European Space Agency: EO4OG onshore

D1: Geo-information requirements consolidating report

OTM Consulting Ltd

D1.1_ESA001_A

Version	Author	Approved	Authority to release	Release date
D1.1_ESA001_A	MJB	ABL	SBM	07 July 2014
Notes:				

Executive Summary

OTM has performed an extensive literature search, leveraged its in-house knowledgebase and conducted 26 interviews with industry experts to identify the challenges faced within the O&G sector in onshore frontier regions that are relevant to a potential Earth Observation solution.

79 O&G challenges were documented throughout this process leading to the identification of 14 geo-information requirements that, when combined in a given combination, can provide the information required to satisfy or contribute towards the satisfaction of these challenges. The list of geo-information requirements is shown in Table 1. The complete list of challenges is shown in Appendix A and in the Excel spreadsheet and challenge proformas on the OGEO portal.

The challenges have been reviewed through industry consultation, and will be subjected to an ongoing review process by the wider OGEO community via their availability on their OGEO portal.

Ref	Geo-information requirement	Description
1	Obtain detailed topographic characterisation	Information describing the ground surface elevation across a given area e.g. to highlight steep slopes, basins or depressions
2	Obtain detailed terrain characterisation	Information to identify different ground types such as swampland, boulder fields, sand plains, road surface/ concrete, etc.
3	Obtain detailed information about vegetation and flora	Information to highlight the presence and type of vegetation e.g. deciduous woodland, jungle, mangrove forest, agricultural crops, grassland, etc.
4	Obtain detailed land-use information	Information regarding the use of land such as residential areas, industrial and urban zones, agricultural land, etc.
5	Identifying location and condition of transport infrastructure	Information to highlight the location and routing of transport infrastructure and its state of repair. This will typically include road and rail networks.
6	Identifying inland water bodies and determining water quality	Information to identify the location and extent of water bodies, coupled with estimation of water quality i.e. the presence of contaminants including hydrocarbons, excessive nutrient loadings, etc.
7	Determining air quality	Information to assist in the estimation of air quality, including the presence of emissions and air quality contaminants such as those generated as a result of O&G activities (NOx, sulphides, CO2, CH4, etc.)
8	Identifying the presence and location of unexploded ordinance (UXO)	Information to assist in the locating of unexploded ordinance or munitions debris.
9	Obtain detailed imagery of assets	Detailed imagery of O&G infrastructure and assets including pipelines, well heads, production sites, site welfare facilities, etc.
10	Identify fauna presence and patterns	Information to assist in the identification and monitoring of fauna, including migration or movement patterns
11	Determine lithology, mineralogy and structural properties of the near surface	Information to assist in the determining of ground properties such as rock type and bearing capacity
12	Identify the presence of sub-surface or covered infrastructure	Information to highlight the presence of infrastructure otherwise hidden from view e.g. below the tree canopy or ground surface
13	Monitor ground movement (horizontal and vertical)	Information to track ground movement in all directions
14	Obtain detailed imagery of the surface	Basic imagery requirement of the Earth's surface

Table 1: Geo-information requirements

The challenges were identified through 5 themes, representative of differing technical areas. These were: seismic planning, surface geology mapping, subsidence monitoring, environmental monitoring, and logistics and operations.

Marked variations were noted in the value that potential EO solutions may have to the O&G sector within each thematic area. Seismic planning challenges and their potential solutions were found to be most applicable in the early lifecycle stages (pre-licence and exploration) where they were considered critically enabling or capable of offering a competitive advantage. This was akin to the value that surface geology mapping had throughout the project lifecycle. Subsidence monitoring challenges were found to have the greatest impact during the production phase where they were perceived to provide a competitive advantage. In contrast to this, environmental monitoring challenges relevant to EO were generally seen to be important but non-essential across the project lifecycle. This is indicative of the fact that EO is more of a complementary technology in this domain. Logistics monitoring and operations challenges were most significant during the early lifecycle stage but particularly during the development phase where the use of EO technology was seen as providing a competitive advantage.

Figure 1 shows the frequency that each of 14 geo-information requirements was needed to satisfy each of the 79 documented challenges.

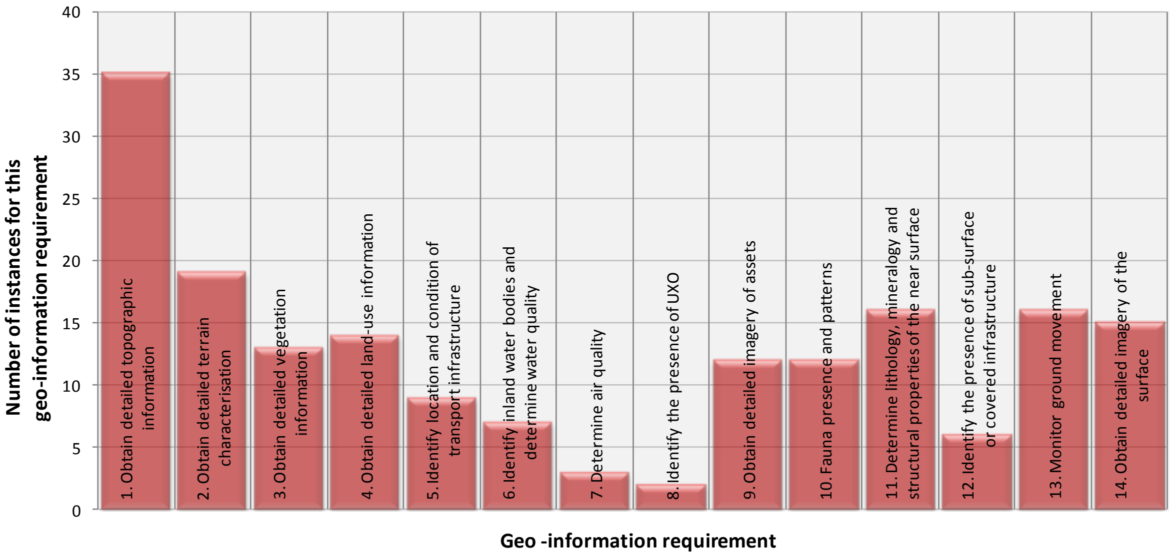

Figure 1: Geo-information requirements associated to documented O&G challenges

The need for accurate topographic information was identified as being the key geo-information requirement throughout the study, required for almost half (44%) of all challenges. Terrain characterisation, understanding the near surface (mineralogy, structural properties, etc.) and monitoring ground movement were found to be the next most frequent geo-information requirements, followed by surface imagery, land-use and vegetation information which were each required for approximately 20% of the challenges. To a lesser extent, imagery of O&G assets and flora and fauna were highlighted as requirements for 17% of the challenges. Of the remaining challenges, the most notable were the identification of transport infrastructure and its condition (required for 13% of challenges), and the identification of UXO and munitions debris. The requirement to identify UXO, although only relevant to 3% of challenges, has the potential to become an enabling technology that would undoubtedly be embraced within and beyond the O&G sector to improve safety and operational efficiency in UXO impacted regions - typically frontier regions in Africa and the Middle East.

Figure 2 shows the area that EO solutions will impact within the O&G sector. EO was found to have the greatest potential impact on O&G operations in relation to data quality and performance (38%), followed closely by environment and sustainability (27%), and health and safety (26%). Generally, performance enhancements were realised as a consequence of cost-efficiencies gained through improved planning and therefore project execution, although more strategic benefits in relation to improved exploration performance were also noted. Environmental and sustainability benefits were recognised through unbiased, objective change detection, where EO was perceived as a complementary tool to existing methods as opposed to an enabling technology. However, its potential for application was evident throughout the project lifecycle. Health and safety benefits were realised through improved risk education prior to the deployment of on-the-ground staff, a reduction in personnel exposure to operational risks (by substituting ground staff for remote observation) and improved project planning and remote decision making capability.

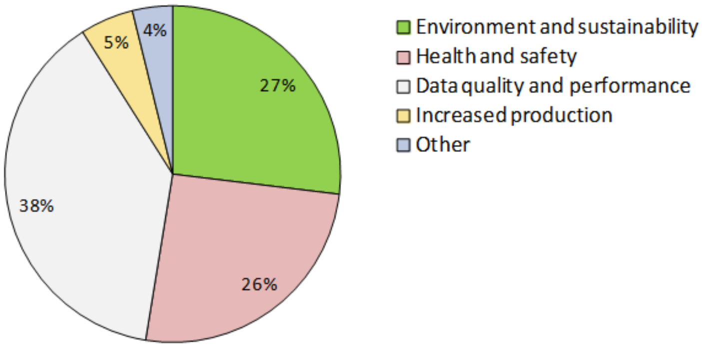

Figure 2: Impact area of geo-information requirements associated to documented O&G challenges

An analysis of our industry consultation was also carried out to reveal the perceived strengths, weaknesses, opportunities and threats to the EO sector, as seen from within the O&G industry.

Strengths were widely recognised as the technology's impartiality, non-invasive nature and applicability in harsh environments.

Weaknesses associated to a need for improved product resolution, a reduction in processing requirements and in some instances e.g. for emergency response, a faster product delivery time. Restrictions on EO application such as cloud cover and a lack of accuracy in densely vegetated areas were also highlighted as instances that deter operators from using the technology.

Opportunities for the EO sector were recognised as the need to develop clear guidelines or agreed standards regarding the application of EO technology and the desire of the O&G industry to establish long-term relationships with product providers that can offer a premium and reliable service. The fact that many operators are creating (or have created) centralised EO and remote sensing functional groups also present a valuable opportunity to EO companies within ESA's area of interest. It should make engagement with operators easier and the use of EO products more widespread throughout client organisations.

Threats to the application of EO technology in O&G persist in a lack of understanding regarding the capability of the technology at both corporate and asset level. The subsidising or funding of case-studies to prove and quantify the value of EO technology in an O&G context has been flagged as a potential solution, making communication of the technologies value statement more applicable to end users in this sector. Threats to the use of ESA sponsored technology include the increased availability of free data and the emerging Asian market capability that may compete at a lower price point. However, if ESA linked organisations position themselves as a premium vendor they may be able to mitigate this.

Contents

1 Introduction

The European Space Agency (ESA) has commissioned four consortia to identify the geo-information needs of the O&G sector (onshore and offshore) across 28 countries and to map the current capability of EO solutions against these needs. The project, referred to as Earth Observation for Oil and Gas (EO4OG) is broadly split into 3 concurrent tasks as shown in Figure 3.

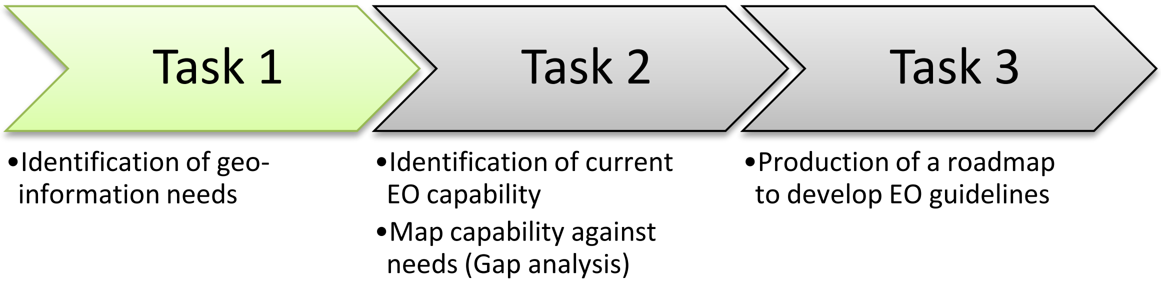

Figure 3: EO4OG project structure

Two of these independent consortia, led by OTM Consulting (OTM) and Hatfield Consultants (Hatfield), have been tasked with performing this analysis for the onshore O&G sector, with particular focus on a total of 16 countries (8 each).

This report describes OTM's Task 1 output and focuses on the identification of onshore geo-information needs identified relevant to 8 specific countries: Algeria, The Democratic Republic of Congo (DRC), Mexico, South Africa, South Sudan, Tanzania, Turkey and Uganda.

Figure 4 depicts the methodology undertaken by OTM to develop their list of geo-information requirements relative to the 8 profiled countries.

