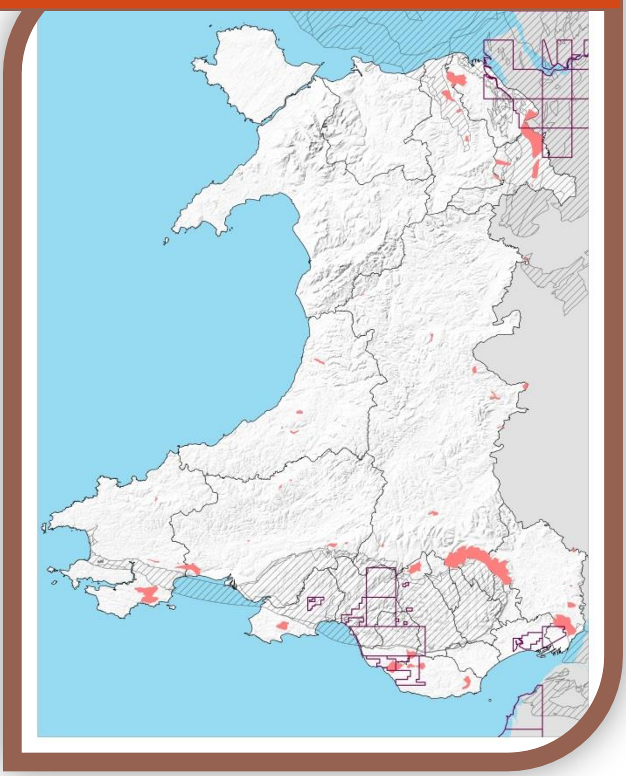
# Study of the potential impact of onshore Coal Bed Methane production in Wales, as defined within the Petroleum Act 1998, with regard to environmental, social and economic factors



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# 1. Contents

## 2. Summary

Natural Resources Wales (NRW) commissioned Cardiff University`s Geoenvironmental Research Centre (GRC) to carry out an investigation into the potential for Coalbed Methane (CBM) production in Wales. Natural Resources Wales was interested in both the potential for Coalbed Methane (CBM) production in Wales, and the potential impact of the production on socio-economic, environmental and public health issues.

The study has been carried out using the Seren Spatial Decision Support System (Seren SDSS), developed by the GRC as a part of the ERDF-funded Seren project. Seren SDSS has been developed to support the decision-making needed to address complex problems related to geo-energy applications such as Site Selection, Site Ranking and Site Impact Assessment. Seren SDSS combines different GIS, Artificial Intelligence and Multicriteria Decision Analysis techniques as well as enabling spatial knowledge discovery (Irfan, 2015; Irfan et al., 2017). This bespoke tool operates in an integrated manner, considering environmental, socio-economic, public health and techno-economic domains.

For Site Suitability and Site Ranking, contemporary qualitative and quantitative spatial information across all aforementioned domains has been analysed and a series of maps, graphs and textual information produced.

The Site Impact Assessment tool of the SEREN-SDSS has been applied to the sites that have been granted planning permission for CBM development, as provided by NRW.

This report contains the obtained maps, indicators used for all four domains (environmental, socio-economic, public health and techno-economic) as well as the relative weights to which they have been assigned for analysis.

# 3. Introduction

Cardiff University's Geoenvironmental Research Centre (GRC) were commissioned by National Resources Wales (NRW) to carry out an investigation into the potential for Coal Bed Methane (CMB) production in Wales. The full brief is reproduced below for completeness.

"Natural Resources Wales is looking to procure a short investigation into both the potential for Coalbed Methane (CBM) production in Wales, and the potential impact of the production on socio-economic, environmental and public health issues. The investigation should analyse contemporary qualitative and quantitative spatial information across economic, socio-economic, environmental and public health issues, thereby enabling policy makers to undertake an informed consideration of the potential impact of CBM production in Wales.

Natural Resources Wales is looking for a supplier that has access to a robust spatial decision support tool, and the expertise to apply the tool to investigate the potential impacts of CBM development in Wales. The spatial decision support tool must be cable of providing visually intuitive representations of the potential CBM reserves in Wales, and the potential impact of production (preferably via shape-files). The tool must also determine the impact of any assumptions or weightings utilised by its operator.

The investigation should consider:

1. Within the existing Welsh Petroleum Exploration and Development licensed areas, what potential exists to extract Coal Bed Methane from sites that are likely:
   a) to have minimum negative impact on the environment,
   b) to have positive impact on the socio-economic conditions of the communities living nearby,
   c) to be located in areas where public health is not already under stress, and
   d) to be economically and technically more viable than other potential areas?
2. For proposed developments that have existing planning consent and environmental permits for Coal Bed Methane exploratory activities (i.e. the location is already fixed), what would be the potential impact should the sites progress to production activities?

**Performance expectations / outputs**

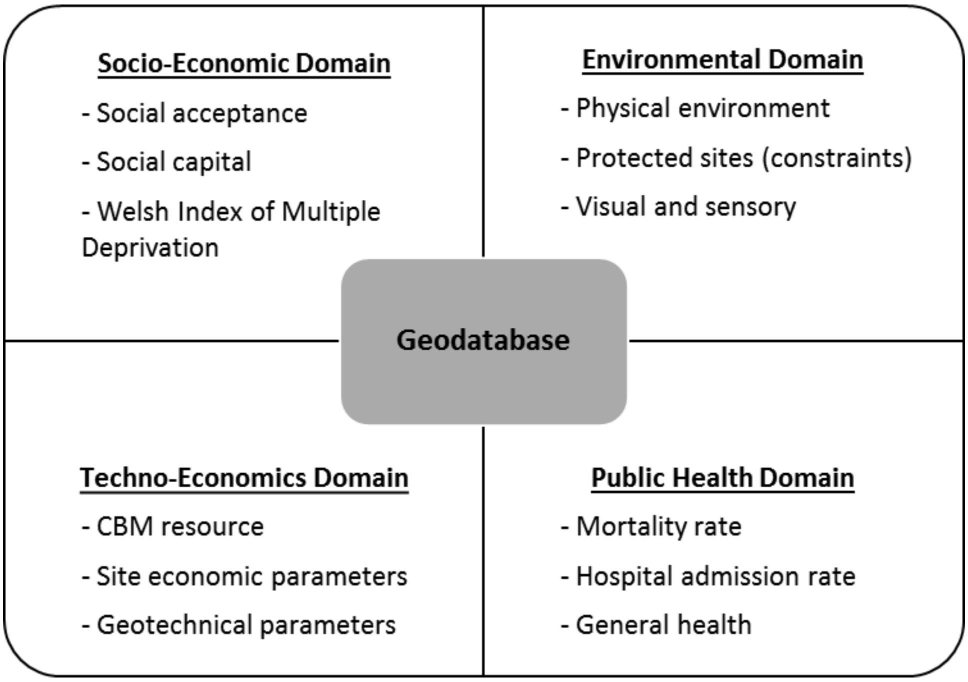
The output of this study should be a series of shape-files that demonstrate the potential impact of CBM production in Wales. It will also be necessary to provide commentary on the findings of the investigations and any assumptions made.

# 4. Approach and methodology

In order to meet the specified tender requirements, the GRC utilised their in-house SEREN Spatial Decision Support System (SEREN-SDSS) and adopted methodology similar to that presented in Irfan (2015).

The system has been developed in order to facilitate decision-making regarding geo-energy developments - in particular, problems related to Site Selection, Site Ranking and Site Impact Assessment. SEREN-SDSS has different modules, either based on Multicriteria Decision Analysis (MCDA) techniques or Artificial Neural Networks (Irfan et. al, 2017).

At the backend of the system, a comprehensive geo-database has been developed, containing key relevant indicators from the four domains: socio-economic, environmental, public health and techno-economic. Some key indictors used in this study are shown below.



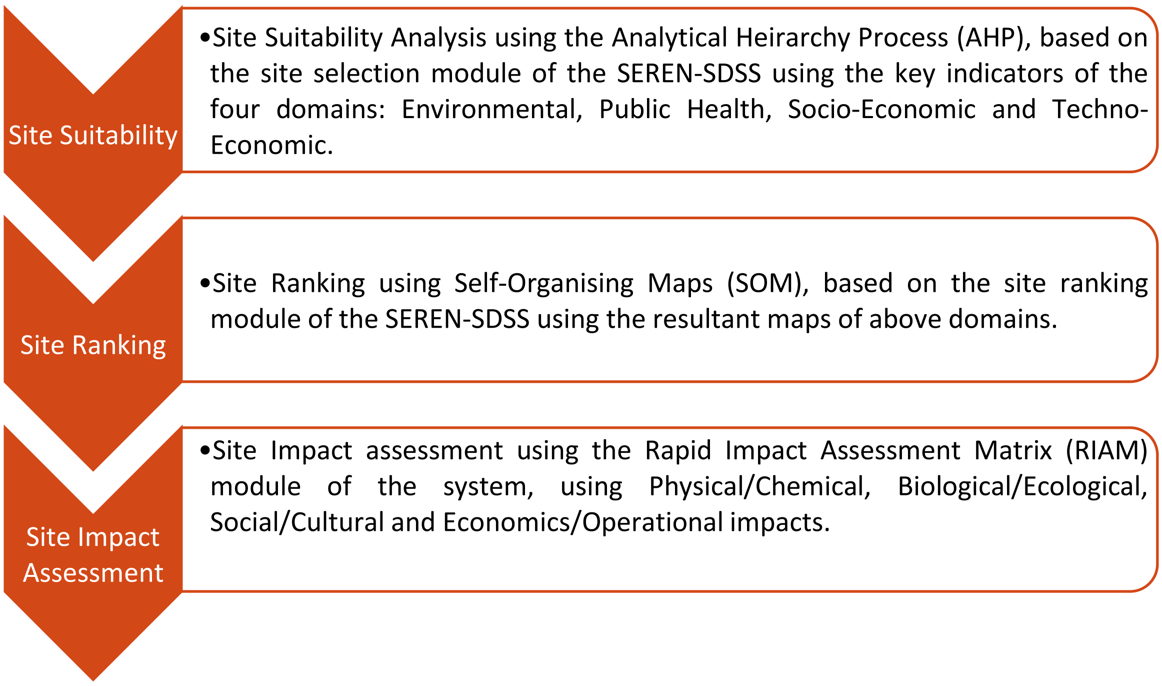

Decision-makers can assign different weights to these indicators based on their relative importance.

For this investigation, the selection of indicators and their relative weights were agreed upon during a consultative meeting between the GRC and NRW. In order to provide a balanced regime, it was decided that equal weights would be given to all four domains.

Sub-weightings were applied to individual indicators within each domain, based on the outcome of the consultation meeting mentioned above. Each is listed below in Tables 1, 2, 3 and 4, in sections 5.1, 5.2, 5.3 and 5.4 respectively.

Artificial Neural Networks find natural clusters in the data and assigns ranks to them based on these indicators. The impact assessment modules also consider these indicators while assessing the existing conditions in the neighbourhood of the proposed sites.

After indicators were selected and their relative weights assigned, the onshore coal bearing areas of Wales were divided into 500m$^2$ cells and populated with the chosen indicators. Following that, SEREN-SDSS was applied in a stepwise manner in order to carry out the Site Suitability, Site Ranking and Site Impact Assessment.




The Site Suitability assessment was undertaken in the first step. The AHP results generated from this step provided numerical values to indicate the suitability of each cell with regard to each of the four domains (environment, socio-economic, public health and techno-economic); these values were used to create suitability maps (See Section 5). After the Site Suitability step, a filtration process was applied in order to remove all the sites intersecting with constraint maps, e.g. Source Protection Zones. After the filtration process, the Site Ranking step was carried out to rank sites according to their suitability in terms of the AHP score from the four domains. Maps of best ranked sites are presented in Section 6.

