provides a tempting prospect for explorationists and energy companies such as Cuadrilla Resources. Initial estimates of gas volumes provided headline news although recoverable amounts of gas would only ever be a fraction of the total amount in place. By using constraint mapping to accurately assess the surface, drilling acreage, together with shale gas production data in this analysis, the fraction of recoverable shale gas was calculated to be a maximum 1/50 or 2 % of Gas-in-Place.

Although much further geological analysis, through seismic studies, exploratory wells and production testing needs to be made before any development road is taken, GIS can play a significant role in focusing on surface considerations to such a development. This spatial 'top-side' analysis should take place before development is undertaken and through constraint mapping, provides information on potential site suitability and consequently can refine resource evaluation.

Although GIS can also have a role to play in subsurface analysis during the potential field development process by estimating volumes and optimizing well patterns, this study has analysed restrictions in the early phase of the UK shale gas story. Many comparisons with the US shale gas industry have been made, but the comparatively limited space and challenges in UK onshore prospects may restrict gas production and prove the saying 'All that glitters is not gold'.

By providing a framework for data integration, a GIS was developed whereby map overlays were constructed representing the potential physical and environmental barriers to shale gas drilling locations. A final site suitability map was created and from this spatial analysis of the non-restrictive areas, an assessment of potential shale gas resources was made. At least two of the key questions asked of the study could be answered positively, as a clearer picture of land availability had emerged and by calculating that a fraction of the original Gas-in-Place could be recovered, a quantitative refinement of the headline figure was made.

From the original area determined by the licensed block acreage it was found that less than half would be suitable for drill-site locations. Although this was revealing, it was not necessarily detrimental to resource estimates. Through horizontal drilling techniques, gas reservoirs can be drained many kilometres from well-site locations. However, any GIS analysis can only be made based upon the available data and though land availability could be calculated, estimates of gas production relied upon data from US shale gas plays.

GIS datasets and resources acquired from a variety of organisations have through ArcMap integration and visualisation, highlighted both geological and non-geological aspects of development. Although resources such as shale gas may play an important part of the UK's future energy needs, it is critical to establish from an early stage, the socio-economic and environmental implications that such change may bring. GIS can combine disparate datasets to reveal patterns and information, allowing decisions to be made, based on a variety of differing perspectives.

In Petroleum and Exploration License area PEDL 165, resource estimates were made based on many non-geological factors. The challenge for Energy Companies and decision-makers in the future is to utilize GIS and constraint analysis at an early stage in planning. These mapping techniques can provide information to submitting teams which can assist in the analysis of exploration and development locations with regards to physical and environmental constraints.

In an ever-congested world where the energy landscape is changing fast, GIS can be used as a decision-support tool in shale gas exploration not only to maximize development but also ensure minimal conflict is achieved by being an integral part of an effective planning process.

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