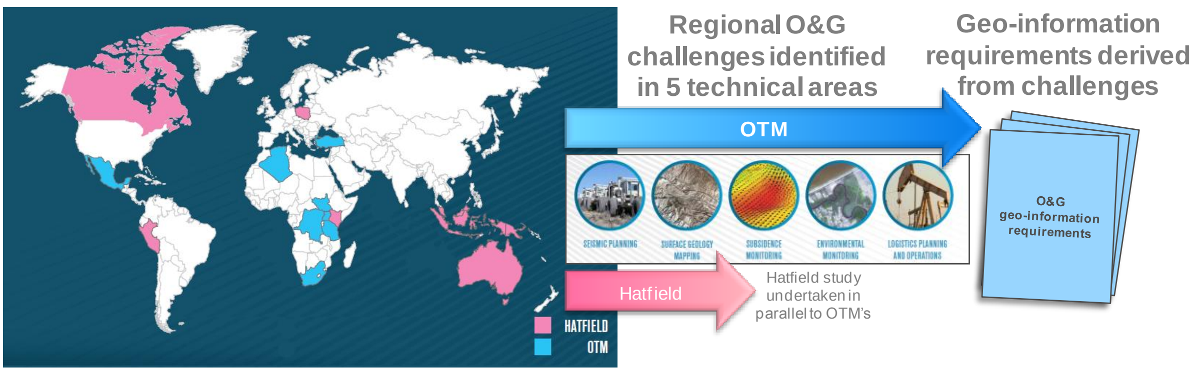

Figure 4: Task 1 methodology

Through consultation with the O&G sector including operators and key service providers, OTM identified the key challenges faced within each of the specified countries relative to 5 technical areas (referred to as themes). These consisted of:

- Seismic planning
- Surface geology mapping
- Subsidence monitoring
- Environmental monitoring, and
- Logistics and operations

Once these challenges had been identified and verified by industry, their geo-information components were drawn out in order to generate a list of key geo-information requirements.

This document describes the findings of this investigation including an overall analysis of the challenges and geo-information requirements as well as a thematic analysis i.e. a breakdown relative to the 5 technical areas listed above.

Each theme is described with reference to:

- The impact that its challenges have throughout the O&G lifecycle
- The geo-information requirements of the challenges
- The challenges with the greatest value to the O&G sector
- The impact area that the challenges and potential solutions address
- The geographic relevance of the challenges (related to the 8 countries of interest)

To contextualise the study and record some key feedback, an interview analysis (Voice of the Customer) has been conducted in order to highlight the perceived position of EO technology by the O&G sector including strengths, weaknesses, opportunities and threats. This is contained within section 2 as an introduction to the main body of the report.

This document is supported by two appendices and an accompanying spreadsheet and challenge proformas available on the OGEO portal.

2 Voice of the customer

The section acts as an introduction to the main body of Task 1 in order to contextualise the use of EO within the O&G sector. It highlights the key messages received throughout OTM's industry consultation and provides some interesting insight to the O&G sector's perception of EO technology. It includes feedback from both EO users and non-EO users from operating and non-operating organisations as shown in Figure 5.

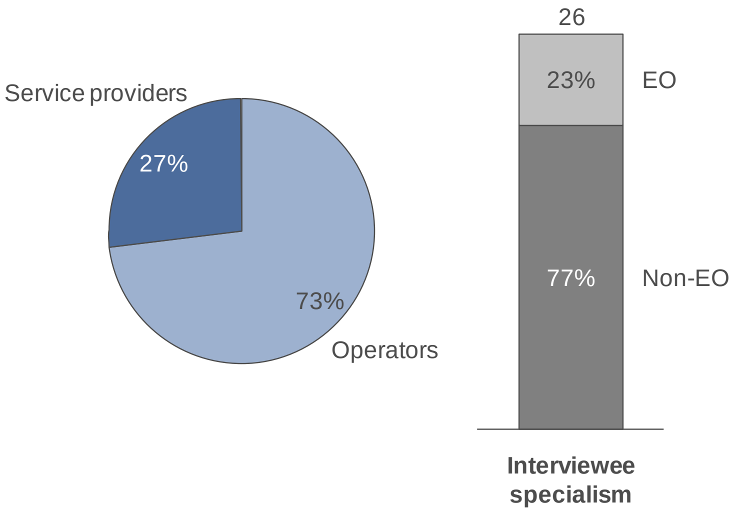

Figure 5: Interview breakdown

In addition to leveraging our in-house expertise of the O&G sector, OTM conducted 26 interviews with operators and service providers who are active in the 8 countries specific to this study. Three quarters of the interviews were with operators, including supermajors, majors, independents and national oil companies. The remaining quarter of interviewees were made up of key service providers including construction companies, logistics companies and specialist service providers such as seismic surveying and environmental monitoring organisations. Approximately one quarter (23%) of the interviewees were directly involved with the provision and distribution of EO technology. Three quarters (77%) of the interviewees were focussed on other elements of the O&G industry, although they may have used, be aware of or have a secondary responsibility associated with EO technology.

The feedback received during industry engagement has been grouped into the perceived strengths, weaknesses, opportunities and threats to the application of EO technology within the O&G sector. This analysis is detailed in sections 4.1 - 4.4.

It is important to note that this analysis is based on the opinion of the industry and it does therefore not necessarily reflect the true strengths, weaknesses, opportunities and threats to EO technology. Consequently the analysis refers to 'perceived' strengths, weaknesses, opportunities and threats.

2.1 Strengths of EO technology

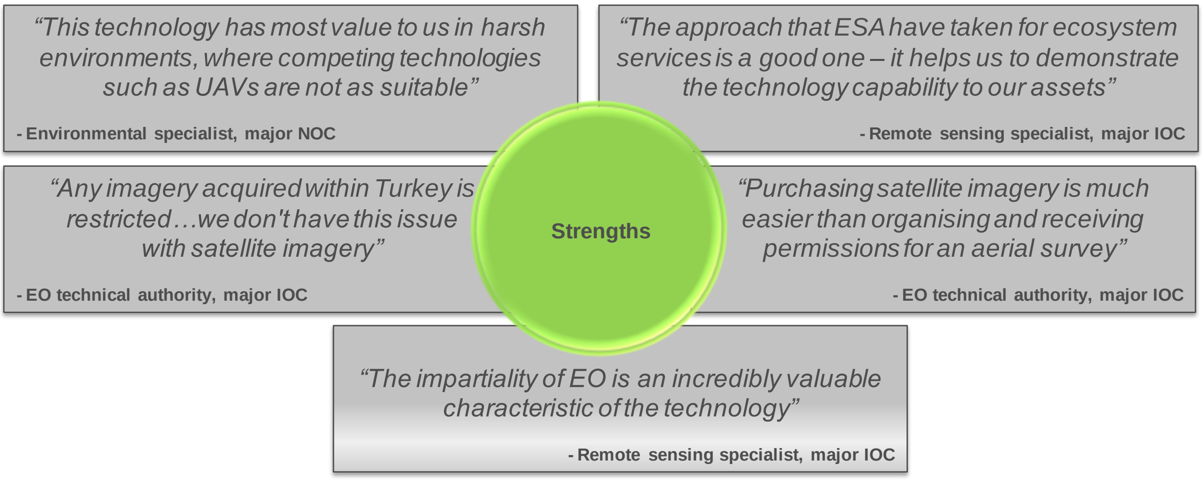

Figure 6: Perceived strengths of EO technology

EO is recognised as having an application within the O&G sector and key advantages are widely accepted to be its impartiality, non-invasive nature and applicability in harsh environments. These advantages allow EO technology to be incorporated into O&G operations in regions where regulation prevents or limits the extent of UAV surveys, those that pose a safety risk to staff and areas where operations may be disruptive to local populations or the environment.

2.2 Weaknesses of EO technology

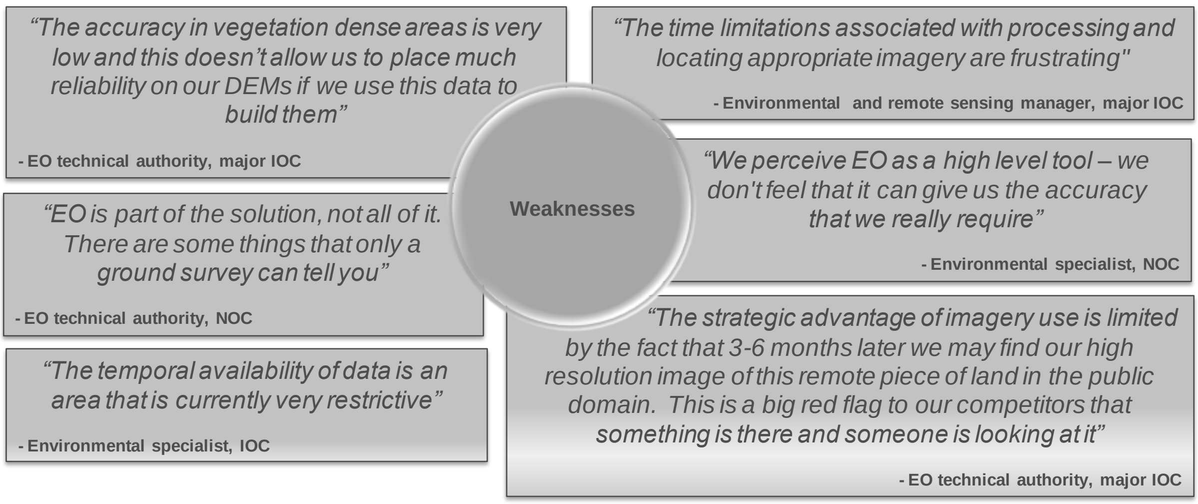

Figure 7: Perceived weaknesses of EO technology

Weaknesses of EO technology were associated to a lack of resolution when compared to more detailed tools such as UAVs and LiDAR. There was a clear desire from interviewees to have products with increased resolution, although they could rarely pinpoint how the increased accuracy would aid in their operations. The timeliness of delivery was also flagged as being critical for some applications. For example, in situations such as responding to emergency events or security monitoring, the timeliness of product delivery is of vital importance, whereas for applications such as environmental monitoring it is less significant.

The timeliness of product delivery is also impacted by the processing requirements demanded of the organisation. Processing was widely perceived as a necessary evil rather than an opportunity to develop a competitive advantage - this is gained through the interpretation and application of the product. Consequently, the development of products with reduced processing requirements emerged as an industry need.

Restrictions on EO application such as cloud cover and a lack of accuracy in densely vegetated areas were also highlighted as instances that deter operators from using the technology. It was widely recognised that EO was part of a suite of complementing technologies available to assist operators in their operations and also that some competing data collection methods could never be replaced by a remote solution. For example, ground survey teams will always be required for environmental surveying, regardless of the capability of EO technology. Some operators were deterred from using particular EO providers due to the fact that the images they acquired would appear on publically available imaging programs such as Google Earth a few months later. This was perceived as a risk to any strategic advantage that they may have in a region, for example, during the early stages of exploration. Not all operators conveyed a similar response, stating that non-disclosure agreements could be put in place to avoid this issue.

2.3 Opportunities for EO technology

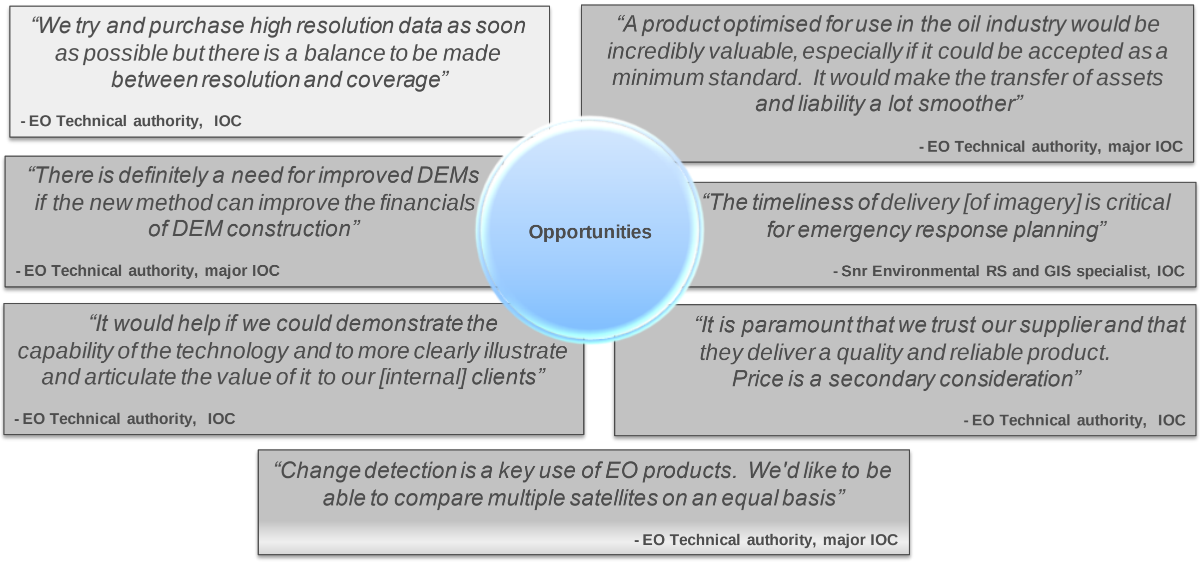

Figure 8: Perceived opportunities for EO technology

A theme that was repeated by a number of interviewees throughout OTM's consultation process was the lack of clear guidelines for the application of EO technology. Different operators make use of EO technology in broadly similar ways i.e. for similar applications, although the sources and processing of the data used varies. The creation of a minimum industry standard has potential to create an environment for increased cross-operator collaborative working e.g. for environmental monitoring of a particular region, and to smooth the transfer of assets between organisations, although this may be at the cost of a reduced pace of innovation sector as operators are less incentivised improve performance.