For the second part of the brief, namely the assessment of all sites already possessing permits from NRW, the Site Impact Assessment step was carried out using a Rapid Impact Assessment Matrix (RIAM) tool. The RIAM approach accounts for the existing condition of key parameters in the surrounding areas of the proposed sites.

# 5. Site Suitability Maps

Site Suitability has been carried out using the AHP-based site selection module of SEREN-SDSS. The tool scales all participating indicators between 0 and 1 in order to normalise them appropriately (gaining objectivity to individual units/currency). Scaling was carried out based on the nature of the indicators i.e. whether a particular indicator is benefit (higher value indicating a better site) or cost (lower value indicating a better site). This ensures that the contribution of each indicator and its sub-indicators to the site suitability analysis is realistic.  Maps produced from these results have been populated using a colour scheme ranging from red (indicating that the site is, on a relative basis, very unsuitable) to green (indicating that the site is, on a relative basis, very suitable). It is important to emphasise that this colour scheme (as used in Figures 1-5) provides an indication of *relative suitability* i.e. a green region is considered very suitable in comparison to the other areas considered in the analysis; it is not an absolute measure that is definitively suitable.

The indicators used in the analysis under all four domains are provided in the following (Tables 1-4) along with the produced maps (Figures 1-4). The sum of the relative weights of the indicators at each level of the decision hierarchy in the AHP is equal to 1 (100%). The relative weight of a given indicator is subdivided into its sub-indicators based on its relative importance. Details of the AHP tool can be found in Irfan (2015) and Irfan et al. (2017).

## 5.1 Environmental Domain

As listed in Table 1, the indicators used for the environmental domain can be grouped into the following categories.

i) *Physical Environment.* The physical environment indicators used in the construction of environmental deprivation ranks in the Welsh Index of Multiple Deprivation (WIMD) were acquired at the Lower Super Output Area (LSOA) level (Welsh Government, 2014).

ii) *Proximity to CCW Protected Sites*. The impact on protected areas is an important consideration for the exploitation of Geoenergy resources. Therefore, the distances from the boundaries of protected sites were calculated.

*iii)* *CCW visual and sensory indexes.* Visual and sensory indicators represent the landscape, scenic beauty, and aesthetics of an area. This includes the Intrinsic Evaluation Matrix, which records information about the ecological, visual, historical and cultural landscapes of Wales. The Intrinsic Evaluation Matrix consists of indicators of the scenic quality, integrity, character, and rarity of the landscape, as well as an overall index classifying the landscape as either “Outstanding”, "High", "Moderate" or "Low". The Land Form indicator, which describes broader land cover, comprised of slope and elevation, was also included within the visual sensory indicators (NRW, 2017).

iv) *Ambient Air Quality.* Modelled ambient air quality maps were acquired at 1km$^2$ resolution. Each map models the annual mean pollutant concentration in μgm$^{-3}$, with the exception of CO, which is modelled in mgm$^{-3}$ (DEFRA, 2017).

**Table 1. Environmental Indicators used in the Site Suitability Assessment**

| Indicator | | | Weight |
|---|---|---|---|
| Physical Environment | | | 0.25 |
| | | WIMD-2014 Indicator of Air Quality (Emissions) | 0.25 |
| | | WIMD-2014 Indicator of Air Quality (Concentrations) | 0.25 |
| | | Flood Risk 2014 | 0.25 |
| | | Proximity to waste disposal and industrial sites 2014 | 0.25 |
| CCW Protected Sites | | | 0.25 |
| | | Distance from - Site of Special Scientific Interest (SSSI) | 0.0833 |
| | | Distance from - Special Areas of Conservation (SAC) | 0.0833 |
| | | Distance from - Special Protection Areas (SPA) | 0.0833 |
| | | Distance from - Wetlands of International Importance (Ramsar Sites) | 0.0833 |
| | | Distance from - National Nature Reserves (NNR) | 0.0833 |
| | | Distance from - Marine Nature Reserves (MNR) | 0.0833 |
| | | Distance from - Areas of Outstanding Natural Beauty (AONB) | 0.0833 |
| | | Distance from - Heritage Coasts | 0.0833 |

| | | | |
|---|---|---|---|
| | | Distance from - Biospheric Reserves | 0.0833 |
| | | Distance from - Biogenetic Reserves | 0.0833 |
| | | Distance from - Local Nature Reserves (LNR) | 0.0833 |
| | | Distance from - Source Protection Zones (SPZ) | 0.0833 |
| CCW Visual Sensory | | | 0.25 |
| | Intrinsic Evaluation Matrix | | 0.5 |
| | | Scenic Quality | 0.2 |
| | | Integrity | 0.2 |
| | | Character | 0.2 |
| | | Rarity | 0.2 |
| | | Overall Evaluation | 0.2 |
| | Land Form | | 0.5 |
| Ambient Air Quality | | | 0.25 |
| | | Benzene (Ambient) | 0.125 |
| | | CO (Ambient) | 0.125 |
| | | NO2 (Ambient) | 0.125 |
| | | NOX (Ambient) | 0.125 |
| | | PM2.5 (Ambient) | 0.125 |
| | | PM10 (Ambient) | 0.125 |
| | | SO2 (Ambient) | 0.125 |
| | | Ozone (Ambient) | 0.125 |

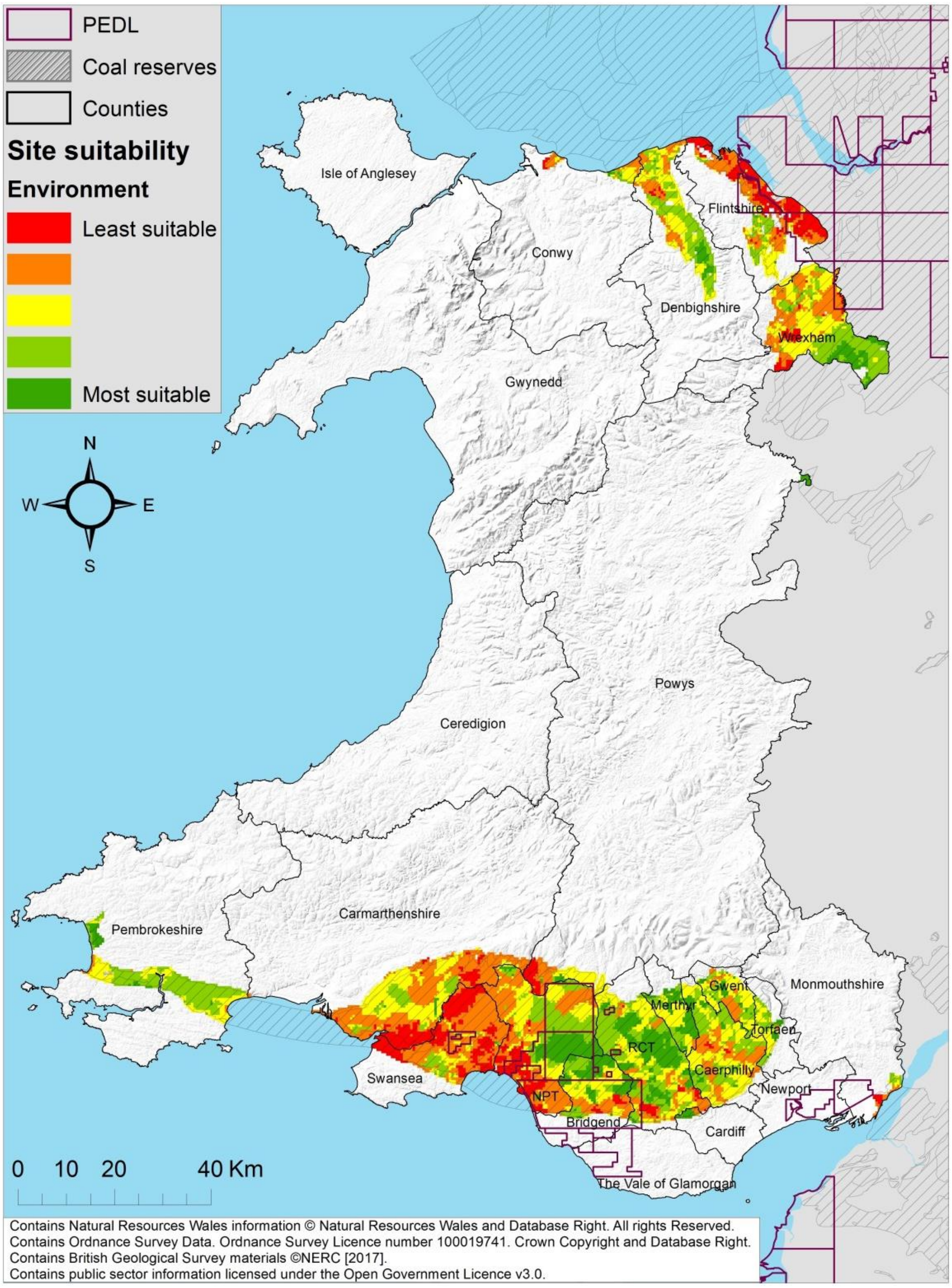



**Figure 1. Site suitability based on the Environmental domain Only**

As shown in Figure 1, based on these indicators, the most suitable areas were found in the South Wales valleys, within the county boroughs of Neath Port Talbot, Bridgend, Rhondda Cynon Taff, Merthyr, Caerphilly, Gwent, and Torfaen, as well as the south-east of Wrexham, and central Denbighshire. The least suitable areas were found around Swansea Bay and along the Dee Estuary in Flintshire.

## 5.2 Public Health Domain

Public health indicators obtained from the NHS Wales Informatics Service (2017) were used to identify sites with the least impact on public health. As listed in Table 2, the indicators used for the public health domain can be grouped into the following categories.

i. *Mortality Rates*. These were obtained for the 'all-cause' case, as well as mortality rates specific to cardiovascular disease and cancer. All data was obtained at the Middle Layer Super Output (MSOA) level.
ii. *Hospital Admission Rates.* These were also obtained at MSOA level, for cancer, cardiovascular and respiratory related admissions. The data is age-standardised as different age groups have different death rates.
iii. *Health per 100,000 people.* Health indicators from the WIMD (Welsh Government, 2014) at the LSOA level were also included in order to provide a finer level of detail.