Many operators have established or are establishing centralised EO and remote sensing functional groups in order to make more efficient and effective use of EO data e.g. by avoiding the duplication of data acquisition. ESA may wish to engage these units to guide R&D to meet future industry needs and to better articulate the capability of their EO products to company assets.

Interestingly, although cost was a key consideration in the decision making process when selecting EO products, it was widely communicated as being less important than product reliability and supplier relationships. In other words, operators are willing to pay a higher price for a quality product from a reliable vendor, providing that the product has value to them. This is a positive message for ESA linked organisations who are unlikely to be able to compete with emerging market service providers on a cost-basis.

2.4 Threats to EO technology

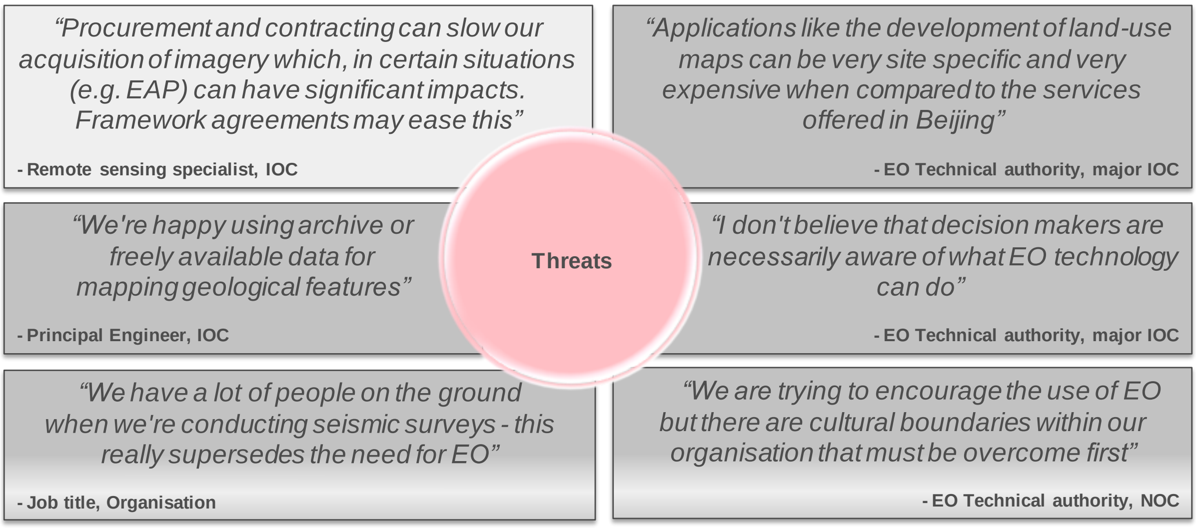

Figure 9: Perceived threats to EO technology

One of the major threats to the implementation of EO technology within the O&G sector is a lack of understanding regarding the capability of the technology. This lack of awareness is relevant at both the asset and corporate level. It was supposed by some operators that this may be attributed to the over-selling of EO capability during the technology's infancy, which has established an association of mistrust with a generation of users that are now typically in decision making and purchasing roles with O&G organisations. It is possible that this challenge may be overcome by ESA through the funding of case-studies to prove and quantify the value of EO technology in an O&G context, making communication of the EO value statement more applicable to their target market.

Other threats to the use of ESA sponsored EO technology include the emerging Asian markets and capability that may compete at a lower price point. The increased availability of free data, especially for the lower resolution images may also pose a threat to users of ESA services. However, this may be mitigated by these organisations positioning themselves as premium EO vendors.

3 Thematic analysis of geo-information requirements

3.1 Introduction

This section describes the research and methodology undertaken to reveal the challenges encountered within the onshore O&G sector relative to 5 thematic areas, within the 8 profiled countries.

3.1.1 Thematic areas

The 5 thematic areas investigated were:

- Seismic planning
- Surface geology mapping
- Subsidence monitoring
- Environmental monitoring
- Logistics and operations

Each of the thematic areas was further explored via sub-themes, providing three levels of granularity: thematic area, sub-theme and the challenge itself. Appendix A displays the 'challenge trees'; a visual breakdown of the theme - sub-theme - challenge relationship for each of the thematic areas. The challenge trees also map onto each challenge the geo-information requirements required to satisfy it. The challenge references on the challenge trees and within this document are consistent with those in the spreadsheet and proformas available on the OGEO portal, where more information about each of the challenges is also provided.

The analysis of each of these thematic areas is described more fully in the sub-sections 3.2 - 3.6.

3.1.2 Challenges associated to multiple themes

Where challenges are evident across multiple thematic areas they have been associated to a 'primary theme' and one or more 'secondary themes'. The primary theme is indicative of where this challenge impact is most prevalent, whilst the secondary themes are representative of less severe impact areas.

3.1.3 Ranking challenge impact

Within each of the thematic areas, the impact of the various challenges has been ranked from 0-4 in order to provide a relative indication of the significance of the challenge throughout each lifecycle stage, which can be considered as a proxy for the value that an EO solution would provide. This information is contained within the accompanying spreadsheet and challenge proformas available on the OGEO portal.

The scoring methodology is described in Table 2.

Score	Title	Description
0	No value	The implementation of EO technologies to meet this challenge would add little or no value
1	Nice to have	EO technologies would provide useable information but little of this is critical to satisfying the challenge
2	Important but non-essential	EO technologies provide valuable complementary information to satisfy the challenge identified
3	Significant/ competitive advantage	EO technologies offer key information required to satisfy the challenge. This is to such an extent that organisations not utilising EO struggle to compete at the same level
4	Critical/ enabling	EO technologies are essential to satisfy the challenge, enabling organisations deploying the technology to operate in a manner that would not be possible without them

Note: It is recognised that this scoring is subjective and open to debate and that a comparison between the value and impact of, for example surface geology mapping challenges with environmental monitoring challenges is not straight forward. However it was felt that an indication of challenge significance was important in order to identify the value of EO solutions to the O&G sector. Scorings were based on OTM's knowledge of the O&G industry and the feedback/ verification received during our consultation process (see section 2).

Table 2: Scoring methodology for challenge impact

3.1.4 Impact area of challenges

Each of the challenges identified may impact O&G operations across a number of different technical, commercial or strategic areas. Comprehensively mapping all of these benefits is a vast and subjective task and consequently, in order to provide an indication of where the benefit of an EO solution may be realised most, only the primary impact area has been suggested in relation to 5 broad areas, as described in Table 3.

Impact area	Description
Environment and sustainability	Enhancements in an organisation's ability to effectively satisfy their environmental or sustainability responsibilities
Health and safety	Reduced risk to personnel (employed and non-employed) during operations
Data quality and performance	Improving data resilience or interpretation capability, typically resulting in improved exploration performance or cost efficiencies
Increased production	Information that is primarily used for the purpose of increasing production
Other	Any topic that does not suit the above categories e.g. for competitor intelligence

Table 3: Scoring methodology for challenge impact

3.1.5 Geo-information requirements

Upon completion of the challenge mapping, a list of geo-information requirements associated to the challenges was derived. This list is displayed in Figure 10 and described more fully in Table 4.

Geo-information requirements

1. Obtain detailed topographic characterisation
2. Obtain detailed terrain characterisation
3. Obtain detailed information about vegetation and flora
4. Obtain detailed land-use information
5. Identify location and condition of transport infrastructure
6. Identify inland water bodies and determining water quality
7. Determine air quality
8. Identify the presence and location of UXO
9. Obtain detailed imagery of assets
10. Identify fauna presence and patterns
11. Determine lithology, mineralogy and structural properties of the near surface
12. Identify the presence of sub-surface or covered infrastructure
13. Monitor ground movement (horizontal and vertical)
14. Obtain detailed imagery of the surface

Figure 10: Geo-information requirements

Ref	Geo-information requirement	Description
1	Obtain detailed topographic characterisation	Information describing the ground surface elevation across a given area e.g. to highlight steep slopes, basins or depressions
2	Obtain detailed terrain characterisation	Information to identify different ground types such as swampland, boulder fields, sand plains, road surface/ concrete, etc.
3	Obtain detailed information about vegetation and flora	Information to highlight the presence and type of vegetation e.g. deciduous woodland, jungle, mangrove forest, agricultural crops, grassland, etc.
4	Obtain detailed land-use information	Information regarding the use of land such as residential areas, industrial and urban zones, agricultural land, etc.
5	Identifying location and condition of transport infrastructure	Information to highlight the location and routing of transport infrastructure and its state of repair. This will typically include road and rail networks.
6	Identifying inland water bodies and determining water quality	Information to identify the location and extent of water bodies, coupled with estimation of water quality i.e. the presence of contaminants including hydrocarbons, excessive nutrient loadings, etc.
7	Determining air quality	Information to assist in the estimation of air quality, including the presence of emissions and air quality contaminants such as those generated as a result of O&G activities (NOx, sulphides, CO2, CH4, etc.)
8	Identifying the presence and location of UXO	Information to assist in the locating of unexploded ordinance or munitions debris.
9	Obtain detailed imagery of assets	Detailed imagery of O&G infrastructure and assets including pipelines, well heads, production sites, site welfare facilities, etc.
10	Identify fauna presence and patterns	Information to assist in the identification and monitoring of fauna, including migration or movement patterns
11	Determine lithology, mineralogy and structural properties of the near surface	Information to assist in the determining of ground properties such as rock type and bearing capacity
12	Identify the presence of sub-surface or covered infrastructure	Information to highlight the presence of infrastructure otherwise hidden from view e.g. below the tree canopy or ground surface
13	Monitor ground movement (horizontal and vertical)	Information to track ground movement in all directions
14	Obtain detailed imagery of the surface	Basic imagery requirement of the Earth's surface

Table 4: Description of geo-information requirements

3.2 Requirements relating to seismic planning

The challenges related to seismic planning were explored through three sub-themes. These were:

- Identification of adverse terrain for trafficability
- Areas of poor coupling
- Identifying environmentally sensitive areas

A total of 9 primary challenges and 6 secondary challenges were identified in relation to seismic planning. See Appendix A: Challenge trees, for a visual breakdown of these challenges.

3.2.1 Value of EO solutions throughout the O&G lifecycle

As displayed in Figure 11, the greatest value of EO solutions relevant to seismic planning is associated with the exploration phase, where the technology is perceived as a critical or enabling tool; a key decision enabler. For a number of challenges it was considered that EO technology could give a company strategic advantage. EO technology for seismic planning is also desired as early as the pre-license phase, where it may be used to begin feasibility planning for exploration. There is little demand for the technology in the development, production and decommissioning phase due to the fact that seismic activity is ceased following exploration (field expansions after initial production were considered as exploration).

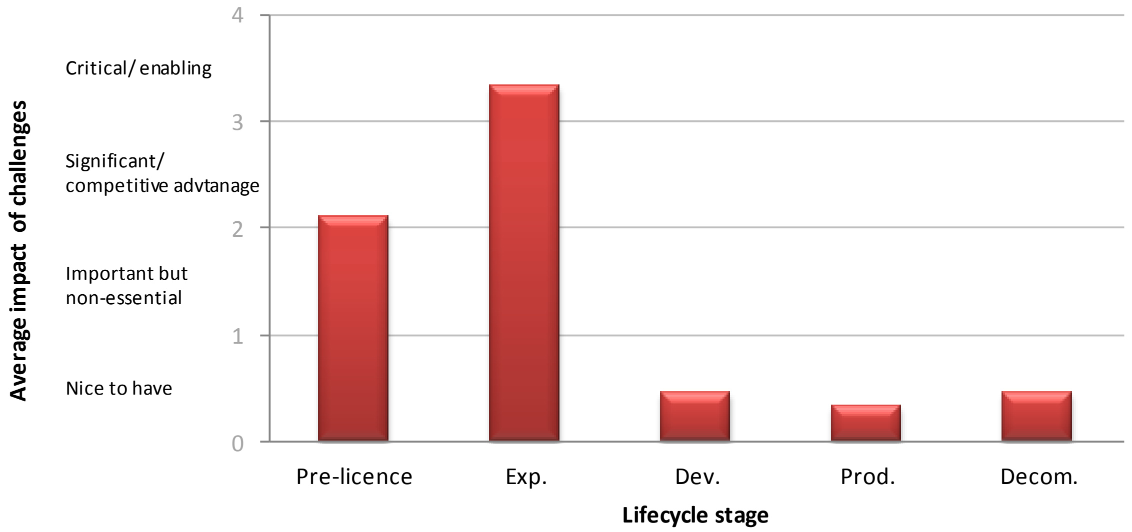

Figure 11: Seismic planning challenge impact throughout the project lifecycle

3.2.2 Geo-information requirements relative to Seismic Planning

Figure 12 shows that the geo-information requirements for this theme are heavily influenced by the need to plan for the capabilities of vibroseis vehicles. This is reflected in the recurring occurrence of the requirement for information on terrain and topography. The ability to plan seismic lines that would not jeopardise the vehicles was seen as very important.

The most frequently encountered challenges are associated with understanding the topography and terrain of the proposed survey area, typically via the development of a digital elevation model (DEM). Numerous parties expressed the difficulty in discriminating the true ground level from that of dense vegetation and this was noted as having a significant impact on planning survey lines.

The geo-information requirements relating to identifying environmentally sensitive areas was noted but these were often generic issues and not unique to the act of planning seismic surveys alone. These challenges are discussed further in section 3.5.

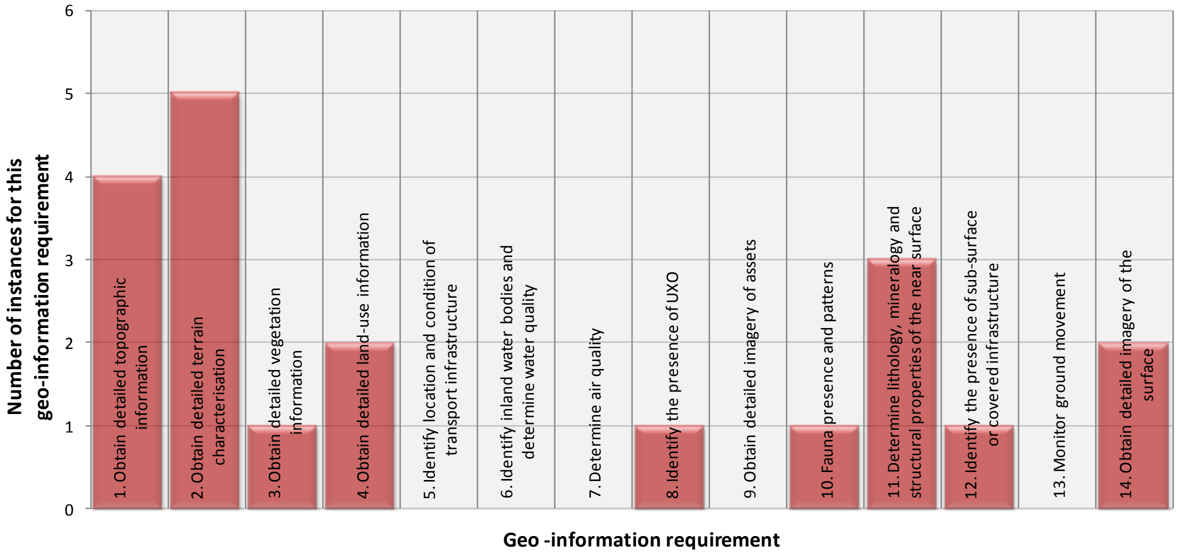

Figure 12: Geo-information requirements associated with seismic planning challenges

3.2.3 High value challenges

High value challenges related to seismic planning are associated with understanding the near surface environment, identifying variations in trafficability (topography and terrain), flagging the presence of UXO and munitions debris, and identifying environmentally sensitive areas. These are described more fully within Table 5.

Ref	Title	Description
OTM:013	Identification of environmentally sensitive areas	The impact of this challenge is scored high because failure to recognise and account for environmentally sensitive areas within the planning process can lead to the postponement of surveying activity until the regulatory authority is satisfied. This was noted as being particularly relevant in the frontier regions which are in a politically stable state, and where environmental performance is able to be scrutinised. In more volatile regions, such scrutiny by regulatory authorities is less vigilant. For the countries that are focussed on by the OTM team, this challenge would thus particularly relate to Uganda and Tanzania. More developed stable countries (for example, South Africa, Mexico and Turkey), would have better base-line mapping from which environmentally sensitive areas would already be identified.
OTM:046	Identifying variations in trafficability for seismic vehicles	One of the key challenges was found to be optimising the routing of seismic vehicles at the planning stage. This may be in the form of selecting appropriate seismic lines and sweep frequency in order to minimise the impact of terrain and topography on vehicle movements or more widely, to take account of environmentally sensitive areas, obstructions to vehicles and understanding the impact that the environment may have on seismic signals to aid data processing.
OTM:048	Identification of UXO and munitions debris	This is the most severe challenge documented within this theme. This challenge may be encountered in all countries but is most significant in those with a recent history of conflict, for example South Sudan, Uganda and the Democratic Republic of Congo. The challenge is currently solved using specialist scouting teams, so an EO solution that could identify the presence or likelihood of UXO would have significant safety benefits and would therefore be highly appealing to the O&G sector. An EO solution for this would be particularly pertinent for surface types which enable UXO to migrate over a period of time. Such a solution would enable charted areas to be corroborated by ground survey teams more safely.
OTM:053	Understanding the near-surface for explosive charge placement	This has been scored as a severe impact because the incorrect selection of explosive technology or an inability to deploy the explosives have significant safety and cost implications.

Table 5: High value challenges associated with seismic planning

3.2.4 Impact area of challenges and potential EO solutions

Figure 13 displays the impact area of the challenges identified within the seismic planning thematic area. Two thirds of the challenges (67%) are associated with data quality and performance, one fifth (22%) is associated to health and safety and the remaining 11% is linked to environment and sustainability benefits.

Enhanced performance through cost reduction may be realised through early identification of issues facing the routing and undertaking of the seismic survey, thus allowing mitigation of these challenges early in the planning lifecycle, either remotely or through the more targeted application of ground survey teams. Likewise, the recognition of areas of high environmental significance also allow for the necessary monitoring, mitigation and protection to be planned and undertaken early in the project lifecycle.

The impact on quality reflects the need for an improved understanding of the near surface and conflicting sources of seismic signal. This includes of the identification of terrain typology and accounting for the varying seismic absorption properties during processes. Health and safety impacts are largely realised through the development of accurate DEMs and imagery that enable ground survey teams to have a better understanding of the survey site before being deployed.

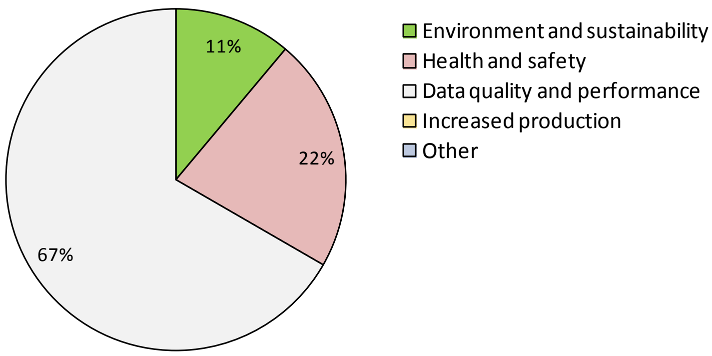

Figure 13: Impact area of seismic planning challenges

3.2.5 Regional variations in geo-information requirements

The challenges encountered with seismic planning are relevant across all of the countries profiled, although they may be more or less pronounced depending on the specific region of exploration and its terrain, topography and prevailing environmental conditions.

In densely vegetated regions and those with high environmental sensitivity such as Uganda and Tanzania the application of EO early in the planning lifecycle has the potential to offer significant efficiency gains. This may be through geo-zoning areas where no work is permitted or highlighting routes of easier trafficability. In mountainous regions such as those seen in the O&G regions of Turkey, the mapping of topography is particularly important to minimise the risk of vehicle roll-over.

The identification of adverse terrain is applicable to many countries, ranging from those with sandy or swampy ground such as the Democratic Republic of Congo and Mexico to those with hard terrains prone to localised boulder fields or gravels. Both can influence seismic surveys through the slowing or diversion of vehicle movements and poor coupling. This also interferes with the seismic grid pattern and sweep locations which can complicate post-processing of the seismic data.

More detail about each of the profiled countries is shown in Appendix B.

3.3 Requirements relating to surface geology mapping

The challenges related to surface geology mapping were explored through five sub-themes. These were:

- Mapping geological features
- Structural interpretation
- Lithological discrimination
- Terrain evaluation and geo-morphology characterization
- Engineering geological evaluation

A total of 9 primary challenges and 13 secondary challenges were identified in relation to surface geology mapping. See Appendix A: Challenge trees, for a visual breakdown of these challenges.

3.3.1 Value of EO solutions throughout the O&G lifecycle

As displayed in Figure 14, the greatest value of EO solutions relevant to surface geology mapping were associated with the exploration and pre-licence phases, where the technology was perceived as a critical or enabling tool. For a number of challenges it was considered that EO technology could provide an organisation with strategic advantage. There is little demand for the technology in the development, production and decommissioning phases - this is a reflection of the predominant need for information relating to planning infrastructure at the beginning of the project lifecycle, together with the inferences that surface geology mapping can give in relation to potential hydrocarbon reserves (i.e. as an exploration tool).

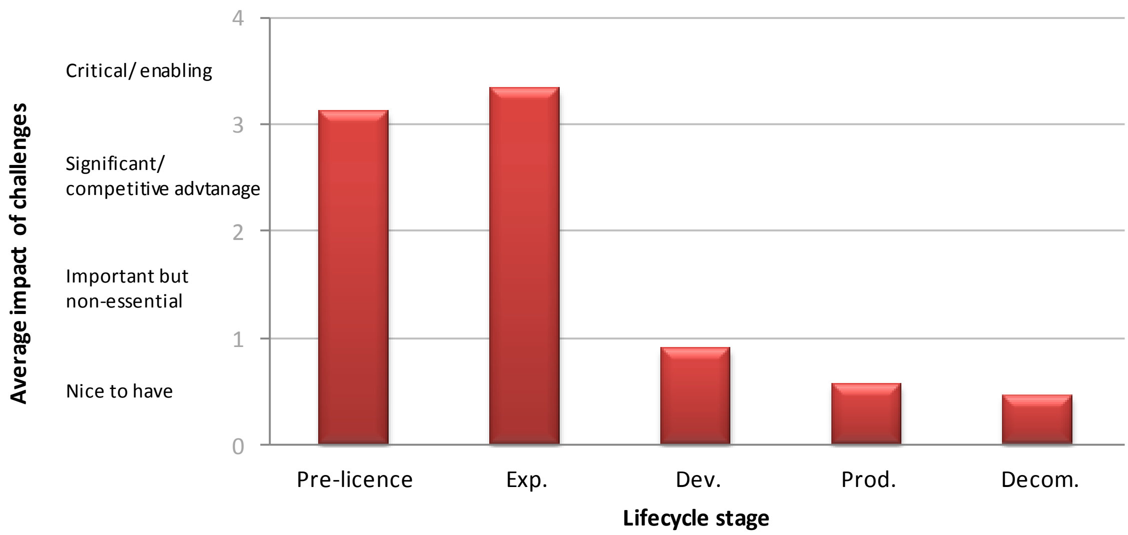

Figure 14: Surface geology mapping challenge impact throughout the project lifecycle

3.3.2 Geo-information requirements relative to Surface Geology Mapping

Figure 15 displays the geo-information requirements that are demanded within the surface geology mapping theme. The challenges documented that related to surface geology mapping cited particular recurrence of the information requirements of "determining the lithology, mineralogy and structural properties of the near surface", together with "obtaining topographic information" and "obtaining detailed imagery of the surface".

These information requirements enable conclusions to be drawn in relation to the locating of surface and sub-surface structures, being indicative of the mineralogy and bearing capacity below the surface. Undertaking outcrop analysis on the ground can be significantly more expensive but is often required in order to achieve the necessary level of detail. A need for EO to achieve these objectives is thus pronounced and would have particular application in politically less stable or other high risk environments such as South Sudan and the DRC.