**Table 2. Public Health Indicators used in the Site Suitability Assessment**

| Indicator | | Weight |
|---|---|---|
| Mortality | | 0.4 |
| | Mortality All Cause - Death Rates (Age-Standardised) per 100,000 population(2010) | 0.1111 |
| | Mortality All Cause - Death Rates (Age-Standardised) per 100,000 population, Females(2010) | 0.1111 |
| | Mortality All Cause - Death Rates (Age-Standardised) per 100,000 population, Males(2010) | 0.1111 |
| | Mortality All Cause - Death Rates (Age-Standardised) per 100,000 population <75 yrs - 2 Yr Range(2009-2010) | 0.1111 |
| | Mortality All Cause - Death Rates (Age-Standardised) per 100,000 population, Females <75 yrs - 2 Yr Range(2009-2010) | 0.1111 |
| | Mortality All Cause - Death Rates (Age-Standardised) per 100,000 population, Males <75 yrs - 2 Yr Range(2009-2010) | 0.1111 |
| | Cancer Mortality - Death Rates (Age-Standardised) per 100,000 population(2015) | 0.1111 |
| | Cancer Mortality - Death Rates (Age-Standardised) per 100,000 population <75 yrs - 2 Yr Range(2009-2010) | 0.1111 |
| | Cardiovascular Mortality - Death Rates (Age-Standardised) | 0.1111 |

| | | |
|---|---|---|
| | per 100,000 population - 2 Yr Range(2009-2010) | |
| Hospital Admission Rates | | 0.2 |
| | Cancer Related - Admission Rates (Age-Standardised) per 100,000 population(FY 15/16) | 0.1 |
| | Cancer Related - Admission Rates (Age-Standardised) per 100,000 population, Females - 3 Yr Range (FY 13/14 - 15/16) | 0.1 |
| | Cancer Related - Admission Rates (Age-Standardised) per 100,000 population, Males - 3 Yr Range (FY 13/14 - 15/16) | 0.1 |
| | Cardiovascular Related - Admission Rates (Age-Standardised) per 100,000 population(FY 15/16) | 0.1 |
| | Cardiovascular Related - Admission Rates (Age-Standardised) per 100,000 population, Females(FY 15/16) | 0.1 |
| | Cardiovascular Related - Admission Rates (Age-Standardised) per 100,000 population, Males(FY 15/16) | 0.1 |
| | Cardiovascular Related -Coronary Heart Diseases-Admission Rates (Age-Standardised) per 100,000 population(FY 10/11) | 0.1 |
| | Respiratory Related - Emergency Admission Rates (Age-Standardised) per 100,000 population(FY 15/16) | 0.1 |
| | Respiratory Related - Emergency Admission Rates (Age-Standardised) per 100,000 population, Females(FY 15/16) | 0.1 |
| | Respiratory Related - Emergency Admission Rates (Age-Standardised) per 100,000 population, Males(FY 15/16) | 0.1 |
| Health per 100,000 people (WIMD-2016 Indicators) | | 0.2 |
| | Rate of all-cause death per 100,000 population(2016) | 0.3333 |
| | Rate of cancer incidence per 100,000 population(2016) | 0.3333 |
| | Rate of limiting long term illness per 100,000 population(2016) (WIMD Indicator) | 0.3333 |
| % of births that are singleton low birth weights(2016) | | 0.2 |

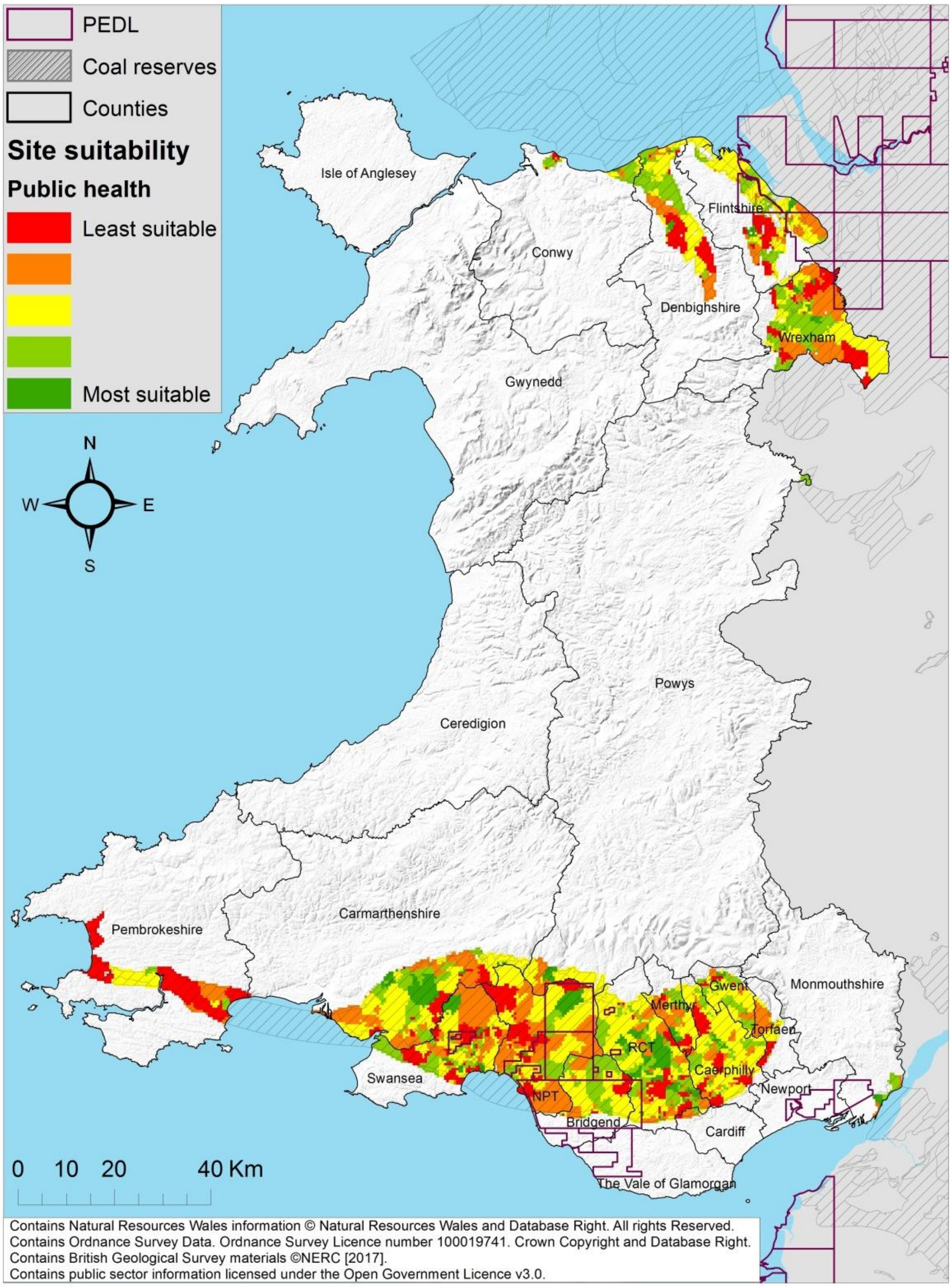



**Figure 2. Site Suitability based on the Public Health domain only**

From Figure 2 it is evident that there is a high degree of spatial variation in public health indicators, resulting in every county borough having a mix of highly suitable and highly unsuitable areas.

## 5.3 Socio-Economic Domain

As listed in Table 3, the indicators used for the socio-economic domain can be grouped into the following categories.

i. *Social Acceptance*. Firstly, the distance between the proposed site and any residential areas was used as a social acceptance indicator since communities closer to the site are more likely to have concerns relating to environmental, health, safety, and socio-economic impacts. Secondly, the Total Economic Value (TEV) of land was considered as it may be more difficult to acquire social acceptance in regions of higher total economic value and it may increase the cost of the project and therefore be financially less viable. TEV covers all the factors governing the market and non-market value of the area (van der Horst 2007) and is a complex indicator; for simplicity, the average household income is used as an indicator of TEV here, using the Experian average household income data acquired at the LSOA level (Experian 2012). Thirdly, the potential recreational value of land was considered since potential sites in areas of high recreational value are less likely to get approval by authorities or attain social acceptance from the public. The proximity of the site to national parks, woodlands, recreational areas, leisure facilities, and RAMSAR sites was used as an indicator. Fourthly, proximity to existing industrial or mining activity has been considered, since communities in the vicinity of prior industrial or mining industry may be more likely to accept similar projects due to benefits of job and business generation (this is somewhat offset by the potential for environmental degradation and subsequent job creation from other sectors (Horst, 2007)). Fifthly, the income level of the community was considered since low and medium income communities are more likely to accept unconventional gas developments, as they can create opportunities to uplift their socio-economic conditions (Garrone & Groppi, 2012). Data was obtained using 'PayCheck' developed by CACI; the figures obtained account for investments, welfare support and income supplements.

ii. *Social Capital*. A range of indicators were used to assess the level of social capital, whether positive or negative (Foxton & Jones, 2011). Civic participation was measured by voter turnout data (Plymouth University, 2013) and crime data was obtained from the Welsh Index of Multiple deprivation Crime index. The other indicators were obtained from surveys (British Household Panel Survey and the National Survey of Wales).

iii. *Social Disadvantage.* Indicators of social disadvantage are used to identify areas of deprivation where new unconventional energy resources can support the local economy, create jobs and build infrastructure, and so alleviate deprivation. The Welsh Indicator of Multiple Deprivation (WIMD) was used as a measure of social disadvantage (Welsh Government, 2015).

iv. *Population.* Population data from the 2011 census (Office for National Statistics, 2017) is used to help with infrastructure and contingency planning.

v. *Labour Market.* Labour market statistics are used to identify areas where a pool of skilled labour is available and also areas with high unemployment

**Table 3. Socio-Economic Indicators used in the Site Suitability Assessment**

| Indicator | | | Weight |
|---|---|---|---|
| Social acceptance | | | 0.25 |
| | | Distance from siting | 0.2 |
| | | Total economic value of the land | 0.2 |
| | | Potential recreational value | 0.2 |
| | | Distance from existing industrial and mining activities | 0.3 |
| | | Income level of the community | 0.1 |
| Social capital | | | 0.25 |
| | Civic participation | | 0.1667 |
| | Crime | | 0.1667 |
| | | Rate of recorded criminal damage per 100 people (day-time population)(2016) | 0.5 |
| | | Rate of adult offenders per 100 people (adult population)(2008-2010) | 0.5 |
| | Social participation | | 0.1667 |
| | | BHPS- Attends religious services | 0.333 |
| | | BHPS- Attend local group/voluntary organisation | 0.333 |
| | | BHPS- Do unpaid voluntary work | 0.333 |
| | Views of the local area | | 0.1667 |
| | | NSW- Belonging to local area? | 0.333 |
| | | NSW- Safety at home after dark | 0.333 |
| | | NSW- Safety walking in local area after dark | 0.333 |
| | Reciprocity and Trust | | 0.1667 |

| | | | |
|---|---|---|---|
| | | NSW- Trusting people in the neighbourhood | 0.25 |
| | | NSW- Safe for children to play outside | 0.25 |
| | | NSW- People from different backgrounds get on well together | 0.25 |
| | | NSW- People treating each other with respect and consideration | 0.25 |
| | Welsh language skills by LSOA. 2011 Census | | 0.1667 |
| Social Disadvantage | | | 0.25 |
| | | WIMD Income | 0.25 |
| | | WIMD Employment | 0.25 |
| | | WIMD Health | 0.25 |
| | | WIMD Physical Environment | 0.25 |
| Population | | | 0.1 |
| | | Total population | 0.6 |
| | | Occupied Houses | 0.4 |
| Labour Market | | | 0.15 |
| | Employment by industry | | 0.6 |
| | | Manufacturing | 0.1 |
| | | Construction | 0.6 |
| | | Accommodation and food service activities | 0.1 |
| | | Administrative and support service activities | 0.1 |
| | | Professional, scientific and technical activities | 0.1 |
| | Economic Activity | | 0.4 |
| | | Economically active: Unemployed | 1 |