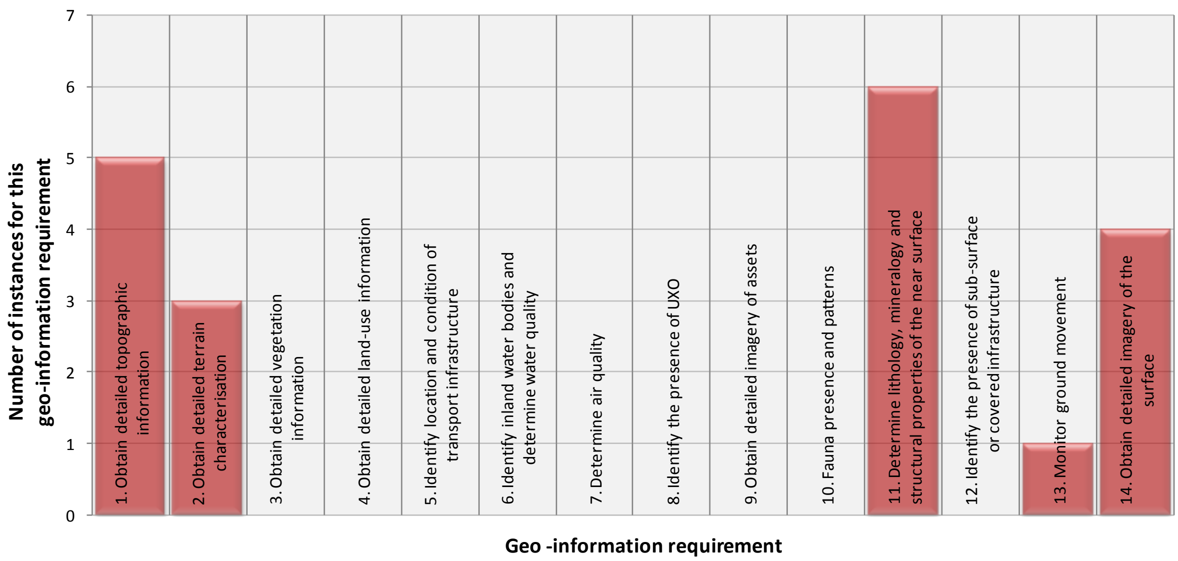

Figure 15: Geo-information requirements associated with surface geology mapping challenges

3.3.3 High value challenges and their geographic relevance

High value challenges related to surface geology mapping are primarily associated with identifying new reserves, although DEM construction also features. These are described more fully within Table 6.

Ref	Title	Description
OTM:025	Early identification of potential hydrocarbon basins	A critical measure of the success of an O&G company is its ability to discover and exploit new reserves. Exploration success is partly dependent on being able to identify hydrocarbon basins before your competitors. This process involves the inspection of the surface over a range of scales in order to identify trends that, when combined with other information such as mineralogy and structural properties of the subsurface, suggest the presence of hydrocarbon basin. EO technology has a clear application in this instance and a high value, notably in the pre-licence lifecycle phase but also in early exploration.
OTM:026	Identifying potential hydrocarbon seepage	Similar to OTM:025, the high value of this challenge is a reflection on the importance of exploration performance. Identifying hydrocarbon seepages or anomalies in characteristics such as in mineralogy and vegetation may indicate that the presence of a reservoir and being able to monitor this over a vast area and a long timescale without diverting a substantial staff resource can offer a significant benefit to operators.
OTM:051	Identification of fault lines	As per OTM:025 and OTM:026, the high value of this challenge is related to the importance of successfully identifying new reserves. The ability to identify and interpret fault lines can give an indication of the likely subsurface conditions and subsequently the presence of a hydrocarbon basin. This is widely performed in clear or desert regions with basic imagery but identifying fault lines in forested or agricultural land where the surface is covered can prove more difficult for operators.
OTM:055	Obtaining detailed terrain mapping for DEM construction	The safety of operational staff is the primary concern for all operators and subsequently this challenge has a high value throughout the project lifecycle. The ability to deploy staff with a thorough understanding of the risks that may be presented to them on-site, prior to their deployment can offer a significant safety benefit through the mitigation of or education about risks. Digital elevation models were highlighted by numerous operators as being key tools used to plan site operations to ensure their feasibility, effectiveness, safety and efficiency.

Table 6: High value challenges associated with surface geology mapping

3.3.4 Impact area of challenges and potential EO solutions

Figure 16 displays the impact area of the challenges identified within the surface geology mapping thematic area. The impact of EO solutions within this theme is almost entirely linked to improvements in data quality and performance, with four fifths (78%) of the challenges linked to this metric. The remaining fifth (22%) is shared equally between health and safety, and environment and sustainability benefits.

The main reason for this is the fact that many of the surface geology mapping applications for EO technology are associated with improving exploration performance. For example, a critical impact could be an improved understanding of the sub-surface at an early stage in exploration which could enable an operator to identify possible reserves. A significant competitive advantage would lie with operators who can leverage this effectively.

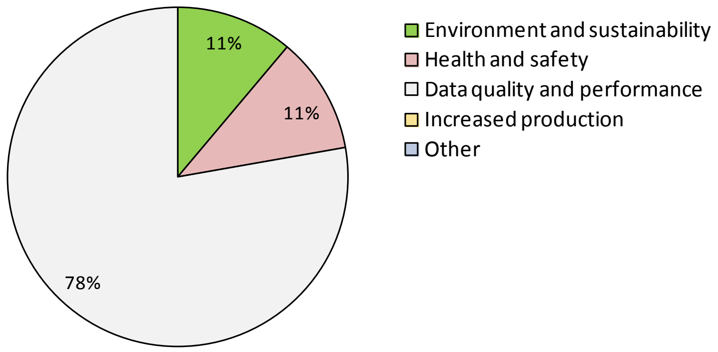

Figure 16: Impact area of surface geology mapping challenges

3.3.5 Regional variations in geo-information requirements

For most of the challenges identified, surface geology mapping requires a clear view of the surface. Regions which are forested covered by snow or where the geology is masked by other surface conditions would not be suitable candidates for an EO solution. For the particular countries examined within the scope of this project, this would mean that much of Algeria and Turkey would be suitable, whilst heavily forested regions such as those seen in DRC and parts of Uganda would not be less so, despite the fact that the need to acquire and understand the same information still persists.

3.4 Requirements relating to subsidence monitoring

The challenges related to subsidence monitoring were explored through three sub-themes. These were:

- Land motion relating to fault lines or other causes
- Infrastructure monitoring
- Reservoir management

A total of 12 primary challenges and 3 secondary challenges were identified in relation to subsidence monitoring. See Appendix A: Challenge trees, for a visual breakdown of these challenges.

3.4.1 Value of EO solutions throughout the O&G lifecycle

Figure 17 demonstrates that EO solutions for subsidence monitoring have the greatest potential to be of value during the production phase. Generally, the technology was noted as being useful but not critical addition to the tool-set available to the industry, despite the fact that in some instances it may provide a significant or critical advantage. The focus on the production stage in the lifecycle reflected the major challenges that could be addressed by monitoring draw-down from producing reservoirs, as well as being an effective tool for reducing losses through damage to infrastructure that result from subsidence.

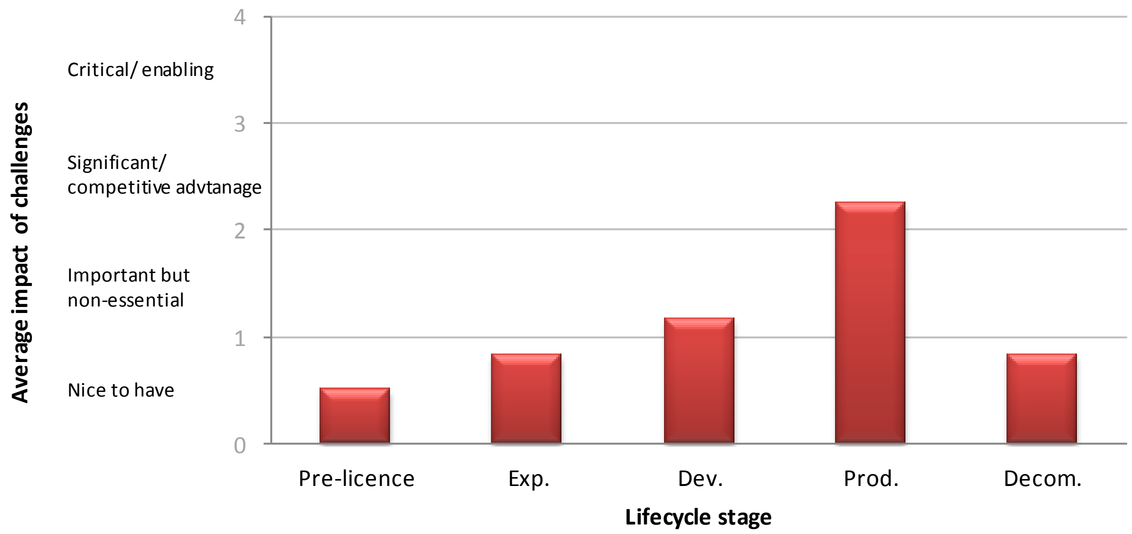

Figure 17: Subsidence monitoring challenge impact throughout the project lifecycle

3.4.2 Geo-information requirements relative to Subsidence Monitoring

As shown in Figure 18, the challenges documented that relate to subsidence monitoring cited particular recurrence of the information requirements of "obtaining detailed topographic information", together with "monitoring ground movement". With this pair of information requirements detailed inferences can be drawn relating to the monitoring of subsidence. These information requirements offer value to companies as an on-going monitoring tool as well as for forecasting future events based on historic activity. For example, information relating to historic ground movement, can enable engineers to hypothesise on the likelihood of future ground movement and plan appropriately to meet this.

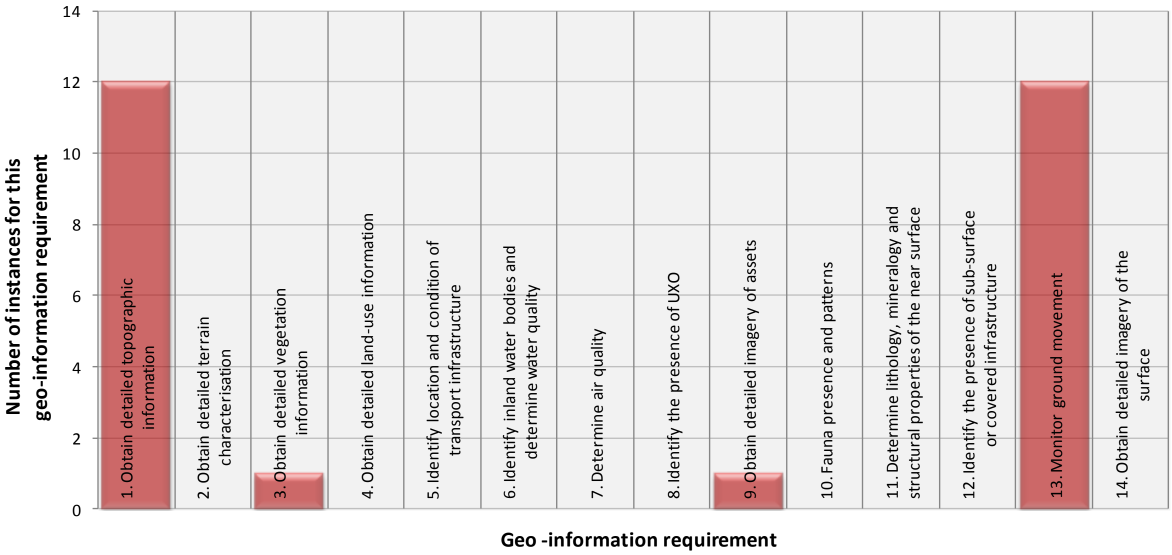

Figure 18: Geo-information requirements associated with subsidence monitoring challenges

3.4.3 High value challenges and their geographic relevance

High value challenges related to subsidence monitoring are associated with the planning and monitoring of key infrastructure components such as transport infrastructure, pipelines and facilities. These are described more fully within Table 7.

Ref	Title	Description
OTM:008	Determine historical ground movement for infrastructure planning	Historical ground movements can give an indication of future movements and the potential for geo-hazards such as landslides, earthquakes, subsidence and dune or river migration. This information is particularly important when considering where to locate infrastructure such as pipelines or surface facilities. This information has most value during the early lifecycle stages: pre-license, planning and development.
OTM:010	Monitoring ground movement along pipelines	Critical during the production phase, the monitoring of ground movement along pipelines can give operators early warning about potential failures, allowing for pre-emptive mitigation against, for example buckling failures induced by subsidence or landslides. Industry feedback suggested that EO would most likely be used as a complementary tool with on-the-ground measurements that were capable of providing more detailed assessments.
OTM:011	Surface infrastructure movement relative to sub-surface	Similar to OTM:008, this challenge is of greatest significance in the latter lifecycle stages of production and decommissioning. The ability to monitor subsidence or lateral movement of infrastructure relative to the surface can allow for pre-emptive mitigation against failures, thus reducing the likelihood of events occurring that may injure staff or cause production to cease.

Table 7: High value challenges associated with subsidence monitoring

3.4.4 Impact area of challenges and potential EO solutions

Figure 19 shows the impact area of the challenges documented within the subsidence monitoring theme. The biggest impact area (33%) is related to increased production. The monitoring of subsidence is this context can identify regions from which a reservoir is being drawn down from, as well as verifying the effectiveness of injection and pressure maintenance regimes in the subsurface. Projects where a secondary or tertiary recovery plan is implemented can both reduce unnecessary costs as well as increasing production by using EO technology to monitor surface ground movement.

The other principal impacts of subsidence monitoring relate to identifying infrastructure movement. Here, the implication can be more effective and cost-efficient maintenance regimes, improving design resilience, an avoidance of an environmentally damage failure and reduced safety risk.

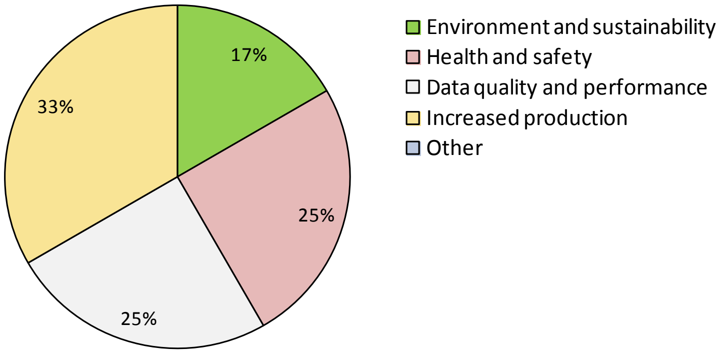

Figure 19: Impact area of surface subsidence monitoring challenges

3.4.5 Regional variations in geo-information requirements

Subsidence monitoring via EO techniques requires a clear view of the ground surface. It is thus not suitable to gain information underneath forest canopies, or on wetland areas. For the portfolio of countries examined in this project, the opportunity for EO based subsidence monitoring would be most applicable to arid regions such as Algeria. Indeed, the technology has been used extensively to assess the effects of CO_2 injection in the In Salah CCS project, where ground uplift over the reservoir has been measured.

These information requirements still exist in other regions but EO technology, at its current maturity, is not considered by users as being capable of satisfying them.

3.5 Requirements relating to environmental monitoring

The challenges related to environmental monitoring were explored through three sub-themes. These were:

- Baseline historic mapping of the environment and ecosystems
- Continuous monitoring of changes throughout the lifecycle
- Natural hazard risk analyses

A total of 19 primary challenges and 15 secondary challenges were identified in relation to environmental monitoring. See Appendix A: Challenge trees, for a visual breakdown of these challenges.

3.5.1 Value of EO solutions throughout the O&G lifecycle

Figure 20 demonstrates that the value of EO solutions to meet environmental monitoring challenges was noted as being useful throughout the lifecycle of an O&G project. The requirement to monitor continuous changes is reflected in the observation that the value of the technology would be similar throughout. The very slight peak of value during the production phase is a reflection that environmental monitoring can also pick up instantaneous events that would not occur during other phases of the lifecycle (e.g. leaks and spills).

The fact that the average value of EO technology was only noted as 'useful' (important but non-essential) is a reflection of the fact it was commonly perceived as a complementary tool, unable to provide the level of detail necessitated for regulatory purposes. To meet these requirements, ground survey teams were typically deployed. EO offers an improvement on existing technologies, but not a step-change in capability.

However, environmental monitoring may offer one of the greatest market opportunities for EO solutions due to the fact that there are a large and diverse number of challenges encountered in this sector which often demand unbiased and objective change detection.

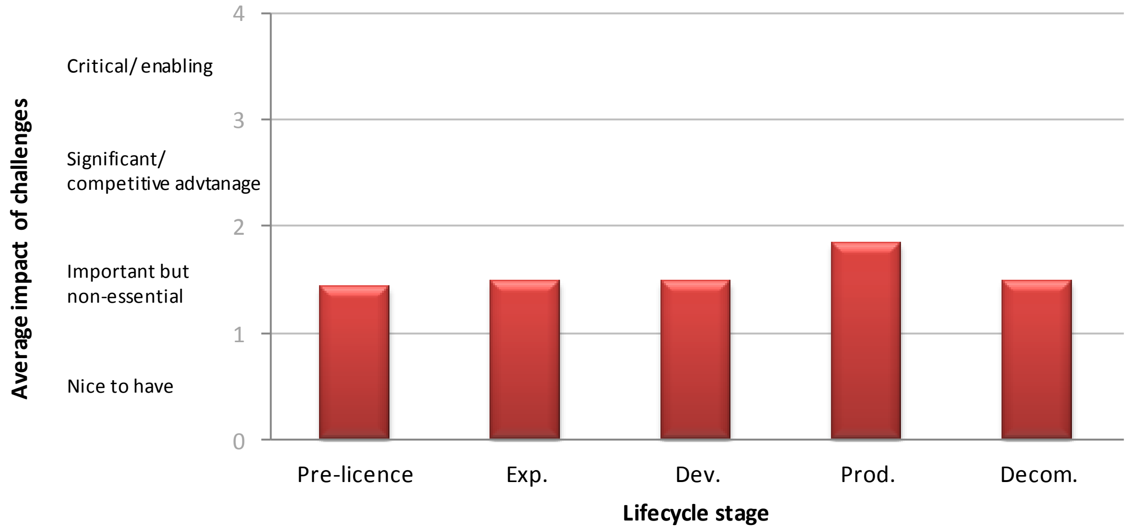

Figure 20: Environmental monitoring challenge impact throughout the project lifecycle

3.5.2 Geo-information requirements relative to Environmental monitoring

Figure 21 shows that the geo-information requirements pertinent to environmental monitoring were widespread and extensive. This was in contrast to the other themes, which required only a few information inputs to address their challenges. The primary geo-information need indentified was the ability to "locate fauna and flora presence", with notable secondary challenges identified as characterising terrain, obtaining vegetation information and determining water quality.

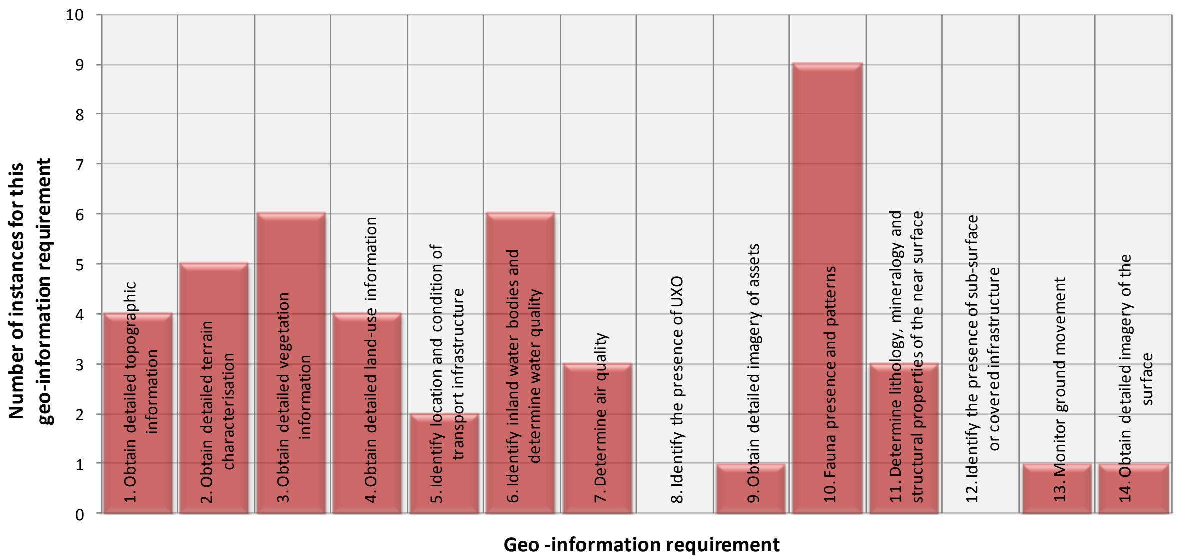

Figure 21: Geo-information requirements associated with environmental monitoring challenges

3.5.3 High value challenges and their geographic relevance

High value challenges associated to environmental monitoring were found to be related to determining and monitoring the condition of the environment through the creation of a reliable and robust baseline, ecosystem inventory and inclusion of social factors.

Ref	Title	Description
OTM:029	Pre-licensing site selection	The mapping of an environmental baseline and identifying trends and natural fluctuations within this is a key concern for operators. This data-set will form the benchmark against which the impact of their operations will be judged, so it is critical that it is accurate and objective. In this sense, although the mapping of the baseline can only take place prior to operations i.e. during the pre-license phase, it will have implications throughout the entire lifecycle.
OTM:030	Ecosystem valuation of potential site (akin to OTM31)	Placing a value on intangible assets such as ecosystems is a challenging and subjective task that can also be resource intense and time-consuming. Being able to quantify the ecosystem value enables operators to estimate the consequences of their operations (both positive and negative) and subsequently develop a plan for rehabilitation, typically after decommissioning a resource. Similar to OTM:029, this challenge is faced during pre-licensing but can have implications throughout the lifecycle.
OTM:033	Mapping of environmental degradation (change)	Monitoring and mapping changes in the environment is a major challenge for operators, who must prove that their operations are sustainable and not causing undue damage to the surrounding environment. Analogous to the derivation of an environmental baseline, it is important that monitoring is unbiased and objective in order to accurately reflect changes. This challenge is evident throughout the project lifecycle from exploration to decommissioning and potentially beyond.
OTM:035	Assessing the social impact of construction work	Akin to the monitoring of environmental change, operators are also required to ensure that their operations do not cause undue social damages that may result from the displacement of communities, indigenous tribes or changes in land use i.e. as a result of the creation of increased traffic or the creation of an urban slums in the proximity O&G infrastructure and associated employment opportunities.

Table 8: High value challenges associated with seismic planning

3.5.4 Impact area of challenges and potential EO solutions

Unsurprisingly, the impact area for organisations using EO to monitor the environmental impact of their operations was overwhelmingly recognised within environment and sustainability (75%). This impact should be considered in both a due-diligence guise, as well as a damage limitation guise. The technology can be used to analyse the before and after effects of O&G operations, as well as alerting the operator to a damaging incident which has occurred (for example a leak in a pipeline) so that action can be taken swiftly, before it gets any worse. This factor can also have safety implications and this has been recognised through the 21% allocation of benefit to this impact area.

Environmental due diligence is an emotive topic that not only effects public relations, but also features high on many host government's considerations when awarding leases. As such, operators are often inclined to invest in technology to demonstrate best practice in this sector.

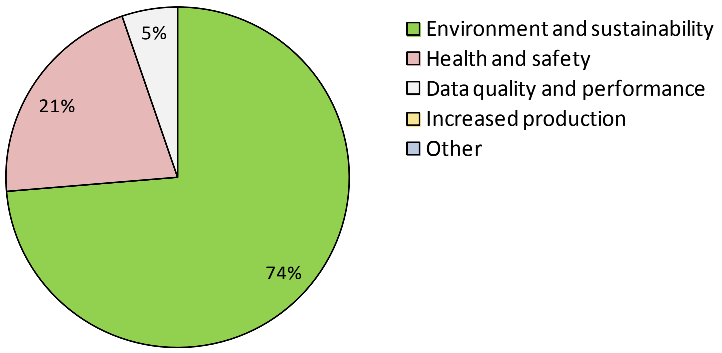

Figure 22: Impact area of environmental monitoring challenges

3.5.5 Regional variations in geo-information requirements

The interest in technology to monitor the environment was seen as being most pronounced in stable countries which have an embryonic O&G sector, and a history of poverty. Those that were unstable tended to have a weaker regulatory environment and the requirement to prove the impact of operations was less rigorously enforced. However, in this situation, major operators or high profile IOCs tend to revert to internal or global standards which may include the use of EO.