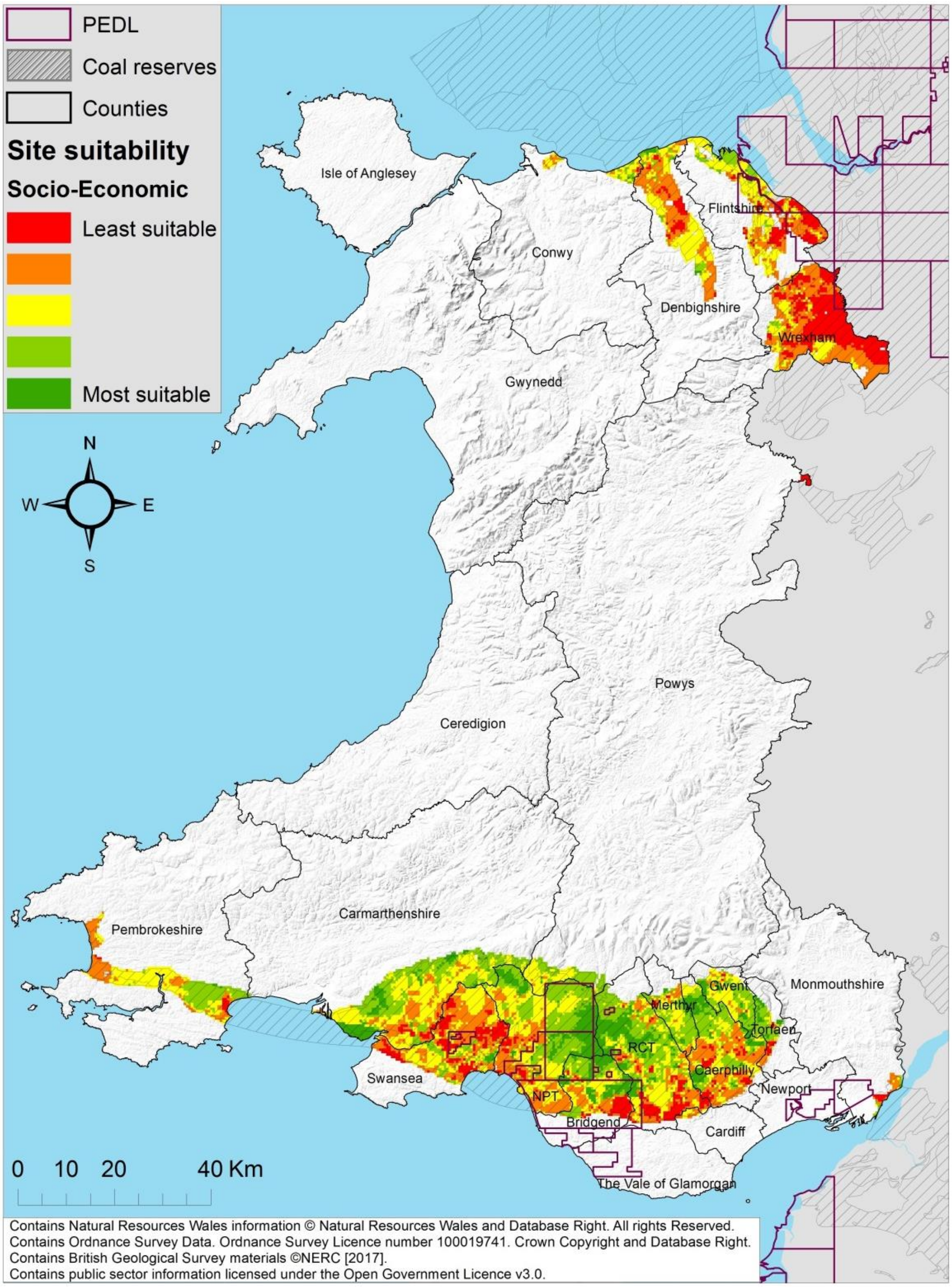



**Figure 3. Site Suitability based on the Socio-Economic domain only**

From Figure 3 it is evident that the most suitable areas according to socio-economic indicators can be found in the northern parts of the South Wales valleys. The least suitable areas are found in the most southern part of the South Wales valleys, and also around Swansea Bay, and in Wrexham and Flintshire.

## 5.4 Techno-Economic Domain

As listed in Table 4, the indicators used for the techno-economic domain can be grouped into the following categories.

i. *Geology.* The distance from geological features (fault lines and geological dykes) was calculated in order to identify suitable sites.

ii. *CBM Resource.* An estimate of the CBM resource was calculated from the BGS coal datasets (Jones, et al., 2004).

iii. *Site Economic Parameters. Assessment of the* economic indicators of the site is important with regard to the economic viability of the site (DECC, 2012). Distance from major $CO_2$ emitters and distance from the gas feeder pipeline network have been considered.

iv. *Terrain.* The elevation and slope are important considerations for the feasibility of the site, also for assessing project costs.

**Table 4. Techno-Economic Indicators used in the Site Suitability Assessment**

| Indicator | | Weight |
|---|---|---|
| Geology | | 0.1 |
| | Distance From Fault Lines | 0.5 |
| | Distance From Geological Dykes | 0.5 |
| CBM (Coal Bed Methane) | | 0.7 |
| | H - Coal Thickness (m) | 0.25 |
| | D - Coal Density (g/cm3) | 0.25 |
| | C- Gas Content (m3/t) | 0.25 |
| | A- Area of Coal (km2) | 0.25 |
| Site Economic Parameters | | 0.1 |
| | Distance from major CO2 emitters | 0.5 |
| | Distance from gas feeder pipeline network | 0.5 |
| Terrain | | 0.1 |
| | Elevation | 0.5 |
| | Slope | 0.5 |

Based on the techno-economic indicators, the area north of the county of Swansea was identified as the most suitable. Suitability generally decreases as one moves further from this area as shown in Figure 4.

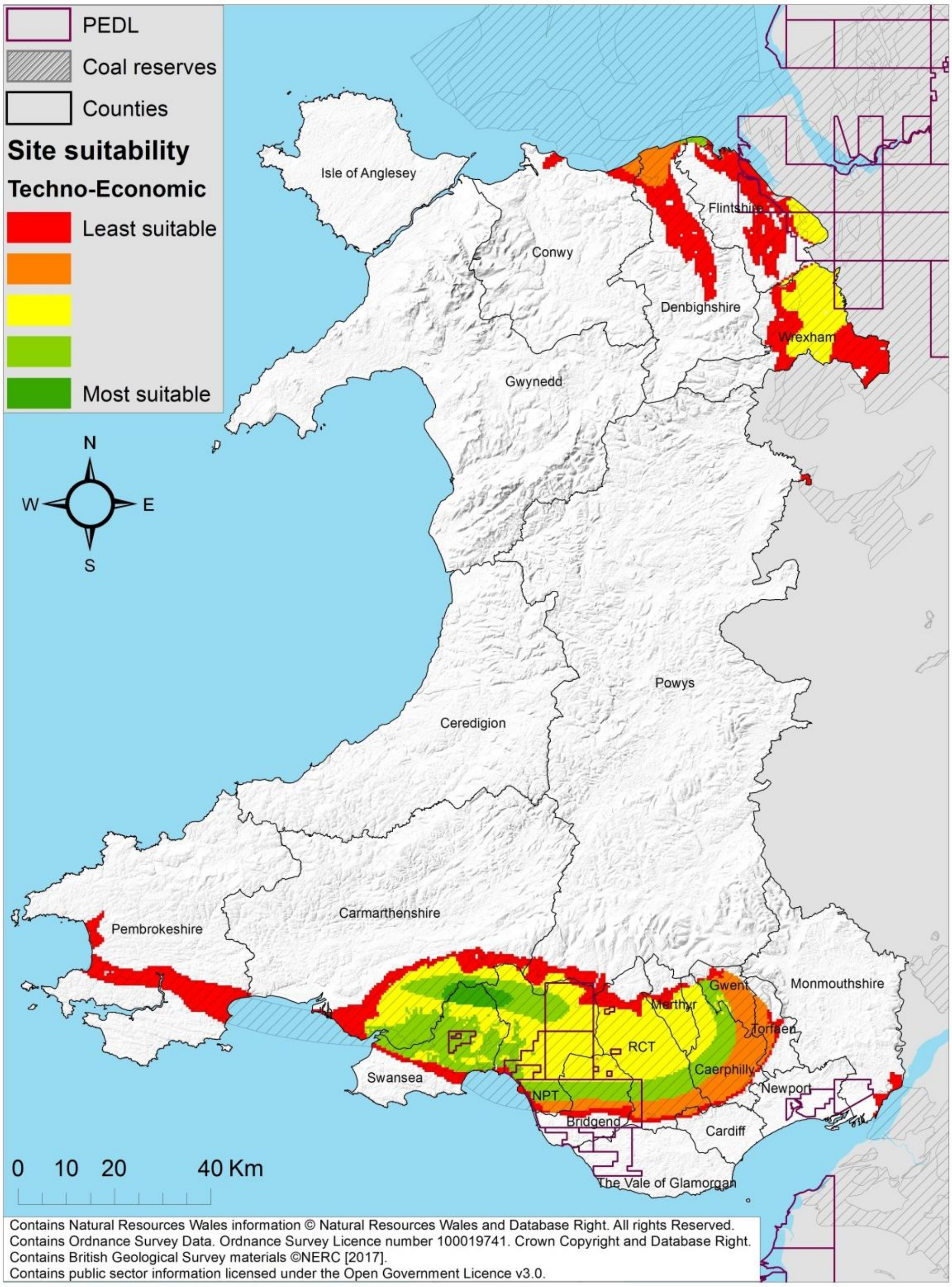



**Figure 4. Site Suitability based on the Techno-Economic domain only**

## 5.5 Combined Domains

In order to consider a balanced approach, equal weights have been assigned to all four domains to analyse combined site suitability. When all of the above indicators are combined, the most suitable areas can be found in the South Wales valleys, central Wrexham, and the Denbighshire coast, as shown in Figure 5. The least suitable areas are found in Pembrokeshire, outer parts of Wrexham, Flintshire, and inland parts of Denbighshire. Some of the most suitable areas in the South Wales valleys also intersect with PEDL license areas, and with coal reserves.

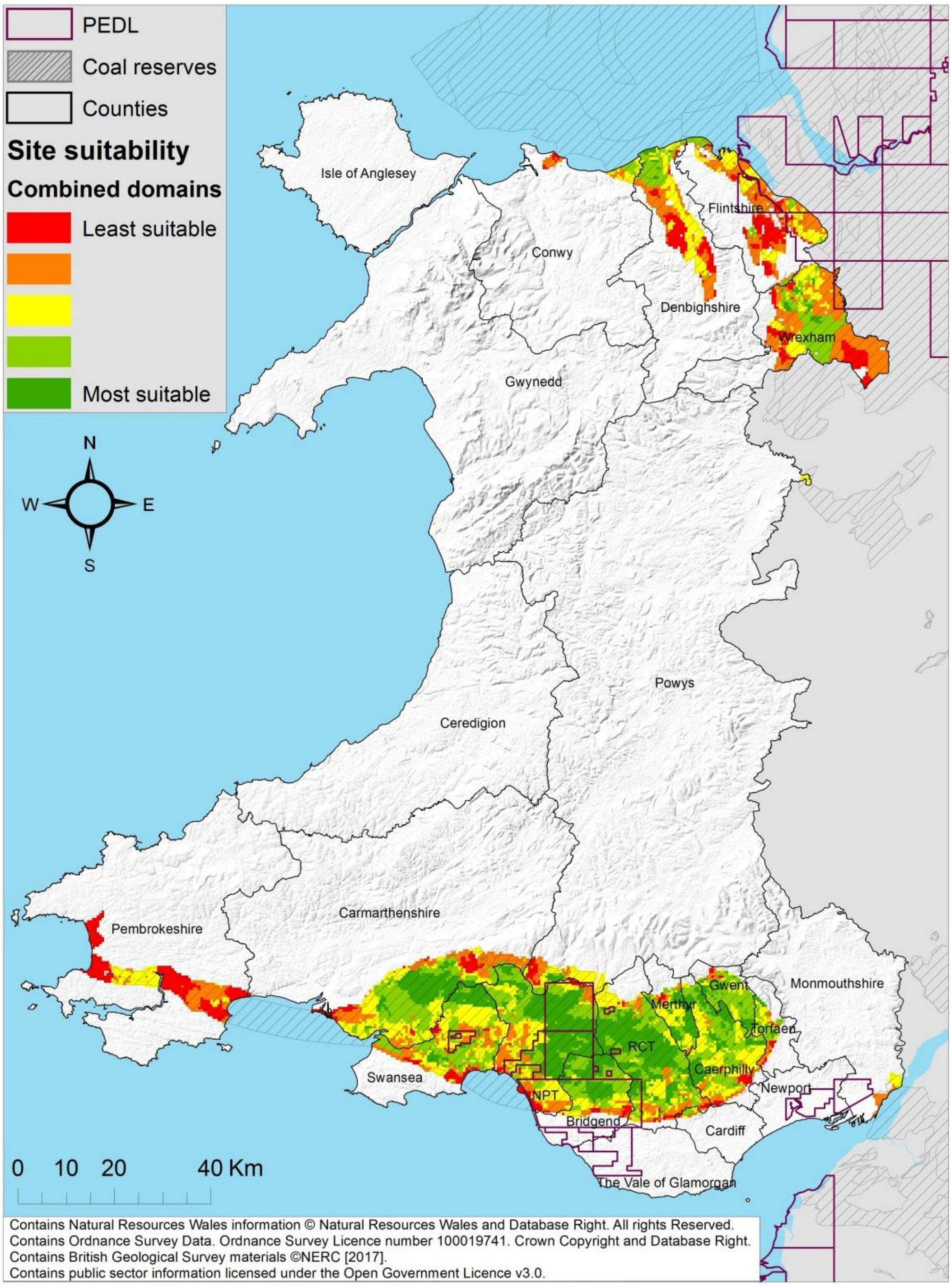



**Figure 5. Overall Site Suitability (Based on combination of the results for all four domains)**

# 6. Site Ranking

Site suitability, as discussed in the preceding section, gave a general overview of the study area in terms of the relative suitability of different areas based on the chosen indicators and their assigned weights. The next step was to reduce the number of potential sites by assigning a rank. Before the ranking was carried out, a buffer of 500 meters was generated around the strategic environmental areas (constraint maps) e.g. Source Protection Zones (SPZ). Any site intersecting with these buffers was removed from the dataset.