EO was generally considered to be less valuable in well developed countries or those with an established O&G sector where sufficient baseline and environmental monitoring information was already available.

3.6 Requirements relating to logistics planning and operations.

The challenges related to environmental monitoring were explored through four sub-themes. These were:

- Baseline mapping of terrain and infrastructure
- Support to surveying crews for planning surveys and H&S
- Facility siting, pipeline routing and roads development
- Monitoring of assets

A total of 29 primary challenges and 22 secondary challenges were identified in relation to logistics planning and operations, making it the thematic area with the most challenges relevant to EO. See Appendix A: Challenge trees, for a visual breakdown of these challenges.

3.6.1 Value of EO solutions throughout the O&G lifecycle

Figure 23 demonstrates that the value of EO solutions relating to logistics planning and operations is seen to be most pronounced early on in the project lifecycle, where it is perceived as important tool that is capable of offering a competitive advantage. This is a reflection of the need for solutions to challenges associated to the construction of roads and infrastructure to support development activity. Once this infrastructure is in place at the beginning of the lifecycle, there is less demand for this information. However, ongoing monitoring is still relevant, especially with consideration for aspects such as security or keeping track of temporarily shut-in wells.

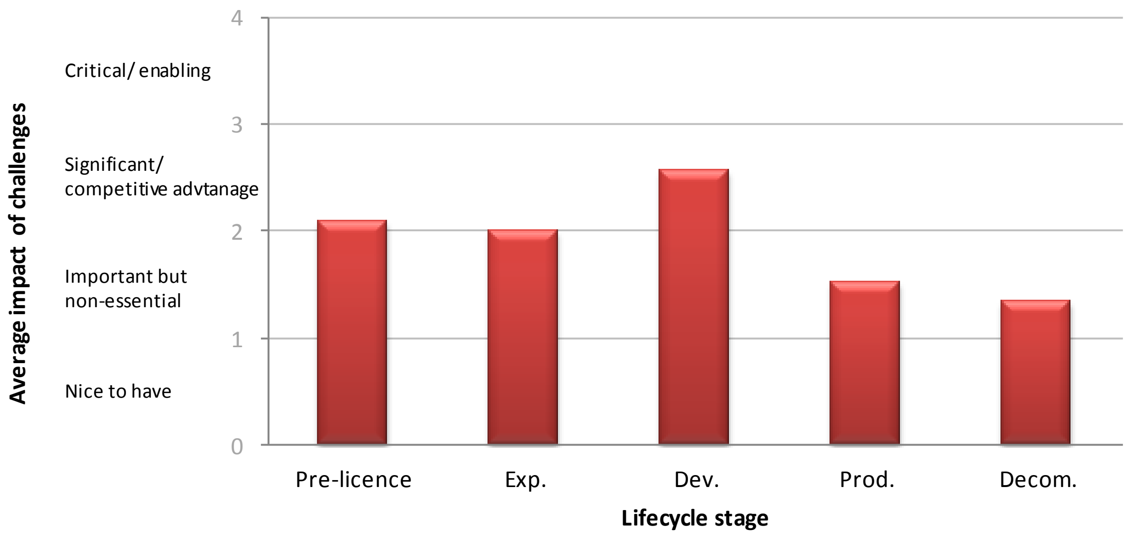

Figure 23: Logistics planning and operations challenge impact throughout the project lifecycle

3.6.2 Geo-information requirements relative to Logistics planning and operations

Figure 24 shows that there are a broad and extensive range of geo-information requirements needed to meet the challenges associated with logistics planning and operations. The most frequently referenced geo-information needs were linked with the need to obtain topographical information, imagery of assets and the surface, identifying transport infrastructure and mapping land-use. This is a reflection of the fact that many of the challenges are associated with identifying transport networks to plan routes, estimate transportation timescales, remotely monitoring operational activity and assets, and to make decisions regarding the feasibility and construction of new facilities or transport networks.

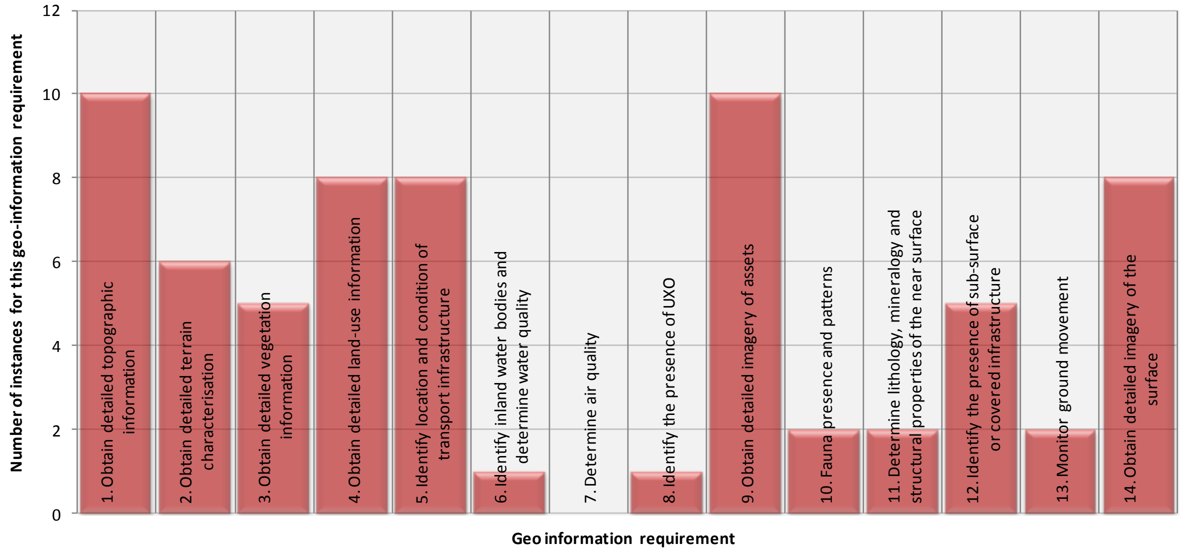

Figure 24: Geo-information requirements associated with logistics planning and operations challenges

3.6.3 High value challenges and their geographic relevance

High value challenges related to logistics planning and operations are associated with logistics planning for emergency response events, competitor intelligence, identifying building resources, remote supervision of operations and understanding activity beneath the tree canopy. These are described more fully within Table 9.

Ref	Title	Description
OTM:047	Logistics planning for emergency events (emergency response planning)	Creating an emergency response plan is important to ensure the safety of staff. Consequently, it is a factor considered by all, throughout the project lifecycle. In addition to the planning carried out prior to an incident, real-time data in the time-zone surrounding an incident has the potential to aid recovery or rescue efforts and to more fully understand the causes of the incident.
OTM:069	Change detection for competitor intelligence	Competitor awareness, especially of peers is perceived as incredibly important by many operators. For example, being aware of a competitor's exploration activity can give an indication of the presence of possible reserves or the strategic preference of an organisation. The application of EO for competitor intelligence is most important during pre-licence, exploration and development due the fact that once production has started and a find is public, any advantage gained through intelligence is diminished.
OTM:073	Identifying sources of building resources	In frontier regions the identification of suitable construction materials can play a major factor in locating a site. Without the supply-chain and infrastructure network of stable, more developed countries, being able to access local materials and minimising logistical concerns can be incredibly beneficial. This challenge is most evident in the early development (planning) phase when site locations are being evaluated.
OTM:076	Understanding activity beneath the tree canopy	In densely vegetated areas where the true ground surface is obstructed from view, it is difficult to locate infrastructure or populations in the local area. This can cause unforeseen delays in the development and commercialisation of a resource as ground survey teams are deployed with less information about the on-the-ground situation. A solution that could lessen this challenge would be incredibly valuable.
OTM:078	Remote supervision of operations	Operators often sub-contract large elements of work that may be carried out in areas that are geographically remote to their key offices. In such a situation, the ability to ensure that work is being performed safely, efficiently and to the organisation's standards would be incredibly beneficial. Moreover, in the long term operators are seeking to increase automation and remote-operations due to, amongst other drivers, health and safety and cost efficiency concerns. As a consequence of this, the ability to reliably monitor operations remotely is predicted to become increasingly valuable to the industry. With consideration to these factors, this challenge is critical throughout the O&G lifecycle.

Table 9: High value challenges associated with seismic planning

3.6.4 Impact area of challenges and potential EO solutions

Figure 25 shows that the two key impact areas related to logistics planning and operations were data quality and performance (45%), and health and safety (35%). Much of the performance related benefits are associated with improved cost efficiency as a consequence of optimising the planning and co-ordination of logistics activity and allowing ground survey teams to be more targeted. Health and safety benefits are realised through measures such as reduced on-the-ground personnel requirements and the enhanced monitoring of operations, as well as more effective security monitoring and improved risk awareness. The 10% of 'other' benefits relate to competitor intelligence challenges.

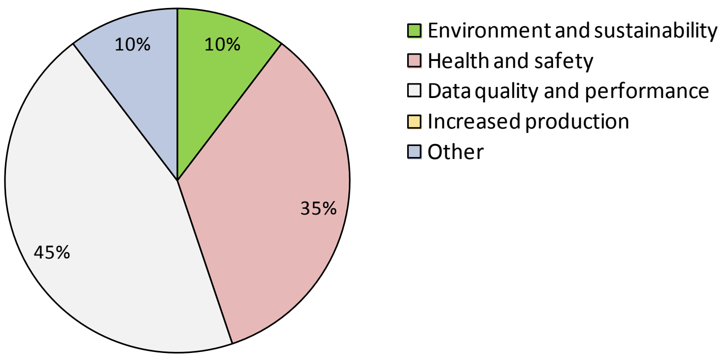

Figure 25: Impact area of logistics planning and operations challenges

3.6.5 Regional variations in geo-information requirements

The regional benefit for EO relating to logistical planning and operations is most clearly seen in countries with a poor or decayed infrastructure. It is in these countries where fresh infrastructure projects will be needed to support O&G developments and where other suitable resources might be less easily available. This could be particularly pertinent to countries such as South Sudan or the DRC. Furthermore, the use of EO to support the security of assets has most use in countries where the political situation is volatile. EO has been used to good effect in relation to security in South Sudan, as well as in Algeria.

3.7 Combined analysis of all themes

This section summarises the overall (all 5 themes) geo-information requirements and challenge impact areas document throughout this project.

Unlike the thematic analysis, the average value of EO solutions has not been considered in this section because the varied impact of each of the themes across differing lifecycle stages generates an average value that is misrepresents the value of EO solutions as low across all lifecycle stages

3.7.1 Geo-information requirements relative to all themes

As shown in Figure 26, the need for accurate topographic information was identified as being the key geo-information requirement. With 35 instances recorded it was required for 44% of the documented challenges. Terrain characterisation, understanding the near surface (mineralogy, structural properties, etc.) and monitoring ground movement were found to be the next most frequent geo-information requirements, followed by surface imagery, land-use and vegetation information which were each required for approximately 20% of the challenges. To a lesser extent, imagery of O&G assets and flora and fauna were highlighted as requirements for 17% of the challenges.

Of the remaining challenges, the most notable were the identification of transport infrastructure and its condition (required for 13% of challenges), and the identification of UXO and munitions debris. The requirement to identify UXO, although only relevant to 3% of challenges, has the potential to offer an enabling technology that would undoubtedly be embraced within and beyond the O&G sector to improve safety and operational efficiency in UXO impacted regions - typically frontier regions in Africa and the Middle East.