Following the aforementioned filtration process, site ranking was carried out using the site ranking module of the SEREN-SDSS. Since site ranking is crucial for prioritising site development, it is important that further intervention from the user (now that the various weights have been assigned) is kept to a minimum at this stage (Irfan, 2015; Irfan et al., 2017). Therefore, the site ranking module of the SEREN-SDSS has been developed using a special type of unsupervised Artificial Neural Networks, called Self-Organizing Maps (SOMs). SOMs have the capability to reduce the dimensions of the problem and to identify naturally occurring clusters in the data; that is, they compact the influence of the many factors (across all domains) that indicate the suitability of the site, into a single-value index (in the case of a one-dimensional SOM) that allows for comparison between sites. Therefore, the output map of a SOM is a low dimensional network of neurons (usually one-dimensional or two-dimensional) which is an abstraction of the high dimensional input data space. SOM preserves the natural structure (similarity or dissimilarity of input data points in terms of the considered domains) of the input data using a neighbourhood function, while mapping it from high dimensional input to a low dimensional output map. One-dimensional SOMs have the inbuilt capability to order themselves in ascending or descending order after convergence. Each neuron in a one-dimensional SOM represents a naturally occurring cluster of data points in the input data space (Kohonen, 2001). Because of its self-ordering capability, these natural clusters in the data are assigned a rank, based on their position in the output one-dimensional map. This ensures that ranking is carried out based on natural data values, without requiring further intervention from the user.

Another advantage of using one-dimensional SOMs for site ranking purpose is that they don't force equal number of input data points (e.g sites) into clusters. Rather each cluster represents a group of data points that naturally fits into that cluster based on the similarity of considered domains. For example, if the input data has to be ranked from 1-10, each ranked cluster may represent a different number of sites. The number of sites represented by each cluster will change if the ranking is increased (e.g 1-20) or decreased (e.g. 1-5), by finding new natural clusters (Irfan, 2015; Irfan et al., 2017).

During the consultative meetings between the GRC and NRW, it was decided that the AHP score of the four domains (acquired during the site selection step earlier) will be used to rank the sites from 1 to 20. Therefore, the input data space had four dimensions and the output was a one-dimensional SOM (1X20). It is important to mention here that these clusters are not to be confused with geographical clusters. A rank being assigned to sites, is not based on their geographical contiguity, rather it is based on how similar they are in terms of the AHP score of the four domains used for clustering and ranking purpose.

Figure 6 shows only the Rank-1 cluster out of the 20. A large section of the highest ranked sites can be found in the north of Neath Port Talbot area. A number of these high ranked sites are within the existing PEDL license areas, and are closed to several Plan & Permit sites.

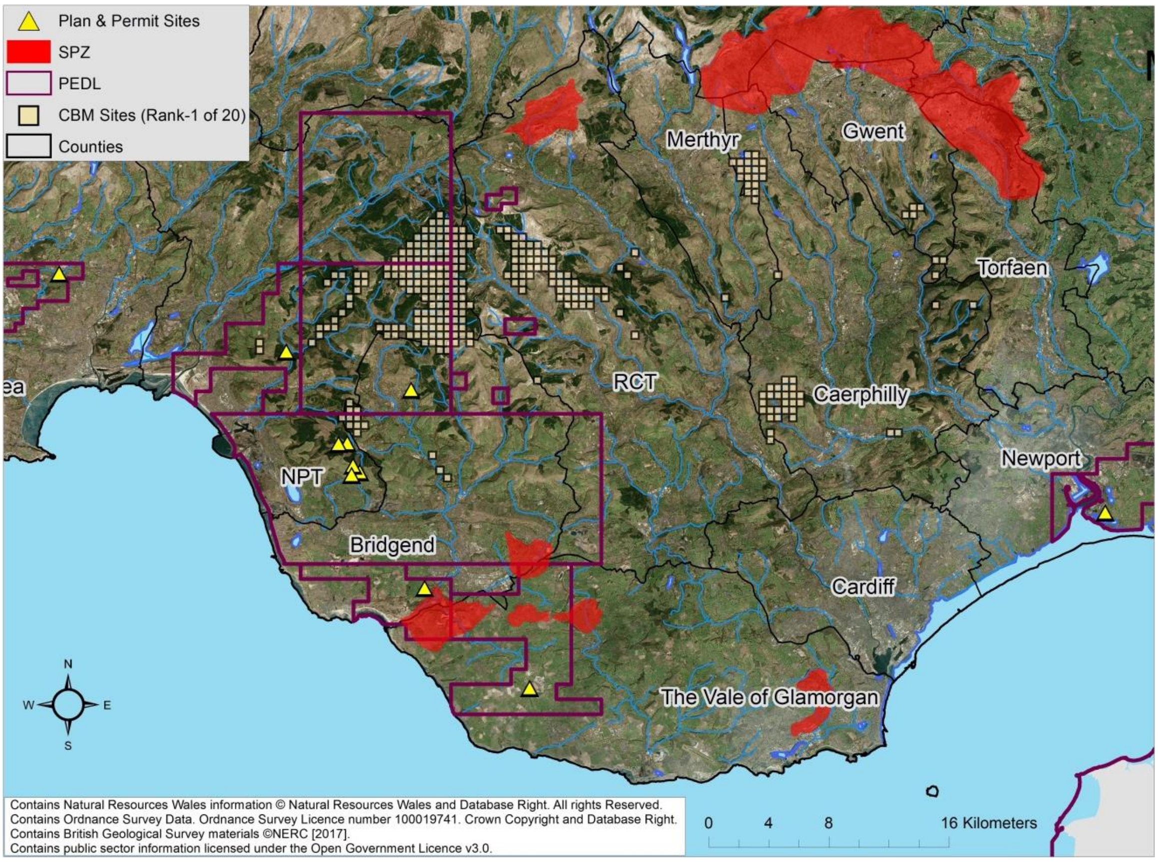



**Figure 6. Map showing sites with Rank-1 only out of 20**

# 7. Site Impact Assessment

This section details an assessment of the impact of CBM on the eleven sites listed in Table 5. These sites have existing planning consent and environmental permits for CBM exploratory activities.

The potential impact of CBM at a particular site has been deduced using the following approach. First, the impact of CBM technology itself has been assessed, independent of any specific site, using the RIAM tool of SEREN-SDSS. Results from this phase of the assessment process are detailed in Section 7.1. Secondly, the current status of each of the sites listed in Table 5 has been assessed with regard to the various factors that are likely to be affected by the introduction of CBM technology to that site. The results of this phase of the assessment are detailed in Section 7.2. In Section 7.3, an interpretation of the results provided in Sections 7.1 and 7.2 is given by considering the impact of the technology itself in the context of the baseline results for each site. For example, an interpretation regarding the significance of job creation is given by setting the potential for job creation arising from the technology itself (as described in Section 7.1) in the context of the need for job growth in the area surrounding each site (as described in Section 7.2).

**Table 5. Proposed sites for CBM development**

| Site | Local Authority | PEDL | Hydrocarbon | Easting | Northing |
|---|---|---|---|---|---|
| A | Newport | 157 | Conventional crude oil exploration | 333548 | 183398 |
| B | NPT | 215 | CBM & Shale exploration | 279045 | 194113 |
| C | Bridgend | 216 | CBM exploration | 288251 | 178367 |
| D | VOG | 217 | CBM exploration | 295245 | 171717 |
| E | Bridgend | 149 | Abandoned coal mine methane production | 287359 | 191561 |
| F | Swan | 214 | CBM exploration | 263927 | 199294 |
| G | NPT | 100 | CBM production | 283113 | 188009 |
| H | NPT | 100 | CBM production | 283930 | 186073 |
| I | NPT | 100 | CBM production | 282525 | 187958 |
| J | NPT | 100 | CBM production | 283496 | 186518 |
| K | NPT | 100 | CBM production | 283392 | 185904 |

## 7.1 RIAM-based impact assessment of CBM

An impact assessment of the CBM technology itself, irrespective of the specifics of the chosen site, has been carried out using the RIAM module of the SEREN-SDSS. In the RIAM method, each aspect of the technology is evaluated against a range of environmental factors; for example, increase in traffic or increase in pollution due to work at site. Each environmental factor is classified into one of four categories:

1. Physical/Chemical (P/C)
2. Biological/Ecological (B/E)
3. Social/Cultural (S/C)
4. Economics/Operational (E/O)

Each environmental factor is evaluated against five criteria: (*A1*) the importance of the condition, (*A2*) the magnitude/effect of the change, (*B1*) its permanence (*B2*) its reversibility and (*B3*) whether it has a cumulative effect. For example, with reference to Table 6, if the 'disposal of water' environmental factor is assigned an *A1* ranking of 3 and an *A2* ranking of -2 then the appropriate interpretation is that 'disposal of water' is important to regional/national interests and can have a significant deterioration to the status quo. Similarly, *B1*, *B2* and *B3* rankings of 2, 2 and 3 respectively indicate that 'disposal of water' is temporary, reversible and cumulative. The overall assessment score (*ES*), which provides an integer-value indication of the impact of a particular environmental factor (such as 'disposal of water') is calculated as follows (Pastakia and Jensen 1998):

$$ES = (AT) \times (BT)$$

where:

$$AT = (A1) \times (A2)$$

$$BT = (B1) + (B2) + (B3)$$

Here we draw attention to the difference between the influence of the *A* criteria (the importance of the condition, and the magnitude/effect of the change) on $ES$ compared with the influence of the B criteria (permanence, reversibility and cumulative nature). In particular we can make the classification:

**Group A**. Criteria that are of high importance and can individually exert a significant bearing on the overall assessment score that is obtained (for example, an *A1* score of 0, indicating that the factor is of no importance, will result in an overall $ES$ score of 0 irrespective of the values of *A2*, *B1*, *B2* and *B3*).

**Group B**. Criteria that influence the overall $ES$ score but cannot, in isolation, have a controlling impact.

**Table 6. Assessment criteria (Pastakia & Jensen, 1998)**

| Criteria | Scale | Description |
|---|---|---|
| A1: Importance of the condition | 4 | Important to national/international interests |
| | 3 | Important to regional/national interests |
| | 2 | Important to areas immediately outside the local condition |
| | 1 | Important only to the local condition |
| | 0 | No importance |
| A2: Magnitude of change/effect | 3 | Major positive benefit |
| | 2 | Significant improvement to status quo |
| | 1 | Improvement to status quo |
| | 0 | No change/status quo |
| | −1 | Negative change to status quo |
| | −2 | Significant deterioration to status quo |
| | −3 | Major dis-benefit or change |
| B1: Permanence | 1 | No change/not applicable |
| | 2 | Temporary |
| | 3 | Permanent |
| B2: Reversibility | 1 | No change/not applicable |
| | 2 | Reversible |
| | 3 | Irreversible |
| B3: Cumulative | 1 | No change/not applicable |
| | 2 | Non-cumulative/single |
| | 3 | Cumulative/synergistic |

Once the overall assessments score (*ES*) has been calculated for an individual environmental factor, a range band can also be assigned to classify it, using Table 7. For example, the *ES* score for 'disposal of water' was found to be -42 and so this is classified into range band -D, meaning 'disposal of water' during CBM possess 'significant negative change/impacts'.

**Table 7. Look up table for Environmental Scores and Range Bands (Pastakia & Jensen, 1998)**

| Environmental Score | Range Bands | Description of Range Bands |
|---|---|---|
| +72 to +108 | +E | Major positive change/impacts |
| +36 to +71 | +D | Significant positive change/impacts |
| +19 to +35 | +C | Moderately positive change/impacts |
| +10 to +18 | +B | Positive change/impacts |
| +1 to +9 | +A | Slightly positive change/impacts |
| 0 | N | No change/status quo/not applicable |
| −1 to −9 | −A | Slightly negative change/impacts |
| −10 to −18 | −B | Negative change/impacts |
| −19 to −35 | −C | Moderately negative change/impacts |
| −36 to −71 | −D | Significant negative change/impacts |
| −72 to −108 | −E | Major negative change/impacts |

Following consultation with NRW, several RIAM components were identified under the four categories (physical/chemical, biological/ecological, social/cultural and economic/operational). Table 8 shows these components along with the values of the impact assessment criteria, overall environmental score (*ES*) and classifying range bands.

**Table 8. RIAM impact components with their individual scores**

| Category | Impact Component | A1 | A2 | B1 | B2 | B3 | ES | Range Band |
|---|---|---|---|---|---|---|---|---|
| Physical/Chemical | Disposal of water | 3 | -2 | 2 | 2 | 3 | -42 | -D |
| | Contamination of surface water due to wellbore integrity | 2 | -1 | 2 | 2 | 3 | -14 | -B |
| | Soil disturbance due to site | 1 | -1 | 2 | 2 | 2 | -6 | -A |
| | Increase in air pollution due to work at site | 2 | -1 | 2 | 2 | 3 | -14 | -B |
| | Increase in air pollution due to transportation | 3 | -2 | 2 | 2 | 3 | -42 | -D |
| | Fugitive methane emissions | 3 | -2 | 2 | 2 | 3 | -42 | -D |
| | Contamination of ground water due to borehole integrity | 3 | -2 | 2 | 2 | 3 | -42 | -D |
| | Contamination of soil in the surrounding areas | 1 | -1 | 2 | 2 | 3 | -7 | -A |
| | Lowered ground water table | 0 | 0 | 1 | 1 | 1 | 0 | N |
| | Minor tremors caused by drilling and extraction process | 1 | 0 | 2 | 2 | 3 | 0 | N |
| | Infrastructure wear and tear | 3 | -1 | 2 | 2 | 3 | -21 | -C |
| | Contamination of aquifer due to wellbore | 3 | -2 | 2 | 2 | 3 | -42 | -D |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | integrity | | | | | | | |
| | Methane migration in aquifers | 1 | -2 | 2 | 2 | 3 | -14 | -B |
| Biological/Ecological | Impact of noise on wildlife | 1 | -1 | 2 | 2 | 3 | -7 | -A |
| | Night time light pollution for wildlife | 1 | -2 | 2 | 2 | 3 | -14 | -B |
| | Effect on aquatic wildlife | 1 | -1 | 2 | 2 | 3 | -7 | -A |
| | Habitat fragmentation and loss | 1 | -1 | 2 | 2 | 3 | -7 | -A |
| | Forest cut down for sitting | 1 | -1 | 2 | 2 | 3 | -7 | -A |
| Social/Cultural | Increase in traffic | 2 | -2 | 2 | 2 | 3 | -28 | -C |
| | Resettlement of people from siting areas | 0 | 0 | 1 | 1 | 1 | 0 | N |
| | Social acceptance | 3 | -2 | 2 | 2 | 3 | -42 | -D |
| | Health and safety of general public due to normal operations | 1 | -1 | 2 | 2 | 3 | -7 | -A |
| | Health and safety on workers in case of accident | 1 | -1 | 2 | 2 | 3 | -7 | -A |
| | Health and safety of general public in case of accident | 2 | -1 | 2 | 2 | 3 | -14 | -B |
| | Migration workers (impact on local communities) | 2 | -1 | 2 | 2 | 3 | -14 | -B |
| | Effect on scenic quality of the area | 2 | -1 | 2 | 2 | 3 | -14 | -B |
| | Employment generation for surrounding communities | 2 | 1 | 2 | 2 | 3 | 14 | +B |
| Economic / Operational | Cost of water treatment | 0 | 0 | 1 | 1 | 1 | 0 | N |
| | Loss of agricultural land | 1 | -1 | 2 | 2 | 3 | -7 | -A |
| | Disturbance in grazing patterns | 0 | 0 | 1 | 1 | 1 | 0 | N |
| | Local jobs creation | 1 | 1 | 2 | 2 | 3 | 7 | +A |
| | Effect on energy situation | 3 | 3 | 2 | 2 | 3 | 63 | +D |
| | Amount and value of methane gas produced | 3 | 3 | 2 | 2 | 3 | 63 | +D |
| | Cost of processing the produced gases | 0 | 0 | 1 | 1 | 1 | 0 | N |
| | Cost of transporting produced gas to be utilised | 0 | 0 | 1 | 1 | 1 | 0 | N |
| | Cost of treatment of CO2 and its transportation to the site | 0 | 0 | 1 | 1 | 1 | 0 | N |
| | Economic growth | 3 | 1 | 2 | 2 | 3 | 21 | +C |
| | Effect on housing and infrastructure | 2 | 1 | 2 | 2 | 3 | 14 | +B |

Figure 7 shows the breakdown of the RIAM results for each of the four domains. Results show that most of the positive scores are associated with the Economic/Operational category. Components in the other three categories have mostly negative scores. However, despite these negative scores, it is notable that none of the impacts are classified as being of major negative change or impact (group – E). Most of the negative impacts are temporary and reversible. It is emphasised that this assessment (the results listed in Table 8 and shown in Figure 7) refer to the assessment of the CBM technology itself, and are not specific to a particular site.

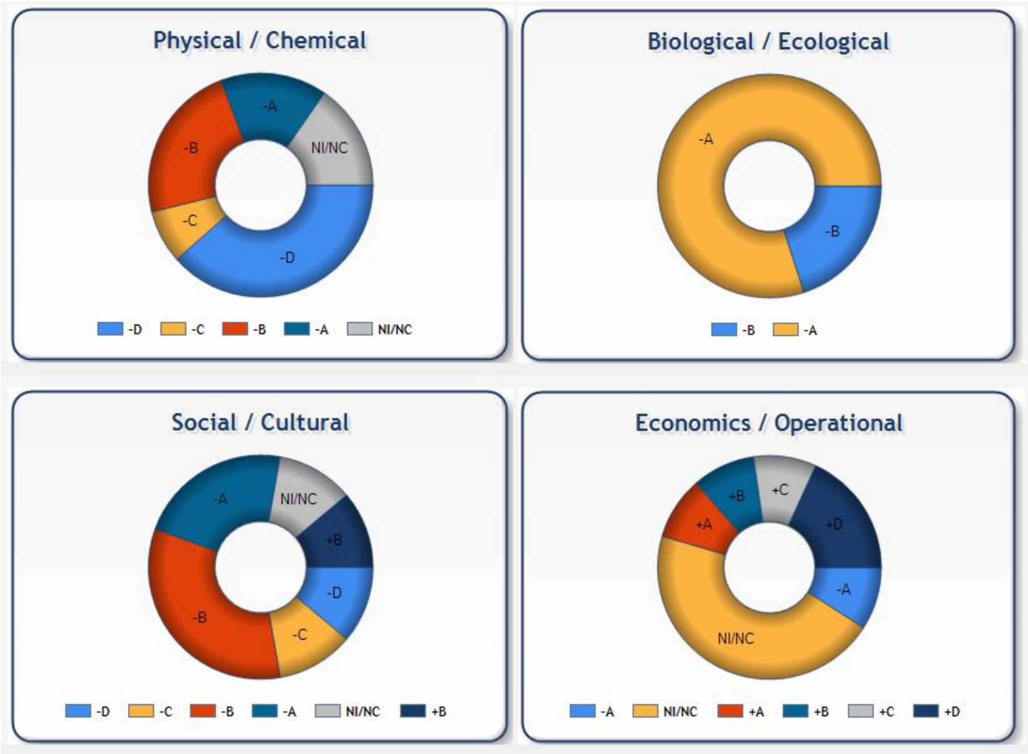



**Figure 7. Results of RIAM analysis, by domain**

## 7.2 RIAM-based site baseline assessment

To carry out the baseline assessment, that is, to establish the current status of each of the considered sites, a subset of the RIAM components listed in Table 8 (i.e. those considered in Section 7.1) have been considered. As listed in Tables 9 and 10, only those depending on geographical data, and are therefore specific to the individual sites, have been considered for the baseline assessment. Table 9 contains the quantitative indicators while Table 10 contains the qualitative indicators. The distinction is clarified here with an example: 'Air Emissions 2014' is a quantitative indicator since it can take varying levels of severity depending on its magnitude whereas 'forest cover' is a qualitative indicator as trees are either present or not. In the case of qualitative indicators, separate classes are considered; for example, five classes are considered for: 'forest cover' for the different types of tree.

For each site, a buffer zone of 1000m radius around each site has been considered as the representative area to carry out the baseline impact assessment. For the qualitative indicators, in order to provide greater insight, the proportion of each buffer zone affected by each indicator has been determined (e.g. for 'forest cover', the percentage area covered by each tree type has been determined). For the quantitative indicators, the system generates maximum, minimum and average values within the buffer zone.

The site analyser tool (a sub-tool of RIAM-based impact assessment tool of SEREN-SDSS) has been used to carry out the baseline assessments.