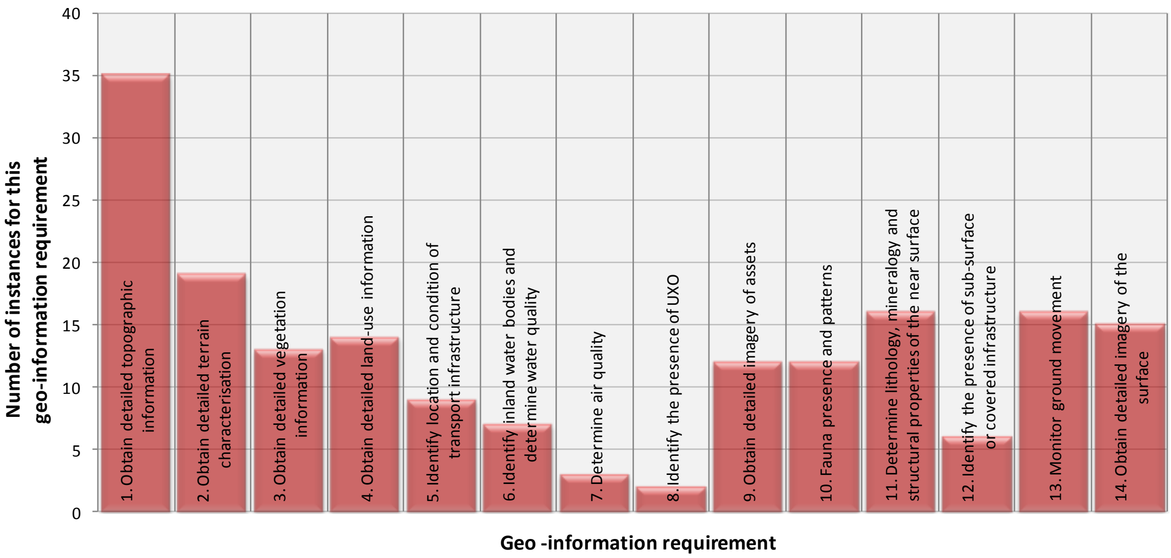

Figure 26: Geo-information requirements associated to documented O&G challenges

3.7.2 Impact area of challenges and potential EO solutions

Figure 27 shows the impact areas that the 79 challenges documented within this study effect. EO solutions have the potential to have the greatest impact on O&G operations in relation to data quality and performance (38%), followed closely by environment and sustainability (27%), and health and safety (26%). Generally, performance enhancements were realised as a consequence of cost-efficiencies realised through improved planning and therefore project execution, although more strategic benefits in relation to improved exploration performance were also noted. Environmental and sustainability benefits were recognised through unbiased, objective change detection, where EO was perceived as a complementary tool to existing methods as opposed to an enabling technology. However, its potential for application was evident throughout the project lifecycle. Health and safety benefits were realised through improved risk education prior to the deployment of on-the-ground staff, a reduction in personnel exposure to operational risks (by substituting ground staff for remote observation) and improved project planning and remote decision making capability.

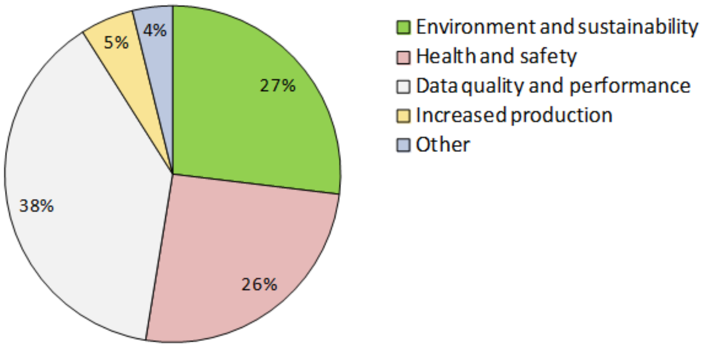

Figure 27: Impact area of geo-information requirements associated to the documented O&G challenges

3.7.3 Regional variations in geo-information requirements

Through the documentation of challenges, identification of geo-information requirements and subsequent industry consultation, it was noted that the industry needs are very rarely restricted to individual countries. Many of the challenges identified, were noted as being particularly pertinent to a given country, although they would also have relevance elsewhere around the world. Subsequently, the processes through which EO technology may be incorporated into a project were often part of company-wide standard protocols. This was encapsulated by one Remote Sensing Specialist of large oil company who during our interviews said:

"Although in this instance our conversation is about South Sudan, the techniques used and challenges faced are of a global nature across our business."

Detailed information pertaining to the market opportunity for each focus country is included at Appendix B.

4 Conclusions

4.1 Voice of the customer

Consultation with the O&G industry revealed the perceived strengths, weaknesses, opportunities and threats relevant to the EO sector. The main strength of EO was recognised as its impartiality, non-invasive nature and applicability in harsh environments.

Assessment of the perceived weaknesses revealed a need for improved resolution products and reduced processing requirements, as well improving the timeliness of delivery for certain applications i.e. emergency response events. Restrictions on EO application such as cloud cover and a lack of accuracy in densely vegetated areas were also highlighted as instances that deter operators from using the technology. However, it was widely recognised that EO was part of a suite of complementing technologies available to assist operators in their operations and that providing the capability of the technology was clearly defined, the information could be used accordingly.

Opportunities for the EO sector were recognised as the need to develop clear guidelines or agreed standards regarding the application of EO technology and the desire of the O&G industry to establish long-term relationships with product providers that can offer a premium and reliable service. The fact that many operators are creating or have created centralised EO and remote sensing functional groups also present a valuable opportunity to EO vendors as it should make engagement with operators easier and the use of EO products more widespread throughout client organisations.

Threats to the application of EO technology in O&G persist in a lack of understanding regarding the capability of the technology at both corporate and asset level. The subsidising or funding of case-studies to prove and quantify the value of EO technology in an O&G context has been flagged as a potential solution, making communication of the technologies value statement more applicable to end users in this sector. Threats to the use of ESA technology include the increased availability of free data and the emerging Asian market capability that may compete at a lower price point. However, if ESA related providers position themselves as a premium vendor they may be able to mitigate this.

4.2 Thematic analysis

79 O&G challenges were documented throughout this process leading to the identification of 14 geo-information requirements that, when combined in a given combination, can provide the information required to satisfy or contribute towards the satisfaction of the challenge. The list of geo-information needs is shown in Table 4 (also shown in Table 1) and the complete list of challenges is shown in Appendix A and in the Excel spreadsheet and challenge proformas on the OGEO portal.

The need for accurate topographic information was identified as being the key geo-information requirement throughout the study, needed for almost half of all challenges. Terrain characterisation, understanding the near surface (mineralogy, structural properties, etc.) and monitoring ground movement were found to be the next most frequent geo-information requirements, followed by surface imagery, land-use and vegetation information which were each required for approximately 20% of the challenges. To a lesser extent, imagery of O&G assets and flora and fauna were highlighted as requirements for 17% of the challenges. Of the remaining challenges, the most notable were the identification of transport infrastructure and its condition (required for 13% of challenges), and the identification of UXO and munitions debris. The requirement to identify UXO, although only relevant to 3% of challenges, has the potential to offer an enabling technology that would undoubtedly be embraced within and beyond the O&G sector to improve safety and operational efficiency in UXO impacted regions - typically frontier regions in Africa and the Middle East.

EO was found to have the greatest potential impact on O&G operations in relation to data quality and performance (38%), followed closely by environment and sustainability (27%), and health and safety (26%). Generally, performance enhancements were realised as a consequence of cost-efficiencies realised through improved planning and therefore project execution, although more strategic benefits in relation to improved exploration performance were also noted. Environmental and sustainability benefits were recognised through unbiased, objective change detection, where EO was perceived as a complementary tool to existing methods as opposed to an enabling technology. However, its potential for application was evident throughout the project lifecycle. Health and safety benefits were realised through improved risk education prior to the deployment of on-the-ground staff, a reduction in personnel exposure to operational risks (by substituting ground staff for remote observation) and improved project planning and remote decision making capability.

A total of 9 primary challenges and 6 secondary challenges were identified in relation to seismic planning. EO technology was highlighted as being of greatest importance during exploration, where it was considered as a potentially enabling tool, critical for operations. The technology was also considered to offer a competitive advantage at the pre-licence stage. The geo-information requirements for this theme were heavily influenced by the need to plan for the capabilities of seismic surveying equipment such as vibroseis vehicles. This is reflected in the recurring occurrence of the requirement for information on terrain and topography in order to construct DEMs. High value challenges related to seismic planning are associated with understanding the near surface environment, identifying variations in trafficability (topography and terrain), flagging the presence of UXO and munitions debris, and identifying environmentally sensitive areas. The primary impact area for EO solutions in seismic imaging was found to be data quality and performance - optimising survey routes and the understanding of the near surface. Countries in which this tool would offer a particular benefit include densely vegetated regions and those with high environmental sensitivity such as Uganda and Tanzania, and countries with regions of adverse terrain such as the DRC, Mexico and Turkey.

A total of 9 primary challenges and 13 secondary challenges were identified in relation to surface geology mapping. The greatest value of EO solutions were associated with the exploration and pre-licence phases, where the technology was perceived as a critical or enabling tool capable of offering a company a strategic advantage to surface infrastructure and to provide an indication of the location of hydrocarbon reserves. Key geo-information requirements associated to this theme included the need to determining the lithology, mineralogy and structural properties of the near surface", together with "obtaining topographic information" and "obtaining detailed imagery of the surface". High value challenges related were primarily associated with identifying new reserves, although DEM construction also featured. The impacts (78%) of the challenges related to this metric. This was primarily as a result of perceived improvements in exploration success as a result of utilising the technology. EO for surface geology mapping was noted as being most applicable to those countries that can provide a clear view of the surface such as large parts of Algeria and Turkey. Heavily forested regions such as those seen in DRC and parts of Uganda would be less applicable, despite the fact that the need to acquire and understand the same information still persists.

A total of 12 primary challenges and 3 secondary challenges were identified in relation to subsidence monitoring, with greatest value provided during the production stage of the O&G lifecycle. Here, the technology was perceived as having the potential to offer a competitive advantage, largely through its ability to assist in the monitoring of ground surface movements associated with the subsidence of infrastructure and reservoir production methods e.g. EOR and IOR. Geo-information requirements related to this theme were almost exclusively referenced as "obtaining detailed topographic information", together with "monitoring ground movement". High value challenges related to were associated with the planning and monitoring of key infrastructure components such as transport infrastructure, pipelines and facilities. The impact area of this technology more evenly distributed than most themes, with increased production, health and safety and data quality and performance all featuring. Increased production was linked to better reservoir management practices, whilst the other benefits were associated with more effective and cost-efficient maintenance regimes, improving design resilience, an avoidance of an environmentally damage failure and reduced safety risk. Similar to surface geology mapping, it was noted that this technology is less applicable where a clear view of the ground surface is not available.

A total of 19 primary challenges and 15 secondary challenges were identified in relation to environmental monitoring. The need for environmental monitoring throughout the project lifecycle was evident as it was considered to be an important challenge throughout each lifecycle phase. EO technology for environmental monitoring was considered as important but non-essential, largely because it was not considered to be capable of providing the suitable resolution. However, it was perceived as a useful complementary tool, primarily due to its objective and unbiased credentials. In contrast to other themes the geo-information requirements pertinent to environmental monitoring were widespread and extensive. The primary geo-information need indentified found to be the ability to "locate fauna and flora presence", with notable secondary challenges identified as characterising terrain, obtaining vegetation information and determining water quality. High value challenges associated to environmental monitoring were found to be related to determining and monitoring the condition of the environment through the creation of a reliable and robust baseline, ecosystem inventory and inclusion of social factors. Unsurprisingly, the impact area for organisations using EO to monitor the environmental impact of their operations was overwhelmingly recognised within environment and sustainability, largely in relation to due-diligence. The application of EO technology for this purpose was seen as being most pronounced in stable countries which have an embryonic O&G sector and a history of poverty such as Uganda and Tanzania. Those that were unstable tended to have a weaker regulatory environment and the requirement to prove the impact of operations was less rigorously enforced. However, in this situation, it was noted that major operators or high profile IOCs tend to revert to internal or global standards which may include the use of EO.

A total of 29 primary challenges and 22 secondary challenges were identified in relation to logistics planning and operations, making it the thematic area with the most challenges relevant to EO. Reflecting the need for solutions to challenges associated to the construction of roads and infrastructure to support development activity, the value of EO solutions relating to logistics planning and operations was seen to be most pronounced early on in the project lifecycle, where it is perceived as important tool that is capable of offering a competitive advantage. The most frequently referenced geo-information needs were linked with the need to obtain topographical information, imagery of assets and the surface, identifying transport infrastructure and mapping land-use. This information was commonly referenced as a need in order to plan routes, estimate transportation timescales, remotely monitoring operational activity and assets, and to make decisions regarding the feasibility and construction of new facilities or transport networks. Two key impact areas of these challenges and potential solutions were identified, including data quality and performance and health and safety. The performance benefit was largely attributed to with improved cost efficiency as a consequence of optimising the planning and co-ordination of logistics activity and allowing ground survey teams to be more targeted. Health and safety benefits are realised through measures such as reduced on-the-ground personnel requirements and the enhanced monitoring of operations, as well as more effective security monitoring and improved risk awareness. The regional benefit for EO relating to logistical planning and operations was most clearly seen in countries with a poor or decayed infrastructure such as South Sudan and the DRC.