**Table 9. Quantitative indicators linked with the RIAM components**

| RIAM Component | RIAM Category | Indicator | RIAM ES Band |
|---|---|---|---|
| Increase in air pollution due to work at site | P/C | WIMD-2014 Indicator of Air Quality (Emissions) | -B |
| | | WIMD-2014 Indicator of Air Quality (Concentrations) | -B |
| Increase in air pollution due to transportation | P/C | WIMD-2014 Indicator of Air Quality (Emissions) | -D |
| | | WIMD-2014 Indicator of Air Quality (Concentrations) | -D |
| Minor tremors caused by drilling and extraction process | P/C | Distance From Fault Lines | N |
| | | Distance From Geological Dykes | N |
| Habitat fragmentation and loss | B/E | Distance from - Site of Special Scientific Interest (SSSI) | -A |
| | | Distance from - Special Areas of Conservation (SAC) | -A |
| | | Distance from - Special Protection Areas (SPA) | -A |
| Employment generation for surrounding communities | S/C | WIMD-2014 Employment | +B |
| Local jobs creation | E/O | Census-2011 Employment by industry (Construction) | +A |
| | | Census-2011 Employment by industry (Manufacturing) | +A |
| | | Census-2011 | +A |

| | | | |
|---|---|---|---|
| | | Employment by industry (Accommodation and food service activities) | |
| | | Census-2011 Employment by industry (Administrative and support service activities) | +A |
| | | Census-2011 Employment by industry (Professional, scientific and technical activities) | +A |
| Effect on housing and infrastructure | E/O | WIMD-2014 Housing | +B |

**Table 10. Qualitative indicators linked with the RIAM components**

| RIAM component | Category | Linked Indicator | Discrete Class | RIAM ES Band |
|---|---|---|---|---|
| Contamination of aquifer due to wellbore integrity | P/C | HydroGeological Features | Coastline Brackish | -B |
| | | | Highly productive aquifer | -B |
| | | | Low productivity aquifer | -B |
| | | | Moderately productive aquifer | -B |
| | | | Rocks with essentially no groundwater | -B |
| Fugitive methane emissions | P/C | Gas Hazard - Methane and CO2 in superficial geology | No Hazard | -D |
| | | | Potential gas hazard from peat | -D |
| Methane migration in aquifers | P/C | HydroGeological Features | Highly productive aquifer | -B |
| | | | Low productivity aquifer | -B |
| | | | Moderately productive aquifer | -B |

| | | | | |
|---|---|---|---|---|
| Contamination of aquifer due to wellbore integrity | P/C | Source Protection Zones (SPZ) | Inner Protection Zone | -D |
| | | | Outer Protection Zone | -D |
| | | | Total catchment | -D |
| Methane migration in aquifers | P/C | Source Protection Zones (SPZ) | Inner Protection Zone | -B |
| | | | Outer Protection Zone | -B |
| | | | Total catchment | -B |
| Forest cut down for siting | B/E | Forest Cover (welsh Forestry Commission) | Broadleaved | -A |
| | | | Conifer | -A |
| | | | Mixed mainly broadleaved | -A |
| | | | Mixed mainly conifer | -A |
| | | | Young trees | -A |
| Effect on scenic quality of the area | S/C | LandMap (Scenic Quality) | High | -B |
| | | | Outstanding | -B |
| Loss of agricultural land | E/O | Corine Land Cover 2006 | Heterogeneous agricultural areas | -A |
| | | | Pastures | -A |
| | | | Permanent crops | -A |
| Disturbance in grazing patterns | E/O | Corine Land Cover 2006 | Pastures | N |

## 7.3 Interpretation

The results of both qualitative and quantitative baseline assessment for each of the eleven proposed sites are provided fully in Tables 11 and 12 at the end of this section. These results provide a critical reference point for assessing changes and impact, as it establishes a basis for comparing the situation before and after the CBM site development. In the following, interpretation of the results is provided on a relative basis, that is, the impact on any one site of a particular RIAM component is evaluated in comparison to the impact of that component on the other sites. To clarify, no findings are drawn on an absolute basis regarding the impact any one parameter will exert on a particular site.

In the following, each of the indicators is considered in turn to highlight the main trends in the data.

- *Air quality*. Analysing the baseline values for proposed sites, it is evident that Site-C has the worst existing air quality among the proposed eleven sites, followed by Site-A, Site-B and

Site-E. The RIAM components for air quality (Table 8) suggest that air quality will deteriorate as a result of work at site and the transport involved during the operation. Therefore, it is anticipated that air quality at these sites will deteriorate further compared to the others considered here, with potentially negative environmental impact.

- *Minor Tremors*. Referring to Table 8, the impact of minor tremors has been classified as N (no change/ status quo/ not applicable). However, for completeness, we note that the baseline data indicates that Site-G and Site-H are closest to geological fault lines, while Site-D is the closest to a geological dyke. Therefore, if there were to be an impact of minor tremors, the analysis reported here indicates that these sites are more vulnerable than the other considered.
- *Habitat fragmentation and loss.* To assess the impact of habitat fragmentation and loss, the distances of each buffer zone from SSSI, SAC and SPA were analysed. As listed in Table 8, the relevant RIAM component has been identified as –A (slightly negative change/impacts). From the baseline data, it is evident that Site-A is the closest to all three critical environmental areas, i.e. SSSI, SAC and SPA. Site-F and Site-E are also very close to SSSI. Site-C is close to both SSI and SAC.
- *Employment generation.* The RIAM component of employment generation for surrounding communities has been linked with the WIMD-2014 (Employment rank) indicator. The impact has been evaluated as +B (Positive change/impact). By looking at the baseline values of the WIMD employment indicator in the neighbourhood of the proposed sites, it is evident that Site-A, Site-E and Site-G are more deprived compared to the other sites based on the WIMD-2014 employment indicator. It is therefore evident that site development at these locations may help improve the employment status of these areas to a greater extent than the others.
- *Local job creation.* The RIAM component for local job creation has been linked with the Census-2011 Employment by Industry dataset. CBM site development is expected to create some local jobs related to construction, manufacturing, accommodation, food services, administrative, support service, professional, scientific and technical activities. This impact component has been identified as +A (Positive change/impact). The baseline data shows that Site-A and Site-B have the highest proportion of the population associated with jobs related to construction. Site-A and Site-D have highest proportion of the population associated with jobs related to accommodation and food services. The surrounding areas of these sites provide an existing skillset for the types of jobs that are likely to be created from CBM development.

- *Accommodation and housing.* The RIAM impact component for accommodation and housing is +B (positive change/impact) and is linked with the WIMD-2014 (Housing Rank) indicator. By looking at the baseline values for each of the eleven sites, it is evident that Site-A is the worst in terms of the existing housing situation. The rest of the sites have much better existing housing situation. Development at Site-A has the potential to increase further pressure on the existing housing situation of this area.
- *Aquifer contamination due to wellbore integrity*. The RIAM component of aquifer contamination due to wellbore integrity has been identified as –D (significant negative change/impact). This impact component has been linked with the Hydrogeological Features data provided by the BGS and Source Protection Zones (SPZ) data provided by NRW. Both these datasets are qualitative in nature, therefore their discrete classes has been used for the baseline assessment. The percentage of the buffer zone area (1000m radius circle) that is covered by the given discrete classes has been analysed. By looking at these baseline figures, it is evident that none of the proposed eleven sites intersect with the 'highly productive' class of the hydrogeological features dataset. However all of the sites intersect with the 'moderately productive aquifers' class. In terms of SPZ data, Site-C is the closest to the 'inner protection zone' class of the SPZ. Its buffer zone area intersects with this critical resource. Therefore, Site-C is the most susceptible to causing contamination due to wellbore integrity. The same indicators have been linked with the RIAM impact component of methane migration in aquifers. Therefore, the susceptibility to causing contamination remains the same for this case. All of the proposed sites intersect with 'moderately productive aquifers' class of the BGS Hydrogeological features data.
- *Fugitive methane emissions.* The impact component of fugitive methane emissions from the site has been identified as –D (significant negative change/impacts). Although the fugitive methane emission can be linked to wellbore integrity (discussed above) and storage at the site, it is also important to analyse the existing hazard of methane in the superficial geology. Therefore, the BGS data of Gas Hazard in superficial geology has been linked to this impact component. It is evident from the baseline values that none of the proposed sites with their applied buffer zones intersect with any designated hazardous areas in terms of methane or $CO_2$ in the superficial geology.
- *Forest cut down for siting*. The RIAM component of forest cutting to allow for site development has been identified as –A (Slightly negative change/impact). This component has been linked with the Welsh Forestry Commission's Forest cover dataset. Site-A and Site-D are the best in terms of this impact component since their buffer zones doesn't have any

forest cover. Sites B, C, F and K have broadleaved forests enclosed within their buffer zones. Sites B and K have significant areas covered under conifer forest. Site B has some area covered by young trees. Sites C and F have some areas under cover of mixed forest types.

- *Effect on scenic quality of the area.* The RIAM impact components related to effects of scenic quality of the area has been identified as –B (negative change/impacts). This impact component has been linked with the LandMap-Scenic Quality dataset provided by NRW. The sites have been assessed in terms of 'Outstanding' and 'High' scenic areas. It is evident from the baseline results that Site-A is the worst in terms of scenic quality impact since a significant percentage of the buffer zone of this Site-A is designated as 'Outstanding' or 'High'. Site-C comes next in this category with a small percentage of area covered by these two classes of scenic quality data. Site-F and Site-K also contain some areas designated as being of 'High' scenic quality. The rest of the sites don't intersect with 'Outstanding' or 'High' scenic areas and therefore are less sensitive to this impact component.
- *Loss of agricultural land.* The RIAM impact component for loss of agricultural land due to site development has been identified as –A (slightly negative change/impact). Relevant discrete classes taken from the Corine Landcover 2006 dataset have been linked with this impact component. By analysing the baseline values of these classes, it is evident that none of the buffer zones of the proposed sites intersect with the regions containing 'permanent crops' or 'heterogeneous agricultural areas'.
- *Disturbance in grazing patterns.* The RIAM impact component of disturbance in grazing patterns, has been identified as N (No change/status quo/not applicable). The Corine Landcover class, 'Pastures', has been linked with this impact component. Although the expected impact is no change, the baseline data suggests that buffer zones of all the proposed sites intersect with land classified under the 'Pastures' class. Sites C, D, F, H, J and K have more than 50% of their buffer zone areas covered under this class. Therefore, an impact on grazing pattern is expected on these sites.

The analysis of the results of Rapid Impact Assessment Matrix (RIAM) along with the baseline values provides an evidence based impact assessment of the proposed sites and their defined neighbourhood (1000m radius buffer zone). As stated previously, these results provide a critical reference point for assessing changes and impact. Interpretation of the results have been provided on a relative basis, that is, the impact on any one site of a particular RIAM component is evaluated in comparison to the impact of that component on the other sites. In particular, no findings are drawn on an absolute basis regarding the impact any one parameter will exert on a particular site.

## Table 11. Baseline Assessment Values of Quantitative Indicators (Sites: A-E)

| | Linked Indicator | Wales | | | Site-A | | | Site-B | | | Site-C | | | Site-D | | | Site-E | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Min | Avg | Max | Min | Avg | Max | Min | Avg | Max | Min | Avg | Max | Min | Avg | Max | Min | Avg | Max |
| Physical / Chemical | WIMD-2014 Indicator of Air Quality (Emissions)[1] | 0 | 17 | 100 | 49 | 49 | 58 | 1 | 5 | 39 | 19 | 26 | 85 | 3 | 5 | 12 | 26 | 35 | 40 |
| | WIMD-2014 Indicator of Air Quality (Concentrations)[1] | 0 | 16 | 100 | 90 | 90 | 93 | 27 | 30 | 46 | 44 | 45 | 57 | 23 | 31 | 33 | 32 | 35 | 36 |
| | WIMD-2014 Indicator of Air Quality (Emissions)[1] | 0 | 17 | 100 | 49 | 49 | 58 | 1 | 5 | 39 | 19 | 26 | 85 | 3 | 5 | 12 | 26 | 35 | 40 |
| | WIMD-2014 Indicator of Air Quality (Concentrations)[1] | 0 | 16 | 100 | 90 | 90 | 93 | 27 | 30 | 46 | 44 | 45 | 57 | 23 | 31 | 33 | 32 | 35 | 36 |
| | Distance From Fault Lines[2] | 0 | 1800 | 26496 | 4719 | 5577 | 6751 | 1549 | 2610 | 3724 | 263 | 1501 | 2890 | 1324 | 2378 | 3484 | 558 | 2144 | 3156 |
| | Distance From Geological Dykes[2] | 0 | 34871 | 86564 | 53714 | 54933 | 55963 | 75839 | 76857 | 78229 | 59144 | 60871 | 64158 | 49526 | 50876 | 52022 | 70758 | 72126 | 74177 |
| Biological / Ecological | Distance from - Site of Special Scientific Interest (SSSI)[2] | 0 | 1343 | 9013 | 0 | 43 | 295 | 5079 | 6018 | 7083 | 217 | 1368 | 2541 | 1122 | 2323 | 3347 | 78 | 1108 | 1949 |
| | Distance from - Special Areas of Conservation (SAC)[2] | 0 | 3103 | 19408 | 0 | 453 | 1392 | 6240 | 7182 | 8276 | 217 | 1445 | 2683 | 5411 | 6492 | 7530 | 6151 | 7468 | 8608 |
| | Distance from - Special Protection Areas (SPA)[2] | 0 | 13220 | 44736 | 0 | 721 | 1862 | 20482 | 21453 | 22584 | 29213 | 30367 | 31632 | 20608 | 21701 | 22778 | 28738 | 29899 | 30970 |
| Social / Cultural | WIMD-2014 Employment[3] | 1 | 1335 | 1908 | 390 | 1115 | 1153 | 517 | 657 | 838 | 1400 | 1475 | 1905 | 1746 | 1769 | 1867 | 233 | 240 | 253 |
| Economics / Operational | Census-2011 Employment by industry (Construction)[4] | 1.3 | 9.4 | 17.5 | 6.1 | 9.0 | 9.2 | 6.2 | 10.6 | 11.7 | 5.6 | 7.0 | 7.2 | 5.9 | 6.8 | 10.7 | 8.4 | 10.2 | 11.1 |
| | Census-2011 Employment by industry (Manufacturing)[4] | 0.0 | 0.3 | 7.4 | 0.0 | 0.0 | 0.3 | 0.3 | 0.4 | 0.4 | 0.1 | 0.3 | 0.3 | 0.3 | 0.5 | 0.5 | 0.0 | 0.1 | 0.4 |
| | Census-2011 Employment by industry (Accommodation and food service activities)[4] | 1.5 | 6.7 | 35.4 | 4.9 | 5.2 | 10.8 | 2.8 | 3.6 | 4.6 | 2.9 | 4.2 | 4.4 | 5.6 | 5.6 | 5.7 | 2.9 | 3.3 | 4.2 |
| | Census-2011 Employment by industry (Administrative and support service activities)[4] | 0.8 | 3.4 | 10.2 | 4.6 | 4.7 | 5.6 | 4.9 | 5.1 | 5.4 | 1.8 | 2.3 | 2.7 | 3.2 | 3.8 | 3.9 | 3.9 | 4.4 | 5.5 |
| | Census-2011 Employment by industry (Professional, scientific and technical activities)[4] | 0.0 | 4.7 | 14.5 | 1.8 | 4.4 | 4.5 | 3.0 | 3.4 | 3.9 | 4.8 | 6.0 | 6.1 | 7.1 | 9.6 | 10.2 | 1.8 | 1.8 | 1.8 |
| | WIMD-2014 Housing[3] | 1 | 877 | 1909 | 61 | 803 | 842 | 1214 | 1517 | 1700 | 1484 | 1553 | 1908 | 1405 | 1646 | 1703 | 1273 | 1348 | 1386 |

## Table 11. Baseline Assessment Values of Quantitative Indicators (Sites: F-K)

| | Linked Indicator | Site-F Min | Site-F Avg | Site-F Max | Site-G Min | Site-G Avg | Site-G Max | Site-H Min | Site-H Avg | Site-H Max | Site-I Min | Site-I Avg | Site-I Max | Site-J Min | Site-J Avg | Site-J Max | Site-K Min | Site-K Avg | Site-K Max |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Physical / Chemical | WIMD-2014 Indicator of Air Quality (Emissions)[1] | 31 | 31 | 31 | 21 | 24 | 32 | 23 | 23 | 23 | 21 | 23 | 23 | 23 | 23 | 23 | 23 | 23 | 23 |
| | WIMD-2014 Indicator of Air Quality (Concentrations)[1] | 61 | 61 | 61 | 35 | 61 | 69 | 69 | 69 | 69 | 37 | 67 | 69 | 69 | 69 | 69 | 69 | 69 | 69 |
| | WIMD-2014 Indicator of Air Quality (Emissions)[1] | 31 | 31 | 31 | 21 | 24 | 32 | 23 | 23 | 23 | 21 | 23 | 23 | 23 | 23 | 23 | 23 | 23 | 23 |
| | WIMD-2014 Indicator of Air Quality (Concentrations)[1] | 61 | 61 | 61 | 35 | 61 | 69 | 69 | 69 | 69 | 37 | 67 | 69 | 69 | 69 | 69 | 69 | 69 | 69 |
| | Distance From Fault Lines[2] | 2082 | 3372 | 4446 | 219 | 2103 | 3202 | 164 | 1412 | 2337 | 219 | 2560 | 3627 | 1204 | 1965 | 2853 | 459 | 1489 | 2539 |
| | Distance From Geological Dykes[2] | 77776 | 79171 | 80099 | 68434 | 71513 | 73740 | 67982 | 69949 | 73146 | 69921 | 71592 | 73740 | 68678 | 70341 | 73338 | 68151 | 69435 | 73146 |
| Biological / Ecological | Distance from - Site of Special Scientific Interest (SSSI)[2] | 0 | 945 | 2112 | 3154 | 3930 | 4641 | 1938 | 2923 | 4018 | 2766 | 3736 | 4529 | 2466 | 3311 | 4260 | 1612 | 2695 | 3657 |
| | Distance from - Special Areas of Conservation (SAC)[2] | 4883 | 5697 | 6569 | 4245 | 5318 | 6479 | 2013 | 3248 | 4245 | 4343 | 5203 | 6185 | 2676 | 3895 | 4912 | 2213 | 3267 | 4343 |
| | Distance from - Special Protection Areas (SPA)[2] | 5221 | 6444 | 7633 | 25661 | 26696 | 27875 | 27006 | 28100 | 29238 | 25186 | 26307 | 27402 | 26352 | 27450 | 28583 | 26546 | 27694 | 28779 |
| Social / Cultural | WIMD-2014 Employment[3] | 1766 | 1766 | 1766 | 221 | 1319 | 1466 | 1466 | 1466 | 1466 | 1314 | 1458 | 1466 | 1466 | 1466 | 1466 | 1466 | 1466 | 1466 |
| Economics / Operational | Census-2011 Employment by industry (Construction)[4] | 7.1 | 7.1 | 7.1 | 6.1 | 6.8 | 10.5 | 6.1 | 6.1 | 6.1 | 6.1 | 6.2 | 8.0 | 6.1 | 6.1 | 6.1 | 6.1 | 6.1 | 6.1 |
| | Census-2011 Employment by industry (Manufacturing)[4] | 0.4 | 0.4 | 0.4 | 0.2 | 0.3 | 0.7 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.5 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 |
| | Census-2011 Employment by industry (Accommodation and food service activities)[4] | 2.8 | 2.8 | 2.8 | 3.1 | 4.0 | 5.0 | 4.1 | 4.1 | 4.1 | 3.1 | 4.1 | 4.1 | 4.1 | 4.1 | 4.1 | 4.1 | 4.1 | 4.1 |
| | Census-2011 Employment by industry (Administrative and support service activities)[4] | 2.8 | 2.8 | 2.8 | 2.7 | 3.7 | 3.9 | 3.9 | 3.9 | 3.9 | 3.5 | 3.9 | 3.9 | 3.9 | 3.9 | 3.9 | 3.9 | 3.9 | 3.9 |
| | Census-2011 Employment by industry (Professional, scientific and technical activities)[4] | 4.4 | 4.4 | 4.4 | 1.9 | 4.9 | 5.8 | 5.8 | 5.8 | 5.8 | 1.9 | 5.6 | 5.8 | 5.8 | 5.8 | 5.8 | 5.8 | 5.8 | 5.8 |
| | WIMD-2014 Housing[3] | 1539 | 1539 | 1539 | 1032 | 1656 | 1836 | 1836 | 1836 | 1836 | 1169 | 1803 | 1836 | 1836 | 1836 | 1836 | 1836 | 1836 | 1836 |

[1] Scored from 0 and 100; [2] Euclidean distance in metres; [3]Rank (1-1908) Lower rank = higher deprivation; [4] Percentage (%) employed, aged 16-74

## Table 12. Baseline Assessment Values of Qualitative Indicators (Sites: F-G)

| RIAM Category | RIAM component | Linked Indicator | Discrete Class | Wales % area | Site-A % area | Site-B % area | Site-C % area | Site-D % area | Site-E % area | Site-F % area | Site-G % area | Site-H % area | Site-I % area | Site-J % area | Site-K % area |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Physical / Chemical | Contamination of aquifer due to wellbore integrity | HydroGeological Features | Coastline Brackish | 3.80 | 25 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | Contamination of aquifer due to wellbore integrity | HydroGeological Features | Highly productive aquifer | 1.43 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | Contamination of aquifer due to wellbore integrity | HydroGeological Features | Low productivity aquifer | 74.99 | 75 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | Contamination of aquifer due to wellbore integrity | HydroGeological Features | Moderately productive aquifer | 18.72 | 0 | 100 | 26.09 | 0 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| | Contamination of aquifer due to wellbore integrity | HydroGeological Features | Rocks with essentially no groundwater | 1.06 | 0 | 0 | 73.91 | 100 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | Fugitive methane emissions | Gas Hazard - Methane and $CO_2$ in superficial geology | No Hazard | 99.38 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| | Fugitive methane emissions | Gas Hazard - Methane and $CO_2$ in superficial geology | Potential gas hazard from peat | 0.62 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | Methane migration in acquifers | HydroGeological Features | Highly productive aquifer | 1.43 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | Methane migration in acquifers | HydroGeological Features | Low productivity aquifer | 74.99 | 75 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | Methane migration in acquifers | HydroGeological Features | Moderately productive aquifer | 18.72 | 0 | 100 | 26.09 | 0 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| | Contamination of aquifer due to wellbore integrity | Source Protection Zones (SPZ) | Inner Protection Zone | 1.77 | 0 | 0 | 43.48 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | Contamination of aquifer due to wellbore integrity | Source Protection Zones (SPZ) | Outer Protection Zone | 0.20 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | Contamination of aquifer due to wellbore integrity | Source Protection Zones (SPZ) | Total catchment | 0.64 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

| | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Biological / Ecological | Forest cut down for sitting | Forest Cover (welsh Forestry Commission) | Broadleaved | 5.19 | 0 | 19.05 | 8.70 | 0 | 0 | 13.04 | 5 | 10 | 5 | 10 | 13.64 |
| | Forest cut down for sitting | Forest Cover (welsh Forestry Commission) | Conifer | 5.75 | 0 | 33.33 | 0 | 0 | 14.29 | 8.70 | 35 | 40 | 40 | 35 | 27.27 |
| | Forest cut down for sitting | Forest Cover (welsh Forestry Commission) | Mixed mainly broadleaved | 0.27 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | Forest cut down for sitting | Forest Cover (welsh Forestry Commission) | Mixed mainly conifer | 0.27 | 0 | 0 | 4.35 | 0 | 0 | 4.35 | 5 | 5 | 0 | 5 | 0 |
| | Forest cut down for sitting | Forest Cover (welsh Forestry Commission) | Young trees | 1.08 | 0 | 9.52 | 0 | 0 | 0 | 0 | 10 | 0 | 5 | 5 | 0 |
| Social / Cultural | Effect on scenic quality of the area | LandMap (Scenic Quality) | High | 41.22 | 30 | 0 | 4.35 | 0 | 0 | 13.04 | 5 | 0 | 10 | 10 | 4.55 |
| | Effect on scenic quality of the area | LandMap (Scenic Quality) | Outstanding | 12.80 | 20 | 0 | 8.70 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Economics / Operational | Loss of agricultural land due to site | Corine Land Cover 2006 | Heterogeneous agricultural areas | 1.35 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| | Loss of agricultural land due to site | Corine Land Cover 2006 | Pastures | 51.13 | 25 | 28.57 | 73.91 | 66.67 | 28.57 | 60.87 | 35 | 50 | 30 | 50 | 68.18 |
| | Loss of agricultural land due to site | Corine Land Cover 2006 | Permanent crops | 0.03 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Social / Cultural | Disturbance in grazing patterns | Corine Land Cover 2006 | Pastures | 51.13 | 25 | 28.57 | 73.91 | 66.667 | 28.57 | 60.87 | 35 | 50 | 30 | 50 | 68.18 |

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